

RECYCLING
OF
BITUMINOUS PAVEMENT MATERIALS



BY

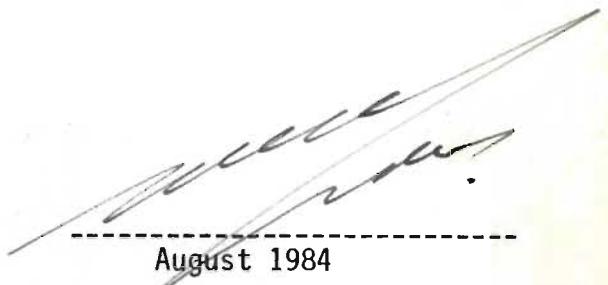
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This thesis is submitted in partial fulfilment of the requirements for
the Degree of Doctor of Philosophy in the Department of Civil Engineering,
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DECLARATION BY CANDIDATE

I, Vladis P Servas, hereby declare that the work presented in this thesis is my own and that it has not been submitted for a degree of another university.



August 1984

DEDICATION

TO MY WIFE

TERESA

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1. INTRODUCTION

- 1.1 Preamble
- 1.2 Background, scope and objectives of the project
- 1.3 Resumé of main recycling concepts
- 1.4 Definition of terms
 - 1.4.1 1979 definitions
 - 1.4.2 Proposed amendments
- 1.5 Selected bibliography

1.1 Preamble

Recent technological developments in the recycling of pavement material have drawn worldwide attention to the potential cost savings and resource conservation that can arise from large-scale reuse of existing road material. In particular, implied possible savings in energy and imports, highlighted by recurring oil shortages, sharply rising prices, and increasing doubts regarding the long-term future availability of oil/bitumen, have made bituminous material recycling highly attractive politically in many countries. The concept is not new. Various methods have been practised on a relatively limited scale and with varying success for quite some time.

The first printed mention of recycling was made in the Warren Brothers' 1915 sales brochure on portable asphalt plant. These plants "heated and reworked existing sheet asphalt pavements with excellent results and considerable savings in the costs of the resultant mix". This recycling was undertaken in the urban areas of the eastern USA for 15 - 20 years until new refineries, by increasing the availability and reducing the cost of new binder, rendered the activity less economically attractive.

In the early thirties the Recondo central plant hot mix recycling process was evolved and patented by N H Taylor and used extensively in Singapore and on a limited scale in Bombay. The method consisted in remixing crushed old asphalt pavement with additional sand or stone and bitumen. Only minor modifications to the mixing plant were introduced and the use of proprietary additives was found unnecessary.

In Pittsburgh, Pennsylvania, Allegheny Contracting Industries recycled thousands of tons of reclaimed asphalt pavements during the fifties and sixties, using a purpose-built recycling plant consisting of feeding, screening and mixing units connected by conveyors. The material was fed to a continuous mixer and exposed to two banks of infrared heaters, one located just before the continuous mixer and the other mounted on top of the mixer itself.

An aromatic asphalt modifier was introduced in the mixer, whereas the addition of new bitumen was optional. The greater part of the recycled mix was used for both base and surface course layers of secondary roads and streets in the Pittsburgh area.

Cold recycling processes, such as reclaimix and retread, have also been available for some time. These processes rehabilitate old asphaltic pavement *in situ* by pulverizing the pavement and treating it with either a softener to dissolve and enliven the bitumen or an additive such as bitumen emulsion, cutbacks, portland cement and lime, before reprofiling and recompaction.

There are many other examples including the regeneration process practised in the immediate post-war period in Holland, when new bitumen was not readily available and environmental awareness was less sensitive.

The reasons why recycling has not been taken more seriously have been those of economic considerations and available technology. Until recently the cost of new hot-mix materials has been less than the cost of handling, transporting and reprocessing *in-situ* materials.

During the last decade we have witnessed considerable changes in the road scene, apparent in the attitudes as well as in the realities of road design, construction, maintenance and usage.

In the West, the earlier aspirations and confidence reflected in ambitious investments and programmes *in the* early seventies, were almost shattered by the economic consequences of the energy crisis following the 1973 Middle East war.

Nevertheless, during this period, much progress was made such as in the advancement in construction and maintenance equipment technology, the increasing concern about energy, the interest in conservation of natural resources and the ability to reuse existing pavement material. In many ways the economic restrictions appear to have had a beneficial effect on the industry and the profession's ingenuity

and skills. In the first few years we are likely to experience further changes and developments which will be predominantly influenced by the expected continuation of the current economic conditions.

The interest has been worldwide, with many countries becoming involved in the various forms of recycling of pavement materials.

However, by 1978, individual countries were carrying out independent investigations into recycling and were taking little advantage of the parallel experience being gained in other countries. Manufacturers were developing and promoting their own modifications and new equipment while patent limitations inhibited the adoption of a common sensible approach. These factors gave rise to a plethora of equipment and techniques and caused considerable confusion. Certainly, in 1978, there appeared to be a general lack of knowledge regarding the scope, limitations, field of application and actual working of the various recycling processes; this was particularly the case with hot surface recycling methods. There was an obvious need to gather all the available information in order to establish the state of the art and to identify problems and areas in need of further research and development.

1.2 Background, scope and objectives of the project

In October 1978, following my involvement in a series of hot surface recycling repaving trials in Hertfordshire during 1976-77, I was seconded by the UK Department of Transport to Colas (UK) Ltd, a Shell International Petroleum Ltd company, to assist in the further assessment and development of repaving.

In the summer of 1979, following successful repaving trials which eventually led to the process's approval as a specified alternative remedial measure for motorways and trunk roads in the United Kingdom, it was decided to widen the scope of the study. Consequently, during the latter part of 1979 and 1980, and under the joint sponsorship of the UK Department of Transport, Colas (UK) Ltd and Shell International

Petroleum Co Ltd, I undertook a project which involved evaluating and reporting on the worldwide experience with and potential of the numerous bituminous pavement material recycling processes.

The project's aims were defined as "To assess the technical, economic, environmental and operational aspects of the various bituminous recycling processes and to make recommendations", and the following objectives were set:

- (i) By study of published information, visits to contract sites, discussions with Road Authorities, Engineering Institutions and Associations, Universities, Contractors, Plant Manufacturers, Research Associations and other interested bodies, post-contract site inspections and examination of available recycling plant, to establish the state of the art and assess the potential of recycling processes.
- (ii) To compare the technical and economic merits and field of application of the following processes:
 - (a) hot surface recycling, including repaving and remixing
 - (b) hot mix recycling with particular regard to
 - pavement removal and sizing by either ripping, breaking and crushing or by milling
 - plant recycling process by batch and drum mixer plant
 - (c) cold mix recycling.
- (iii) In the assessment specific regard to be given to:
 - (a) types of existing material
 - (b) category of road and traffic loadings
 - (c) mix design and quality control
 - (d) pre-contract testing and post-contract monitoring and feedback
 - (e) energy and resource conservation
 - (f) environmental aspects
 - (g) recycling additives
 - (h) projected savings to taxpayers/ratepayers
 - (i) effect on and likely reaction from related sectors of the industry, e.g. quarry owners, haulage contractors, asphalt producers, surfacing contractors, bitumen suppliers and plant manufacturers.

- (iv) To make recommendations on options available and policies to be adopted by
 - (a) the UK Department of Transport
 - (b) Shell International Petroleum Co Ltd.

The successful outcome of the project enabled me to establish the state of the art, to propose amendments to definitions and the adoption of new categorization and contractual procedures, to identify gaps in knowledge and development, and to make recommendations for further research.

On the basis of my final report on the project, Shell International Petroleum Co Ltd published, in 1981, a summary of my findings entitled "Asphalt Recycling - the state of the art, 1980".

In October 1981, I joined the National Institute for Transport and Road Research in Pretoria, where I am continuing my research into various aspects of recycling. This work involves:

- (i) examination and assessment of developments in the Republic of South Africa
- (ii) initiation of research projects based on the findings of the previous survey but adapted to suit South African requirements
- (iii) further consideration of issues such as contractual procedures and differences in involvement with regard to urban or rural situations.

The objectives of this thesis, which is based on my total experience in the field of recycling since 1976, are to give:

- (i) a full account of the various recycling processes, based largely on the 1979/80 survey but updated where significant new developments have occurred;
- (ii) the results of the survey with regard to the state of the art in the countries examined;
- (iii) the current position and historic developments in the Republic of South Africa; and
- (iv) details of the research currently being undertaken at the National Institute for Transport and Road Research of the CSIR.

A further aim of this work is to examine the main factors restraining the growth in the acceptance of recycling and to contribute to the development of methods for overcoming these factors.

1.3 Resumé of main recycling concepts

In general the conventional methods of maintaining flexible pavements involve planing and recarpeting, reconstructing or surface treatment. With these processes the existing material is either replaced or covered up with further new material. This resource, or reserve of material already in place on roads, must be made use of, thus minimizing the cost of using new materials, and conserving aggregates and hydrocarbons.

Bitumen mixes are viscoelastic, being viscous and workable at high temperatures and elastic at low temperatures. These properties, which are used to advantage in the manufacture, laying and performance of hot-mix surfacings, enable pavement materials to be reused through hot-mix or hot-surface recycling processes.

Moreover, full reutilization of these pavement resources can also be achieved by many cold, in-place or central-plant recycling methods.

With regard to bituminous pavements, there are three main categories of recycling:

- (i) Hot-mix, central-plant recycling : in general there are two broad approaches. Firstly, in cases where the reclaimed asphalt pavement material is obtained from relatively large projects and is reasonably homogeneous, a recycled hot-mix can be produced of a standard comparable to that of conventional mixes for asphalt courses on primary networks. Secondly, when the reclaimed material is less homogeneous, having been obtained for instance from several resurfacing projects, the resulting mixes will normally be suited to secondary uses.
- (ii) Cold-mix, central-plant or in-place recycling : this type of recycling is normally suited to less heavily trafficked roads. Roads made up with surface dressings on gravel or gravel oil roads make ideal candidates. However experience has shown that

this process is also applicable to full bituminous pavements, producing, at least, a satisfactory base course.

(iii) Hot, in-place, surface recycling : processes under this heading are applicable only to treatment of the surface layer and their use should be strictly limited to cases where the underlayers and foundations are sound.

In pavement maintenance, the selection of the appropriate treatment option is, or should be, made on the basis of the pavement's condition, the probable causes, new design requirements, environmental and traffic interference considerations, and, naturally, economics.

If the approach to the reuse of material is based on the two broad alternatives of either recycling in-place or removing the pavement materials with provision for subsequent reprocessing, the maintenance options additional to the current conventional procedures will simply be:

- hot surface recycling;
- cold in-place recycling;
- removal of pavement material with subsequent reprocessing safeguarded.

Following a decision to reuse the existing pavement material, the above options must be considered with the aid of a limited amount of preliminary laboratory testing, needed for establishing the suitability of the material for the various forms of recycling.

Once a decision on the broad option is made, in the case of options one and two, the specific process is selected on the basis of detailed laboratory testing.

The reuse of otherwise discarded pavement material has been found particularly attractive by road authorities, producers of pavement mixes and surfacing contractors, for a variety of reasons, some of which are outlined below:

- rapidly increasing binder costs

- shortages of quality aggregates, at least in particular areas and countries
- rising disposal costs of removed pavement material
- haulage costs for new material
- ecological concern regarding new quarries, conservation of resources, dumping of pollutants, etc.
- economic considerations in individual projects
- desire to keep abreast of technological developments
- energy conservation
- shortage of funds
- geometric limitations of existing highways.

However, there are also valid restricting factors. Basically these are:

- current relative obscurity of associated cost savings
- concern regarding quality of product
- associated complexities in the organization of such a project.

1.4 Definition of terms

1.4.1 1979 Definitions

In November 1979, the National Asphalt Pavement Association (NAPA) and the Asphalt Institute revised their original definitions (March 1977) relating to the recycling of pavement materials, and established the following:

Pavement Material Removal - a pavement rehabilitation alternative
Methods of Material Removal:

- (i) ripping and crushing
- (ii) cold milling
- (iii) hot milling
- (iv) heater planing.

Reclaimed Asphalt Pavement (RAP) - removed and/or processed pavement materials containing asphalt and aggregate.

Reclaimed Aggregate Material (RAM) - removed and/or processed pavement materials containing no reusable binding agent.

Recycling - the reuse, usually after some processing, of a material that has already served its first-intended purpose.

Methods of Recycling

- (i) Hot-mix Recycling - a process in which reclaimed asphalt pavement materials, reclaimed aggregate materials, or both, are combined with new asphalt, and/or recycling agents, and/or new aggregate, as necessary, in a central plant to produce hot-mix paving mixtures. The finished product meets all standard material specifications and construction requirements for the type of mixture being produced.
- (ii) Cold Mix Recycling - a process in which reclaimed asphalt pavement materials, reclaimed aggregate materials, or both, are combined with new asphalt, and/or recycling agents in place, or at a central plant, to produce cold-mix base mixtures. An asphalt surface course is required.
- (iii) Surface Recycling - a process in which an asphalt pavement surface is heated in place, scarified, remixed, relaid and rolled. Asphalts, recycling agents, new asphalt hot mix, aggregates, or combinations of these may be added to obtain desirable mixture characteristics. When new asphalt hot mix is added, the finished product may be used as the final surface. Otherwise, an asphalt surface course should be used.

The above definitions have adequately achieved the principal aim of the revision, which was to establish a clear distinction between the pavement material removal and recycling activities. In doing this, the use of terminology such as 'recycled hot-mix asphalt' and 'asphalt pavement recycling' has become obsolete.

1.4.2 Proposed amendments

The new definitions are not devoid of shortcomings, partly reflecting on NAPA's primary position as a central plant hot-mix producer

association, and the natural consequent bias against cold-mix and surface recycling.

I believe that changes in the definitions, on the lines of the following comments, would be appropriate.

Hot Mix Recycling: The finished product does not necessarily have to meet all the standard material specifications. The requirements can hardly apply in the case of "method-based" specifications. In fact it will be argued that, in certain circumstances, changes to some aspects of even an "end-result" based specification will optimize the recycling benefits. (It is assumed that the definition, as it stands, accepts this type of recycling for the production of 'inferior' mixes for a variety of secondary uses.)

Cold-Mix Recycling: This process is not limited to the production of base mixes. In fact on numerous occasions this form of recycling has been successfully used to produce a wearing course layer, with or without surface dressing. Further restrictions on the availability of maintenance funds may well make this the standard approach for secondary roads.

It is worth noting that in an article ("The three basic designs in asphalt recycling" - Rural and Urban Roads, March 1980) Vaughn Marker, chief engineer of the Asphalt Institute, stated "...After it has been processed, mixed, and placed, it will normally require a new wearing surface of some type. This wearing surface can be a new asphalt concrete mixture or a surface treatment".

Further supporting evidence is provided in the documents

- (i) National Co-operative Highway Research Program Synthesis of Highway Practice 54
"Recycling materials for highways"
- (ii) "Interim guidelines for recycling pavement materials", prepared by the Texas Transportation Institute for the National Co-operative Highway Research Program, which include cold-surface recycling in their lists of options for bituminous pavement material recycling.

Surface Recycling: Apart from the title, where "Hot Surface Recycling" would have been more appropriate in view of the content of the "Cold Mix Recycling" definition, further criticisms apply. Firstly, the description does not include the repaving process. This is particularly odd, as repaving has been the most widely used of the hot-surface recycling processes.

Secondly, in cases where no new hot-mix is added, an asphalt surface course is by no means essential, and at times is undesirable. There are many examples of an adequate wearing surface having been provided by hot-surface recycling with no additional hot-mix used.

Another option that falls into this recycling group, and should have been mentioned, is the operation to restore lost skid resistance.

Although nothing may be added to the reworked mix, the final surface is coated with new chippings before compaction.

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2. RECLAIMING OF PAVEMENT MATERIAL

- 2.1 Development of reclaiming equipment
 - 2.1.1 Need for planing
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2.1 Development of reclaiming equipment

2.1.1 Need for planing

In the last few years we have witnessed considerable changes in the field of planing usage and planer technology. This development has greatly influenced road maintenance thinking and techniques and is the prime factor behind some of the bituminous pavement material recycling processes. On the other hand, the evolution of road maintenance techniques, coupled with the ever-increasing importance of maintenance, has itself been the cause of improvements and developments in planing and is likely to bring about further progress including another generation of planers, operationally and economically equal to the tasks demanded by full-depth reconstruction and recycling.

The need for planing has long been established. Repeated overlays have created their own problems such as

- exaggerated crowns
- buried kerbs, channels and manhole covers (or the need to raise them)
- clearances reduced below acceptable levels in tunnels and under bridges
- increased weight on bridge decks
- the need for alterations to the height of guardrails and barriers.

Planing is, of course, essential in resurfacing operations affecting only part of the carriageway width, such as a slow lane, or limited sections along the length where an overlay will cause level differences between adjoining existing and new surfaces.

Furthermore, planing of deformed and wheel-tracked pavements prior to the application of an overlay will often eliminate the need for a separate levelling course, while ensuring more uniform compaction.

A less well known but important adverse effect of overlaying is that old wearing course layers are eventually buried in positions subject to high horizontal strains. These strains caused by vertical loads reach their peak values typically at depths of 100 to 150 mm below the road surface. Therefore there is a danger that such wearing courses that have proved stable in their original function, during their service life, may suffer distress when buried under other material.

2.1.2 Historical development

Planing was probably first undertaken using a steam roller with a scarifier tine, a process still **in use**. The first heating-planing techniques were based on the application of intense local **heat** to the surface of the existing pavement, followed by scraping. The existing material was heated to a high temperature, almost **burnt**, to facilitate the scraping; needless to say the effect of such overheating was that the planed-off material was of limited further use.

In the post-war period, Jackson led the development in the USA with machines made by taking a Blaw Knox paver apart and fitting it with a heater bank, wheel and elevator; these machines are still in use. A number of surfacing contractors and plant manufacturers produced their own versions of heater-planers. Some were based on a design similar to that of the Jackson machine while others incorporated innovations such as vertical rotary cutting heads, horizontal drum cutters, infra-red heating, sufficient power to give the option of operating without the application of heat, extra heater banks, electronic controls and so on to produce a generation of higher technology planers.

Meanwhile, various attempts were made at cold planing, and some quite successful machines were produced which are still operational (BJD, UMM, Johnson). BJD was the first manufacturer to produce cold planers on a large scale; its machines were based on the conversion of a motor grader by replacing the blade with a drum fitted with

cutting tools. Since the mid-70s cold planing technology has advanced significantly with CMI producing the Roto-Mill series, Barber-Greene the Dynaplanes, and Wirtgen, Sakai, Volvo, Joad, Galion and others their versions.

2.1.3 Availability

Currently there are four main variations in the types of planer available:

- (i) Heater-planers applying heat by oil or gas prior to shearing or scraping the pavement with a blade(s).
- (ii) Rotary disc heater-planers carrying cutting edges which rotate round a vertical axis.
- (iii) Hot planers applying radiant heat prior to grinding or milling the pavement with a horizontally rotating drum fitted with picks.
- (iv) Cold planers grinding or milling the pavement without the aid of preheating.

These machines come in various sizes and are normally classified as small (less than one metre wide), medium (about half lane width), and large (lane width). The depth of material which can be removed in one pass is about 40 mm for a small machine and up to 100 mm for a larger planer, depending on working conditions (including ambient temperature) and the composition of the asphalt mix.

The following list gives an idea of the variety of planers currently available:

BJD: "Medium Planer", a cold planer with rubber tyres and a 645 x 800 mm drum. The smaller version, "Miniplaner" has a 435 x 310 mm drum.

WIRTGEN: "SF 3800", hot planer, variable working width from 100 to 3 750 mm, infra-red heaters, dual-steering optional conveyor loader, 80 mm cutting depth in one pass. Other models: SF 2450, SF 100, SF 1000 and SF 800.

"Cold Milling Machine 22000", variable working width from 100 to 2 200 mm, maximum cutting depth 180 mm, 750 hp engine. Other models: 3800C, 2100C, 1200C and 500C. The 2100C and

1200C models are rubber-tyred.

JOAD: Hand-operated planers capable of working on asphalt or concrete pavements to a depth of 30 mm and a width of 245 mm.

CMI: "Roto-Mill PR750", the largest of the cold profilers in their series, 750 hp engine, cutting widths of 2,5 metres with maximum cutting depth of 130 mm, and 3,81 metres for wider shallower cuts. "Hydramation" control system and loading conveyor; leaves heavily textured surface pattern. Other models: PR225, PR275 (rubber-tyred) and PR525.

BARBER-GREENE: "Dynamaplane RX 75", with 750 hp engine, interchangeable cutting widths of 10ft 5in and 12ft 5in, maximum cutting depth $7\frac{1}{2}$ in, vertically adjustable suspension system to control the depth of cut and transverse slope of the cutter, dual controls and loading conveyor. The other model is the "RX 40", a zero side clearance machine with a cutting width of 6ft 3in.

MILLARS: "Road Razer", heater-planer introduced in 1972, utilizing four individually operated cutter heads.

SAKAI: "ER-160 Road Cutter", maximum cutting depth 80 mm, drum can be shifted 400 mm to either side giving an effective cutting width of 1,86 metres, three control panels, 206 hp engine.

2.1.4 Cold versus hot operations

A lot of thought has been given to the relative merits of hot and cold planing and the various types of planing machine. Many of the published opinions are based on subjective and sometimes emotional arguments. Hot planers have been critisized as expensive, inefficient, wasteful, obnoxious and potentially lethal on a catastrophic scale. Similarly cold planers have been termed costly, over-complicated, less accurate, liable to break down and expensive on picks. In any serious examination the following factors have to be taken into account.

Reliability or production performance: This tends to be measured as a function of downtime. It would be fairer to assess performance on the square metre output rather than on the working hours availability

per unit of time. The daily outputs vary considerably depending on local working and traffic conditions and are substantially lower in towns than on freeways where the operation can be carried out without stopping and overbridging manhole covers, etc. In comparing outputs, the speed of operation is important with the ranges of planing speeds being about 3 to 5 mpm for hot and 6 to 10 mpm for cold planers. In general, reliability depends less on the type of planer and more on its make, on the type and usage of picks, preventive maintenance, the skill and discipline of operatives and on the expertise in applying the right technique and equipment to particular tasks and conditions. In practice a critical operation is often neglected: this is the systematic replacement of picks to ensure that those in use retain their sharp cutting edge. The actual range of production performance is extremely wide. Apart from the above factors, pre-job planning, site supervision, traffic control, support equipment and labour allocation are important additional influences on the rate of output. Experience has shown that lower rates of production are normally achieved on hot rolled asphalt with precoated chips (gap-graded asphalt) than on asphaltic concrete (continuously-graded asphalt).

Maintenance requirements and costs: The importance of preventive maintenance in reducing downtime has already been stated. Periodic maintenance can be taken to include filling with LPG (applicable of course to hot planing only) and changing of picks, a more frequent activity with cold planing. Picks vary depending on their make and type, and their life normally ranges between 3 500 and 10 000 square metres. Special picks are used for concrete pavements, and these are naturally more expensive. In practice all planing machines require daily maintenance and routine checks. In the case of hot planers it is important that all aspects relating to safety are checked regularly. Current experience indicates that in general less maintenance is required for cold planers.

Energy: There is no question that cold planers consume less energy. The consumption of LPG varies considerably and depends on the make and size of the machine, depth of cut, nature of material, site

conditions (ambient temperature, wind, etc.) and many other factors. A rough average for a one-lane machine planing 40 mm is about one ton of LPG for some 7 000 square metres. The variation in the consumption rates for diesel is as wide as for LPG. Nevertheless, it can be taken that, as more powerful machines are usually needed for cold-planing, the relative consumption of diesel for cold operations will be higher.

Environment: Hot planing has been much criticized in terms of environmental pollution. In practice, when the operation is carried out correctly, smoke is emitted only when the existing pavement is either surfaced dressed or rich in binder on the surface. Under normal working conditions and using infra-red heating, the appearance of smoke is a sign of erroneous application of heat, e.g. heater bank too near the surface, machine standing, or travelling too slowly. Contrary to what is usually assumed, due to the incorporation of effective sound suppression systems, there is no appreciable difference in the level of noise emitted by either type of planer. In any case noise levels have been found to be sufficiently low for planing to be carried out in residential streets at night. With regard to dust, which could be a problem with cold planing, modern techniques can suppress this pollutant to a satisfactory working level by damping down and collecting.

Safety: Recently considerable concern has been shown about the safety aspects relating to the transportation and usage of LPG in planing operations. For example, in the United Kingdom in 1979 a consultative document "Proposals for Dangerous Substances (Conveyance by Road) Regulations" was published by the Health and Safety Commission. It is envisaged that new safety legislation will have a significant bearing on hot planing methodology.

Side benefits: Planed material can be used for a number of different purposes ranging from fill or foundations, to car park or footpath surfacings, or even to use as part of a low-grade mix for bases on minor roads. An advantage of hot planing is that the planed material can be used while hot and pliable as a top surface

layer. With cold planing, however, material can be stored for later use without the danger of congealment while stockpiled. An additional side benefit of hot planing technology has been the utilization of modified planers in two-step surface recycling processes or even, following further modifications, in repaving and remixing. With the advent of hot-mix recycling, the need has arisen to remove the existing bituminous materials in a cold state; this has to be done by either the traditional method of ripping and breaking with subsequent crushing, or cold planing. On the other hand, hot planed material can be successfully stored for reprocessing in cases where further degradation of reclaimed material, by the mixing in of added sand (about five per cent) is allowable.

Utilization: The versatility and manoeuvrability of a particular machine must be carefully considered. The ability to plane pavements, to plane adjacent to bridge deck joints or channels, to cut around manhole covers, to operate independently of the weather (e.g. in wet conditions or low temperatures), to work in narrow streets, to leave the planed edges clean - all these must be taken into account, as well as the ability to plane accurately, to follow an existing longitudinal profile and to produce a uniform texture. In addition the operating speed, the maximum depth of cutting and the methods of control must be examined. Already in the USA, specification requirements include "to use equipment with automatic grade and slope controls" and "the speed of the machine shall be variable and adequate in order to leave the desired grid pattern", and also specify a minimum production performance.

2.1.5 Further uses

In the past planing has been primarily used for removing an existing bituminous layer before replacing it. Currently, with the advancement of planing technology and the availability of ranges of equipment, there are various further uses, of which examples are given below.

Levelling and bonding: The traditional remedies for deformed wearing courses were either complete replacement or an overlay, possibly preceded by a levelling course. By producing a level, textured surface and thus a substantially increased bonding area, modern planing techniques enable thinner overlays to be used, avoiding differential compaction and slippage problems.

Surface refinishing: A deformed but otherwise sound pavement can be planed to a specified grade and slope, providing a new riding surface without the addition of new materials. Because the aggregates are sliced and not ripped out, the operation produces a fine-graded textured surface. In the USA, where this method is used on both asphaltic concrete and concrete pavements, the specification for the process includes "... shall have a mosaic appearance clearly showing 75 per cent of the surface aggregate sheared ...". This technique is obviously unsuitable for hot rolled asphalt pavements with precoated chippings.

Pavement repair: Planing can be used to excavate deteriorated pavements down to the subbase.

Pavement removal: Repeated overlays have caused pavement build-up to become a problem in urban areas. Currently due to the increased versatility, manoeuvrability and accuracy of modern planers, and their ability to produce a surface suitable for traffic use, it is possible and economical to reduce such pavements to desirable levels.

Surface retexturing: This is an effective and inexpensive method for improving the skid resistance of a bituminous or concrete pavement that is otherwise reasonably sound. This technique, although inappropriate for hot rolled asphalt, is widely used in the USA where the process specification includes "the required pavement texture shall be a series of discontinuous longitudinal striations spaced approximately $\frac{1}{2}$ -inch apart. Individual striations shall be four to eight inches in length, spaced as to produce a uniform grid pattern. The depth of the striations shall be $1/8$ to $3/16$ inches".

Surface texturing is also used in some countries to prepare deteriorated bridge decks for the placement of concrete overlays.

Pavement mining: Until recently ripping and breaking was the only practical way to excavate pavements in reconstruction. This method has certain disadvantages. The road is closed during the operation. The subbase has to be reprofiled and recompacted. Drainage systems or structures can be damaged. If the excavated material is to be of further use it has to be hauled to a crushing plant and reprocessed. There are now planers available that can tackle the full-depth removal of pavement layers without disturbing the base or subbase and process the old material as sized, crushed aggregate, ready for a variety of uses including central-plant recycling. Moreover, as it is possible to remove the pavement in separate layers, leaving a fully drivable surface, traffic flow may be maintained as the process proceeds or a section of the carriageway may be re-opened to traffic during peak periods.

In-place cold recycling: There is an increasing tendency to incorporate cold planers in any in-situ cold mix recycling operation, requiring full-depth cutting. In many cases the cutting drum has a dual function, being used for both the pulverizing and mixing operations.

2.1.6 Current situation

Although the term planing has been used throughout this chapter, strictly speaking it no longer applies to all of the current activities. The term planing was adopted to describe the actual physical operation and naturally it still applies when reference is made to the activity of a machine utilizing blades or scrapers for pavement removal.

However, when pavement removal is undertaken using a drum fitted with cutting tools (picks), the actual operation is different and the appropriate term is milling. The terms cold milling and hot milling differentiate further between the two forms of milling. In

in the USA the term profiling tends to be used. This applies to the automatically controlled cold milling operation.

CMI's Rotomills, Wirtgen's C series machines, Barber-Greene's Dynaplanes, and others are significant developments enabling the existing pavement to be removed and recovered in one reasonably economical and productive operation.

Nevertheless, there is still room for further progress in areas such as machine stability and the design of picks. There is an increasing demand for guaranteed production performance and degree of accuracy. If cold milling is to provide a practical alternative to ripping and crushing for all types of asphaltic layers, there is a need for machines capable of efficiently and reliably removing pavements to full depth.

The recycling concept is likely to bring about further technological changes with new devices such as sonic planers and through the possible use of lasers for the cutting processes.

In hot planing, concern about safety may well speed the development of different methods of pre-heating the pavement.

2.2 Removal, sizing and stockpiling

There are two broad alternative methods of removing bituminous pavement material for subsequent reuse: firstly, the traditional full-depth pavement removal method incorporating ripping and breaking, and secondly, cold or hot milling and planing operations.

2.2.1 Ripping and breaking

In this process, contamination of the reclaimed bituminous material, with underlying courses, may present a problem. However, if the underlying courses, untreated aggregate or lean concrete, are to be reclaimed as aggregate in hot-mix processes, it is imperative that they remain free of bituminous contamination. The broken pavement

is loaded and hauled to another location where it is either stored or reduced in size by crushing. Storage presents one of the main advantages of this reclaiming method if the material is not needed for immediate reprocessing. A stockpile of broken pavement is less susceptible to congealment, absorption of moisture and contamination than a stockpile of crushed or milled pavement. Experience has shown that the crushing of bituminous pavements does not present special problems, it can be undertaken in hot weather conditions, and does not require heavy-duty units. In fact most crushing to date has been done by jaw and roll crushers, although manufacturers are developing units designed especially for this purpose. The required size is predetermined by the type of recycling, the mixing plant process, and naturally, the mix specifications.

In selecting the type of crushing equipment, special consideration must be given to the increase of fines produced. The increase must be kept to a minimum in order to avoid limiting the percentage of reclaimed material below the level which would have been otherwise appropriate.

2.2.2 Milling and planing

With these processes, different bituminous layers can be removed separately. This is of particular advantage in the reclaiming of hot rolled asphalt material. The option of conveyor loading, normally available provided the haulage logistics allow its use, can offer distinct advantages over conventional methods.

Material reclaimed by cold milling is already reduced in size and, provided it is not stored for unduly long periods, is suitable for central plant recycling without further reduction except the possible scalping-off of oversized chunks. To date, the main problem experienced with cold milling has been the generation of fines. Many attempts have been made to alleviate this problem by using various pick configurations, varying the depth of cut as well as both the forward and rotational speeds of the drum, and reversing the direction of rotation. Although more research is needed into

this important and controversial area, it is now recognised that the generation of fines is a function of the characteristics of the material removed, the ambient temperature, and the type of machine used, as well as the above factors.

When circumstances permit, material reclaimed by hot milling and planing can be immediately processed through an asphalt plant utilizing the inherent heat of the reclaimed material. However, normally it is stockpiled and this presents major problems. The material is either degraded by the mixing-in of sand to prevent congealment, or else it is allowed to congeal thus necessitating breaking-up and crushing before reprocessing.

2.2.3 Haulage and stockpiling

The haulage costs element of the removal of reclaimed pavement material is possibly the most widely varying factor in central plant recycling economics. Haulage economic balances depend on the following:

- (a) haulage distance from project to central plant;
- (b) savings in the haulage costs of new material;
- (c) haulage distance from project to tip or other conventional disposal site; and
- (d) savings in tipping fees or loss of revenue by not utilizing the material's conventional reuse value.

The stockpiling of sized, crushed or milled reclaimed material is of paramount importance. Unless adequate provision is made the material will be prone to congealment, moisture absorption, and contamination. In addition, if a poor technique is used, size segregation will occur during stockpiling. This factor will not only adversely affect the resultant mix but is also likely to be the cause of additional air pollution problems during reprocessing.

The degree of congealment depends on the length of the storage period, the prevailing temperature conditions, the height of the stockpile, and the nature of the reclaimed material. If congealment

does occur to any significant degree, then, apart from the obvious economic disbenefits of the further breaking and crushing operations, the resizing of the material will generate additional excess of minus-200-mesh fines.

In hot-mix recycling, high moisture levels in the reclaimed material lead to a waste of the energy needed to evaporate the excess moisture, and increase in the water vapour/dust emissions, a drop in the final mix temperature, and a reduction in the amount of the recycled element in the mixture.

Ideally, storage of size-reduced reclaimed pavements should be avoided. If undertaken, the material should be stockpiled in conical piles to minimize the surface area exposed to weather, and the lowest stockpile height that space will permit should be used to avoid congealment in the lower half. For long storage periods consideration should be given to covering the stockpiles with waterproof material. This latter precaution will also safeguard against possible contamination by dust and other pollutants.

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3. HOT MIX RECYCLING

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 - 3.2.2 Mixer heat transfer - alternative method
 - 3.2.3 Mixer heat transfer method - mobile modifications
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3.1 Preface

Quite apart from the techniques used to reclaim the pavement material, haulage economics, and other considerations, the validity of the process will naturally depend on the availability of recycling plant with the ability to:

- (a) produce the specified mix;
- (b) process a variety of combinations of reclaimed and new materials;
- (c) conform to environmental regulations;
- (d) operate at acceptable productivity levels; and
- (e) switch easily from recycling to conventional operations and vice versa.

The process has been undertaken successfully using modified mixing plant of either the batch or drum-mixer types. These modifications range from simple additions to existing plant, to highly complex equipment, preferably incorporated during the manufacture of new plant.

In practice the degree of complexity appears to have a direct relationship to the ability of the plant to economically produce mixes containing high proportions of reclaimed material and conforming to standard specifications, without infringing upon environmental regulations.

However neither the inherent complexity nor the high proportion of reclaimed pavement material are sacrosanct. Frequently, a modest ratio of old to new material is preferable in considerations such as grading requirements and the availability of reclaimed material for reuse. In addition, a producer can choose to recycle and meet all the requirements without having to invest a large amount of capital in complex plant modifications or having to acquire new plant.

Modifications can enable existing batch plant to be used successfully for recycling operations, including operations where the proportion

of reclaimed material is at least 30 to 40 per cent of the total mix.

Higher proportions of reclaimed material in the mix are possible through the use of modified drum mixers. The acceptable limit for most types of equipment is about 70 per cent, although with some processes 100 per cent recycling is at least theoretically achievable.

3.2 Batch plant recycling

3.2.1 Mixer heat transfer method

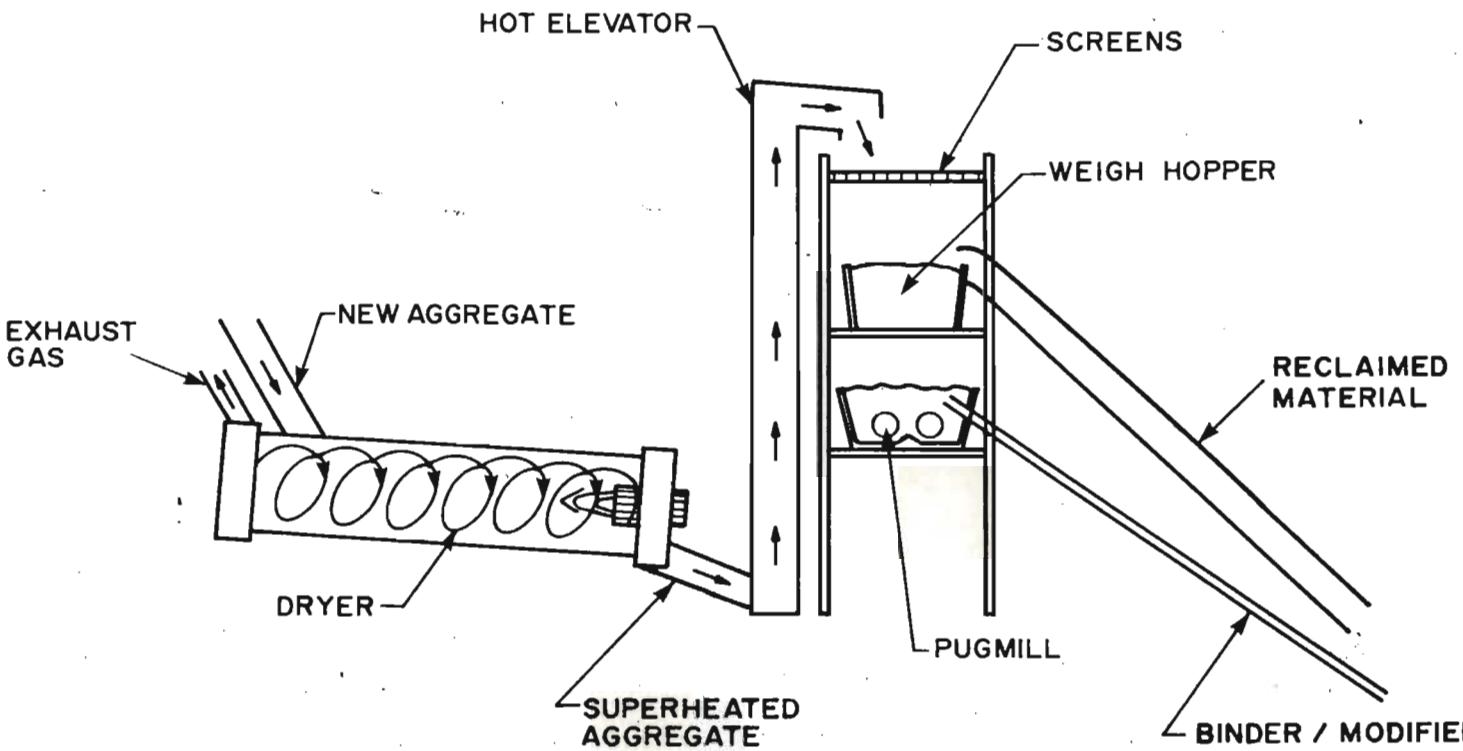
This method was first used in the USA, in 1976, and is known as the Maplewood Method or the Minnesota Method. It is easily installed on any conventional batch type plant and it is widely used in many parts of the world.

In this method (Figure 1) the reclaimed material is introduced directly into the pugmill, by-passing the dryer, hot elevator and screens. The new aggregate is superheated in the dryer and is introduced into the pugmill through the normal flow pattern.

The surplus heat in the new aggregate is transferred to the reclaimed material during the blending with additional binder or modifier.

This process prevents both smoke pollution and material build-up problems in the dryer, hot elevator and screens but is limited in the percentage of reclaimed material which can be used. This limitation is determined by the:

- (i) temperature of the superheated aggregate - highest practical temperature is probably about 300 °C;
- (ii) temperature of the stockpiled reclaimed material - a satisfactory, or pollution free, method of preheating this material has yet to be devised;
- (iii) moisture content of the reclaimed material - as this becomes



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FIGURE I
BATCH PLANT RECYCLING - MIXER HEAT-TRANSFER METHOD

greater the required superheating of the new aggregate increases significantly. A high moisture content will also result in water vapour/dust emissions in the pugmill area; and

- (iv) recycled mix discharge temperature - this assumes even more significance as the proportion of reclaimed material increases.

The plant modifications needed for recycling operations are as follows:

- (i) Aggregate dryer. Due to the superheating of a reduced volume of new aggregate, compared with normal heating, some changes may have to be made to the dryer flights. It is particularly important that an adequate veil is maintained in front of the burner flame. Some increased maintenance may be needed on the inside of the dryer, especially on the flights at the discharge end. A reasonable cooling period, running the dryer drum empty at the end of each production cycle, is recommended as a precaution against possible warping of the dryer shell and its internal parts.
- (ii) Dryer exhaust system. Because of the superheating, the dryer exhaust temperature is likely to be considerably higher than normal and some modifications may be necessary in cases where baghouse air pollution systems are used. The exhaust gas temperature can be controlled by redesigning the dryer flights. In addition, the baghouse gas entry temperature may be lowered by the use of long duct work, the addition of cooling air, or the introduction of water spray into the exhaust system.
- (iii) Screen deck. If the screen deck bearings are located inside the dust housing, excessive temperature build-up may occur. The use of special lubricants in these bearings is recommended.
- (iv) Hot bins. To prevent excessive falls of temperature in the superheated aggregate, consideration should be given, depending on the bin sizes and the material storage time, to insulating the outside of the hot bins.
- (v) Binder feeder. If a modifier is to be added, then some

provision for this should be made.

- (vi) Reclaimed material cold feed bin. In order to avoid congealment, this bin should be relatively small with steep sides and a large discharge opening.
- (vii) Reclaimed material feeder and conveying system. Since the reclaimed material is normally fed into the weigh hopper after the superheated new aggregate has been weighed in, the feeding and conveying capacity should be sufficient to ensure that the reclaimed material can be placed in the weigh hopper without delaying the mixing process. Furthermore, unless a special surge bin above the hopper is provided, the conveyor will be continuously starting and stopping during the operation, in which case a heavy-duty motor will be needed to power it.
- (viii) Weighing reclaimed material. The entrance chute into the weigh hopper should be as steep as possible, of constant width, and so directed that it deposits material in the centre of the hopper. It should also be equipped with a counterweigh draft gate in order to prevent the escape of dust when the new aggregate is introduced.
- (ix) Weigh hopper and pugmill emissions. During the weighing and mixing operations, emissions of both moisture and dust can occur. These are caused by the escape of moisture, in the form of steam, from the reclaimed material. The rate of release of this steam vapour can be quite high and can be calculated from the formula

$$R = \left(\frac{a}{1-b} - a \right) \frac{27,83}{c}$$

where

R = the release rate in cubic metres per minute,

a = the weight, in kilogramme of the reclaimed material per batch,

b = the percentage of moisture in the reclaimed material, and

c = the release time in seconds.

When the steam released carries dust particles, a real problem can occur. Dust entrainment can be largely prevented by minimizing the dry mixing time; this can also be achieved by keeping the moisture content of the reclaimed material as low

as possible, or by reducing the proportion of reclaimed material in the mix. Of course, adequate venting of the weigh hopper and pugmill will alleviate this problem.

3.2.2 Mixer heat transfer - Alternative method

In this method (see Figure 2) the reclaimed material is introduced during the process of flow by adding it to the superheated aggregate at the dryer discharge.

This approach, although considerably cheaper with regard to the modifications it necessitates, has certain important shortcomings. These are associated with congealment and emissions during the screening (at times by-passed) and weighing processes, and result in the process being suitable only for producing mixes containing smaller proportions of reclaimed material.

3.2.3 Mixer heat transfer method - Mobile modifications

Mobile modifications are now commercially available and are based on the alternative approach described above.

3.2.4 Dryer heat transfer method

In this method the aggregate dryer heats the reclaimed material together with any necessary new aggregate. The heated mixture is then fed into the hot bin on the plant tower, by-passing the screens. Any necessary binder, or modifier, is added in the pugmill. Theoretically, the percentage of reclaimed material is controlled only by the mix specification. However as the problems of smoke emission and material build-up on internal surfaces remain largely unresolved, this process is not currently available for commercial use.

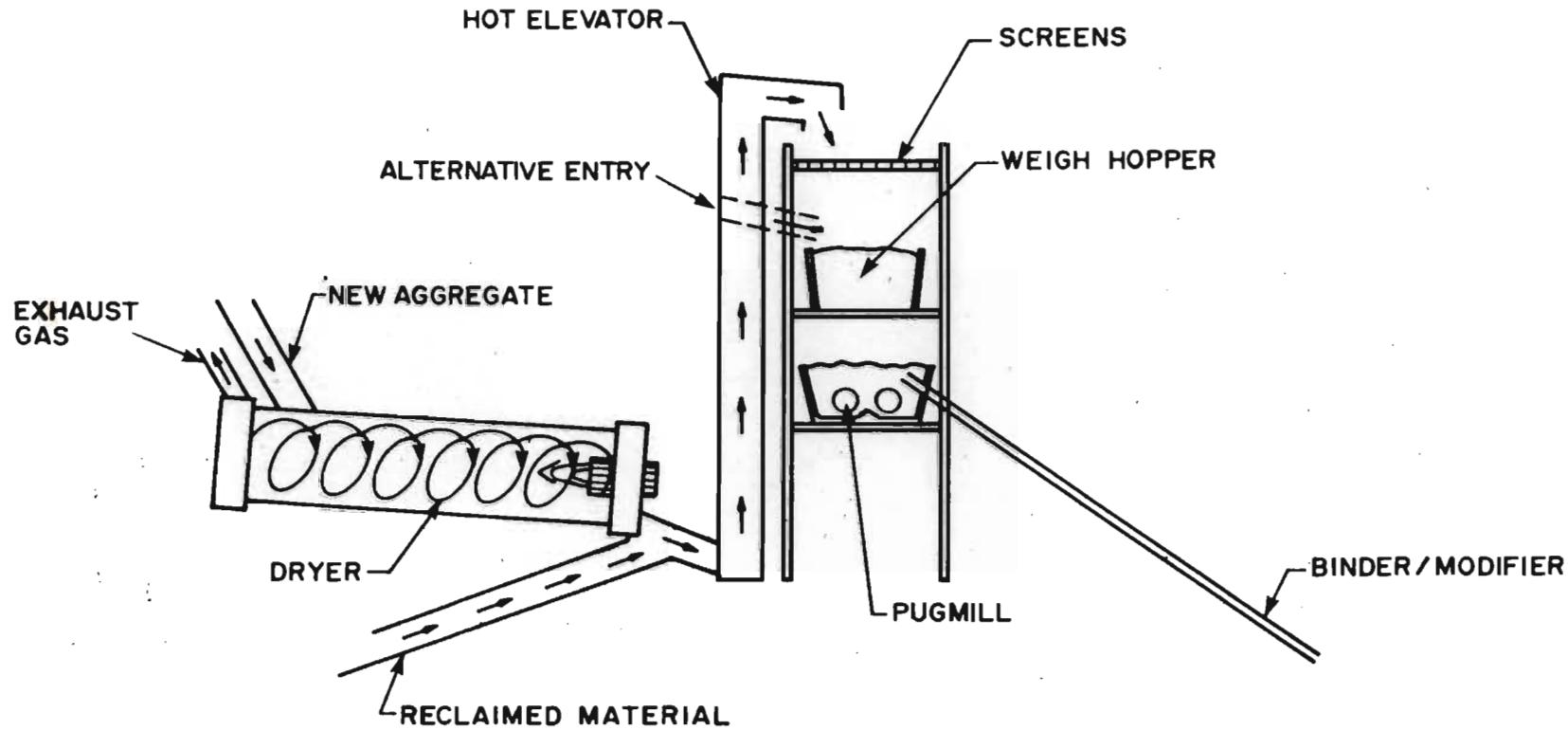


FIGURE 2

BATCH PLANT RECYCLING—ALTERNATIVE METHOD

3.3 Drum mixer recycling

3.3.1 Conventional plant

Standard drum mixer plant has been used in various experiments.

The reclaimed material is reprocessed, together with any necessary new aggregate and binder, in the drum mixer. The main problems with this approach are smoke emission and material build-up inside the drum. Exposure of the reclaimed material to high temperatures causes evaporation of the bitumen coating. The evaporated bitumen recondenses in the atmosphere, forming blue smoke with particle sizes in the 0,1 to 0,5 micron range. The collection of these hydrocarbon condensates from the exhaust system is not as yet practicable. Of course, smoke emissions can be prevented by operating at substantially reduced productivity levels, but this is not a reasonable alternative.

Despite the air pollution problems encountered when unmodified plant is used for recycling, the resultant mixtures obtained have been sufficiently good to encourage further experimentation and development (see Figure 3). The several attempts and developed methods include those discussed below.

3.3.2 Split-Feed, Direct-Fired method

Las Vegas Corporation (Mendenhall), following their introduction of the RMI Thermo-matic prototype plant in 1974, developed a split-feed system in which the reclaimed material was divided into several sizes, each entering the drum at different points, the coarse material entering at the burner end and the finer sizes entering progressively further away from the flame.

This has been the basic concept behind the centre-feed recycling processes developed later by CMI, Barber-greene, Standard Havens, Aztec Industries and other manufacturers.

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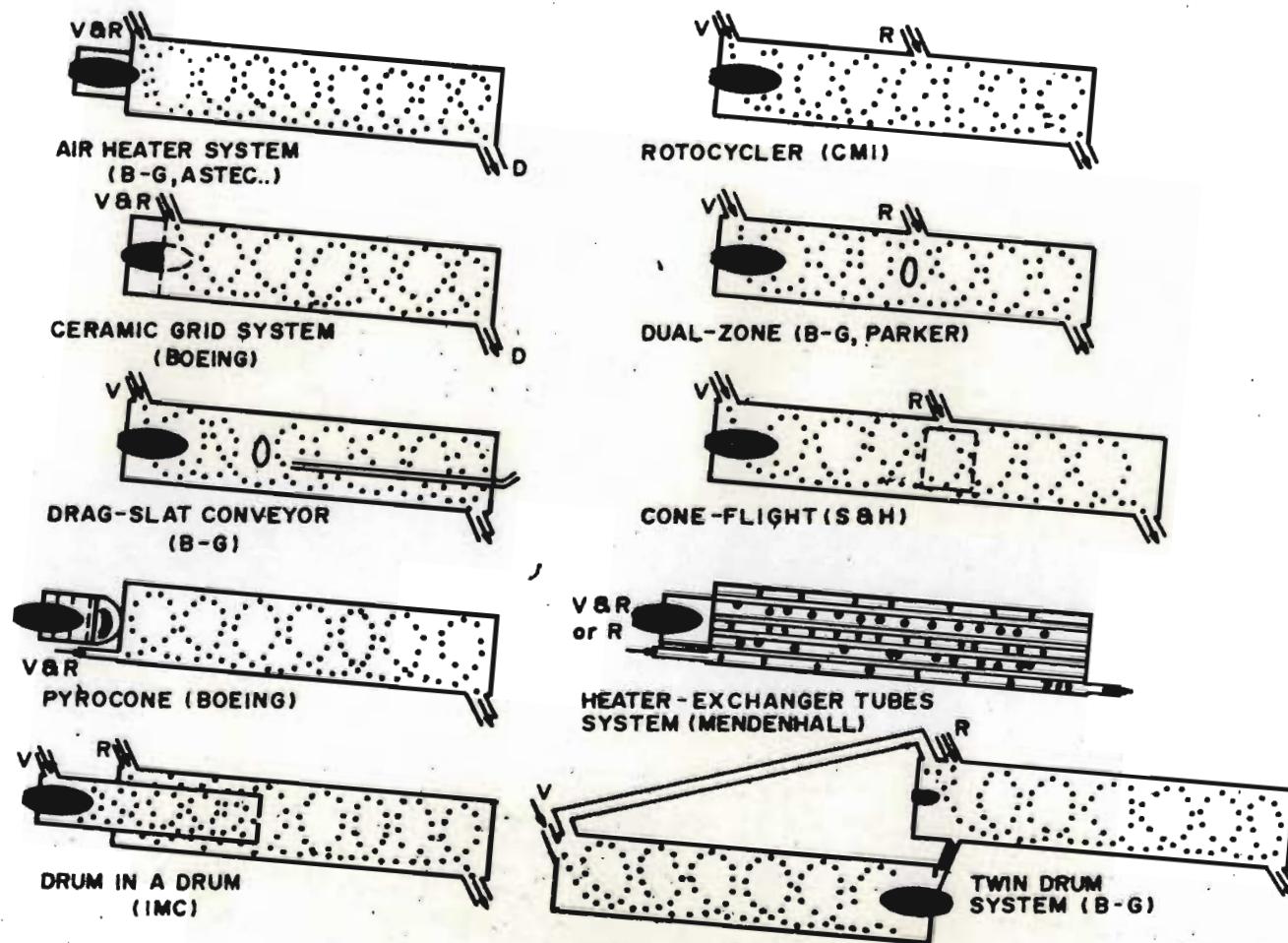


FIGURE 3
SOME DRUM MIXER RECYCLING SYSTEMS

3.3.3 Low-temperature convention heating method or air heater system

In this modification the burner was moved back from its normal position and a combustion chamber extension placed between the burner and the drum.

This arrangement allowed complete burning of the fuel before the combustion gases entered the drum and came into direct contact with the reclaimed material.

At times, in an effort to further reduce the effect of direct radiation on the reclaimed binder, the combustion gas temperatures were lowered by the introduction of large amounts of excess air. On the other hand, in some cases the hot exhaust gases were recirculated in the process.

However, this system was not successful in fulfilling the basic productivity and environmental requirements when substantial proportions of reclaimed material were recycled.

3.3.4 Ceramic grid method

This approach involved the installation of a grid between the burner combustion process and the cascading material inside the drum mixer, thus altering the heat transfer rate. In addition, the combustion gases were cooled by drawing excess air into the burner end of the drum, and the reclaimed material was sprayed with water while being fed to the drum.

3.3.5 Split-feed, drag slat conveyor method

In this method, developed by Barber-Greene, a rear feed, drag slat conveyor was used for introducing the reclaimed material into a 'Dual-Zone' drum mixer. A radiant heat shield, located at the centre of the drum, separated the radiation zone from the coating zone. The reclaimed material was introduced behind the shield in the coating zone where the temperature of the combustion gases was

sufficiently low to prevent the formation of blue smoke.

The main problems encountered concerned mechanical difficulties with the operation and maintenance of the drag slat conveyor.

3.3.6 Pyrocene system

This method was developed by Boeing as an extension to the low-temperature convection heating method.

In this process a conical heat shield, 'Pyrocene', is added in front of the burner. The Pyrocene diffuses the flame without appreciably affecting the gas temperature. The latter is reduced by drawing-in excess air through slots in the combustion chamber. Further cooling is achieved by spraying water onto the reclaimed material, just before entry to the drum, to assist in trapping the fines.

The ability to recycle very high percentages of reclaimed material and the elimination of a second cold feed and conveyor are significant advantages. However, the additions of water and excess air have a considerable effect on the thermal efficiency.

3.3.7 Drum within a Drum system

This process, developed by IMC (Cedar Rapids), was based on a smaller diameter drum inserted in the charging end of a conventional drum mixer. New aggregate was introduced into the inner drum and was heated by the combustion gases which were channelled entirely through this drum. The reclaimed material, introduced into the outer drum through a second chute, cascaded over the inner drum and was heated to some extent before meeting the new aggregate at the discharge end of the inner drum. Mixing and heat transfer occurred in the remaining section of the outer drum.

The advantages of this process included pollution-free operation and the maintenance of high thermal efficiency and productivity

levels during recycling. However one of the main disadvantages of the system was the limitation of production when processing all-virgin material. The capacity of the plant was significantly reduced unless the inner drum was removed. The concept of the drum within a drum was consequently abandoned in favour of a centre-feed system.

3.3.8 Centre-feed, roto-cycler system

In this process, developed by CMI, the new aggregate is fed in at the burner end, and the reclaimed material is introduced into the system at about the midpoint of the drum, where it is heated by the combined effect of the overheated aggregate and the hot combustion gases. The reclaimed material is protected by the dense veil of the new aggregate produced by specially designed flight arrangements.

3.3.9 Centre-feed, dual-zone system

In this process, Barber-Greene further developed their split-feed method by replacing the drag slat conveyor with a rotary charging system.

3.3.10 Dual-zone with added cooling air system

This is a further modification by Barber-Greene in an effort to overcome the environmental problems encountered while producing recycled mixes containing more than 50 per cent reclaimed material.

In this method cool air is introduced into the drum behind the heat shield, at the end of the radiation zone. The lower quantities of new aggregate produce a lighter veil resulting in higher gas temperatures at the drum midpoint. The addition of cooling air at this critical point has a less adverse affect on thermal efficiency than does the introduction of excess air at the burner.

3.3.11 Cone-flight system

This is another process, developed by Standard Haven, based on the split-feed concept. The reclaimed material is introduced downstream from the new aggregate inlet, where it cascades down the outer walls of a short hollow cone inserted in the drum. The new aggregate produces a denser veil as it travels within the cone, while the reclaimed material is heated to some extent by the cone walls before the two materials are brought together in the main drum.

3.3.12 Twin drum system

This process consists of two drums in series: a counterflow aggregate dryer and a parallel-flow drum mixer. The new aggregate is overheated in the dryer before being combined with the reclaimed material on entering the second drum, where heat transfer and mixing take place. The exhaust gases from the dryer are reheated and introduced into the drum mixer. The combination of the drum mixer's burner, the overheated aggregate, and the dryer's exhaust gases provide the necessary heat for the mixing process.

3.3.13 Heat-exchanger tubes system

In this process, developed by Mendenhall, the reclaimed material, together with any necessary aggregate, was processed in a special drum fitted with internal tubes which ran the entire length of the drum and terminated at each end at the head plate. The burner combustion gases entered and exited through holes in the plate and passed within the tubes through the drum. The heated discharge material was finally processed through a mixer, where any necessary binder or modifier could be added. The system was supposed to be capable of recycling 100 per cent reclaimed material. However, following the granting of licences for the manufacture overseas (Japan and the Netherlands) the method became suspect due to excessive build-up of material in the drum, and was consequently abandoned.

The material that built up was a combination of some of the residual binder and the minus-200-mesh portion of the reclaimed material. This problem was further aggravated when material containing high-penetration binders was reprocessed or treated with sealing agents or special additives.

3.3.14 Steaming system, Japan

This process has been developed in Japan and it entails steaming the ripped and broken bituminous material before introducing it into the drum dryer. The steaming process helps to break down the reclaimed material still further and increases its moisture content, so that smoke emissions are prevented in the dryer during the heating process. The heated material is mixed with any necessary new aggregate in a pugmill where additional binder may also be added.

Apparently, this method, which is widely used in Japan, enables mixes to be produced containing 100 per cent reclaimed material, without significant environment pollution.

3.3.15 Lemminkainen system, Finland

In this process a conventional drum is used for processing high percentages of reclaimed material with few, if any, modifications. In an effort to prevent smoke emissions the delivery conveyor is speeded up so that the material, which is heavily sprayed with water as it enters the drum, passes quickly through the burner flame.

3.3.16 Wibau system, West Germany

In this method the new aggregate was passed through a special exhaust gases filter, a 'Dribblefilter', before it was introduced, together with the reclaimed material, into the burner end of the drum. The use of new aggregate in the exhaust gas filtration process had the double effect of purifying the gases and preheating

the aggregate. Special flights, 'shadow flights', in the burner end of the drum protected the reclaimed material from direct radiation.

This system was used on the two West German autobahn recycling projects, in 1978 and 1979, producing base course mixes containing up to 65 per cent of reclaimed material. Wibau have currently abandoned this system due to the cumbersome nature of the filtration process, rendering the plant almost immobile, and to the inability of the shadow flights to protect the reclaimed material adequately.

3.4 Design and quality control

Until recently the main concern in hot mix recycling has been with the development of plant capable of reusing high percentages of reclaimed material without a significant loss of normal productivity and thermal efficiency, and without infringing environmental regulations. However, recycling will be of little use unless a satisfactory mix is produced.

The determining factor in arriving at the optimum reclaimed material/new aggregate ratio must not continue to be the capability of recycling plants, but the normal specification requirements with regard to grading, binder content and binder characteristics. An important criterion is the quantity of fine aggregate (particularly the minus-200-mesh material) produced by the crushing or milling operations. Typical values for material finer than 200-mesh have ranged from 8 to 13 per cent, although much higher percentages have been also reported.

To produce a satisfactory grading, a substantial quantity of new coarse aggregate material, with negligible mineral dust content, will have to be incorporated in the mix. Moreover, the grading of the added aggregate must be such as to blend with that of the reclaimed material so that the mix meets the specification requirements for conventional hot mixes.

To do this satisfactorily, the grading of the reclaimed material has to be established after it has been crushed or milled. It will be preferable to stockpile the reclaimed material, ideally in separate lots according to type and degree of uniformity, and to work from these stockpiles as if they were conventional processed aggregates.

The binder content in the reclaimed material must be established together with the penetration values of the recovered binder. The quantity and type of new binder is determined, taking into account not only the need to supplement the reclaimed binder but also the desired reconstitution of the properties of aged binder to those typically specified for conventional use.

The extent to which reconstitution of the reclaimed binder is necessary can be established by preliminary testing, and remedial action can be taken before full production gets under way. There are basically three corrective options:

- (i) selection of a different binder;
- (ii) reduction of the percentage of reclaimed material; and
- (iii) utilization of an additive.

With regard to the grading and binder requirements, it is unlikely that a high-quality mix can be produced if the content of reclaimed material is far above 50 per cent, except in rare instances where little or no dust correction is required.

In any case, the primary use of the hot mix recycled product is the subject of conflicting opinions. According to one standpoint, the product of hot mix recycling operations is no different from conventional bituminous mixes. On the other hand, there are those who maintain that hot mix recycling products are mostly suitable for car parks and private roads, or, at best, for secondary public roads.

There is also a strong argument that, if correctly designed, recycled mixes are better than new. This opinion is based on:

- (i) the belief that the currently available binders are

- unpredictable and inferior to the old types;
- (ii) the shortage of high quality aggregate;
 - (iii) the theory that binders in pavements can improve by being subjected to solar heating and cooling, which in time lowers their penetration and raises their viscosity. This is seen as the equivalent to continuing the refining process.

Only time and experience will show which standpoint is correct.

Road authorities have an important role in furthering understanding of the hot mix recycling process and establishing its particular applicability to their own material and specification requirements. However, various questions need to be answered. These include:

- (i) What effect do recycling agents have on the behaviour of pavement mixes?
- (ii) How efficient is the mixing of recycled pavement mixes?
- (iii) How do the life cycles of new and recycled mixes compare?

3.5 Recommended approaches and contractual procedures

It is accepted that recycling will not benefit all the various sectors of the asphalt industry; it is unlikely to benefit quarry owners, haulage contractors, aggregate producers and, possibly not, at least directly, oil companies. It must also be accepted that road authorities ought to be the main beneficiaries of recycling operations utilizing substantial quantities of their existing pavement material.

Road authorities should welcome and support the initiative for reusing existing pavement material resources, and emphasize the importance of adopting correct approaches and of exercising a certain amount of caution during the early stages of their involvement in hot mix recycling.

As pavement recycling has progressively gained acceptability, its full acceptance as a maintenance option has been increasingly advocated. Certainly this is valid for in-place recycling.

However, with regard to central-plant recycling, there will be many cases where the material removed from one site is used, after reprocessing, on a different site. In such instances a recycling decision will not necessarily have to be taken for the project involving removal of pavement material. On the other hand, a decision to accept a recycled mix will be needed for the project receiving the material.

Attempts by road authorities to opt for a comprehensive approach, although superficially and theoretically attractive, in practice will invariably lead to unnecessary complexities and, often, to the failure to proceed with a recycling package.

Furthermore, it will be extremely difficult to monitor and control the quality of the hot mix recycling material that is produced on the basis of a broad recipe-specification and contains a very high pre-determined proportion of reclaimed material. Experience in South Africa has highlighted the shortcomings of such an approach. Basically, it creates a contractual situation in which no one is responsible for the quality of the product. It has led to a great number of bad reclaiming, stockpiling and reprocessing procedures, all of which were detrimental to the quality and uniformity of the product.

In contrast, if the removal and safeguarded availability of the pavement material for recycling is considered to be the sole recycling consideration in the initial planning of resurfacing or reconstruction maintenance projects, then the whole recycling involvement will be much simplified. It will leave open the option for reclaimed material to be considered for incorporation in any project, including of course, the project from which the material was generated, always provided that the recycled product meets the appropriate specification requirements.

Adoption of such an approach will go a long way towards overcoming the current inherent resistance to central-plant recycling. Moreover, if road authorities were to incorporate in tender documents a simple statement such as:

'Bituminous mixes containing reclaimed pavement material will be accepted provided they meet the normal specification requirements'

then the industry would be able to make full use of this available commodity to the benefit of both themselves and their clients. It would certainly help to counteract the main reasons preventing fuller exploitation of the available recycling technology.

I strongly recommend the adoption of the above contractual concept which will enable clear areas of responsibility for the product's quality control to be established.

Such an approach will enable contractors to offer a recycling alternative based on a reclaimed/virgin material ratio which provides them with sufficient confidence that they will be able to adhere to the specification requirements. Furthermore, it will bring about a situation in which recycling will not be viewed in terms of special projects, but will be regarded as reclaiming of material which can be used on any project.

It will also bring the following benefits:

- Proper quality control of the resultant mix.
- Contractors will be able to tender for projects independently of their ability to recycle.
- 'Recycle benefits' on the contract from which the reclaimed material originated even if the recycling product is eventually used elsewhere, and vice versa.
- The decision, whether or not to recycle, can be left with the industry.
- The road authorities can be flexible with regard to either some relaxation in the specification (encouraging the industry to recycle), or the introduction of special tests for recycling products and restrictions on the proportion of reclaimed material in different pavement layers (providing additional safeguards).

The recycling of pavement material in urban areas, and in particular

that undertaken by local road authorities merits special consideration. Naturally, urban recycling will invariably produce significant and worthwhile cost savings over conventional options with regard to haulage economics. On the other hand the need, and corresponding extra effort required to segregate the reclaimed material according to type and degree of uniformity will be much greater as this material is likely to be obtained in comparatively small quantities from a number of different maintenance activities within an urban area.

Before becoming fully involved in the reutilization of existing material, the road authority must assess the possible savings on the basis of a realistic reclaimed/new material ratio, bearing in mind that, in view of the expected variability in the reclaimed material, its proportion in a mix, other than one intended for secondary uses, is likely to be small.

In any event the average proportion of reclaimed material need not exceed the ratio of existing material, available for removal, to new asphaltic mix requirements in the area. The preliminary assessment of the viability of recycling should include a correlation between the planned quantities of removed material which may be reused, the total premix demand and feasible recycling ratios.

With regard to reprocessing plant, it would be advisable to relate plant capability to actual needs before considering the acquisition of sophisticated and expensive equipment. Normally, modest modifications to available plant will suffice and experience has shown that modified batch plants can cope adequately with the requirements of urban recycling.

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4. COLD MIX RECYCLING

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4.1 Preface

As economic restrictions bite harder into road maintenance funds, road standards deteriorate. In general, the secondary network suffers the most, subjected as it is to the double effect of general shortfalls coupled with diversions of funds to the primary network.

In developed countries this phenomenon has been experienced relatively recently. However, in some western countries secondary road networks have been neglected, as part of a policy dictated by monetary shortages, for quite some time. As expected, the effect of not maintaining the roads has been a widespread deterioration, with many cases of pavement failure.

Pavement distress is not unique to any particular country. Rutting, ravelling and flushing, and crocodile, transverse and longitudinal cracking are commonplace on many surfaced secondary networks. Normally, the distress on unsurfaced (gravel) roads is even more pronounced. Pavement failures are likely to follow if these faults remain unrepai red.

In developing countries, by far the largest portion of the road network is unsurfaced, with or without a thin bituminous seal as a wearing course. Asphaltic layers are not common on low-volume roads.

The shortages in funds for road maintenance, with the resulting and anticipated deterioration in the secondary networks, have made cold mix recycling a viable maintenance option.

Cold recycling is not a new idea. It has been undertaken, in some form or other, ever since the first pavements deteriorated. Bituminous binders and portland cement have been used since the early 1940s in cold recycling operations involving the use of conventional equipment for the crushing of old bituminous surfacings and the combination of the pulverized material with part

of the unstabilized base and/or new aggregate, to form reconstituted pavement layers.

4.2 Stabilizers

Naturally, the binder in a reclaimed material has a residual value and will be reused. In addition, new binders are used in cold mix recycling in order to:

- increase structural capacity
- facilitate compaction
- reduce permeability
- reduce PI values
- reduce freeze-thaw potential.

Currently several binders are used to upgrade or stabilize existing pavements. Among the more widely used are emulsions, lime, portland cement, and fly ash in combination with lime or cement. Each of these, when properly used, is capable of meeting the appropriate design requirements. However, the determination of the correct quantity and type of binder additive is of extreme importance.

The selection of an additive is not always straightforward as there can be several possible candidates that can fulfil the particular circumstances and requirements. In such cases, the selection is based on cost and availability considerations.

Bituminous binders are best used with well-graded blends of material and they offer considerable benefits due to their versatility, the particle bond achievable, and the resultant flexible strength. Use of these binders facilitates compaction and increases the resistance of pavement layers to the effects of water ingress. Moreover, the existing hard and brittle binders can be modified by special bituminous additives and incorporated in the production of satisfactory new mixtures.

Emulsions are often the best choice, due to the inherent moisture content of the treated material. Both medium-setting and slow-

setting types are used. To ensure adequate adhesion, it is important that the proper emulsion, either cationic or anionic, is selected. There are some eleven distinct methods available for the design of mixtures incorporating emulsified asphalt.

A predominance of fine-graded or plastic material in bases and subbases is likely to preclude the use of asphaltic binders due to problems in achieving efficient and homogeneous mixing. Lime and portland cement binders can ameliorate the undesirable characteristics of such pavement layers. Lime stabilization is more suitable for use on highly plastic clays. Lime can also be used as a preliminary modifier, rendering the existing material suitable for the application of another binder such as emulsion or cement.

On the other hand, the incorporation of inferior material from the subbase can be avoided, or minimized, by the addition of new aggregate which can also improve the existing grading, a main factor in determining the quantity of additive needed. Such a procedure can make it possible to use asphaltic binder and to realise the benefits from the existing binder.

If cement is selected as the binder, preliminary testing for the deleterious percentage of organic matter, and the quantity of harmful sulphates, must be done. Recycling with portland cement has the advantage of producing relatively high-strength bases. However, both cement and lime have the drawback of not utilizing the binder content in the existing reclaimed pavement material.

4.3 Research findings

The correct design of cold mix recycled pavement layers entails understanding and knowledge of their structural capabilities. In the USA, extensive laboratory tests to determine the resilient modulus (AASHTO Structural Coefficient), coupled with in-situ deflectograph tests (Thickness Equivalency), were used to evaluate in-place recycled layers against standard bases. Comparisons

between the effective thickness of the new recycled layers and that of the control bituminous layers indicated that the stiffness of many recycled bases was equal to that of conventional layers.

Another study, part of the research project 'Recycling of Bituminous Pavements', jointly sponsored by the Indiana State Highway Commission and the Federal Highway Administration, and undertaken by Purdue University, investigated the influence of certain factors on the properties of a cold-mix recycled asphalt paving mixture. The factors investigated were the quantity of added binder, the quantity of added moisture, the type of added virgin aggregate, the compactive effort, and the curing time. A special high-float emulsion was used as the additive.

The study showed that the most important factor in the performance of a cold recycled mixture is the total effective binder content. Recycled mixtures with higher binder contents generally showed greater resistance to the action of water.

Further findings were as follows.

- (a) The addition of water facilitates the mixing process, but does not have much effect on the stability.
- (b) New aggregate can be added to reclaimed material, to produce a fairly stable mixture.
- (c) Stability values increase with curing time.
- (d) The effect of water increases with decreasing binder content, and decreases with curing time.
- (e) Excessive binder content leads to instability.

Many other studies have of course been undertaken. However, much work needs to be done in the development of appropriate laboratory and in-situ tests, if the indifferent performance of some cold mix recycled layers is to be improved.

4.4 In-situ methods

4.4.1 General approach

In general the equipment for these processes is similar to that used for in-place stabilization operations. In fact the cold mix in-place recycling of bituminous pavement layers often includes the stabilization of the material in the underlying unbound layer.

In-place cold recycling has been undertaken using plant such as rollers with fixed tines, bulldozers, scarifiers, planers, milling machines, rotary mixers, motor graders, windrow devices, power brooms, self-propelled vibratory or steel-tyred tandem and pneumatic-tyred rollers, pressure distributors, water distributors, and many other pieces of equipment.

The only additional requirement over soil stabilization equipment is the ability through extra power and wear resistance to size existing bituminous pavement layers effectively.

Several different approaches have been used for in-place surface recycling and base stabilization. In general the approaches differ according to the following factors:

- (a) thickness of the bound pavement (in cases where this does not exceed about 50 mm, pulverization can be performed without preliminary ripping and breaking operations);
- (b) incorporation of base or subbase stabilization;
- (c) type of new binder and/or modifier used;
- (d) incorporation of new aggregate;
- (e) degree of structural improvement needed;
- (f) use of cold-mixed product as a subbase, base, or surface layer with or without surface dressing.

In recent developments in pulverizers, travelling hammer mills, and cold milling machines, have had a significant influence on the construction techniques and acceptability of cold-mix recycling as a rehabilitation option. Currently, leading plant manufacturers

are developing equipment to improve this recycling method even further.

Some of the many, past and current, cold-mix in-place recycling systems are discussed below.

4.4.2 Reclamix

Reclamix was developed in the USA as a process for rehabilitating old asphaltic pavements by pulverizing the pavement, treating it with a softener to dissolve and enliven the asphalt and then relaying the mixture. The softener was 'Shell Asphalt Softener', a highly aromatic gas oil fraction claimed to have "superior penetrating and fluxing quality".

The first full-scale demonstration of the process was carried out in 1950 on a state highway in California. This work was sufficiently successful for the intended seal coat to be abandoned, and the reworked mixture to be allowed to be used as a wearing course layer.

The equipment used in the demonstration included:

- Hyster Grid Roller, a dual-purpose plant used for compaction and bituminous pavement material reclaiming. Its peripheral surfaces are cast steel grids of 40 mm bars on 125 mm centres.
- Athey Force Feed Loader and Portable Breaker Unit, a self-powered unit with a force feed loader which picks up broken pavement chunks up to 250 mm in size from a windrow and conveys them to a portable breaker unit attached at the rear. The hammer mill type of impact breaker reduces the old pavement to the original aggregate size in one pass.
- Gardner Road-Mixer, a self-propelled unit, mounted on a motor grader chassis, consisting of two rearward rotating drums in tandem on which are placed staggered spades alternately angled to provide maximum mixing in addition to pulverizing. A canopy which houses the rotating drums also contains a breaker plate and baffles to further assist breakage, and a series of

spray nozzles for the incorporation of liquid asphalt or asphalt softener.

The above plant is of course not essential in the application of the process which can be adapted to locally available plant with similar functions.

4.4.3 Retread

This is a method currently used in the United Kingdom for the rehabilitation of relatively lightly trafficked roads.

The retread process is specified in BS 434, and has been in use over the last twenty-five to thirty years in basically its present form. It provides an economical option for the treatment of deformed, cracked or crazed macadam roads on a sound foundation, by recoating the existing aggregate with bitumen. Due to current scarification limitations, retread is not suitable for use on hot rolled asphalt wearing courses.

Suitability for retreading and the precise form of treatment are established by a preliminary analysis of the road pavement material. The grading of the macadam is not critical provided that it contains a reasonable proportion of 40 mm stone, normally found in basecourse macadam.

The existing surface is scarified to a depth of approximately 80 mm and the pavement material is broken to a size less than 75 mm. This is accomplished by initial scarification using 8 to 10 ton rollers with fixed tines, followed by harrowing with specially designed reciprocating harrows. If required, 40 mm aggregate can be added to correct any deficiencies in the stone content or the existing profile.

The scarified material is reprofiled with a blade grader and emulsion is applied by a bulk pressure sprayer at a total rate of 5,5 to 6,5 litres per square metre, in two or three applications

depending on the grading of the existing material. Each application except the last is followed by harrowing to ensure adequate distribution of the emulsion.

The surface is then reprofiled and consolidated with a 8 to 10 ton roller. 14 mm clean chippings are applied during the rolling to fill in the voids between the stones and to close the open texture.

In order to provide impermeability and skid resistance, the surface is sealed with 62 per cent bitumen emulsion at the rate of 1 to 1,4 litres per square metre and blinded with 6 mm chippings before the final compaction.

It is recommended that a final surface dressing or asphalt carpet should be applied after the retreaded surface has been left open to traffic for a period of two to three months.

Although the process was first developed for use on minor rural roads, in the last few years it has been mainly used for the maintenance of suburban roads. Apart from the relatively low cost of the process, the main advantage has been its ability to reshape and strengthen road pavements while maintaining existing surface levels and avoiding the need to raise kerbs, sidewalks and manhole covers.

However, currently, with the limited maintenance funds and the concern about conserving material, retread is increasingly being used on rural roads. The process is at present applied annually, in the UK, to some 85 000 square metres of road.

It is more than likely that the demand for cheaper maintenance measures, coupled with further rationalization and modernization of the process, will substantially increase its usage and applicability.

Already successful trials have been undertaken using a milling machine for the pulverizing process, instead of the traditional rollers with fixed tines and reciprocating harrows. This is now

likely to be adopted as the standard procedure.

4.4.4 Midwest Asphalt Paving Corporation, USA

The company is one of the pioneers in the development of both equipment and techniques for in-place recycling, in which they first became involved in the early 1940s.

Their process involves the following steps:

- (a) pulverizing the existing pavement to a predetermined maximum size;
- (b) blending the pulverized material, and 50 to 100 mm of the underlying base, with an additive (usually liquid asphalt or portland cement);
- (c) grading the cold recycled mixture to the correct elevation and slope; and
- (d) compacting to the required density.

Modified Koehring and BROS equipment has been used for the above operations, producing pavements which have performed satisfactorily under urban traffic. More recently cold milling machines have been used for pulverizing. The availability of these machines in various shapes and sizes has overcome earlier misgivings relating to their bulk and expense. The only modification to conventional cold millers required is for the cutting drum rotation to be reversed, which will provide a down-cutting system. Even this is optional and at times counterproductive.

4.4.5 Independent Construction Company, USA

This company's method is based on the use of Metradon Model 127 Pulverizer and it consists of:

- (a) ripping with a tractor equipped with ripper teeth;
- (b) reducing the chunks to sizes of about 100 to 150 mm, using a drum compactor equipped with cutter pads;
- (c) reducing the chunks further with a segmented-wheel roller;
- (d) pulverizing the material to 40 mm maximum size, using the

Metradon;

- (e) stabilizing the reclaimed material using conventional equipment.

The Metradon is pulled by a bulldozer and as it moves forward the reclaimed material moves into the scraper and is impacted by blades attached to a rotating shaft.

4.4.6 Bell and Flynn Incorporated, USA

This company has been reusing bituminous pavement material since 1964, using BROS travelling hammer mills, motor graders, rubber-tyred loaders, static rollers and water trucks to produce untreated basecourses.

Portions of reclaimed base material may be incorporated to achieve the required gradation. The sized reclaimed material is fine-graded and compacted before a tack coat and new surfacing are applied.

4.4.7 Pulvi-Mixers

These machines can be used for both pulverizing and mixing operations. These are accomplished in two separate passes. The binder additive is applied in between the two operations.

Pulvi-mixers are produced by Rex, BROS, Seaman, Bomag, and others.

4.4.8 Bomag

The Bomag MPH-I pulverizer/stabilizer forms the basis of this approach.

Pulverizing is done with a single pass and the pavement layer is reduced to a recommended sizing of 95 per cent passing the 50 mm sieve. Any chunks produced are retained in front of the rotor to be struck repeatedly until they are satisfactorily pulverized. The

sized material is graded before any necessary new aggregate is added.

Liquid asphalt and lime slurry additives can be applied through the spraying system of the stabilizer. If cement or dry lime are selected as additives, these are spread at the required application rate and the stabilizer's liquid additive system is used for spraying the needed water directly into the mixing chamber. This procedure replaces several passes by a distributor truck. To facilitate the evaporation of excess moisture, additional passes of the MPH-I can be used for aeration.

The company recommends vibratory compaction and the overlaying of the recycled layer with a wearing course, which may consist of as little as a 20 mm double seal coat or as much as medium lifts of hot-mix asphalt.

4.4.9 Pettibone Equipment

The Pettibone company has developed special equipment for undertaking in-place cold-mix recycling. The equipment, whose use dates back to 1975, includes:

- P-500, P-550, P-660 Travelling Hammer mills (not self-propelled). The P-500 contains 24 rotating hammers, each weighing 27 kg and has a maximum production rate of about 200 tons/h.
- SM-750 Speedmixer. This machine can mix to a depth of 400 mm.
- C-205 Vibratory Roller.

Work undertaken with the above plant has included projects in California, Wisconsin, Indiana, Washington, Texas, Kansas and Michigan.

4.4.10 Portland Cement Association Method

In their guide, 'Recycling failed flexible pavements with cement', published in 1976, the PCA state that 'alive' bituminous material

should not be used in the production of cement-based recycled mixtures.

When the old bituminous surface material is practically 'dead', however, it may be used, given the normal control factors for soil-cement:

- adequate pulverization
- proper cement content
- proper moisture content
- adequate density
- adequate curing.

Their recommended procedure is as follows:

- (i) Scarify and pulverize the bound layers.
- (ii) Scarify and break up the base material.
- (iii) Blend the reclaimed material.
- (iv) Shape to the approximate crown and grade.
- (v) Spread and mix the cement.
- (vi) Apply water and mix.
- (vii) Compact.
- (viii) Finish.
- (ix) Cure.

4.4.11 CMI Equipment

The CMI equipment has been used for normal cold milling and also in several novel approaches. Some examples follow.

- (a) A rejuvenator agent, 2 per cent by weight of the reclaimed material, was applied through the internal spraying system of a PR750 rotomill, while the machine was milling 100 mm of the bituminous pavement. Once mixed, the sized reclaimed material and rejuvenator were windrowed behind the rotomill. A following paver, fitted with a CMI Clarco Windrow Elevator, relaid the rejuvenated pavement which was subsequently compacted in a conventional manner. This successful trial was undertaken on a half mile section of a 12-mile hot recycling

project in Kansas.

- (b) On a cold mix, in-place, recycling project in Michigan, on interstate 75, a rotomill was used to convey the pulverized material directly into the mixing chamber of a following P&H mixer-paver. The asphalt additive was also introduced in the mixer. Some difficulty was experienced in adjusting the production rate of the rotomill to the capacity of the mixer-paver, when at the same time allowances had to be made for geometric deficiencies in the existing pavement.
- (c) On a section of the California interstate 395, a PR750 rotomill was used to mill some 80 mm of bituminous material. The rotomill towed a 40 mm vibrating screen and a roll-crusher mounted on a trailer. About 90 per cent of the milled material was screened and deposited in a windrow. The rest was reduced by the crusher to minus 25 mm and discharged on the windrow. The cold-mix recycling train included a standard loader which picked up the reclaimed material and placed it in the hopper of a Midland Mix paver, where the recycling agent, Cyclogen ME, and 3 per cent of water were added.

4.5 Central-plant operations

Although central-plant, cold-mix recycling is much less frequently used, it has considerable advantages over in-situ recycling. These are listed below.

- Better quality control can be maintained with regard to gradation, binder content and homogeneity of the mixture.
- The resultant mix can be used in any new layer in the altered pavement structure.
- The resultant mix can be used on sites other than the one from which the material was reclaimed.
- Reclaimed material can be stockpiled for future processing.
- If the action of additives is time-dependent, this can be more easily controlled.
- A greater variety of applications is possible as the way in

which the reclaimed material is reused does not depend on the underlying layers of a pavement remaining in-place.

- Geometric alterations to the road can be undertaken more freely.
- The by-products of sizing and grading can be used to supplement aggregate or as filler in other operations.

However, the process will only be economically practical if there is a recycling plant available within a reasonable haulage distance from the reclaiming site. Furthermore, if the recycled product is to be used on the site from which the material was reclaimed, central-plant operations are likely to cause considerably more traffic disruption than in-situ recycling.

4.6 Relevant parameters

I think that the ultimate success of cold-mix recycling operations on any project must depend on the:

- understanding of the structural requirements of the pavement;
- undertaking of thorough preliminary investigations and the laboratory analysis of representative samples to determine consistency, gradation and effective residual binder;
- compliance of the recycled mix with conventional specifications and whether gradation can be corrected by the introduction of new aggregate;
- selection of the correct type and quantity of binder or modifier;
- use of the right plant and construction procedures;
- availability of appropriate testing procedures and facilities;
- cost savings being satisfactory.

On this last point, there are two main factors which tend to make this recycling option particularly attractive.

- (i) Most of the binders normally used for cold-mix recycling are easily available and relatively cheap.
- (ii) Conventional pulverizing and mixing equipment is used, albeit that minor modifications are sometimes needed.

4.7 Concrete materials

4.7.1 The case for recycling

In general cold-mix recycling involves breaking up and sizing existing pavement layers, mixing the reclaimed material with new aggregates and binder, and using the resultant mix for new pavement layers.

However, strictly speaking, any reuse of existing pavement material falls within the definition of recycling. Thus, it can be argued that cold-mix recycling includes certain maintenance operations on gravel and other unsurfaced roads, and even the use of old pavement material as fill or backfill. However, it is clearly beyond the scope of this thesis to examine such forms of pavement material recycling as well.

Similarly, the recycling of concrete pavement material should also fall outside the scope of an examination of bituminous pavement recycling. Nevertheless, concrete layers are often an integral part of a pavement structure. Furthermore, I believe that a thorough examination of pavement material recycling will not be complete without reference to concrete material recycling.

The recycling of concrete road pavement, airfield runway, foundation and building material is by no means a new idea. Understandably, as cement is not a reusable binder, concrete material recycling has never been subjected to the international attention given to the recycling of bituminous material. Nevertheless it is a practical and normally simple activity which does not give rise to environmental pollution problems or require expensive and complicated reprocessing equipment. Moreover, at least in cases where old concrete is used to produce aggregate for unstabilized bases and subbases, the process is entirely free of the technical uncertainties and prejudices associated with bituminous pavement recycling.

The broken and crushed portland cement concrete simply provides an alternative source of aggregate. This reclaimed material can be successfully used to produce stabilized and unstabilized bases and subbases, lean concrete, portland cement concrete and bituminous mixtures. The reuse of old concrete would not only conserve raw materials but would also reduce construction costs and conserve energy for projects in regions which are short of aggregate. It would also eliminate the need to haul and dispose of concrete materials removed from reconstruction projects.

The possibility of reusing old concrete should be carefully considered whenever good quality aggregates are not readily available locally, or the cost of disposing of the old concrete material will be greater than the cost of reclaiming.

4.7.2 Aggregate reclaiming

The process involves the preliminary breaking up of the pavement in situ and its further reduction by primary and secondary crushing at a central plant. The sizing of the reclaimed aggregate can be specified for the intended use and the crushed material* can be blended with new aggregate to meet the required grading. Both the breaking and crushing operations are undertaken using conventional equipment.

Reinforcing steel can present a problem. However this can be easily removed at any of the following stages:

- (i) in situ, following the breaking operation;
- (ii) during the stockpiling operations;
- (iii) just before primary crushing;
- (iv) on the belt following primary crushing;
- (v) on the belt following secondary crushing; and
- (vi) in the stockpile before reprocessing.

Torches or pneumatic shears can be used to cut and remove steel bars, and any wire mesh reinforcement tends to break away easily

*Primarily pyramidal in shape with a slightly higher absorption and lower specific gravity than most natural aggregates.

when the reclaimed concrete is pushed into piles for loading. Some modern crushing plant is able to remove reinforcing steel automatically as the crushed concrete moves forward for screening.

4.7.3 Applications

There are five distinct options for reusing concrete material. Old concrete can be recycled to produce:

- (1) Aggregate for unstabilized bases and subbases.
- (2) Stabilized base mixtures. The binder used can be either bitumen emulsion or portland cement.
- (3) Lean concrete using conventional concrete mixers and slipform pavers.
- (4) Portland cement concrete. Preliminary tests are necessary to establish whether the new concrete, containing the reclaimed aggregate, has acceptable strength and durability.
- (5) Asphaltic mixtures. The binders used in hot-mix reprocessing can be either bitumen or bitumen emulsions.

4.7.4 Quality control

Some contamination, in the form of fines or asphaltic particles, can be tolerated if the reclaimed material is used to produce graded material, stabilized mixtures or lean concrete. However, good-quality reclaimed aggregate must be used in the production of concrete or asphaltic mixtures. For these purposes the reclaimed aggregate must be free of chemical reactivity, reinforcing steel, excess of fines, organic matter and other deleterious materials. In particular, reclaimed pavement material intended to be used as aggregate in the production of concrete must be free of significant quantities of bituminous pavement material. In fact, in all pavement material recycling operations, bituminous overlays and concrete slabs must be removed and crushed separately.

Reclaimed aggregate from building demolition contains varying quantities of gypsum, glass, plastics, bricks, wood and metals. Wood and gypsum are particularly harmful, the former because it is

soft and subject to considerable volume changes, and the latter due to its chemical reactivity to portland cement. However, due to their relatively low densities, both these contaminants can be easily removed by conventional aggregate beneficiation equipment.

With regard to aggregate sizing and grading, reclaimed-new material proportioning, binder content and mixture homogeneity, satisfactory control can be achieved in central-plant recycling operations. The theoretical design principles are no different from those applicable to conventional mixtures. Nevertheless, in practice special attention should be paid to aggregate sizing and preventing an excess of fines.

4.7.5 Research findings

Laboratory research in the Soviet Union in 1946 and more recently by the US Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi has shown that the compressive strengths of recycled portland cement concrete is marginally lower than that of conventional mixtures. The two studies also found that mixtures containing crushed concrete as fine aggregate require more cement than those using natural sand. The Mississippi research also showed that the reclaimed coarse aggregates have improved resistance to frost. This was attributed to the sealing-off of voids in porous aggregates by the old mortar.

Recent research by the Massachusetts Institute of Technology has shown that reclaimed aggregate can be used successfully for the production of portland cement concrete. Moreover, it was found that concrete containing high-quality reclaimed aggregate has greater flexural strength than conventional concrete of equivalent crushing strength, and possesses more favourable freeze-thaw resistance and volume stability under thermal and moisture changes than conventional concrete.

4.7.6 Energy and cost savings

The energy that can be saved through the use of reclaimed concrete rubble aggregate for the production of new concrete pavement material, was demonstrated in a paper presented by Ray and Halm in the United States, at the 1978 Transportation Research Board meeting. Their main findings were:

- (i) In energy terms, the reuse of reclaimed pavement aggregate to produce concrete pavements appears to be economical when the haulage distance for new aggregate is over 80 km.
- (ii) Less energy appears to be needed to crush waste concrete than to produce new natural aggregate.

At the same Transportation Research Board session, Professor Frontistou-Yannas, of Massachusetts Institute of Technology, presented a paper exploring the economics of concrete recycling. The paper demonstrated that a metropolitan commercial crushing plant, obtaining concrete rubble as waste and producing 225 000 tons of aggregate per year, should be able to sell the reclaimed aggregate at \$1,67 per ton compared with \$3,30 per ton for natural aggregate.

That concrete pavement recycling is economical was clearly demonstrated on several individual projects in the United States, where recycling was done because it was the cheapest option tendered.

4.7.7 Historical background

Concrete pavement recycling in the USA dates back to the post-World War II reconstruction period when crushed concrete pavement material was used as aggregate in the unstabilized basecourse of a project on US 66 in Illinois. In 1964 reclaimed concrete aggregate was used to produce the cement-stabilized subbase of the Love Field runway in Texas. The first large-scale use of existing concrete pavement as aggregate for asphaltic concrete occurred on State Highway 36 in Burleson County, Texas, in 1969. A number of other

concrete recycling projects followed in Texas during the seventies.

In 1975 reclaimed concrete and asphalt pavement aggregate were used for the first time to produce the lean concrete subbase of a concrete road in California. Since then the California Department of Transportation has developed specifications which have been used on several other similar projects. The first concrete pavement containing reclaimed concrete aggregate was laid on US 95 in Lyon County, Iowa in 1976. This project also included a composite section consisting of a 175 mm layer of lean concrete, produced using reclaimed concrete and asphalt pavement material, and a 100 mm concrete wearing course containing concrete aggregate. The Iowa Department of Transportation followed up this project with several others including contracts involving 25 km of roadway on I-680 in Pottawattamie County and on Iowa Route 2 in Page and Taylor Counties during 1977. Also in 1977, reclaimed concrete aggregate was incorporated in the drainage system and used in producing the lean concrete base of a runway at the Jacksonville International Airport, Florida.

During 1980 concrete recycling in the USA included projects on the I-84 Connecticut, US 59 Minnesota and I-94 Chicago, Illinois. Other areas with experience in concrete pavement recycling include Wisconsin, where several projects have been undertaken since 1972, Michigan and Washington D.C.

Of course, the USA has not been alone in recycling concrete. Since World War II several countries have undertaken projects involving the breaking and crushing of old concrete road pavements and airfield runways to produce coarse aggregate material. Thus, concrete has been recycled in one form or another in the Netherlands, United Kingdom, West Germany, France, Soviet Union, Canada, South Africa, Japan and many other countries.

In the Netherlands successful recycling work has been carried out using selected rubble from demolition sites as aggregate for basecourse mixes. The hard core consists of concrete, brick and

other materials, and is mixed with bitumen. Extensive investigations have established the performance equivalencies of hard core asphalt layers (of various thicknesses) and layers of conventional asphaltic mixtures.

On a strict project basis, the economic considerations do not justify this form of recycling. However considerable savings can be realised on a wider basis, taking into account the disposal costs of this material. There is also strong support for the process in cities such as Amsterdam and Rotterdam which are prepared to pay high prices for the recycled product in order to prevent the accumulation of waste.

The Netherlands has also carried out concrete pavement recycling. On an airfield, 20 000 tons of a 20 mm thick concrete pavement were crushed and respread after mixing with 20 per cent sand and 16 kilogramme of cement per square metre to produce a lean concrete base. A Bross soil-cement stabilizing machine was used.

In South Africa recycling of cracked cement-treated bases has been carried out fairly widely, mainly in the Transvaal. Usually the process is undertaken *in situ* where it involves pulverizing the pavement with grid rollers, applying emulsion, mixing of the reclaimed material and emulsion with disc ploughs, and then reprofiling the recycled material with graders. After compaction, a new wearing course is applied. Relatively recently a project has been carried out, in the Orange Free State, involving the removal and crushing of a cement-treated base and asphalt wearing course and their subsequent recycling in a central plant. While the crushing and recycling operations were being undertaken, the subbase was stabilized in place with emulsion. As there are many kilometres of rapidly deteriorating roads with cement-treated bases, other similar projects are planned.

In Japan, concrete recycling is quite common. The Niigata engineering company has developed central-plant equipment which can undertake both the cold-mix recycling of concrete and asphalt hot-

mix recycling. The steam method is used for reprocessing bituminous pavement material, whereas conventional methods of primary and secondary crushing are used for recycling concrete. The capacity of the plant is 70 tons per hour for hot-mix recycling and 150 tons per hour for cold-mix recycling. The cold-mix recycled material is used for the construction of subbases and basecourses.

In France concrete recycling is receiving serious attention. Concrete pavements are presenting serious problems mainly due to loss of skid resistance. Surface dressings were applied with limited success, and grooving techniques and thick overlays are considered to be too expensive.

In the United Kingdom, following the establishment of the Working Party on Reconstruction of Motorways and Trunk Roads, a sub-committee on recycling of pavement material was set up in 1980 by the Department of Transport. With regard to concrete recycling, a project was carried out that year involving the reclaiming of type I subbase and lean concrete material from an M1 reconstruction site in Buckinghamshire and the use of the reclaimed material as subbase aggregate and for the production of a fairly consistent lean concrete material. The products were marketed on a normal commercial basis by Hartigan who carried out the crushing and reprocessing operations at a central-plant site nearby the reconstruction project.

4.7.8 Commercial recycling

An important development in concrete recycling has been the setting-up of numerous commercial concrete-reclaiming plants in metropolitan areas throughout the USA.

Areas where such plants have been established include Washington DC, Chicago, New York, Detroit, New Orleans, Los Angeles, Savannah Georgia, Cleveland Ohio and Pontiac Michigan. In addition to using such plant on permanent reprocessing sites, several operators find it more economical to move portable crushing plant to fixed dumping

sites whenever sufficiently large stockpiles accumulate.

These plants process waste concrete material from road pavements, buildings, kerbs, channels, columns and sidewalks. The recycling operations help to solve serious waste disposal problems for the city authorities and demolition contractors, reduce haulage costs and disturbance, save resources, and provide supplies for contractors in metropolitan areas.

4.7.9 The current situation

As good-quality aggregates become increasingly expensive and scarce, old concrete pavements and demolition sites are being recognised as potential sources of readily available material. The reclaiming of this resource has become technically possible as well as commercially and economically practical.

The undertaking of projects such as the 16 mile long two-lane section of US 59 Minnesota and the 15 mile long six-lane section of Edens Expressway I-94 Chicago, show that both the road authorities and the construction industry have great confidence in the validity of concrete pavement recycling. The spread of commercial concrete recycling activities is also very encouraging.

The American Concrete Paving Association is actively promoting the use of recycled concrete in subbases and composite or full-depth concrete pavements, and the Federal Highway Administration has a programme, started in 1978, to encourage highway agencies to use recycled concrete pavement in their projects and evaluate the subsequent performance. Demonstration Project No 47, "Recycling Portland Cement Concrete Pavement", is aimed at broadening the experience of highway agencies and developing additional techniques for the recycling of concrete pavements. Individual demonstration projects qualify for federal funding if the recycled concrete is to be used as aggregate for bases and subbases, or in producing lean concrete or concrete for new pavements.

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5. HOT SURFACE RECYCLING

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5.1 Preface

Bituminous surface courses may have various compositions and thicknesses, but their fundamental function is to provide, in conjunction with basecourses, pavements of acceptable riding quality which can withstand the effects of traffic and climate. A surface course has four basic critical requirements: stability, flexibility, durability and surface texture. These are discussed below.

- (i) Stability - The mix must be resistant to permanent deformation or plastic flow as caused by traffic; in other words, it must not rut, corrugate, shear or push. In general, dense mixes using crushed coarse and fine aggregates give maximum stabilities, with stability increasing as the stone content increases. Such maxima are not necessarily the optimum for other properties.
- (ii) Flexibility - The mix must be resistant to cracking, as cracked mixes will not be able to distribute traffic stresses effectively and will allow water to penetrate the pavement. Fracture of a mix is caused by fracture of the bitumen, and the permissible breaking strain and breaking strength are functions of the stiffness of the bitumen. The bitumen content, grading and density of the mix all affect the magnitude of the strain in the bitumen that will result from the stress/strain conditions to which the mix is subjected. In general, dense mixes with high bitumen contents of the harder penetration road grades show the maximum resistance to fracture.
- (iii) Durability - The mix must be resistant to changes caused by water and air. The entry of water into a mix can, in certain instances, result in loss of adhesion, whereas the entry of air causes ageing of the bitumen. In all cases the higher the void content of the mix, the higher the water absorption and air permeability. When mix durability is compared, the major factor is permeability since this gives an indication of the interconnection of voids. Dense mixes of the hot rolled type

have high durabilities.

- (iv) Surface texture - The mix must provide adequate skid resistance but must not disintegrate due to fretting or ravelling. The skid resistance depends largely on the resistance to polishing of the aggregate in the surface, and the texture depth of the surface. The latter factor is critical at high traffic speeds not only to prevent aquaplaning but also to minimize traffic spray. Traffic volume affects both polishing and texture depth, as do temperature and climate. Furthermore, lower bitumen contents give better skid resistance.

It will be understood that the optimum mix involves a compromise between the above properties. In general, in gap-graded mixes emphasis has been placed on producing mixes of high durability and high resistance to fatigue, surface texture being provided by the use of selected precoated chippings, whereas, in continuous graded mixes the greatest importance is placed on stability. In the United Kingdom there is increasing use of design mix rolled asphalt relating stability to traffic flow, and with the introduction of stiffer mixes, particularly on motorways and other heavily trafficked roads, and the stringent texture depth requirements, it is expected that longer lives will be obtained from wearing courses.

Where base or drainage problems are not involved, surface maintenance is required on the primary routes to correct surface irregularities and surface texture.

Problems of durability or cracking are unusual, although they obviously can occur, particularly on secondary roads where traffic is light and when open-graded mixes have been used. Conditions of critical durability and cracking are more associated with countries such as North America, where the climate has extremes of hot and cold and the asphalt mixes are of the continuous-graded type and relatively low in bitumen and filler.

The development of rutting in the wheel paths and an unsatisfactory surface texture is usually a gradual process caused by traffic repetitions along channelized lanes. The mix is not usually defective, and removal is only necessary if the mix has so deformed that overlays will result in differential compaction, or road furniture and drainage levels are such that only an inadequate thickness of overlay can be superimposed.

5.2 Resurfacing options

Although there are many variations, the basic methods available for restoring the surface texture and/or riding qualities of a distressed road surface are as follows:

(i) Surface treatment - This process is susceptible to adverse weather conditions and dust, which impair adhesion. The specification must be well suited to the condition and characteristics of the existing road surface. Workmanship and aftercare are also critical.

Substantial improvements and innovations have been made with surface treatments in the past and, providing the surface profile is acceptable, it is possible to apply a surface treatment which will meet most traffic requirements. In effect, it is particularly suited to restoring the surface texture and decreasing the permeability of most roads other than those carrying high-speed traffic and heavy traffic volumes.

(ii) Overlay - The use of overlays as a means of restoring riding qualities and surface texture is well established, and where irregularities are not large and drainage and road levels allow, this can be an economical method. Furthermore, such overlays can significantly strengthen the pavement structure. However, the thickness is governed by the maximum stone size and, in gap-graded mixes, the need to apply precoated chippings which can result in a thickness which might otherwise be unnecessary.

- (iii) Removal and resurfacing - Removal of the old surface and replacement with new materials is the ultimate solution. It is used if the old mix material is considered to be defective, or the surface irregularities are such that they will reflect through the new surface, and if levels are critical: for example when renewing one lane of a highway. Undoubtedly very satisfactory results can be obtained by this method both for reprofiling and renewal of surface texture. However, up to 100 kg per square metre of old materials is thereby discarded and a similar amount of new mix introduced. The total consumption of materials seems wasteful of resources. There can also be considerable interference with traffic due to the two-stage process although new types of milling equipment speed up the operation considerably.
- (iv) Surface refinishing and retexturing - These processes are not appropriate for surfacings with precoated chippings. Nevertheless they are a practical surface treatment for other mix types.
- (v) Surfacing recycling - Developments with equipment have resulted in innovations which allow utilization of part or all of the existing surfacing material. These methods result in substantial savings in material and minimum traffic disturbance, and may be considerably cheaper than other methods.

5.3 Recycling systems

Various forms of hot surface recycling have been practised since 1930, when heater-planer machines were first developed. One such example is the use of heating to allow new polish-resistant chippings to be embedded in the wearing course, thus restoring the skid resistance of a pavement surface. Other approaches include the various heating and fill-in/overlaying techniques used in countries such as Norway and Sweden.

A major development has been the incorporation of scarifiers behind the heater bank, which enables a bituminous pavement to be heated and scarified almost to the full-depth. The various surface recycling processes based on this approach have been particularly attractive due to their ability to:

- deal with a variety of wearing layer distress forms, including ravelling, rutting, bleeding and corrugations
- reduce reflective cracking
- provide a strong bond between existing and new pavement layers
- save on costs by using thinner overlays.

Recent innovations have made it possible to correct deficiencies in existing wearing course material by either introducing modifiers or mixing the scarified pavement material with appropriate proportions of corrective new mixes.

Where the pavement distress is limited to the wearing course, surface recycling techniques are extremely effective and are unquestionably the appropriate form of recycling. This is because the hardening and oxidation of the bitumen are most severe in the top 3 mm, so the part of the wearing layer most in need of rejuvenating is well within the range of most types of surface recycling (see Figures 4 and 5).

There is a wide variation in both the equipment and methods used for surface recycling. At least 19 distinct surface recycling processes, all based on the heating-scarifying approach, have been used to date. These variations are represented in Figure 6.

The equipment varies in both appearance and design, and includes plant produced by:

Ajax Paving Industries : heater-scarifier unit.

Asphalt Equipment Inc. : heater-scarifier unit (fires horizontally).

Angelo Benedetti Inc. : "Recycler", can reprofile and relay the scarifier material (indirect heating).

Cutler Recycling Inc. : "Metro" and "Jumbo" repavers can reprofile scarified material and add new mix and/or

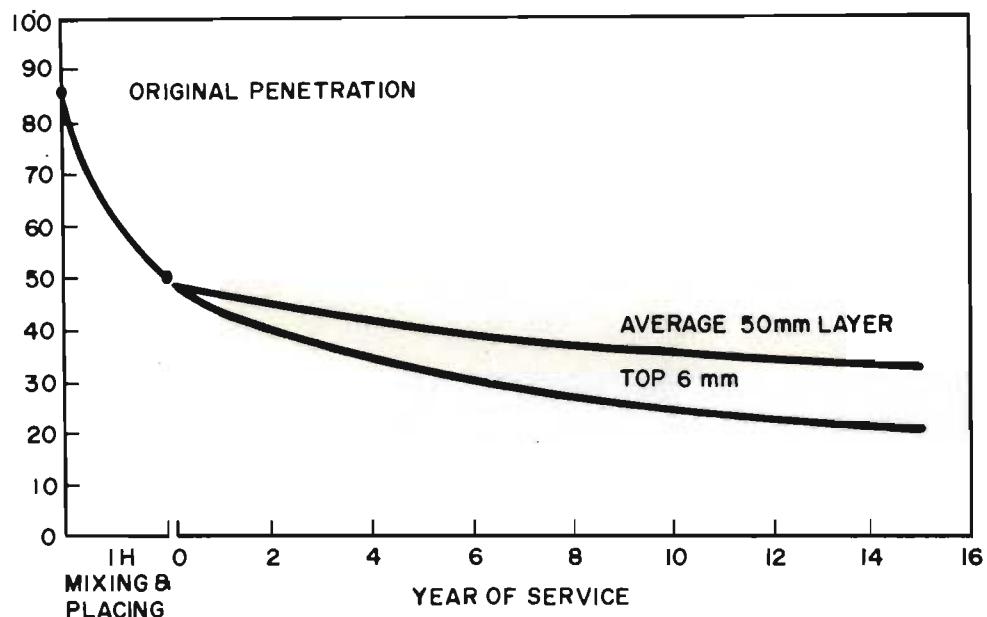
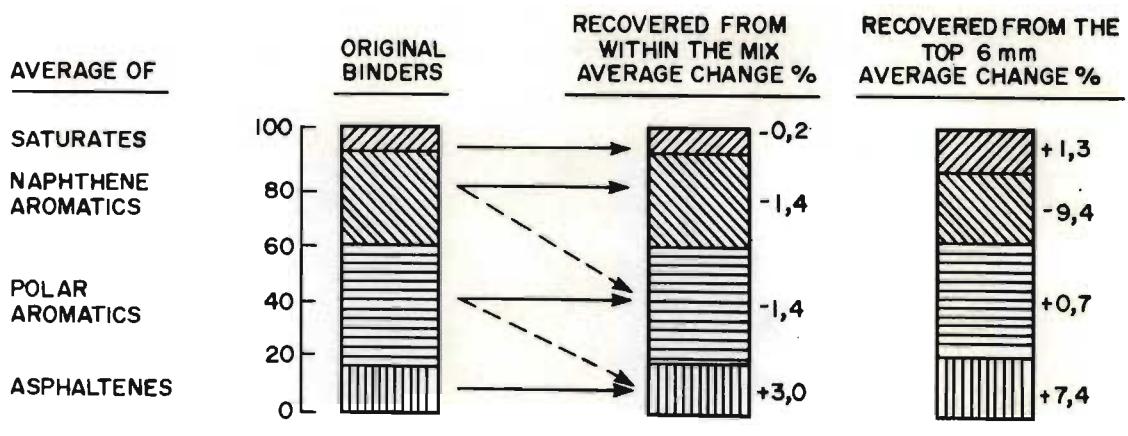


FIGURE 4
TYPICAL BITUMEN HARDENING
IN AN ASPHALTIC SURFACE LAYER
(ASPHALTIC INSTITUTE GRAPH)



AVERAGE OF SIX BITUMENS AFTER 18YR. SERVICE

FIGURE 5
EFFECT OF AGING ON BITUMEN COMPOSITION

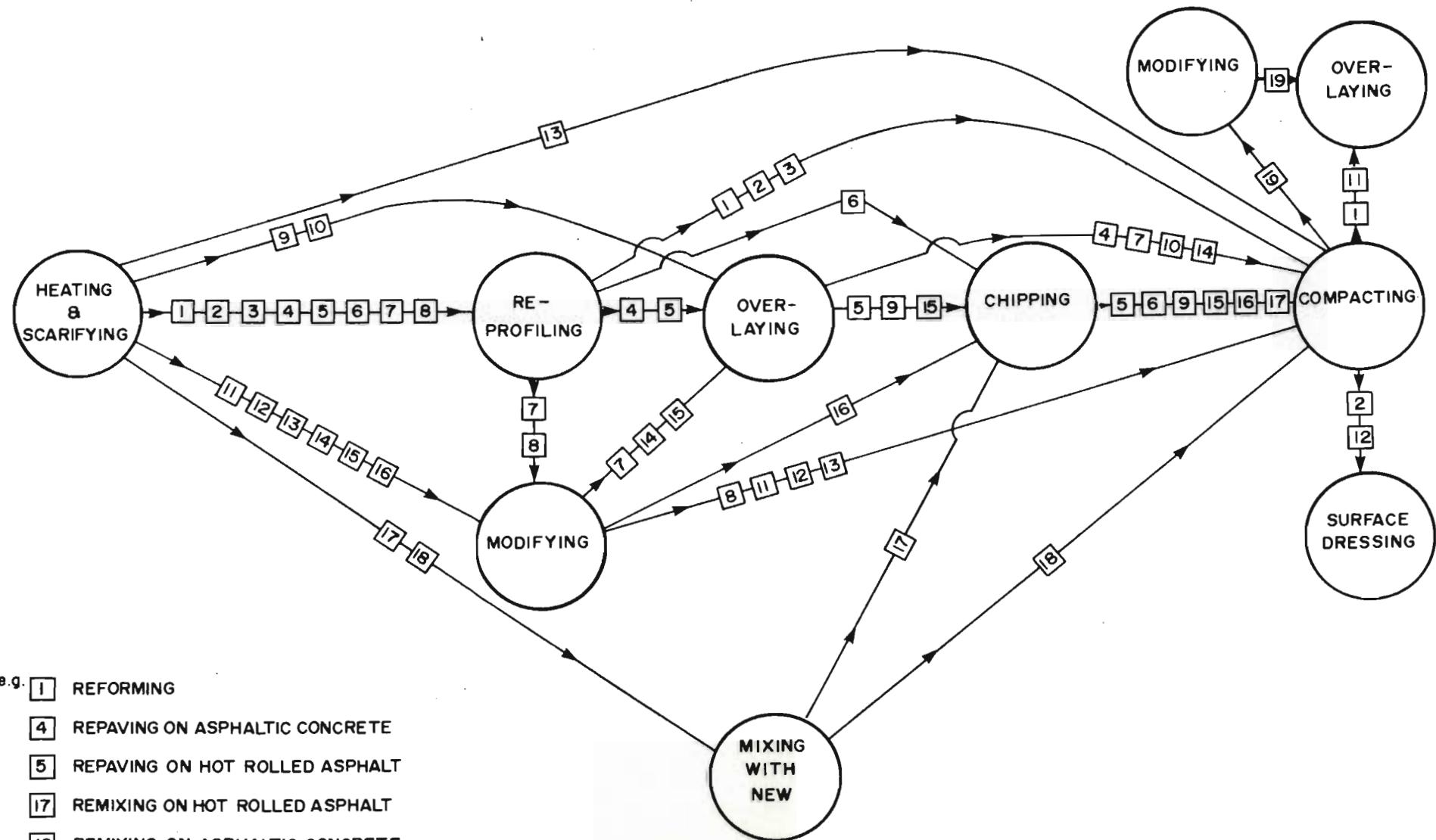


FIGURE 6

HOT SURFACE RECYCLING ON THE BASIS OF THE HEATER - SCARIFIER APPROACH

modifier in one operation (heavy-duty vibrating screed - indirect heating).

Jim Jackson Contractor : "Heater-Scarifier", can reprofile and relay scarified material. Some models can spray and mix modifier (direct heating).

Johnson Recycling International Inc. : "Asphalt Recycler", can reprofile and relay scarified material, and add modifier (indirect heating).

Montanari : a three-stage process in which the heating, scarifying and remixing-with-modifier operations are carried out by separate units working in tandem.

G L Payne : heater-scarifier unit.

Repelg Oy : Repaver, can reprofile the scarified material and add new mix in one operation. The paving unit is detachable.

Oy Viarecta Ab : a two-stage process in which the heater is followed by a paver with fixed scarifiers under its material-receiving hopper. The scarification process is optional.

Vogele (Scholkopf) AG : "Asphalt Surface Remover, Super 1700 ARF", can reprofile and relay scarified material (indirect heating).

Wirtgen GmbH : Repaver, can reprofile the scarified material and add new mix in one operation. Mixer, can pick up the scarified material, mix it with additional corrective pavement mix, and lay the mixture in one operation (heavy-duty vibrating screed - indirect heating).

The plethora of the various types of equipment and associated processes has led to considerable confusion regarding the terminology used in reference to specific methods. A division of the available hot surface recycling methods into generally recognisable broad categories has been long overdue.

To this effect, a differentiation into the following types may well be appropriate.

- | | |
|----------------------------|--|
| Repaving
(see Figure 7) | : heating, scarifying, reprofiling, adding new mix and compacting. This process can be undertaken using either the integral or paving train methods. |
| Remixing
(see Figure 8) | : heating, scarifying, mixing with the new asphalt mix, relaying and compacting. |
| Reforming | : heating, scarifying, reprofiling and compacting. An overlay, or surface dressing may be added. |
| Rejuvenating | <p>: (i) paving train method: heating, scarifying, spraying with modifier, reprofiling and compacting. Alternatively, compaction may precede application of the modifier. An overlay, or surface treatment, may be added.</p> <p>(ii) integral method: modifier is sprayed on before the repaving process. Alternatively, the modifier may be added by the repaver unit after scarification.</p> |
| Reshaping | : heating, adding new mix and compacting. |
| Regripping | : heating, spraying with chippings and compacting. Alternatively spraying with chippings precedes the heating operation. |

Repaving, remixing, reforming and rejuvenating are discussed in detail below.

5.4 Repaving

5.4.1 The process

In this process the existing bituminous pavement is heated, scarified and reprofiled, and a new overlay is bonded to the existing material and compacted to form a dense monolithic carpet (see Figures 9 and 10). There are two main ways in which the process is applied, inlay and overlay repaving.

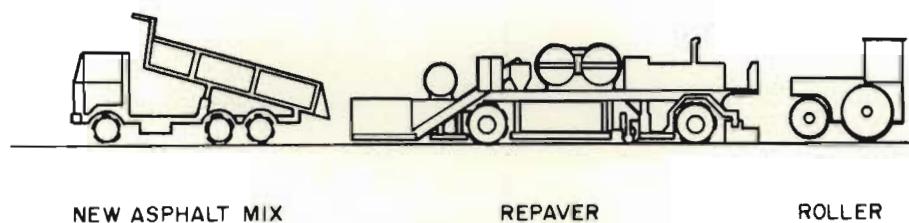


FIGURE 7
REPAVING TRAIN

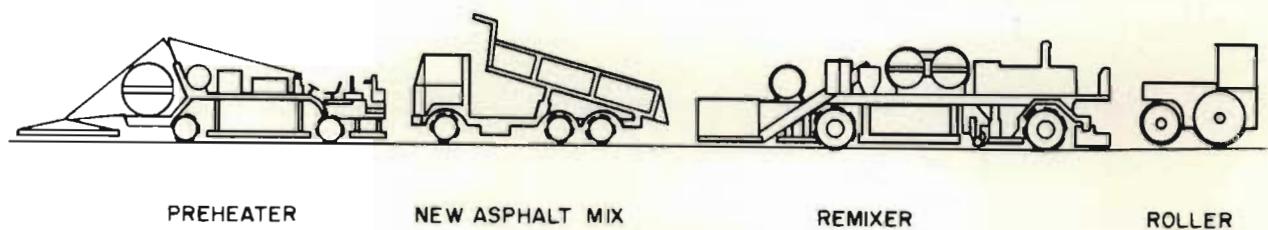


FIGURE 8
REMIXING TRAIN

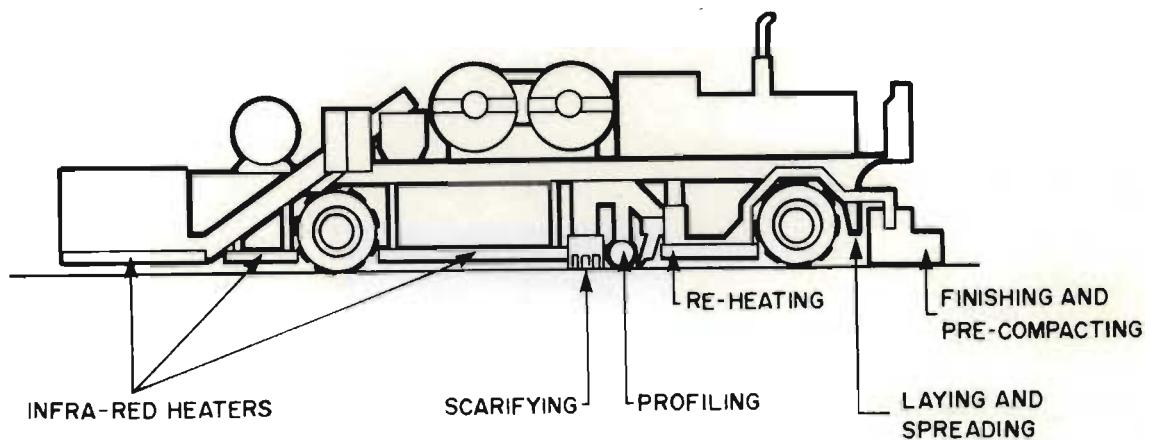


FIGURE 9
COMPONENTS OF A REPAVER

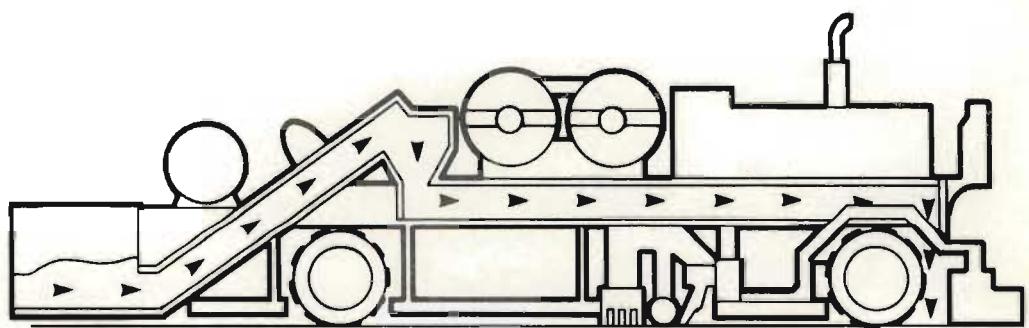


FIGURE 10
CONVEYANCE OF NEW MIX THROUGH A REPAVER

The difference is as follows: in inlay work part of the existing wearing course is planed and removed, and the remaining part is subsequently heated, scarified, reprofiled and covered with a layer of new mix; whereas in overlay work only the top part of the existing wearing course is treated and the addition of the new asphalt layer raises the final pavement level.

Inlay work is applicable where there are level limitations, such as when only one lane is in need of remedial treatment. This process is naturally more costly than overlay repaving, although it still compares favourably with conventional resurfacing.

The heating of existing material will naturally cause some hardening of the binder. Providing this hardening does not bring the penetration value too near the limit where loss of mix flexibility could significantly reduce the resistance to cracking, then it can be regarded as a beneficial effect, at least as regards the stability of the mix and its resistance to subsequent permanent deformation.

Laboratory tests at the Transport and Road Research Laboratory (TRRL) and Shell Thornton Research Centre (UK) showed that the penetration of a bitumen after repaving is on average about 70 per cent of its initial value, with greater reductions normally occurring when the penetration of the recovered bitumen was relatively high. Table 1 gives typical examples of penetration hardening following repaving. Further investigation into the effect of binder viscosity on mix stability indicated that a 30 per cent reduction in penetration will typically increase the resistance to deformation of a rolled asphalt by a factor of 1.2. In fact TRRL's wheel tracking tests, on cores taken before and after repaving, showed a marked improvement in the resistance to deformation.

With gap-graded surfacings, the overlay process has a considerable side benefit in that the precoated chippings are retained as part of the lower scarified and reprofiled layer, thus tending to create a more stable mix with a higher stone content. This is particularly

advantageous where the existing pavement has deformed and a stiffer design mix is appropriate.

Table 1 : Change in binder penetration after repaving

<u>Site</u>	<u>Penetration at 25 °C</u>	
	<u>Before</u>	<u>After</u>
Birmingham, Holyhead Road	51	36
Birmingham, Cape Hill	33	28
Birmingham, Lichfield Street	32	23
A74, Trunk Road, chainage 100	74	61
A74, Trunk Road, chainage 2600	81	52
A74, Trunk Road, chainage 4700	40	32

Laboratory wheel-tracking tests showed that when a hot rolled asphalt with a 30 per cent stone content and a 40/50 penetration pitch bitumen was reheated and remixed, the binder hardened to 30/40 penetration and the wheel tracking deformation after 100 passes decreased from 12 to 6 mm.

Other advantages of this process over conventional overlay are that the problems of adhesion between polished road surfaces and new overlays is removed and that, by minimizing the raising of the final pavement surface, the subsequent need to lift the kerbs could be avoided. In both processes the longitudinal joints are welded by cutting back, and the additional heating at the kerb ensures satisfactory bonding of the new mat and makes a tack coat unnecessary.

Obviously the main benefit of both applications is the direct saving on material and the associated savings on haulage and traffic delays, by using effectively thinner wearing courses. Typically, conventional resurfacing involves the removal and replacement of the full depth of wearing course, 40 or 50 mm, whereas repaving either by overlay or inlay requires only 15 or 20 mm of new hot rolled asphalt material and considerably less asphaltic concrete due to the absence of precoated chippings.

5.4.2 Applications

Repaving can be used on most types of flexible surfacing, ranging from hot rolled asphalt to dense bitumen macadam and asphaltic concrete. It is normally considered in the case of the following conditions:

- deformed surfaces
- cracked or fretted surfaces, and
- inadequate skid resistance.

In common with all other surface recycling processes, repaving should not be done where there are fundamental faults in the base, drainage or asphalt, or on very thin wearing courses of less than 25 mm. Surface treatment layers must be removed prior to repaving; their incorporation into the existing mix is undesirable and they have an adverse effect on the process.

The suitability of a site for repaving is decided on from a visual inspection coupled with laboratory core analysis and measurements. Generally, sites that are deformed but have no significant cracking are likely to be suitable, whereas sites with widespread cracks and a dry appearance are mostly unsuitable.

The actual investigation procedure as well as the applicable criteria of suitability for repaving depend on the condition of the existing pavement:

- (a) Deformed surfaces - It is necessary to determine whether the deformation visible at the surface is the result of plastic flow in the wearing course, or of movement in the base and subgrade. This is easily established by coring across the pavement through the bituminous layers and comparing the individual layer thicknesses of each core. If variations in the surface thickness do not account for most of the visible deformation, reconstruction is likely to be necessary; naturally the need for reconstruction will normally be determined by deflectograph readings. If the deformation is

principally in the wearing course, then, provided that the recovered bitumen binder is not excessively soft, the material is considered suitable for repaving.

Experience has shown that in the case of hot rolled asphalt, normal binder contents with a penetration of 70 or harder are worth reusing, but higher contents and softer binders are doubtful.

In the earlier days of repaving it was usual to use the criteria of Marshall Stability (S), Flow (F) and Quotient (Q) at 60 °C. Currently the Marshall Quotient is established **only** in cases of excessive deformation and even then, as its value is generally found to be low it is not regarded as a prohibiting factor provided it is above a minimum of about 1,0.

- (b) Cracked or fretted surfaces - Individual cores will show the depth to which the cracks exist. If the cracks extend into the basecourse, reconstruction may be the answer; here again this can be determined by the deflectograph readings. However, on comparison of 'present value' serviceability of such pavements with the cost of complete reconstruction, the chance that existing cracks will eventually be reflected into the newly restored profile may be considered acceptable. If cracking is limited to the wearing course, or if repaving is still considered worth undertaking as a 'temporary' remedial measure, then the cores are tested for compacted density, composition and binder penetration. In the case of cracked pavements, the analysis will generally show a low binder content and/or hard binder. In hot rolled asphalt the acceptable lower limit of penetration value is currently taken to be around 25, although recent experience indicates that a harder binder may be acceptable. Occasionally the mix is found adequate in respect of binder content and hardness, but of low compacted density (equivalent to air voids of 9 per cent or more), indicating undercompaction at the time of laying; repaving will be suitable in these circumstances.

- (c) Surfaces with inadequate skid resistance - Repaving to restore surface texture is important on freeways and other heavily trafficked roads where a surface treatment cannot be relied upon to provide a durable skid resistance and the alternative is replacement of the full depth of wearing course. The factors that determine suitability are the penetration of the recovered binder and minimum thickness of the wearing course.

A summary of conditions for repaving is given in the table below.

Table 2 : Applicability of repaving

<u>Condition of existing pavement</u>	<u>Suitable for repaving when:</u>
1. Deformed surface	1a. Deformation is mainly limited to wearing course. 1b. Penetration of the recovered bitumen binder is not excessively soft (below 70). 1c. Marshall Quotient is above 1,0. 1d. Thickness of wearing course is above basic minimum (25 mm).
2. Cracked or fretted surface	2a. Cracks are mainly limited to wearing course. 2b. Penetration of the recovered bitumen binder is not unduly hard (above 25). 2c. Thickness of wearing course is above basic minimum.
3. Polished surface	3a. Thickness of wearing course is above basic minimum. 3b. Penetration of recovered bitumen binder is within acceptable limits (25 - 70).

5.4.3 Ridability

Since the early trials with repaving, the standard of riding quality produced by this method has been the subject of recurring criticism. In fairness, although in general the riding quality compared badly with that provided by conventional work, on measurement it was seldom, if ever, found not to comply with the specified requirements.

Naturally a lot of attention was given to this aspect by contractors and plant manufacturers, as well as road authorities. In repaving the ridability can be adversely affected by the following factors:

(a) Operational skills - These relate to items such as compaction and surface texture and are equally applicable to conventional resurfacing.

(b) Temperature profile - A variable longitudinal or cross temperature profile in the existing material while it is being reused will have a marked effect on the riding quality of the final surface. Experience has shown that variations in the temperature to which the existing material is heated are more likely to occur across rather than along the carriageway.

Attention must be given to the prevailing weather conditions, with special regard to cross-winds, and the level of heating across the machine must be adjusted to ensure uniformity in the temperature profile of the pavement cross-section. The fitting of protective skirting along the edges of the heater bank has proved quite effective. The introduction of temperature sensors, which can be fitted on selected scarifiers, may be worth considering.

(c) Uniformity of scarification - Existing grade limitations, uneven temperature profiles and other factors can cause variations in the level of scarification which can lead to differential compaction and thus detrimental effects on the final surface. For this reason alone sites with frequent grade

changes are not suited to repaving. Under normal conditions, this problem can be alleviated by skill and diligence in the operation of the manual controls. When automatic controls are fitted, the equipment must be capable of accurately establishing and controlling the grade elevation and cross-slope of the scarification to pre-determine settings.

- (d) Screed (breadth and weight) - The elimination by major modifications of the surging effects experienced by the machine during the feeding operation and some screed flutter/wobble, greatly improved the performance of the first (Cutler) repaver in the UK. However a satisfactory riding quality was not achieved until the original screed was replaced by a heavier solid combination screed.

During preliminary, off-road trials with another repaver (Wirtgen) it became apparent that the riding quality varied in accordance with the 'density' of the material used. It was found that additional weight on the screed improved the riding quality, until a denser material was tried. As with the Cutler machine, the riding quality only became satisfactory when the screed was eventually replaced. Apparently machines with a proven record of producing a consistently good riding quality on asphaltic concrete need to be modified for use on the more viscous hot rolled asphalt (gap-graded) material. Incidentally, this phenomenon has also been experienced in Denmark, where the riding quality of hot rolled asphalt surfaces is not considered comparable to that of asphaltic concrete.

5.5 Remixing

5.5.1 Scope

With the development of repaving and the corresponding increasing demand for this remedial method, it became more apparent that the applicability of this process was limited to certain types and conditions of existing wearing course material.

It had always been accepted that the repaving process, in common with all surfacing options, was suitable as a remedial option for wearing course only problems. However, experience soon showed that not all wearing course problems could be resolved by this method.

Guidance on existing pavement conditions that make repaving appropriate is given in the previous section. Basically, problems may arise when part of the existing wearing course is reused without any mixing in of new material. In such a case any deficiencies in or problems with the existing wearing course material will remain uncorrected, with the exception of the hardening of the binder due to the heating process, and, in the case of overlay work on hot rolled asphalt pavements, the incorporation of the precoated chippings into the existing layer; both of these factors tend, of course, to improve stability.

The remixing process offers an opportunity to correct these deficiencies by mixing the existing material with new material of appropriate properties and composition. This has become possible by the incorporation into the conventional repaving machine of arrangements by which the existing scarified material is collected and mixed with imported material. This should produce a homogeneous new mix, which, depending on the requirements, can be either stiffer or less brittle than the original material.

5.5.2 The process

The existing surface layer is preheated to a temperature of around 110 to 130 °C, by a gas-fired, infra-red heater unit which travels some ten to fifteen metres ahead of the remixer. The remixer unit, a modified repaver, has five functions (see Figures 11 and 12):

- (a) the further heating of the existing surface material to a temperature between 140 and 160 °C;
- (b) the scarification of the heated material to the full depth of the wearing course;
- (c) the collection by a levelling blade, and the transportation by an auger, of the reclaimed material to the centre of the

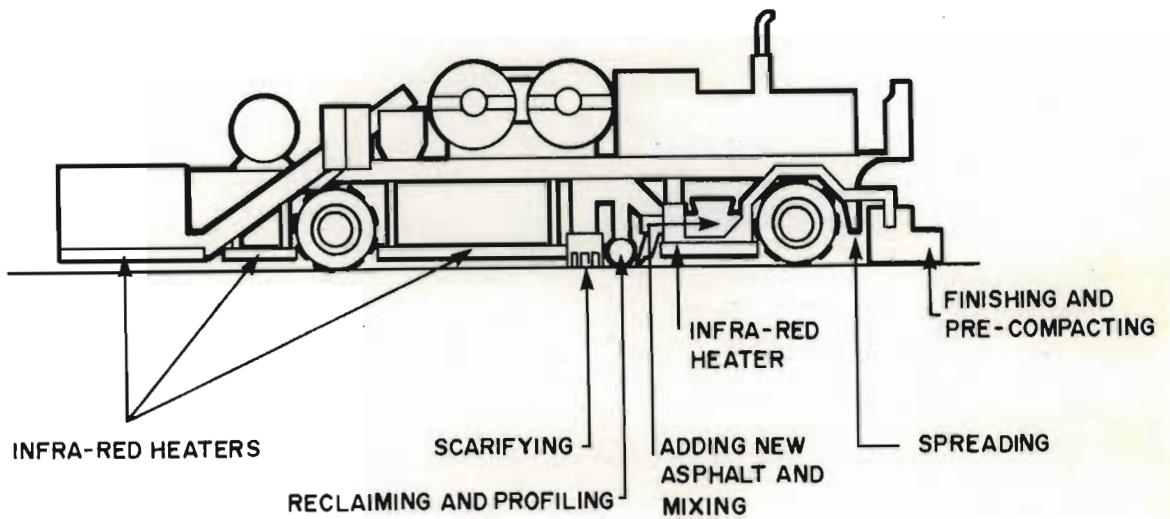


FIGURE 11
COMPONENTS OF A REMIXER

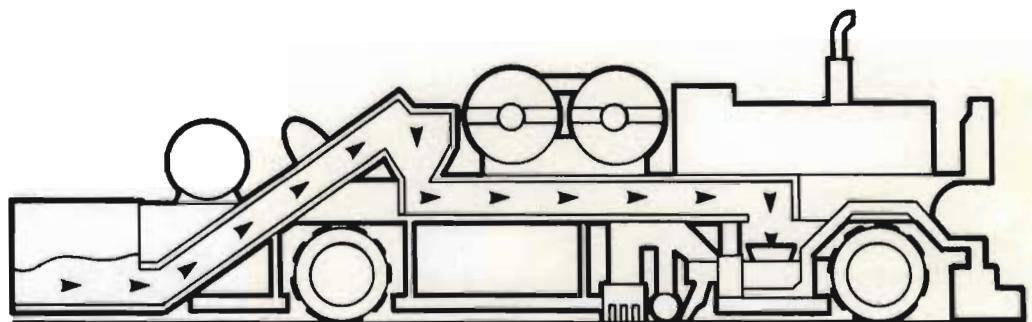


FIGURE 12
CONVEYANCE OF NEW MIX THROUGH THE REMIXER

machine and into the mixing unit, a flow-through double-shaft mixer;

- (d) the conveyance, through a measuring unit, of the new material to the mixing unit; and
- (e) the distribution, by a further auger, of the resulting mix onto the pavement and its pre-compaction by a vibrating and tamping screed.

The newly laid material is then treated in the conventional manner. It should be noted that the remixer can be used as a normal repaver if required.

5.5.3 Development and first road trial

The remixing process was developed by Wirtgen GmbH in West Germany during 1978, as an extension to the scope of their surface recycling operations. Remixing was particularly needed for the repair of surface courses with plastic deformation, where the applicability of repaving is limited.

Following a series of off-road trials, sufficient confidence was gained in the performance of the machine and the effects of the process to enable a full-scale freeway trial to be undertaken in November 1978.

The trial section was a 2,250 metres long two-lane section of the federal freeway A62 Landstuhl-Trier between the junction of Landstuhl West and Hutsenhausen.

The existing surface course, an asphaltic material of 12 mm maximum stone size, was laid in 1965. Since then, mainly due to the effect of studded tyres, approximately one-third of the original thickness of 35 mm had worn away. However the binder course and basecourse were still in good condition.

From preliminary testing of the existing material it was decided to add a new asphaltic mix, in a ratio of two parts old to one part

new, of such composition that the resulting mix would conform to the specification requirements of TV bit 3/72. In order to ensure that the existing material would be sufficiently workable during a contract period when the ambient temperature was between 2 and 8 °C, an additional surface heater was introduced. In fact, its incorporation proved so successful that it subsequently became standard procedure even for work undertaken during warmer weather conditions. During a visit to the trial section, I saw new material being delivered at temperatures between 165 and 170 °C, and measured the laying temperature to be above 140 °C.

A considerable amount of smoke was emitted throughout the operation and the existing surface showed some signs of carbonization just prior to being scarified. However, subsequent tests showed that there was no appreciable hardening of the binder. During and after the trial, material samples and cores were taken for the testing of layer thickness, homogeneity, aggregate gradation, binder content and penetration, Marshall Stability and Flow, void contents, and uniformity of mixing, in order to determine whether the desired mix was achieved.

Reportedly (Prof Gragger and Dr Loffler's "Final report on the trial") the results of the tests demonstrated that:

".... the method makes it possible to heat an existing bituminous course, to take up such a course without modifying the material composition, and, using an added mix of any desired composition, to mix this thoroughly in any desired mix ratio and to place the resulting mix according to the profile and to compact it in accordance with the specifications".

The costs of the remixing trail were about 30 per cent less than the estimated costs of the conventional method.

5.5.4 Situation in 1979

Four remixing/repaving machines were available for work during the

1979 season. During this period some 420 000 square metres of remixing were undertaken in Europe with projects in West Germany (60 000 square metres), Italy (240 000 square metres), Denmark (15 000 square metres), Yugoslavia (93 000 square metres), and France (12 000 square metres).

5.5.5 Applications

There are three broad types of application of the remixing process:

- (a) For the restoration of skid resistance - normally with asphaltic concrete and similar material it would be sufficient to heat, scarify, reprofile and recompact the existing wearing course. However, in the case of hot rolled asphalt, the embedment of the precoated chippings would prove difficult. Remixing can overcome this difficulty either by mixing the existing precoated chippings into the whole of the wearing course material, or, in extreme cases, by adding to the mix a small amount of new asphalt (possibly sand asphalt with no stone). If a 10 mm layer of sand asphalt is mixed with about 25 mm of existing hot rolled asphalt wearing course, the incorporation of the existing precoated chippings into the mix will not alter significantly the original stone content.
- (b) For the reprofiling and stiffening of a deformed wearing course - this can be achieved by mixing the existing material with a stiffer mix. The additional mix can contain rock fines aggregate, a high PI binder, polymer, a high stone content or a combination of these. If the existing material is soft because the bitumen content is too high, then the addition of dry or lightly coated sand may be sufficient to increase its stiffness to a suitable level.
- (c) For the repair and softening of a cracked wearing course layer - a new mix made with soft binder (e.g. 100 pen) can be added to the existing mix, thereby reducing the hardness of the binder and preventing recurrence of the cracking. Alternatively,

if it can be metered accurately, a fluxing oil can be sprayed into the scarified mix. If this oil were to increase the binder content to an undesirably high level, the effect could be countered by adding some sand.

5.6 Reforming

In this process the existing bituminous surfacing is heated, scarified and reprofiled. An overlay on the uncompacted reformed pavement layer can then be added by a conventional paver. The distance between the reformer and the paver must be sufficient to enable new paving material to be delivered to the hopper of the paver as required.

A reformed pavement surface can be compacted and used as a wearing course with or without a surface treatment. Alternatively, addition of an overlay can be delayed until the reformed surface shows signs of deterioration.

When an overlay is incorporated in reforming, the process is very similar to repaving and comparisons between the relative cost and effectiveness of the two methods are unavoidable.

In general reforming has the following advantages:

- (a) Lower investment costs: The combined cost of the reformer and conventional paver is considerably less than that of a repaver. Moreover, normally only a reformer will have to be purchased.
- (b) Lower incidental expenses on transportation and maintenance.
- (c) Ability to undertake smaller projects.
- (d) Flexibility in usage. The two machines can be utilized independently of each other on different projects.

However, there are also considerable disadvantages to reforming when comparing with repaving:

- (a) There may be heat loss before the application of the overlay; in cold windy weather conditions this factor is likely to have a critical effect on the bonding between the two layers.

- (b) The reprofiled existing surface layer is disturbed by the manoeuvring of trucks delivering new material to the paver.
- (c) The truck manoeuvres in the middle of the paving train are likely to cause greater interference with traffic than is normally experienced.

5.7 Rejuvenating

Fairly recently modifiers have been developed which enable aged binders to be replasticized by replacing certain constituents of bitumen that are lost through oxidation and polymerization. As the ageing of the binder is more pronounced in the top part of the surface layer, hot surface recycling techniques permit the application of these rejuvenating agents to the portion of the pavement where they are likely to be most effective.

There are several procedures in surface rejuvenation. These include:

- (a) Paving train method - standard procedure: In this method the pavement is heated, scarified and recompacted. A modifier is applied by a distributor truck and an overlay is then placed by a conventional paver and compacted. The whole operation is carried out within a distance of 120 to 150 metres. The difficulties encountered in co-ordinating this operation, ensuring an even application of modifier, and allowing sufficient time for the moisture released from emulsified binders (when these are the rejuvenators) to evaporate, has led to a two-stage procedure. Alternatively, the recompaction of the scarified pavement prior to the application of the modifier can be omitted. This omission is likely to result in a better bond with the overlay but it can also lead to problems of evenness of compaction and ridability, due to the effect of the distributor truck, and paver, on the scarified uncompacted pavement surface.
- (b) Paving train method - two-stage procedure: The pavement is

heated, scarified and recompacted and the rejuvenating agent is applied, usually at the end of the working period, permitting a continuous and uniform application. Placing of the overlay is delayed until the modifier has been absorbed into the existing pavement. Frequently, there is a delay of several days between the spraying of rejuvenator and overlaying, and some caution should be exercised to prevent high-speed traffic from degrading the surface.

Generally the two-stage method is cheaper than the standard procedure. Moreover it encourages a more uniform application of rejuvenator and minimizes the risk of bleeding through the overlay when high rates of application are used; a sufficiently long period between the two stages should ensure complete absorption of the modifier into the pavement.

- (c) Integral method: Equipment (repavers and remixers) is available which permits the heating, scarifying and reprofiling of existing material, and the addition of rejuvenator and new bituminous material in one operation. The rejuvenated material and new paving mixture are compacted simultaneously to form a monolithic layer. Naturally when remixers are used the rejuvenator can be incorporated into the new paving mixture which is combined with the existing material to form a homogeneous layer. Alternatively the rejuvenator can be sprayed on by a distributor truck prior to the repaving or remixing operation.

5.8 Comparison of the options

The great number of different surface recycling options, coupled with the variety of possible procedures within any one option, make comparisons between these methods and conventional resurfacing processes very difficult. However, if surface recycling is to be effectively adopted as an accepted maintenance procedure, some form or measure of the relative merits of the different options and the conventional practices is required.

Already experience has shown that once the road authorities have accepted a particular surface recycling method, interpretation regarding its usage differs widely. In fact, there are two distinct schools of thought:

- (a) The decision to use a particular surface recycling method on a particular project should rest with the road authority involved.
- (b) Following the general acceptance of a surface recycling method, contractors should be allowed to offer this method as an alternative to conventional forms of resurfacing on any project.

Unfortunately both of the above interpretations have serious shortcomings.

In the first case, the decision by a road authority to recycle must entail full knowledge of the scope and applicability of a particular recycling option, considerable cost in preliminary testing, interest in recycling and confidence that competitive prices will be forthcoming from a relatively limited industrial involvement.

In the second case, the responsibility for proving applicability will be left to the industry. The contractors will, or should, have available the necessary expertise and resources to undertake this task. Moreover, the process will only be undertaken on projects where the savings over conventional resurfacing are realised subsequent to successful tendering. However, there is a serious disadvantage in that it may be reasonably argued that the offered alternative does not provide an equal alternative to conventional methods.

What is needed is an understanding of the extra benefits achievable by the various available surface recycling options. These benefits can be evaluated in terms of new material thickness, thus making possible fair monetary comparisons between recycling and conventional options. This is a difficult and complex task, but necessary if the potential benefits are to be fully exploited.

If such evaluations were successfully undertaken, not only the problems relating to a particular surface recycling operation will be resolved, but there will be wider benefits. It will also be possible to make valid cost-benefit comparisons between the various applicable surface recycling procedures. An acceptable ranking system can be established which will enable the industry to develop further the various surface recycling methods and will form the foundation for open and fair competition between conventional and recycling options.

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6. RECYCLING ADDITIVES

- 6.1 Preface
- 6.2 Research and development
- 6.3 Availability
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6.1 Preface

Asphalt modifiers, such as softening agents, rejuvenators, flux and aromatic oils, have been used as additives in the recycling of bituminous pavement materials, in attempts to rejuvenate hard and brittle aged binders. These additives are used either alone or in combination with new conventional bitumens.

Each different modifier has distinct effects on each aged binder. Similarly, the same modifier affects different aged binders in different ways. The type of recycling process, and parameters such as mixing temperature, mixing time and reclaimed/new material ratios, all cause significantly different effects. Naturally, when an additive is combined with a new binder, the picture is further complicated.

6.2 Research and development

A considerable amount of research work has been done on the development and selection of appropriate additives by many commercial organizations and the findings are discussed below.

Laboratory testing undertaken during 1978 at Shell's Thornton Research Centre showed that an aged mix can be restored to its original properties by the addition of a hydrocarbon oil. The rejuvenators used in these experiments were spindle oil and spindle oil furfural extract. Further tests indicated that reclaimed material can be recycled with the addition of polymers to produce a mix with a significantly improved resistance to permanent deformation.

During 1978 and 1979, the Research and Development Department of Ashland Petroleum Company undertook an extensive laboratory and field study, whose principal aim was to determine the effectiveness of various recycling agents and virgin bitumen on aged bituminous pavement mixes containing both conventional and rubberized bitumen.

The conclusions of the study included the following:

- Bituminous mixes produced with bitumen, hot-mix emulsion and rubberized hot-mix emulsion can be recycled with soft virgin bitumen or recycling agents to meet the original design specifications.
- Substantially more soft bitumen than recycling agent is required to achieve the same penetration as the original binder.
- Aged rubberized bitumens do not exhibit the properties of the original rubberized bitumen, such as higher viscosities and ductilities, and can be recycled without difficulty.

During 1978, Witco undertook an extensive laboratory-based study to test the validity of their recycling concept, which was the addition of a single reclaiming agent rather than two additives. The study programme was based on three basic design requirements:

- bring the bitumen to its optimum chemical composition for durability;
- restore the bitumen's physical characteristics to give it an appropriate consistency; and
- provide the amount of bitumen specified in the mix design.

Witco found that several recycling agents tended to reduce the consistency or hardness too much. This was resolved by the addition of asphaltenes as a bodying agent, since the other four basic components of bitumen (nitrogen bases, first and second acidaffins, and paraffins) are known to affect durability.

It was further established that recycling agents with higher viscosities than that of aged binder could be used in substantial quantities without affecting the paving-grade consistency of the resultant mix. With regard to compatibility between the modifier and the existing binder, the study showed that the agent must contain a sufficient amount of fraction N (nitrogen bases) to peptize the asphaltenes and not exceed a maximum amount of fraction P (paraffins), a gelling agent for the asphaltenes, in order to prevent syneresis (separation of paraffins from oil).

6.3 Availability

A great number of proprietary additives have been developed since the first commercial use, in 1961. Some of the additives which are, or have been, commercially available are listed in Table 3 below.

Table 3 : Some commercially available additives

Petroleum or Chemical Company	Modifier
Ashland	Medium aromatic oil Slurry oil Plasticizer oil (APO) Nuflex 100 Nuflex 330
Cenex	Dust oil
Chevron	Chevron X109 Chevron X90
ICI	Evatane
Koppers	BPR
Lion	Smackover flux asphalt Rejuvenator oil
Mobil	XMTY-125B Mobilsol 30 Mobilsol K
Pax	Paxole
Phillips	Petroset 10 Extract 20 Extract 250 Extract
Saunders	SA-1
Satchem	Tar rejuvenator
Shell	Dutrex RJ3 RJ02
Sun	Sundex 840T Sundex 790T
Union	Rejuv-Acote-Base
Witco	Reclamite Cyclogen series Cutback Asphalt Califlux GP

Most of the above products are, or have been, applied as surface-penetrating treatments and their influence on existing asphaltic pavement layers is typically restricted to less than the top 20 mm.

Developments in the reclaiming and reprocessing of existing asphaltic pavement material have generated a demand for additives suitable for central-plant recycling and in particular for the hot-mix process. Consequently, new proprietary products appear on the market quite frequently.

6.4 Selection of type and quantity

The selection of the appropriate type and correct quantity of additive is extremely important. The reclaimed material must be properly evaluated in terms of properties such as bitumen content and recovered bitumen characteristics, and the degree of uniformity of the reclaimed material, deriving from one or more projects, in respect of the above properties must be determined.

A useful guide is provided by Witco's premise that an additive with compositional parameters

$$0,8 > \frac{N+A_1}{P+A_2} > 0,4$$

where

N = nitrogen bases

A₁ = first acidaffins

P = paraffins

A₂ = second acidaffins

combined with most aged bitumens should produce a blend of longer durability than the existing bitumen. With regard to durability, it should be noted that there is no single recognized test for its assessment. Properties such as resilient modulus, creep, fatigue and Marshall and Hveem Stabilities have been used to give a measure of expected performance.

Viscosity-blending and viscosity/penetration-blending nomographs have been developed for the derivation of the appropriate type and quantity of recycling additives. One such nomograph, developed by the Michigan Department of Transportation, is shown below (Figure 13). The binder blending ratios are based on a log-log viscosity relationship developed by Neppe.

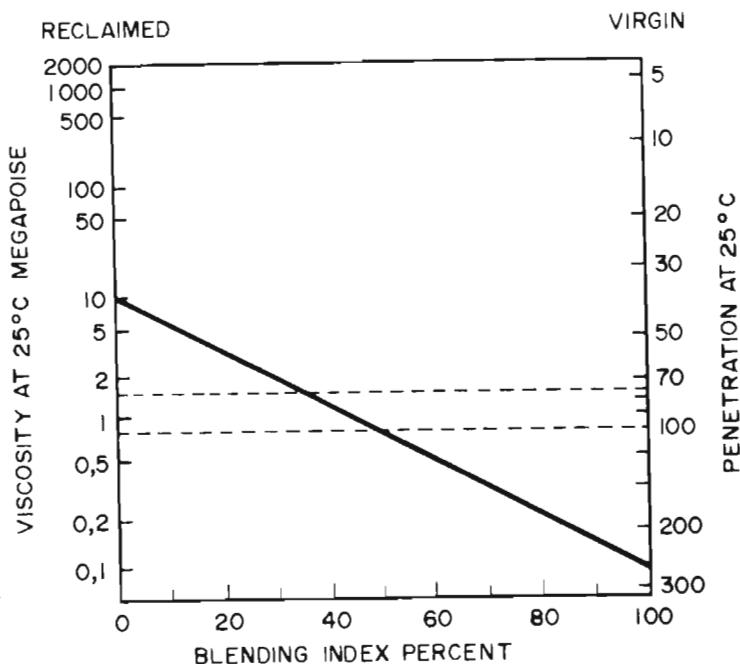


FIGURE 13
NOMOGRAPH OF VISCOSITY AND PENETRATION
BLENDING (MICHIGAN DEPT. OF TRANSPORTATION)

6.5 Proposed specification

Until recently, most studies and reports on recycling additives were based on a limited number of modifiers, usually the products of the company undertaking the study. Consequently very little was accomplished in the evaluation and classification of the available additives. In order to fill this gap in recycling knowledge, the 13th Pacific Coast (USA) User-Producer Conference on Asphalt Specifications established a committee to develop prototype specifications for recycling agents.

The test programme was based on the committee's definition of a recycling agent as: "A hydrocarbon product with physical characteristics selected to restore aged bitumen to the requirements of current asphalt specifications".

Thirty-three recycling additives were tested and characterized. The prototype specifications were developed primarily from the test

results obtained from blends containing artificially aged (air-blown) California Coastal bitumen. This aged bitumen was considered representative of the most difficult aged binders likely to be encountered in recycling.

The following specification tests were selected:

- (1) Flash Point, COC (Cleveland Open Cup), degrees F : safeguard against exposures to temperatures in excess of 300 degrees F, during the hot mix recycling process.
- (2) Viscosity at 140 degrees F, Centistokes : for grade identification and product consistency.
- (3) Saturates content, weight % : for defining compatibility and solvency.
- (4) Viscosity Ratio (the ratio of the residue from thin-film, oven test viscosity at 140 degrees F, cSt over the original viscosity at 140 degrees F, cSt) : for indicating durability.
- (5) Loss on Heating Test (RTF-C oven weight change), % : to measure volatility and blending capability.
- (6) Specific Gravity : to measure quantity.

The Pacific Coast User-Producer committee's proposed specification for hot mix recycling agents is set out in Table 4 below.

Table 4 : Proposed specification for hot mix recycling additives

<u>Test</u>	<u>Grades</u>									
	RA 5		RA 25		RA 75		RA 250		RA 500	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Viscosity at 140 F cSt	200	800	1000	4000	5000	10000	15000	35000	40000	60000
Flash Point ^o F COC,	400		425		450		450		450	
Saturates, wt. %		30		30		30		30		30
Viscosity Ratio		3		3		3		3		3
RTF-C Oven Weight Change, %		4		3		2		2		2
Specific Gravity	state		state		state		state		state	

The above grades are aimed at offering flexibility in the selection of additives to provide for a wide range of existing binder characteristics and reclaimed/new material ratios, and hence existing binder/additive ratios.

6.6 Recent research

6.6.1 University of Illinois

The University of Illinois has carried out a FHWA-funded research project whose objective was the direct comparison of the performance of pavements constructed with recycled and conventional mixes. Based on the results obtained, a paper entitled "Modifier influence in the characterization of hot mix recycled material" was presented at the 59th Annual Meeting of the Transportation Research Board, in January 1980.

This paper reported on the investigations of the diffusion phenomenon associated with recycling operations involving modifiers, and pointed out the serious problems this implied in the characterization of such materials for long-term performance predictions and in evaluating the effects of various laboratory conditioning procedures. For example, the artificial ageing of samples, in laboratory-based studies, is meaningless if this is done before the diffusion process is complete as it will accomplish the ageing of the modifier only and not of the combination of modifier and existing binder. The same argument applies to accelerated moisture and freeze-thaw conditioning.

The fact that different modifiers in different concentrations may diffuse at different rates, and that the characteristics of the existing binder may also affect the diffusion rate of the modifier, further aggravates the situation. The Illinois tests showed that, for the material investigated, immediately following the preparation of the sample the mix had high stiffness and resistance to rutting, whereas a week after preparation the stiffness had decreased by a factor of two and the resistance to rutting had decreased accordingly.

Recycled mixes containing modifiers should be tested throughout their initial life period in order to establish a fuller understanding of the diffusion phenomenon, to enable it to be quantified and subsequently accounted for.

6.6.2 Texas A & M University

In their presentation to the Annual Conference of the Association of Asphalt Paving Technologists in February 1981, Little, Holmgreen and Epps reported on a portion of a Federal Highway Administration study, titled "Softening or rejuvenating agents for recycled bituminous binders", concerned with the mechanical characterization of recycled mixes.

On the basis of laboratory tests on two recycled mixes with the same recycling additive, two recycling additives with the same reclaimed material, and a conventional material used as control, pavement performance and layer coefficients were predicted.

Their main conclusions were:

- (i) the recycled mixes generally performed better than the control mix;
- (ii) there was a substantial and statistically significant difference in performance when the two additives were used on the same reclaimed material;
- (iii) there was a substantial and statistically significant difference when two different reclaimed materials were recycled with the same additive.

Notwithstanding the limited nature of the investigation, the above findings not only show that additives have a role in recycling, but also highlight the importance of selecting an appropriate additive for a particular reclaimed material.

6.6.3 University of Washington

Terrel and Mahoney are the principal investigators for the Federal

Highway Administration's research project entitled "Tests for the efficiency of mixing recycled asphalt pavements", which is being undertaken by the University of Washington.

The objective of the project is to develop a technique and the necessary testing equipment to establish the ability of mixing operations to produce an intimate mixture consisting of reclaimed bituminous materials, modifying agent, new bitumen, and new and reclaimed aggregates.

A method for measuring the dispersion of the recycling agent into the aged binder will not be developed. Although desirable, such a method is not considered a practical proposition, due to the associated costs and level of expertise required by users of such a potential testing technique.

The technique and associated testing equipment will be based on a macro-scale, i.e. it will measure the dispersion of recycling agents throughout the recycled mixture and not necessarily the distribution on an individual piece of aggregate.

Potentially relevant parameters such as penetration, viscosity and volatility were rejected early on in the study because they all involve extraction/recovery techniques likely to mask the actual dispersion of the recycling additive.

Following preliminary investigations, the resilient modulus test was also considered inadequate due to the time it takes to carry out this test (up to 40 days).

Consideration of techniques such as ultrasonic scanning, fluorescence or infrared spectroscopy, dye chemistry, nuclear magnetic resonance, chromatography, and X-ray image analysis, showed dye chemistry to be the most promising. Consequently this has been adopted as the relevant test and, to date, beta naphthol has produced the best dye prints on a fabric made up of 35 per cent cotton and 65 per cent polyester, with an optimum dye proportion of 10 per cent (by mass)

of the additive, applied pressures of about 14 kPa, and two-hour reaction times.

6.7 Current position

There is little doubt that additives will play an increasing role in recycling. However, there is still much controversy regarding their use. In fact the arguments appear to be gaining momentum and to contain at least some emotional and subjective bias.

The misgivings are mainly based on indications that recycled mixes containing modifiers will not always behave like conventional mixes, and on the fact that laboratory-based tests in which extracted binders are mixed with additives do not represent actual operational conditions and therefore cannot be readily accepted as validating evidence. Furthermore additives have been tested mainly on artificially aged binders by investigators suspected of strong bias towards their use. Moreover, most additives are very expensive, compared with conventional binders, and, at times, their use could well tip the economic balance away from recycling.

On the other hand, those in favour of using additives view the opposition to their use as being based on prejudice and short-sighted economic considerations. They recognise that in appropriate situations soft binders can be used instead, but believe that in certain circumstances recycling of asphaltic materials will be pointless unless a modifier is used.

I consider that recycling will be pointless if the long-term performance of recycled pavement material mixes proves to be significantly inferior to that of conventional mixes. Therefore, in my opinion, before the validity of using special additives in bituminous recycling operations is accepted, the following questions need to be answered:

How intimately does the small amount of additive mix with the existing aged, stiff and brittle binder?

Once it gets into close contact, how exactly does it restore?

What effect does an additive have on the conventional new binder?
Is the process time-dependent?
If so, does it improve the mix with time or degrade it?
What about compatibility considerations?

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7. ENERGY CONSERVATION

- 7.1 Preface
- 7.2 Energy equivalents
- 7.3 Energy savings through recycling
- 7.4 Selected bibliography

7.1 Preface

Since 1973, the fluctuating position regarding oil supplies, and the increasing uncertainties over the long-term availability of this commodity, have focused attention on energy and highlighted the need to conserve natural resources, and in particular oil. Oil supplies are now regarded as one of the critical world geo-socio-economic influences.

The newly acquired importance of energy is reflected by the growth in status of the International Energy Agency, the regular appearance of energy and oil on national and international agendas, the government-sponsored research into alternative energy sources and means of conservation, the numerous legislative measures and the continuous barrage of words, analyses, forecasts, outlooks, forebodings, encouragement and dismal prognostications.

Much of the comment concerns technical, economic and political disputes over current and possible solutions. Unfortunately, a great number of the latter either contain subjective bias or are put forward to promote causes which have little to do with energy.

The oil price rises that followed the 1973/74 and 1979/80 supply crises, each of which precipitated a major economic recession, have resulted in fuel price increases, during the last few years, well in excess of the inflation rate. At present the situation appears to have stabilized, but the growth rate in world energy demand has been reduced from 5 per cent a year, over the period 1965 to 1973, to the current 2.4 per cent a year, which is also the projected growth rate until the end of the century.

The implications of the following factors are, or should be, understood by both governments and consumers:

- world oil supplies are exhaustible
- since about 1970 discoveries have not kept pace with demand*
- the area containing most of the world's oil reserves is potentially unstable.

*See Figures 14 and 15

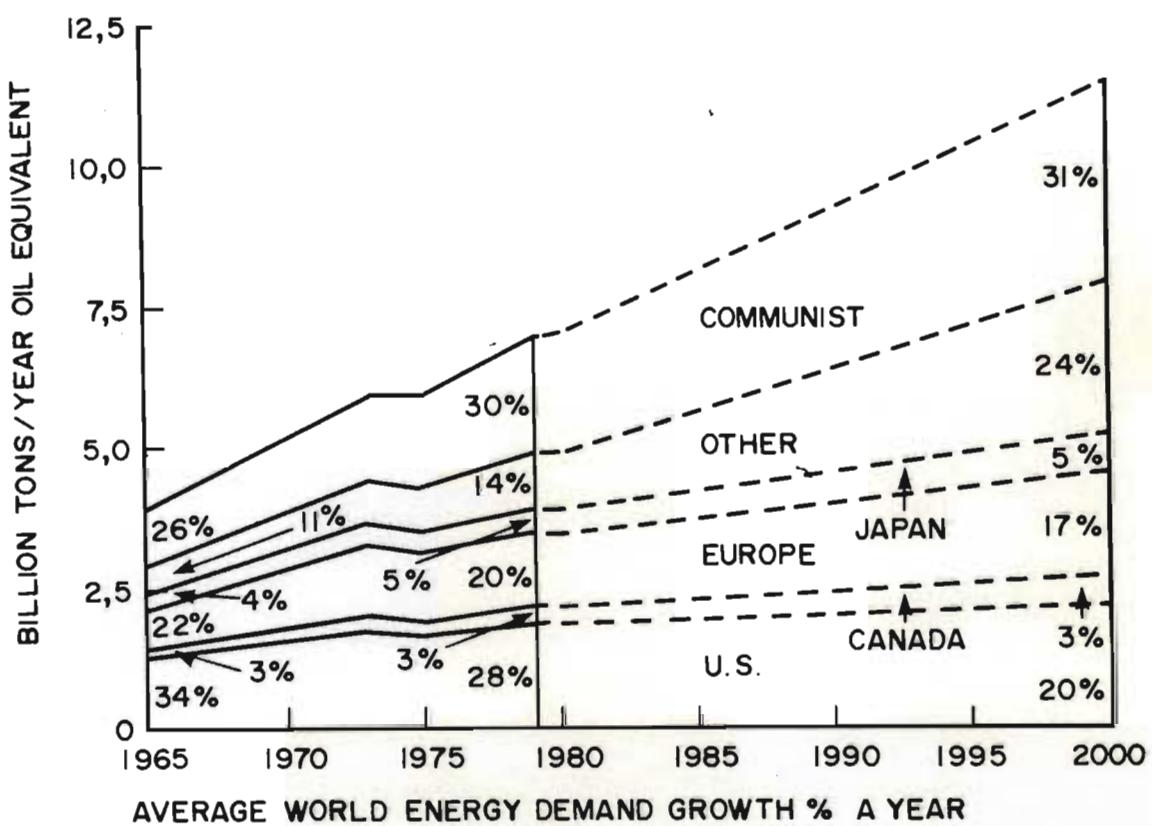
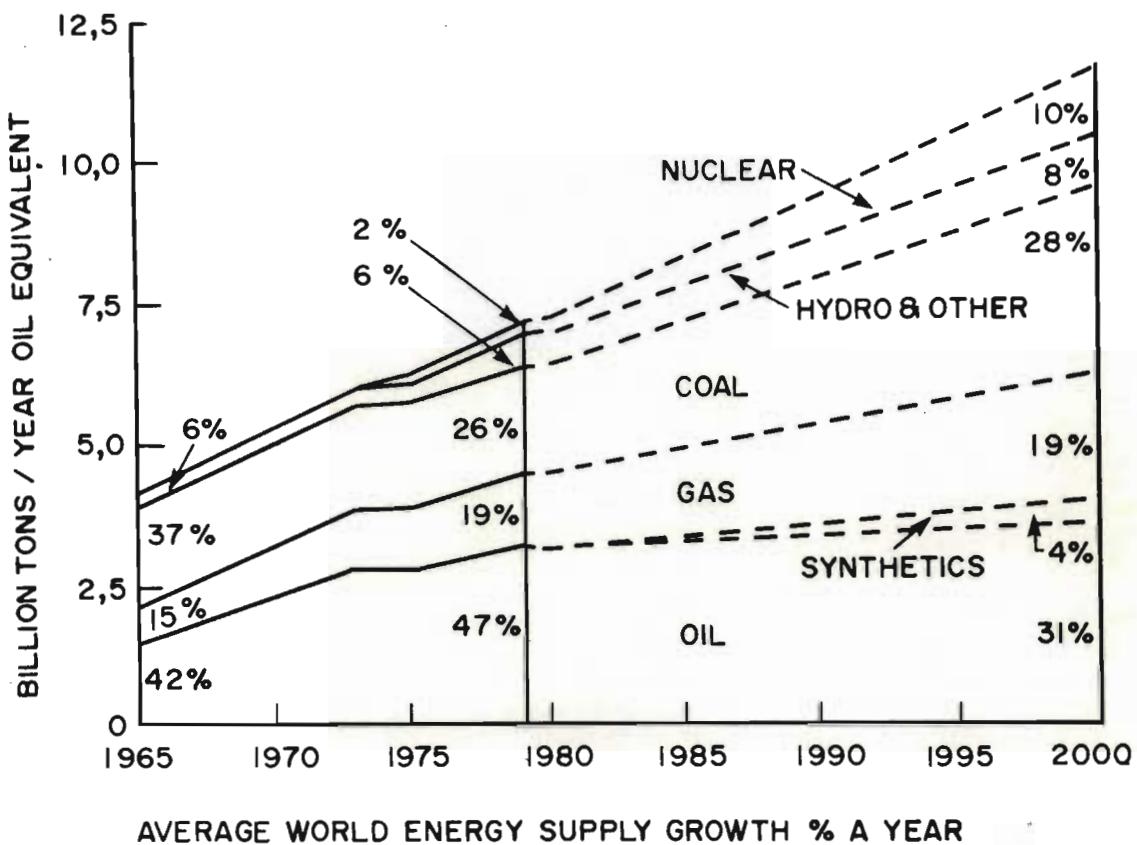


FIGURE 14

WORLD ENERGY DEMAND (FROM: EXXON CORPORATION - WORLD ENERGY OUTLOOK 1980)



	1965-73	1973-79	1979-
OIL	7,7	2,2	0,4
SYNTHETICS	—	—	13,8
GAS	7,3	3,6	2,6
COAL	1,0	2,4	2,8
NUCLEAR	27,8	20,9	10,0
HYDRO & OTHER	3,9	4,6	3,5
TOTAL	5,3	2,9	2,4

FIGURE 15
WORLD ENERGY SUPPLY (FROM: EXXON CORPORATION - WORLD ENERGY OUTLOOK 1980)

7.2 Energy equivalents

During the past few years, several studies have been carried out to calculate the energy consumed in the undertaking of various road construction and maintenance operations and in the utilization of certain materials, in terms of equivalent energy units such as Btu's and Joules. (A British thermal unit (Btu) is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit, when water is at or near 39.2 °F. A Joule is a unit of work and energy; 4,186 Joules are needed to raise the temperature of one gram of water by 1 °C.

Consequently, tables of fuel equivalents, energy requirements for the operation of construction and maintenance equipment, energy used in the manufacturing of materials, energy consumption for pavement materials in place, etc. have appeared in many publications and are readily available. However, although energy analyses have been conducted on several hot mix recycling projects, energy requirement data for recycling operations are largely unavailable.

The appropriate classification of bitumen binders, as either sources of energy or construction materials, has been the subject of considerable controversy. It must be noted that as the density of a petroleum product increases, its energy equivalent increases. Bitumen, a high-density petroleum product, has quite a high energy equivalent. Nevertheless, as it is currently uneconomical and impractical to burn it, mainly due to environmental regulations, bitumen should be considered as a construction material. If the economic situation becomes worse, it may be necessary to reconsider the uses of bitumen.

7.3 Energy savings through recycling

The recycling of aged bituminous pavement materials is regarded by many as an important energy-saving innovation. Graphs have been prepared to illustrate the potential energy savings for various ratios of reclaimed material to virgin aggregate used in hot mix

recycling, compared with conventional rehabilitation projects. In most of these graphs, the haulage distances for new aggregate and binder are the factors used in determining the magnitude of energy savings (see Figures 16 and 17).

Of course, the premise that pavement material recycling conserves energy has not met with general acceptance. An interesting example of the controversy that surrounds this topic was provided at a session of the 1979 PTRC Summer Annual Meeting, at the University of Warwick, UK. Two successive papers presented opposing evidence and viewpoints. Akeroyd and Pooley, Mobil Oil Company Ltd, quoted figures from a paper by C S Hughes, "Problems and solutions to a hot mix recycling plant" (Proceedings of Association of Asphalt Paving Technologists USA, 1978) and held that the recycling of old asphalt is likely to consume more energy than the laying of new asphaltic material. In his presentation Ledbetter, Texas Transportation Institute, USA, included the recycling of pavement materials in the five examples he gave to demonstrate the potential for energy conservation in the construction and maintenance of highways. In fact, using hypothetical situations, he showed potential energy savings for each of the main three categories of recycling, **these** savings being in the proportions of 4 : 5 : 27 for hot surface, hot mix and cold mix recycling respectively.

To date, as far as is known, no comparisons of these **savings have** been made based on actual projects. With regard to the **repaving and** remixing hot surface recycling processes, in the United **Kingdom the** Department of Energy, in cooperation with the Department of Transport, sponsored a study of this aspect of recycling. The results of this study have not yet been made available, but the two processes are likely to show only marginal savings in energy consumption.

Naturally, in practice the situation is complex. Many additional factors have to be taken into account on individual projects in realistic attempts to quantify the energy savings. These additional factors usually include:

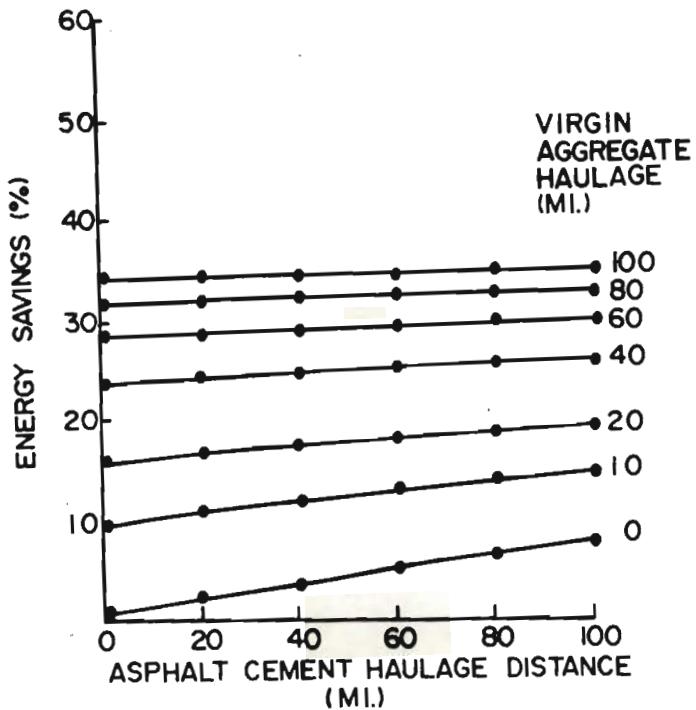


FIGURE 16
ENERGY SAVINGS RECYCLED vs. CONVENTIONAL
50-50 BLEND
(FROM: FHWA DEMONSTRATION PROJECT NO 39 INTERIM REPORT)

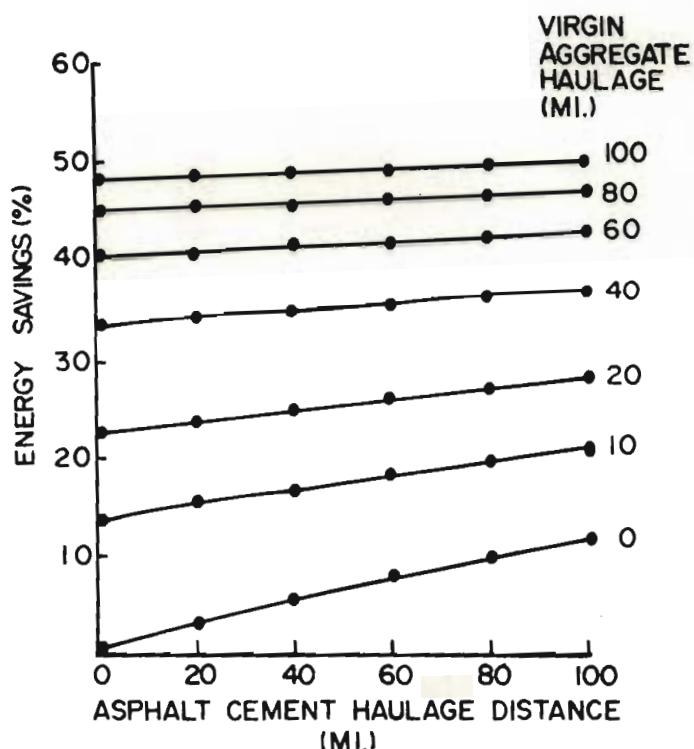


FIGURE 17
ENERGY SAVINGS RECYCLED vs. CONVENTIONAL
70-30 BLEND
(FROM: FHWA DEMONSTRATION PROJECT NO 39 INTERIM REPORT)

- pavement material removal method
- pavement size reduction method
- haulage distance to disposal tip
- haulage distance to reprocessing site
- recycling method and type of equipment used
- moisture content of reclaimed material
- moisture content of virgin aggregate
- quantity of new binder needed.

Furthermore, proper energy comparisons should be based on the service life of the recycled material and not solely on the energy initially consumed in the reprocessing and laying operations. This last consideration is likely to be a major factor in energy comparisons.

The conservation of energy in recycling is made possible by the reduced haulage requirements usually associated with the process, the smaller amount of energy required to produce new binder, and the fuel conserved as a result of less drying being required (new aggregates typically contain greater amounts of moisture than reclaimed bituminous pavement materials).

Nevertheless, in general, the energy that can be saved through recycling has been over-estimated, due to the tendency to confuse savings related to energy conservation with actual cost savings arising from recycling operations. Documentation that proves cost savings, and that shows energy conserved in terms of units such as Btu's saved, but is mostly based on theoretical studies, is often offered as an additional motivation when recycling is advocated. In fact, there is even support for selecting the appropriate alternative on the basis of the lowest energy intensiveness rather than on the traditional lowest cost criterion. Superficially, this above approach appears attractive. However, it would necessitate extremely complicated calculations, largely founded on theoretical assumptions, for each and every individual project. Furthermore, it would entail the adoption of a selection procedure which could not possibly take all the relevant factors into account, but only those

energy parameters that can at present be quantified. In any case, quantifiable energy conservation benefits will (or should) lead to actual cost savings to the producer/contractor, which in turn will lead, through the open competition system, to lower prices for the consumer.

7.4 Selected bibliography

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8. COST SAVINGS

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- 8.2 Direct savings arising from recycling
- 8.3 Cost savings model for hot mix recycling operations
 - 8.3.1 Contributing factors
 - 8.3.2 Symbols used
 - 8.3.3 Haulage savings
 - 8.3.4 Savings in virgin material requirements
 - 8.3.5 Extra costs in reclaiming
 - 8.3.6 Savings in drying moisture
 - 8.3.7 Plant modification costs
 - 8.3.8 Removed material disposal fees or revenues
 - 8.3.9 Value of stockpiled reclaimed material
 - 8.3.10 Total cost savings
 - 8.3.11 Average values for rural operations in the RSA
 - 8.3.12 Example of calculations
 - 8.3.13 Economic evaluation
- 8.4 Selected bibliography

8.1 Preface

Although the conservation of energy and materials is the main theoretical reason for bituminous pavement material recycling, the actual motivation for such operations is that they are less expensive, financially, than the conventional measures. In other words, despite the importance attached to conserving natural resources, recycling will only be used to the full if it can be seen to be cheaper than the conventional options.

There are no fixed values for the cost savings associated with the different forms of pavement material recycling. Ranges of savings have been suggested, forecasted and claimed in various publications, but these can only be viewed as broad guides, based mostly on either limited experience or promotional reasoning. Each recycling project must be evaluated individually, although it is important that the evaluation takes into account the applicable overall controlling parameters and any other directly related undertakings.

The controlling parameters are likely to include a combination of the following:

- the cost of virgin material and any prevailing shortages of aggregates and binders;
- the road industry's commitment to the particular recycling process and hence the likely degree of competition;
- the possible need for and extent of capital investment in specialized equipment and/or modifications to existing plant;
- the extent of anticipated future demand for the process.

With regard to directly related projects, apart from the obvious straightforward cases where material reclaimed from one project is reused on another, consideration should also be given to the possibility of using a different rehabilitation technique on one project in order to obtain significant benefits for another. For example, in some areas, it has proved worthwhile to remove a wearing course, containing high-quality skid-resistant aggregate, before applying an overlay. The removal of the wearing course in such a

case, is wholly justified by the reusable value of the salvaged material.

Naturally, central-plant recycling operations, involving as they do a choice of reclaiming methods, ownership of material, haulage economics, a wide range of possible mix proportions, etc., present by far the most complex problems regarding the calculation of potential cost savings.

8.2 Direct savings arising from recycling

Several road authorities, mainly in the USA, have carried out cost analyses of hot mix recycling projects and have compared the actual costs of these operations with the estimated costs of conventional methods. In general, cost savings were reported, except where the projects were actually development trials (e.g. the 1978 and 1979 hot mix recycling projects in West Germany). The wide range of cost savings realized is reflected by the examples below:

- o The Interim Report (April 1979) of the Federal Highway Administration's Demonstration Project No 39, listed:
 - \$4.02 per ton savings on a 25 000 ton project.
 - \$3.05 per ton savings on a 47 900 ton project.
 - \$.98 per ton savings on a 60 700 ton project.
 - \$3.29 per ton savings on a 42 100 ton project.
 - \$5.16 per ton savings on a 106 800 ton project.
- o A report (April 1980) by the Minnesota Department of Transportation included the following cost comparisons:
 - a 4.8 per cent saving on a 23 000 ton urban reconstruction project, Conway Avenue, Maplewood. The conventional option included the expensive disposal of the salvaged material, and the saving on this operation was therefore reflected in the lower cost of recycling (Table 5).
 - a 20 per cent saving on a 50 000 ton rural project, in which the 2-inch thick bituminous layer and 2 inches of the aggregate shoulder were used to produce a 4-inch thick

Table 5 : Cost comparison - Urban reconstruction project

Conway Avenue
Maplewood, Minn, USA

<u>Item</u>	<u>Unit</u>	<u>Unit Price</u>	<u>Recycled (As-built)</u>	<u>Conventional (Hypothetical)</u>		
			<u>Quantity</u>	<u>Amount</u>	<u>Quantity</u>	<u>Amount</u>
Mobilization	Lump sum	\$35 000		1 \$35 000	1	\$35 000
Salv. & Dispose of In-Place Bit.	Ton	2.80	---	---	9 709	27 185
Salv. Bit. Mixture	Ton	2.80	9 709	27 185	---	---
Salv. & Dispose of In-Place Agg.	Ton	2.40	---	---	9 112	21 869
Salv. Aggregate	Ton	2.40	9 112	21 869	---	---
Bit. Mat'l for Mixture	Ton	65.00	784	50 960	885	57 525
Binder Course Mixture - Conv.	Ton	7.80	622	4 852	4 472	34 882
Binder Course Mixture - Recycled	Ton	6.95	3 850	26 758	---	---
Basecourse Mixture - Conv.	Ton	7.80	1 779	13 876	15 193	118 505
Basecourse Mixture - Recycled	Ton	6.95	13 414	93 227	---	---
Bit. Mat'l for Wearing Course Mixture	Ton	65.00	165	10 725	165	10 725
Bit. Wear Course	Ton	13.95	2 359	32 908	2 359	32 903
Plant Modification	Lump sum	5 000	1	5 000	---	---
TOTALS				\$322 360		\$338 599

Table 6 : Cost comparison - Rural reconstruction project A

Recycled versus Conventional Bituminous Mixture

<u>Item</u>	<u>Unit</u>	<u>Unit Price</u>	<u>Quantity</u>	Recycled (As-built)	Conventional (Hypothetical)
Mobilization	Lump sum	\$70 450	1	\$70 450	1 \$70 450
Field Lab.	Each	1 000	1	1 000	1 1 000
Salv. & Dispose of In-place Bit.	Ton	1.95	---	---	32 889 64 134
Salv. Bit. Mix- ture (Stockpile)	Ton	1.95	32 889	64 134	---
Salv. & Dispose of In-place Shoulder Agg.	Ton	1.65	---	---	12 835 21 178
Salv. Agg. (In Stockpile)	Ton	1.65	12 835	21 178	---
Shoulder Prep. Road Sta.		10.00	2 044	20 440	2 044 20 440
Common Labourers	Hr.	10.00	871	8 710	290 2 900
Bit. Material for Mixture	Ton	75.00	1 368	102 600	2 699 202 425
Recycled Bit. Basecourse	Ton	5.20	26 837	139 552	---
Conv. Bit. Basecourse	Ton	6.50	658	4 277	27 495 178 718
Recycled Bit. Shoulder Wearing Course	Ton	5.20	22 864	118 893	---
Conv. Bit. Shoulder Wearing course	Ton	6.50	2 044	13 286	24 908 161 902
Bit. Material for Tack Coat	Gal.	0.20	5 431	1 086	5 431 1 086
Stockpile Agg. for Bit. Mixture	Ton	1.77	7 430	13 151	---
Traffic Control	Lump sum	20 000	1	<u>20 000</u>	1 <u>20 000</u>
TOTALS				\$598 757	\$744 233

Table 7 : Cost comparison - Rural reconstruction project B

Recycled versus Conventional Bituminous Mixture

<u>Item</u>	<u>Unit</u>	<u>Unit Price</u>	<u>Quantity</u>	Recycled (As-built)	Conventional (Hypothetical)
Mobilization	Lump sum	\$50 000	1	\$50 000	1 \$50 000
Salv. Bit. Mix. in Stockpile	Ton	2.50	72 848	181 210	--- ---
Salv. & Dispose of In-Place Bit.	Ton	2.00	---	---	72 848 144 968
Aggregate Shouldering	Ton	2.50	20 810	52 025	20 810 52 025
Recycled Bit. Basecourse	Ton	4.58	72 168	330 539	--- ---
Conv. Bit. Basecourse	Ton	5.23	3 361	17 578	75 529 395 017
Recycled Bit. Binder	Ton	4.58	12 951	59 316	--- ---
Conv. Bit. Binder	Ton	5.23	644	3 368	13 595 71 102
Recycled Bit. Shoulder	Ton	4.58	15 193	69 584	--- ---
Conv. Bit. Shoulder	Ton	5.23	434	2 270	15 627 81 729
Bit. Material for Mixture (AC)	Ton	87.00	3 627	315 549	5 597 486 939
2361 Wearing Course Mix	Ton	16.38	7 444	121 933	7 444 121 933
Bit. Material for Wearing Course (AC)	Ton	95.00	462	43 890	462 43 890
Bit. Material for Tack Coat	Gal.	0.45	21 067	<u>9 480</u>	21 067 <u>9 480</u>
TOTALS				\$1 256 742	\$1 457 083

recycled bituminous layer (Table 6).

- a 13,7 per cent saving on a 72 000 ton rural reconstruction project (Table 7).
- o A report (April 1980) by the Wisconsin Department of Transportation includes tables showing that, on 13 contracts let in January, February and March 1980, the average (7 projects, average size 37 000 tons) cost of a 50 per cent reclaimed material recycled mix was 28 per cent cheaper than the average (6 projects, average size 34 000 tons) cost of a conventional asphaltic concrete mix.
- o The Michigan Department of Transportation reported (Table 8) that the following estimated savings were achieved on their major recycling projects during the 1979 construction season:
 - 23,8 per cent on the I-94 project.
 - 12,7 per cent on the I-75 project.
 - 19,7 per cent on the M-99 project.
 - 34,3 per cent on the Iron Mountain project.

Table 8 : Cost comparisons - Michigan DOT

1979 CONSTRUCTION SEASON

PROJECT	EQUIVALENT MIX	CONVENTIONAL COST PER TON	RECYCLED COST PER TON
I-94	3.05	17 - 20.00	\$14.11
I-75	4.11	18 - 24.00	\$18.34
M-99	4.11	18 - 24.00	\$16.85
Iron Mountain	4.12	22 - 27.00	\$16.11

- o In 1978, the Wyoming State Highway Department, by using recycling (70-30 reclaimed-new ratio), achieved a 20 per cent saving over the estimated \$2.5 million cost for conventional reconstruction of 9.2 miles of the I-80, between Walcott Junction and Laramie (reported in Asphalt News, Volume 1, Number 4, November 1978).

Urban, 'grocery store', recycling operations undertaken on a regular basis for the production of mainly 'secondary' mixes containing small proportions of reclaimed material, have also proved that they are economical. For example Colas Vejmateriale, Denmark, save on average 8 per cent of the cost of conventional hot-mix asphalt when producing mixes containing some 15 per cent of reclaimed material.

By far the widest range of cost savings has been reported for cold mix recycling. This is due to both the variety of available methods and equipment, and the difficulty in deciding which recycled and conventional products are equivalent. Examples of cost savings include:

- Savings of up to 75 per cent in maintenance expenditure by Clark County, Illinois.
- During 1978-79 Jackson County, Mo, saved 43 per cent of the estimated cost of a conventional 4-inch overlay on a 2.2 mile section of a county road by recycling. The in-place cold mix recycling operations resulted in a 6-inch surface dressed pavement (considered structurally equivalent to a conventional pavement).
- In 1979, the California Department of Transportation saved 33 per cent of the conventional remedial cost by using in-place cold mix recycling on a section of Route 395.
- In the United Kingdom, 'retread' saves on average 15 to 20 per cent of the cost of conventional overlay resurfacing.

Naturally, cost savings on hot surface recycling also vary widely depending both on the method used and on the existing conditions. With regard to repaving on asphaltic concrete material, savings in the region of 30 to 40 per cent of the cost of conventional resurfacing are normally achievable. Considerably lower savings are possible on hot rolled asphalt material, due to the complexities connected with using precoated chippings.

To sum up, although cost savings are unlikely to be achieved when new equipment or techniques are being developed, or when jobs are small in relation to the equipment used, there is no doubt that

substantial savings are possible when fully proven equipment is used on projects which are large in themselves or are part of a large continuing programme over which the extra capital cost can be spread.

8.3 Cost savings model for hot mix recycling operations

The need to predict the cost savings likely to be gained from undertaking hot mix recycling rather than conventional operations has been recognised for some time. In fact, the lack of such means has been one of the main factors limiting the growth in acceptance of hot mix recycling.

In 1982, with the above in mind, I decided to examine the possibility of producing a formula which would include all the factors likely to influence the economics of hot mix recycling and could be used to calculate the total cost savings that could be expected from the undertaking of the process.

The final cost will of course depend on the contractors' tender prices. Nevertheless, the road authorities, before embarking on these options, will need to know the potential savings and weigh these against the expected quality of the product.

However, there is some difficulty in estimating the cost savings. This stems from the great number of factors involved in recycling operations which have not been itemized and costed in the literature.

The situation where a certain thickness of asphalt surfacing is removed and replaced by another thickness of hot mix is analysed below. The various factors and their relationships in assessing the cost savings are identified and used to produce cost saving equations.

This task was undertaken in the knowledge that no matter how substantial the cost savings resulting from hot mix recycling operations on any rehabilitation project, their significance

becomes meaningless unless recycling produces mixtures whose life expectancies are comparable to those of conventional mixtures.

In the following deliberations it is assumed that recycling mixtures are equivalent to conventional mixtures. When life equivalency factors for recycled mixtures are determined they will have to be accounted for in the cost savings calculations.

8.3.1 Contributing factors

The following factors have been considered in the formulation of the cost savings model:

Asphaltic mixtures consist of aggregate stone, sand, filler, and binder (bitumen in conventional mixtures; bitumen and/or recycling agents in recycled mixtures). The quantities of these materials depend on the size of the project and on the mix design and recycling ratio used. The unit cost and haulage distance are different for each material and depend on the locality of the project; e.g. in the RSA bitumen haulage distances differ widely for coastal and inland projects. The unit costs of haulage (per ton per kilometre) are also different; e.g. in the RSA the haulage cost of filler normally includes a railway carriage charge.

Quantities of removed or reclaimed pavement material can be hauled to a tip, to a stockpile for future use, or to the central plant for crushing and/or reprocessing. Existing material can be removed after ripping and breaking, or after reclaiming by cold-milling; in the latter case the bulking factor is much smaller and thus the unit cost of haulage is lower than in the former. The cost of ripping, breaking and crushing is normally lower than the cost of milling. The disposal of removed material could entail tipping fees or revenues. Reclaimed material, stockpiled for future use, has an inherent value. Moisture in the virgin stone aggregate and sand, and in the reclaimed material where applicable, needs to be dried off. The moisture content varies and the unit cost of reducing it (per ton per per cent) is different for each type of material.

Normally, the cost of plant modifications, or acquisition of new recycling plant, cannot be allocated to any one project. The extra cost loading (per ton) per project, depends largely on the contractor's prospects for further work.

8.3.2 Symbols used

In the ensuing calculations and formulae the following symbols are used:

Quantities

Qm	total mixture
Qac	virgin aggregate in conventional mixture
Qsc	virgin sand in conventional mixture
Qfc	virgin filler in conventional mixture
Qbc	virgin bitumen in conventional mixture
Qar	virgin aggregate in recycled mixture
Qsr	virgin sand in recycled mixture
Qfr	virgin filler in recycled mixture
Qbr	virgin binder in recycled mixture
Qr	removed material
Qrr	reclaimed material for recycling
Qrs	reclaimed material for stockpiling
Qrt	reclaimed material to tip

Haulage distances

Ha	virgin aggregate
Hs	virgin sand
Hf	virgin filler
Hb	virgin binder
Hrt	removed material to tip
Hrr	reclaimed material to recycling plant
Hrs	reclaimed material to stockpile

Moisture contents

Ma	virgin aggregate
----	------------------

Ms virgin sand
 Mr reclaimed material

Unit costs

Ca virgin aggregate
 Cs virgin sand
 Cf virgin filler
 Cb virgin binder
 Crs reclaimed material in stockpile (value of)
 Ct tipping (or value of disposal revenue)
 Cr existing material removal (ripping, breaking and
 loading)
 Crm material reclaiming by milling
 Crc material reclaiming by crushing
 Cha aggregate haulage
 Chs sand haulage
 Chf filler haulage
 Chb binder haulage
 Chr removed material haulage (ripped and broken)
 Chrm milled material haulage
 Cma reducing moisture in virgin aggregate
 Cms reducing moisture in virgin sand
 Cmr reducing moisture in reclaimed material
 Cpm plant modification
 Crf rail carriage of filler

Savings or extra costs

Sh haulage
 Svm virgin material requirements
 Sr reclaiming (rather than removing)
 Sm drying off of moisture
 Sp plant modifications
 Srd removed material disposal fees or revenues
 Srs value of reclaimed material in stockpile
 St total

8.3.3 Haulage savings

Savings on haulage will arise from the reduced requirements for virgin materials and will also be influenced by the distances from the project to tip, stockpile and recycling plant, and by the quantities of removed or reclaimed material hauled to each destination. These can be calculated by

$$Sh = (Qac - Qar) Ha Cha + (Qsc - Qsr) Hs Chs + \\ (Qfc - Qfr)(Hf Chf + Crf) + (Qbc - Qbr) Hb Chb + Qr Hrt Chr^{(1)} \\ - Qrr Hrr Chrm^{(2)} - Qrs Hrs Chrm^{(3)} - Qrt Hrt Chr^{(1)}$$

- Notes:
- (1) if removed material is milled rather than ripped and broken, Chrm is substituted for Chr
 - (2) if reclaimed material for recycling is removed after ripping and breaking rather than after milling, Chr is substituted for Chrm
 - (3) if reclaimed material for stockpiling is removed after ripping and breaking rather than after milling, Chr is substituted for Chrm.

8.3.4 Savings in virgin material requirements

Savings arising from the reduced requirement for virgin materials are calculated by

$$Svm = (Qac - Qar) Ca + (Qsc - Qsr) Cs + (Qfc - Qfr) Cf + \\ (Qbc - Qbr) Cb$$

8.3.5 Extra costs in reclaiming

Reclaiming is more costly than ripping and breaking. The extra cost is calculated by

$$Sr = Qrr (Crm^{(4)} - Cr) + Qrs (Crm^{(5)} - Cr)$$

- Notes:
- (4) if the reclaiming for recycling is accomplished by ripping, breaking and crushing rather than by milling, Crc is substituted for Crm
 - (5) if the reclaimed stockpile is made up of ripped and

broken rather than milled material, Cr is substituted for Crm.

8.3.6 Savings in drying moisture

Virgin material has a higher moisture content than reclaimed material. The savings realised through the decreased requirements for drying off excess moisture are calculated by

$$Sm = (Qac - Qar) Ma Cma + (Qsc - Qsr) Ms Cms - Qrr Mr Cmr$$

8.3.7 Plant modification costs

The portion of the plant modification costs carried by a particular project is calculated by

$$Sp = Qm Cpm$$

8.3.8 Removed material disposal fees or revenues

The savings arising from not incurring tipping fees, or the loss of revenue from removed pavement material disposed of, are calculated by

$$Srd = (Qr - Qrt) Ct$$

8.3.9 Value of stockpiled reclaimed material

In metropolitan areas the value of reclaimed pavement material can be considerable. The value of a stockpile of reclaimed material in any locality is calculated by

$$Srs = Qrs Crs$$

8.3.10 Total cost savings

The total savings are obtained by

$$St = Sh + Svm - Sr + Sm - Sp + Srd + Srs$$

By substituting the individual savings formulae, the total savings can be calculated as follows:

$$\begin{aligned}
 St = & (Qac - Qar) Ha Cha + (Qsc - Qsr) Hs Chs + \\
 & (Qfc - Qfr)(Hf Chf + Crf) + (Qbc - Qbr) Hb Chb + Qr Hrt Chr^{(1)} \\
 & - Qrr Hrr Chrm^{(2)} - Qrs Hrs Chrm^{(3)} - Qrt Hrt Chr^{(1)} \\
 & + (Qac - Qar) Ca + (Qsc - Qsr) Cs + (Qfc - Qfr) Cf + \\
 & (Qbc - Qbr) Cb - Qrr (Crm^{(4)} - Cr) - Qrs (Crm^{(5)} - Cr) + \\
 & (Qac - Qar) Ma Cma + (Qsc - Qsr) Ms Cms - Qrr Mr Cmr - Qm Cpm \\
 & + (Qr - Qrt) Ct + Qrs Crs
 \end{aligned}$$

Notes (1) to (5) as in individual savings formulae.

8.3.11 Average values for rural operations in the RSA

Through consultation with the asphalt industry I established the following average values of haulage distances, moisture contents and unit costs (September 1982 prices) in rural operations in the RSA.

Ha	19 km
Hs	16 km
Hf	10 km from railway station
Hb	40 km in coastal areas; 125 km in inland areas
Hrt	5 km
Hrr	7,5 km
Hrs	19 km
Ma	3 per cent
Ms	6 per cent
Mr	no moisture content when reclaimed
Ca	R9 per ton
Cs	R10 per ton
Cf	R72 per ton
Cb	R186 per ton
Crs	R3 per ton (ripped and broken) R6 per ton (milled)
Ct	nil
Cr	R2 per ton
Crm	R5,5 per ton

Crc	R5 per ton
Cha	R0,12 per ton-kilometre
Chs	R0,12 per ton-kilometre
Chf	R0,12 per ton-kilometre
Chb	R0,09 per ton-kilometre
Chr	R0,168 per ton-kilometre
Chrm	R0,126 per ton-kilometre
Cma	R0,37 per ton per per cent
Cms	R0,43 per ton per per cent
Cpm	R0,5 per ton or R1 per ton depending on future prospects
Crf	R15 per ton

8.3.12 Example of calculations

In the calculations below the following assumptions are made:

- this is a rural inland project
- reclaiming is done by milling
- recycling agents are not used
- any excess reclaimed material is hauled to a stockpile
- there are limited prospects of the recycling plant being used again in the near future.

The project involves the production of 50 000 tons of a typical 30 per cent stone gap-graded mixture, the existing available asphaltic material consists of 20 000 tons with 5 per cent effective bitumen content, and a recycling ratio of 40/60 reclaimed/new material can be used, in which case Qrr will equal Qr, and Qrs and Qrt will be nil. The virgin material requirements for a conventional mixture would have been

$$Qac = 0,33 \times 50\ 000 = 16\ 500$$

$$Qsc = 0,58 \times 50\ 000 = 29\ 000$$

$$Qfc = 0,02 \times 50\ 000 = 1\ 000$$

$$Qbc = 0,07 \times 50\ 000 = 3\ 500$$

The new binder requirement for the recycling option is

$$Qbr = 3\ 500 - 0,05 \times 20\ 000 = 2\ 500$$

and the requirements for aggregate stone, sand and filler can be

taken as

Qar 10 500

Qsr 17 000

Qfr nil

On the basis of the average values in section 8.3.11, the likely total savings are R411 690 and the cost saving per ton of the total mixture is likely to be R8,23, or 20,5 per cent of the average cost (R40 per ton).

8.3.13 Economic evaluation

The procedure detailed in the previous sections allows the difference in costs between two rehabilitation options, one conventional option and one recycling option, to be calculated. However, there are other economic considerations. The comparative durability of the options must also be taken into account. Since recycling is a fairly recent development, there is little experience to fall back on and durability must be assessed subjectively. Such assessment may be difficult to justify rationally. The use of concepts of decision theory can assist in defining the main factors for consideration. These are: the cost of each option; the possible outcome of adopting each option; and the probability of each outcome.

Example

Consider two options : a conventional rehabilitation measure and a recycling option. In this particular case the recycled product is known to be 20 per cent cheaper than the conventional material. The durability is expressed as the probability of failure after eight years. This probability is worked out to be 25 per cent for the recycled product and 10 per cent for the conventional material. With both materials failure would mean that the surfacing would have to be milled off and replaced with a new asphalt layer.

The costs for this case are:

- placing of asphalt with recycled material - R40 000/km
- placing of asphalt with conventional material - R50 000/km
- milling and replacing with new mix after eight years -

R50 000/km.

These values are shown in Figure 18. By setting out the important factors in their correct perspective, a decision can be made on a rational basis. If necessary, the choice of mix can be based on expected costs. For each alternative this is given as:

$$E_i = C_i + d \sum P_j \phi_j$$

where C_i = Cost of alternative i

d = discount factor = $(1 + r)^{-n}$ for discount rate r at time n years from now

P_j = probability of outcome j for alternative i

ϕ_j = cost of outcome j

For this example with $r = 0,8$:

The expected cost of the recycled mix = R46 800/km

The expected cost of the conventional mix = R52 700/km

In this example, recycling is shown to be cheaper. Note that if a much higher risk of failure were considered, the conventional alternative might well prove to be cheaper.

In section 12.8.1 the cost savings model is used to determine the sensitivity of the initial savings to factors such as the proportion of reclaimed material in the mix.

It is further used to relate risk to cost savings and hence to determine the most economical design.

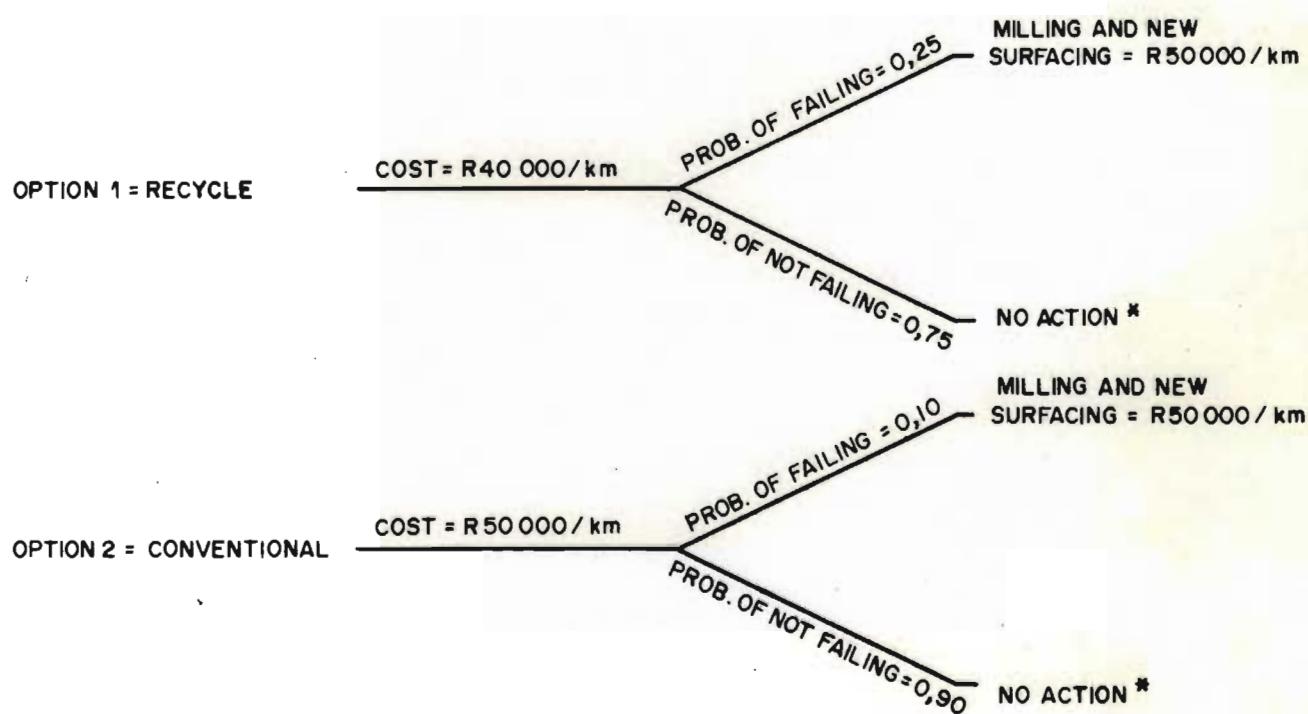
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* NOTE : THE CASE "NO ACTION" IMPLIES SOME ACTION
AT A LATER DATE WHICH WILL BE THE SAME FOR BOTH OPTIONS

FIGURE 18 DECISION ANALYSIS DIAGRAMS FOR THE CHOICE BETWEEN RECYCLED AND CONVENTIONAL MIXES

9. SURVEY OF SELECTED COUNTRIES, 1980

9.1 Australia

9.1.1 Background

9.1.2 Recycling

9.2 Belgium

9.2.1 Background

9.2.2 Repaving and reforming

9.2.3 Cold mix recycling

9.2.4 Hot mix recycling

9.3 Denmark

9.3.1 Background

9.3.2 Hot surface recycling

9.3.2.1 Repaving

9.3.2.2 Remixing

9.3.3 Hot mix recycling

9.4 Finland

9.4.1 Background

9.4.2 Hot surface recycling

9.4.2.1 Repaving

9.4.2.2 Reforming

9.4.3 Cold mix recycling

9.4.4 Hot mix recycling

9.5 France

9.5.1 Background

9.5.2 Hot surface recycling

9.5.2.1 Repaving

9.5.2.2 Reforming

9.5.2.3 Remixing

9.5.2.4 Rejuvenating

9.5.3 Cold mix recycling

9.5.4 Hot mix recycling

9.6 Italy

9.6.1 Background

9.6.2 Hot surface recycling

9.6.2.1 Repaving

9.6.2.2 Reforming

- 9.6.2.3 Rejuvenating
- 9.6.2.4 Remixing
- 9.6.3 Hot mix recycling
- 9.7 Japan
 - 9.7.1 Background
 - 9.7.2 Cold mix recycling
 - 9.7.2.1 Central-plant
 - 9.7.2.2 In-situ
 - 9.7.3 Hot mix recycling
- 9.8 Netherlands
 - 9.8.1 Background
 - 9.8.2 Repaving and reforming
 - 9.8.3 Cold mix recycling
 - 9.8.4 Rubble recycling
 - 9.8.5 Hot mix recycling
- 9.9 New Zealand
 - 9.9.1 Background
 - 9.9.2 Recycling
- 9.10 Norway
 - 9.10.1 Background
 - 9.10.2 Hot surface recycling
 - 9.10.2.1 Heater resurfacing
 - 9.10.2.2 Repaving
- 9.11 Sweden
 - 9.11.1 Background
 - 9.11.2 Hot surface recycling
 - 9.11.2.1 Reshaping (preheating methods)
 - 9.11.2.2 Repaving
 - 9.11.3 Hot mix recycling
- 9.12 Switzerland
 - 9.12.1 Background
 - 9.12.2 Hot surface recycling
 - 9.12.2.1 Repaving
 - 9.12.2.2 Kemna Bau process
 - 9.12.3 Hot mix recycling
- 9.13 United Kingdom
 - 9.13.1 Background

- 9.13.1.1 New construction
- 9.13.1.2 Effect of traffic loading
- 9.13.1.3 Maintenance
- 9.13.1.4 Mechanistic design
- 9.13.1.5 "End-result" specifications
- 9.13.1.6 Shortages of resources
- 9.13.1.7 Road network
- 9.13.2 Hot surface recycling
 - 9.13.2.1 Repaving
 - 9.13.2.1.1 Background
 - 9.13.2.1.2 Cost savings
 - 9.13.2.1.3 Position in 1980
 - 9.13.2.2 Reforming
 - 9.13.2.3 Remixing
 - 9.13.2.3.1 Hot rolled asphalt considerations
 - 9.13.2.3.2 First remixing trial
 - 9.13.2.3.3 Trunk road trial
 - 9.13.2.3.4 Costs
- 9.13.3 Cold mix recycling
 - 9.13.3.1 Retread
 - 9.13.3.2 Central-plant
- 9.13.4 Hot mix recycling
- 9.13.5 Other developments and general considerations
- 9.14 United States of America
 - 9.14.1 Background
 - 9.14.2 Recycling situation in 1980
 - 9.14.3 National Asphalt Pavement Association (NAPA)
 - 9.14.4 The Asphalt Institute
 - 9.14.5 Asphalt Recycling and Reclaiming Association (ARRA)
 - 9.14.6 The Transportation Research Board (TRB)
 - 9.14.7 Universities
 - 9.14.7.1 Iowa State University
 - 9.14.7.2 Texas A & M University
 - 9.14.7.3 University of Washington
 - 9.14.8 Departments of Transportation
 - 9.14.8.1 Iowa
 - 9.14.8.2 Michigan

9.14.9 Plant manufacturers

9.14.9.1 Iowa Manufacturing Company (IMC) Cedarapids

9.14.9.2 Standard Havens

9.14.9.3 CMI Corporation

9.14.9.4 Barber-Greene

9.14.9.5 Boeing Construction Equipment Company

9.14.10 Ashland-Warren Inc

9.14.11 1 94, Eden's expressway, reconstruction project

9.14.12 Cutler Repaving Inc

9.14.13 Jim Jackson, Contractor

9.14.14 Las Vegas Paving Corp

9.15 West Germany

9.15.1 Background

9.15.2 Hot surface recycling

9.15.2.1 Repaving

9.15.2.2 Reforming

9.15.2.3 Remixing

9.15.3 Cold mix recycling

9.15.4 Hot mix recycling

9.1 Australia

9.1.1 Background

The total length of the road network in 1974 was 837 000 kilometres and consisted of:

National roads	120 593 kilometres
Regional roads	146 252 kilometres
Other roads	571 021 kilometres

25 per cent of this network was paved.

In Australia, pavement construction traditionally consisted of unbound granular material with a bituminous surface layer. However in the last few years there had been a growing trend towards full-depth reconstruction in urban areas, and bound bases or subbases for new construction in areas of high rainfall.

Pavement design procedures varied between the different road authorities. The National Association of Australian State Road Authorities was producing a road pavement thickness design manual and was involved, with the Australian Road Research Board, in collecting data to enable realistic dimensional tolerances to be set for various standards of road. With regard to materials, such as crushed stone aggregate and bituminous concrete, their acceptability was based increasingly on statistical methods of quality control.

9.1.2 Recycling

The developments in other countries, coupled with the rapidly escalating cost of asphalt, had focused attention on this subject, which was the theme of the Australian Asphalt Pavement Association's Fourth International Asphalt Conference in 1979. However the consensus of opinion appeared to be that it would take some years before Australia was involved in recycling to any great extent due to the lack of pavements suitable for recycling.

There had been little recycling of bituminous materials. Any such

recycling was undertaken as part of improvements, such as widening schemes. Two such projects were carried out on the Warrego Highway, South West Queensland. The material from the existing gravel base and the 50 mm asphaltic layer of two dual carriageway sections, one 4 km and the other 2 km long, was used to construct the cement-treated bases of the wider new pavements.

9.2 Belgium

9.2.1 Background

The total length of the road network in 1978 was 125 765 kilometres and consisted of:

Freeways	1 128 kilometres
Other main roads	11 277 kilometres
Regional roads	13 845 kilometres
Other roads	99 515 kilometres

94 per cent of the above network was paved. In 1980, with only a hundred kilometres of freeway left to construct in order to complete the freeway network, 50 per cent of the road budget was spent on maintenance. About 370 surfacing contractors, with 92 mixing plants (70 operating) and some 425 pavers, produced and laid 4 to 4,5 million tons of hot mix asphalt per year (the peak production figure, in the early 70s, was 6 million tons). 425 000 tons of bitumen was used by the road industry.

As the country (southern part) is rich in stone and sand, aggregate saving was not considered a serious reason for recycling. On the other hand, due to the escalating price of bitumen, potential savings in binder made recycling an attractive proposition.

The permanent deformation of flexible surfacing, predominantly in wearing courses, caused by the hot summer of 1976, has been the subject of numerous studies. The road authorities, who previously supported rich mixes because these were held to be maintenance-free for long periods, modified the composition of mixes, the conditions of their placing, and the system of checks in the model

specification No 150, while CRR (Centre de Recherches Routieres) published a method of designing flexible surfacings aimed at producing the best balance between the contradictory requirements of resistance to cracking and resistance to deformation.

In recent years the cement and steel industries had seen their overseas markets substantially reduced and the building programme shrink, and had therefore increased the pressure on the road industry. After a Ministry of Works directive had been issued to use a 50:50 ratio between cement-bound and flexible materials in new pavement construction, the problems with excess cement and steel were at least partly alleviated. However it appeared that concrete pavements had created rideability problems.

The specification, in Belgium, was completely end-product orientated, with an accompanying system of penalties and bonuses. In theory payments for completed work could vary between 0 and 110 per cent. Individual bituminous layers were judged separately and wearing courses were subjected to stricter criteria on void content, dispersion, bitumen content, filler content and thickness. Wearing courses also had to meet friction and rideability requirements. Consequently some anomalies arose, such as very cheap wearing courses and expensive basecourses.

The Service Infrastructure Des Routes is the nearest equivalent in Belgium to the NITRR. Their main function is to 'advise' on the specification aspects of road pavements and bridges. The Centre de Recherches Routieres, founded in 1952, is a private institution funded by obligatory contributions from contractors (0,8 per cent of the contract value), as well as by the Ministry of Economic Affairs, with other small contributions from institutions and companies. Apart from research, the activities of the Centre include involvement in revisions to specifications, conferences, training, and assistance to contractors and road authorities.

9.2.2 Repaving and reforming

Experience in these processes had been very limited. The road authorities considered that these methods were only applicable in cases where the wearing course was not subjected to plastic deformation. However this opinion was formed from experience in neighbouring countries. In Belgium, prior to 1980, only three trials were undertaken and they did not involve material subject to plastic deformation. None of these trials was particularly successful.

Wirtgen SPRL undertook a repaving trial on a site of 10 000 square metres in Welkengaadt. Apparently the road authority was prepared to accept a 50 per cent chance of success on what was considered to be predominantly a machine performance trial. The trial was carried out in November 1979, on a surface-dressed wearing course material.

Two more trials were carried out in 1979 using the Vogelete reformer. These trials took place in the Kleine-Brogel airfield and on the RN21, Beverlo-Hepren.

Two further trials were scheduled for 1980. In both cases, remedial measures were needed to rectify the road geometry to increase the transverse profile from 1 to 2 per cent; the actual surface layer material was considered satisfactory. It was envisaged that these trials should be carried out using the Wirtgen repaver on one and the Vogelete reformer on the other.

9.2.3 Cold mix recycling

Since 1957, gravels coated with bitumen had been used on secondary roads in certain parts of the country. This material was originally used as a wearing course with some form of surface treatment, and later predominantly as a flexible subbase for asphaltic concrete. It was thought that cold mix recycling would be a valid potential alternative remedial measure for these layers.

9.2.4 Hot mix recycling

In the spring of 1980, the dualzone drum mixer recycling plant belonging to the Strimont-Enrobes consortium was installed at a site in Strimont, near Liege. It was intended to start recycling operations in two distinct forms.

Firstly, using material removed by planing from municipal roads and stockpiled indiscriminately, it was intended to produce a low-quality mix for use on car parks, footpaths, minor roads, etc. Secondly, using reclaimed material from freeways, it was intended to produce a mix for use on state roads.

Recycling was to start with a modest reclaimed material content of about 20 per cent and, as confidence and experience grew, to progress to higher proportions. The reclaimed material had not yet been tested, although some testing equipment, for determining binder content and gradation, was to be used. It was envisaged that more sophisticated tests, such as the penetration of recovered binder, would be carried out by various testing laboratories.

The Service Infrastructure Des Routes and the Centre de Recherches Routieres were surprised when I informed them of these important trials in hot mix recycling, although they were aware that contractors had been considering some form of involvement in the process. Both organizations expressed a keen desire to participate in monitoring the recycling activities.

Reportedly 15 to 20 000 tons of recycled mix were subsequently produced in 1980, with a wide range of reclaimed pavement material contents (maximum 60 per cent) without encountering serious problems.

9.3 Denmark

9.3.1 Background

The total length of the road network in Denmark in 1978 was 67 523 kilometres and consisted of:

Freeways	464 kilometres
Other state roads	4 201 kilometres
Regional roads	6 807 kilometres
Other roads	56 051 kilometres

The whole of the above network was paved.

A four-year project was undertaken which entailed subjecting a full-depth asphalt pavement to tests aimed at determining the effect of axle loads and the resistance to plastic deformation. This project led to additional tests to further investigate the performance of resource-saving pavement types.

Because of strict friction requirements, Danish asphaltic concrete was 'leaner' than normal pavement mixes. A 100 pen binder was normally used with 200 pen for winter and 60 pen for summer work. The 1980 life expectancy of asphalt concrete pavements was approximately 11,3 years, although considerably shorter lives had been experienced on freeways. Apparently this was due to the use of thin layers and the high percentage of calcined flint aggregate (up to 30 per cent and more) in the mix. The use of calcined flint was the subject of considerable controversy. This material is attractive due to its light colour and the consequent safety benefits. On the other hand it has disbenefits in that it absorbs bitumen and causes adhesion problems. In 1980 its use was limited to smaller percentages.

Hot rolled asphalt was first introduced into Denmark some thirteen years ago, in an effort to counteract the damaging effect of salt. The riding quality achieved with this material was considered considerably inferior to that produced when using asphaltic concrete. Hot rolled asphalt has not been used in the last four to

five years. Some 100 kilometres of hot rolled asphalt surfacing is currently in use.

Apart from the sharp increases in the price of bitumen and the general environmental and political interest in conserving natural resources, there was an additional reason for reusing pavement material. This was the anticipated acute shortage of good quality aggregates.

All the parts of Denmark that are directly accessible are sedimental, and gravel provides most of the aggregate. As this is basically an agricultural country, there is considerable difficulty in obtaining planning permission for new gravel pits. Granite for high quality wearing courses is imported from places such as Sweden, Norway and the small Baltic island of Bornholm. It could be reasonably argued that the biggest stone quarry in the country is the existing road network.

9.3.2 Hot surface recycling

9.3.2.1 Repaving

In 1976 Colas, Phoenix, Superfos and Ecopal, four companies commanding some 75 per cent of the blacktop market, set up a working party to investigate the position, prospects and potential market of repaving. Their broad conclusion, in 1977, was that even if the four companies were to combine in becoming involved in repaving, the total market, estimated at 100 000 square metres per annum, would not support the purchase of a repaving unit.

Apparently one of the main reasons for the low estimate of the size of the potential market for repaving had been the size of the country in relation to the number of asphalt plants. In 1980 there were about 60 hot mixing plants in Denmark, with 30 kilometres being the maximum haul distance. This factor significantly reduced the haulage benefits of repaving.

Despite this pessimism, in 1976, 52 000 square metres of repaving work were carried out. In 1977 the figure was 84 000 square metres. During this period repaving was undertaken by the Wirtgen company, 72 000 square metres, and by the R & S Swedish company, 64 000 square metres, the latter using a Cutler repaver. In 1979 the Wirtgen company repaved some 225 000 square metres.

However a certain degree of scepticism remained. It was considered that repaving should only be accepted if proof could be shown of applicability, a direct benefit in cost savings of at least 10 per cent, and given the normal five-year guarantees.

9.3.2.2 Remixing

Naturally, as with repaving and other innovations, the development of remixing was not an uninterrupted success. While in Denmark, January 1980, I was given an opportunity to inspect the remixing site on the A13, Viborg to Strowring. The operation entailed reusing some 40 mm of the existing material with 20 per cent new material on a 2 kilometre section (about 15 000 square metres). The northern half of the site appeared satisfactory. However, the southern half left a lot to be desired with large fretting areas, patches of remedial work, substantial potholes and bad longitudinal joints.

Although the contract was undertaken during August, the weather was unfavourable for part of the contract period, with strong cross-winds. Apparently great difficulty was experienced in achieving the required temperatures; in fact on certain days temperature readings on the scarified material did not exceed 97 °C.

Obviously it is important to undertake a complete preliminary analysis of the existing material and to establish the amount and type of new material to be added in producing the mix. However, equally important are the prevailing weather conditions (e.g. rain, temperature, wind) and the skill and experience of the operators.

9.3.3 Hot mix recycling

From 1978 Colas Vejmateriale recycled bituminous pavement material obtained by their hot planing operations. The recycling was carried out in two of their thirteen batch-type asphalt plants and was undertaken by means of simple and inexpensive modifications to the plants. The company produced 3 000 tons in 1978 and 17 000 tons in 1979 of mixes containing about 20 per cent of reclaimed material.

On arrival at the asphalt plant, the reclaimed material was mixed with 5 to 10 per cent sand in order to prevent congealment during storage. During recycling the virgin aggregate was superheated by about 50 °C. The reclaimed material was loaded in a specially built bin from which it was conveyed as required to the discharge of the dryer. The superheated aggregate and the reclaimed material entered the hot elevator together and were fed into the weigh hopper and mixer, bypassing the screen.

The company was content to continue using only a modest percentage of reclaimed material for the following reasons:

- The quantity of reclaimed material was limited.
- There was little homogeneity in the reclaimed material, which came from numerous small sites.
- There was an excess of fines in the reclaimed material; this was particularly problematic in view of the small size of the hot planers used in removing the pavement material.
- The capital investment required for plant modifications was small.

Colas Vejmateriale was saving on average about 8 per cent of the cost of conventional mixes through its recycling operations. The 17 000 tons of recycled material produced during 1979 represented some 2 per cent of the total blacktop market of 860 000 tons.

While in Denmark I visited the plant at Herfolge. Unfortunately it was during the shutdown period (normally January, February and March), although it was still possible to examine the recycling

modifications. The reclaimed material stockpile was covered with snow. There was no apparent concern about excess moisture and, reportedly, the material could, due to being mixed with sand, be stockpiled for periods exceeding a year without congealment.

Colas Vejmateriale were considering the possibility of manufacturing mobile modification units to enable the rest of their mixing plants to carry out recycling.

9.4 Finland

9.4.1 Background

The total length of the public road network in 1978 was 74 430 kilometres consisting of:

Freeways	194 kilometres
Other main roads	10 794 kilometres
Secondary regional roads	29 204 kilometres
Other roads	34 237 kilometres

In addition there were some 30 300 kilometres of private roads subsidized by the state. By the end of 1978, 45 per cent of the public roads were paved, 98 per cent of the main roads, 59 per cent of the secondary regional roads and 15 per cent of the other roads.

Pavement wear due to the use of studded tyres used to be the major maintenance problem in Finland. Studded tyres could be legally used between the 16th of October and the 15th of April (in Lapland the period was four weeks longer). The wear due to the use of studs ranged between 1 and 3 cm yearly and, in extreme cases, it could be as much as 4 cm. By 1980, in order to reduce wear, both the size and scope of the studs had been restricted.

In March, during my visit, most of the roads observed in Helsinki were moderately to badly deformed by the effect of studs. Some sections of freeway (Turunvalva, Lahdenvalva, and others) were so extensively worn that the basecourse was exposed and special speed limits were applicable. Most of the damage had been done to the

slow lanes, although at times it extended to the middle lanes.

In general, the design standards provided a choice of several technically equal options for each road type for the design of the bearing capacity and frost control. This enabled the option with the most attractive total cost (construction and maintenance as well as road user cost) to be chosen.

Nearly 90 per cent of the loose soil types are frost-susceptible. The depth of the non-frost-susceptible structure was designed on the basis of the freezing index occurring once in 10 years, at the same time taking into account the frost-susceptibility category, the dampness of the ground, and the road category.

A predominantly end-product specification was used. Penalties for non-compliance ranged up to 8 per cent of the contract value (in theory the total payment could be withheld). The average penalty imposed during 1979 was 0,8 per cent.

About 300 000 tons of bitumen were used yearly in Finland. The State Oil company, with 77 per cent of the market, had the monopoly for the state highway requirements and the only two bitumen refineries in the country. Savings in aggregates did not make pavement material recycling particularly attractive. Recycling was undertaken for commercial reasons based on the price of bitumen and project economics.

9.4.2 Hot surface recycling

9.4.2.1 Repaving

Both the Cutler and Wirtgen repavers had been tried. However repaving using these machines was considered too expensive compared with the cost of repaving and reforming undertaken using local machines.

Repelg Oy manufactured and operated their own repaving machines.

Pettri Elg first became involved in the process in 1977, after using a Scandinavian repaver which did not particularly impress him. The Repelg system involves two machines coupled together. The first heats, scarifies and reprofiles the pavement, while it conveys material from its hopper to the hopper of the second machine, which is a conventional paver.

The Company had produced four models. The latest model appeared capable of a performance comparable to that of the Cutler/Wirtgen repavers, although it was much less expensive. Moreover the use of two machines gave complete flexibility in that the plant could be used in either repaving or conventional work. On average the company had repaved about one million square metres per year, since 1978, hiring out their repaver and key operatives to surfacing contractors in Finland.

Kestoasfaltti Oy repaved about 400 000 square metres between 1978 and 1980. This Company normally uses the Repelg repaver. They used the Wirtgen repaver in 1977 before rejecting it as too expensive.

9.4.2.2 Reforming

Oy Viarecta Ab used the Swedish Cutler repaver, for which they were agents, on three projects during 1975, and the Repelg machines on two projects during 1978. In 1979 the company produced their own reformer. Their system consisted of two units: a heater bank followed by a paver with scarifying equipment attached to the hopper. The scarifier, which was not always used, scarified the edges and the middle section of a lane to a depth of up to 30 mm. Oy Viarecta Ab believed that the importance of scarification in repaving was overestimated and that, provided adequate heating was applied, it could be omitted from the process.

The reformer was first used by the Helsinki Direct Labour Department, during a period of apparently atrocious weather, to undertake (quite successfully) remedial measures on the Helsinki Airport road. I visited the reformed site (two outer lanes of a 6 kilometre section

of a three-lane carriageway) in March 1980. In general the work appeared satisfactory, although some irregularities in the longitudinal joints indicated that in places the scarification at the edges, during reforming, had been insufficient.

9.4.3 Cold mix recycling

This process had been tried in an in-situ form some time ago with unsatisfactory results. The climatic conditions are not ideal for cold mix recycling processes.

Nevertheless it was increasingly looked into as a cheaper alternative in both its in-situ and central-plant forms. The state highway authority was prepared to examine and try out any promising new approach. It is possible that oil gravel pavements may render themselves to such a maintenance method despite the adverse climate.

9.4.4 Hot mix recycling

In 1974, Lemminkainen Oy, in co-operation with ARA (Auran Rautateollisuus) manufacturing company, produced a drum mixer of 100 tons per hour capacity. This plant was used in extensive testing aimed at the recycling of pavement material and led to the Renovator system.

Two further recycling drum mixers were produced. One was sold to the Soviet Union, where the plan was to use it for recycling during the summer. The other was a static plant with a capacity of 200 to 250 tons per hour. The two drum mixers in Finland were used for the production of conventional as well as recycled mixes.

Although the first commercial recycling was undertaken using 100 per cent of cold planed material to produce a basecourse mix, subsequently recycling produced mixes containing 70 to 80 per cent reclaimed material, which at times were used as wearing courses. By the end of 1979 some 20 000 tons of recycled mixes had been produced, with about 7 000 tons used on state roads in the area of

Oulu. Apparently, the results were rather mixed.

According to Lemminkainen Oy, the actual recycling process presented no special problems. The reclaimed material was heavily sprayed with water (2 per cent) as it entered the drum at a faster than normal speed, so that it could pass quickly through the burner area. Some problems had arose with the storing and handling of the material reclaimed from the planing operations. These were resolved either by adopting the ripping, breaking and crushing method, or by mixing the planed material with 20 per cent of virgin material before storing. The crushing operation was so undertaken to ensure maximum breaking of the existing stones and the production of naked surfaces so that the need for virgin material was kept to a minimum.

9.5 France

9.5.1 Background

The total length of the road network in 1978 was 801 504 kilometres and consisted of:

Urban freeways	1 060 kilometres
Other freeways	3 544 kilometres
Other main roads	28 100 kilometres
Regional roads	346 800 kilometres
Other roads	422 000 kilometres

100 per cent of the national roads, 99,5 per cent of the regional and 85 per cent of the local roads were paved.

The 1977 Standard List of Structures established a policy of heavy initial investment in highly trafficked roads (over 50 vehicles per day in one direction), coupled with a minimum maintenance allowance.

There were three stages of quality control of materials:

- preliminary examination,
- control of manufacture,
- acceptance control.

With regard to hot mix asphalt, there had been little change in the use of asphaltic concrete 0 - 10 mm and 0 - 14 mm as defined by the 1969 Regulations.

Before the 1970s, 180 - 220 penetration binder was the only one used. In 1980 in the north of the country 80 - 100 pen binder was used in the winter and 60 - 70 pen binder in the summer; the corresponding values for the south were 60 - 70 and 40 - 50.

Developments in the use of new types of wearing course included the specification of "chip seal asphaltic concretes", increasing use of ^z open-textured coated materials, and the production of high-performance materials such as:

- bitumen-coated materials + polymers (copolymer, ethylene, ^z vinyl, styrene, butadiene);
- bitumen-coated materials + sulphur (20 to 30 per cent; by-product of the natural gas exploration);
- bitumen-coated materials + asbestos (short-fibred).

Concrete pavements were presenting serious problems, mainly due to the loss of skid resistance. Surface dressings were attempted but had limited success, and grooving techniques and thick overlays were considered to be too expensive.

The maximum axle load was set at 13 tons, although this limit appeared to be generally disregarded. Apparently measurements indicated, that on the most heavily trafficked routes 2 to 3 per cent of the axle loads were as heavy as 21 tons.

2,6 million tons of bitumen were used annually (about 50 per cent by the road industry). By the mid 1970s, the sharp price increases in this commodity, coupled with the government's directive to use products with lower bitumen contents, appeared to have created favourable conditions for the recycling of bituminous pavement materials.

9.5.2 Hot surface recycling

9.5.2.1 Repaving

There were at least eight repavers permanently based in France, as well as machines imported for specific projects (e.g. Repave A G's Cutler from Switzerland) and Vogelete-Scholkopf reformers. Consequently there was much competition for available work and although such competition was beneficial from the point of view of savings to road authorities, it tended to have a detrimental effect on the quality of repaving work undertaken at low rates.

In 1980 four companies were involved in repaving activities:

- Jean Lefebvre: 4 Wirtgen machines on hire from Sofar (2 repavers and 2 repaver/remixers)
- Colas: 2 Wirtgen machines (1 repaver and 1 repaver/remixer)
- Bourdin & Chausse: 1 Cutler repaver
- Screg: 1 Cutler repaver.

Between October 1976 and the end of 1979, Jean Lefebvre carried out some 2,5 million square metres of repaving. Reportedly the company was able to offer competitive prices on freeways and municipal roads; repaving did not provide an attractive economic proposition on the national highways where, normally, overlays were not considered appropriate measures.

In the spring of 1980, the average resurfacing prices per square metre were 23 francs for a 90 kg overlay and 47 francs for removing and resurfacing 60 mm. Repaving prices (35 - 40 kg overlay) ranged between 23 and 35 francs per square metre.

9.5.2.2 Reforming

Sacer was one of three members of the consortium RRR (Regeneration Revetement Routier) which was formed in 1979. RRR had an agreement with Vogelete-Scholkopf, West Germany, where they could hire reforming machines as needed. Between May 1979 and June 1980, the consortium

undertook some 310 000 square metres of reforming with projects on all types of road.

The reforming work included a section of a 45-kilometre, four-lane repaving project on the A10, Paris-Tours, freeway. The existing wearing course was aged and brittle (penetration 10 to 15) and the surface was extensively cracked. The project was divided into sections and awarded to four companies: Jean Lefebvre, Colas, Bourdin & Chausse, all using repavers, and Sacer, using a reforming machine.

Sacer maintained that the reforming process was superior to repaving, as in reforming the existing scarified layer was compacted by two vibrating plates to ensure that the two layers, existing and new material, did not mix.

9.5.2.3 Remixing

Jean Lefebvre undertook a remixing project, involving 12 000 square metres, on the A1, Boulevard Peripherique, freeway during the autumn of 1979. The existing wearing course was badly deformed.

The original mix was improved by the addition of a small amount of hot mix asphaltic concrete (3 to 6 mm) and the incorporation of the existing surface chippings into the resultant mix. No special problems were encountered in completing this project, the first time that remixing had been undertaken in France.

Apparently, the typical asphaltic concrete wearing course materials in France have a low binder content and are therefore suitable for remixing operations in which the only material added is binder.

9.5.2.4 Rejuvenating

Rejuvenating trials were scheduled for the late summer of 1980, by Jean Lefebvre and Colas, using their respective remixers. At the request of the Ponts et Chaussees, various additives were to be

used, e.g. reclamite, RJ3, Colas' rejuvenating agent.

Screg also planned to rejuvenate on a project, by spraying on an additive (compodyl) before commencing repaving operations.

9.5.3 Cold mix recycling

In the summer of 1980, Screg carried out some cold mix recycling trials in the west of France (Laval area). The existing pavement layers were pulverized using a BJD medium planer and treated with an emulsion additive, based on a RJ03 rejuvenating oil.

9.5.4 Hot mix recycling

The development of hot mix recycling in France was based on close cooperation between the Ponts et Chaussees and the Ermont plant manufacturing company. Such development was greatly facilitated by the fact that the Ponts et Chaussees was involved in the commercial production of hot-mix asphaltic concrete material (some 70 000 tons annually). The special binder, RJ3, used during the development trials was produced and supplied by Shell Francaise.

Ermont produced a pilot drum mixer recycling plant (TSM-8), with a 12 tons per hour capacity, in 1977. The reclaimed material was introduced into the TSM-8 together with the virgin aggregate, at the burner end of the drum. Consequently the reclaimed material, unprotected from the flame and hot gases, burned and hardened.

In 1978 Ermont produced a full-size recycling plant (TSM-17), with a 200 tons per hour capacity, and installed it at the Ponts et Chaussees' regional laboratory at Blois. The TSM-17 had undergone considerable testing and modifications. The entry arrangements were different from those of the pilot plant, providing separate entries for the reclaimed material and virgin aggregate. Trials showed that there was no appreciable advantage to the recycling of cold rather than hot planed material. Both types required further size reduction by crushing before they were reprocessed in the drum mixer.

The earlier problems with the hardening of reclaimed binder were largely resolved although during trials with high ratios of reclaimed material to virgin aggregate (70 - 30), environmental problems were still encountered and baghouse equipment was damaged by excessive heat.

Recycling with high proportions of reclaimed material also created problems regarding the homogeneity of the reclaimed material and the achievement of the desired grading in the resultant mix.

The road authority became convinced that 30 to 40 per cent was the optimum reclaimed material content in central-plant hot mix recycling. The recycling trials met with considerable interest from many quarters. Ermont received provisional orders for some ten recycling plants. However there were some remaining problems and the plant was subjected to further modifications before another series of trials, which were scheduled for August - September 1980.

9.6 Italy

9.6.1 Background

The total length of the road network in 1977 was 292 737 kilometres consisting of:

Freeways	5 615 kilometres
Other main roads	44 336 kilometres
Regional roads	101 120 kilometres
Other roads	141 666 kilometres

Apart from ANAS (Autonomous State Highway Authority), there are other bodies responsible for the construction and maintenance of freeway sections. The State contributes up to 33 per cent of the cost of constructing these sections of freeway which in theory revert back to State ownership after about 30 years. During the intervening period tolls are charged. These tolls are fixed by the State and they differentiate between two types of freeway network (mountain and other routes) and three types of traffic (private cars, small commercial vehicles, heavy commercial vehicles). The

charges take no account of the relative traffic densities or of the extra damaging effects of the heavier axle loads.

Since the late 1970s, in order to reduce the extent of rutting on the most heavily trafficked routes, there had been a tendency to use a fairly open-graded asphaltic concrete hot mix material instead of the traditional dense-graded mix. This helped to alleviate rutting problems, due to better interlock and the reduced bitumen content of the mix, but increased the damage due to fatigue. Reportedly some pavements lasted only five years rather than the 15 to 20 years envisaged.

More recently maintenance practice consisted of undertaking a series of temporary repairs, which served to keep the roads in operation at a reasonable level of service for as long as possible. Some of the results of this policy were observed during my visit. Several freeway sections showed extensive cracking and other irregularities arising from the policy of carrying out numerous individual repairs on relatively small surface areas. Often, resurfacing, in some form or other, was undertaken, when the fault lay well below the surface layers, resulting in the appearance of numerous reflective cracks only months after completion.

A combination of method specification and end-product specification was used. Control over the work and the materials was regulated by official procedures established for the projects carried out for the state road authorities. These procedures provided penalties or deductions for non-fulfilment of the specifications.

The penalty system was based on criteria such as thickness of layers, rideability, composition and characteristics of mixture, temperature, void content and sometimes friction coefficient.

Considerable problems were involved in the introduction of drum mixers to Italy. Drum mixers are ideally suited to the production of large quantities of uniform mixes, which were no longer needed after completion of the major part of the freeway system.

Furthermore a supply of uniform, good-quality aggregate could not always be guaranteed. Another requirement for the successful operation of drum mixers, that could not usually be met, is the need for fully equipped site laboratories to perform periodic checks before and during the mixing operation. Nevertheless, Loro & Parasini, under Boeing licence, produced drum mixers for use in Italy, albeit for the production of basecourse material in areas of apparently little environmental pollution control.

In general there was no shortage of aggregate, although the quality was very variable, with some regions being forced, for economic reasons, to use medium or even poor quality aggregates. The rising price of bitumen (the road industry were using about 2 million tons annually) provided a strong incentive for reusing bituminous pavement material.

Although some freeway agencies had had experience with surface recycling, the state road authority had not been involved as yet in recycling operations. A balance between economic advantages and compliance with technical specifications was still being sought.

9.6.2 Hot surface recycling

9.6.2.1 Repaving

Wirtgen Italiana in association with CIS (a Fiat company) repaved 300 000 square metres of the Milan to Turin freeway in 1976. The contract was sufficiently unsuccessful to stop any further repaving activities in Italy. About half of the completed work was subsequently resurfaced.

The repaving project was undertaken on sections of the slow and middle lanes of the Turin-bound carriageway. The surface layer on these two lanes, constructed on the old Milan to Turin concrete road pavement, exhibited a considerable amount of reflective cracking throughout its length.

9.6.2.2 Reforming

CIS reformed 8 000 square metres of the Milan to Turin freeway in 1979, using a Jim Jackson reformer. Twenty millimetres of the existing wearing course material was treated before an overlay of 10 mm was applied.

9.6.2.3 Rejuvenating

In conjunction with the reforming project, CIS carried out a wearing course rejuvenating trial on 1 600 square metres of the Milan to Turin freeway. The trial, undertaken despite Jim Jackson's advice regarding the unsuitability of the plant, involved the mixing of 20 mm of the existing pavement material with an asphalt modifier. The experiment ended in complete failure.

Further rejuvenating trials were planned for 1980. These trials were to involve the removal of 20 mm and the treatment of the remaining 20 mm of surface layer plus 10 mm of the binder course with an asphalt modifier. The original level was to be restored by the application of a 20 mm layer of new material.

During 1979, the Montanari company developed a rejuvenating system based on their planing machines. This system consists of a truck attached to an infra-red heater bank, connected by a 16 metre tube to a planer, which is followed by a collecting, mixing and relaying unit. One to 1,5 per cent of additional bitumen is added in the mixing process. This method was tried in the Parma area in 1979 and further trials were planned for the summer of 1980.

9.6.2.4 Remixing

Remixing was first introduced in July 1979, on a 140 000 square metres section of the Turin to Piacenza freeway and it was followed by contracts in the city of Aosta (22 000 square metres) on the Milan to Turin freeway (45 000 square metres) and on the Milan freeway ring (32 000 square metres).

During a visit to Italy, in March 1980, I took the opportunity both to inspect the latter two remixing sites and to discuss the process and the work with the relevant road authorities, and Wirtgen Italiana.

The Milan to Turin work was undertaken on part of the slow and middle lanes of the Turin-bound carriageway. The surface course was made up of two 40 mm layers of asphaltic concrete. Two distinct processes were carried out. On the slow lane as much as 80 mm of material was heated, scarified and remixed with little or no new material. Work on the middle lane was preceded by the removal of 10 mm of material, and then 40 mm of the surface course was heated, scarified and remixed with 10 mm of new material. The appearance of the surface would have been excellent but for the all-too-frequent reflective cracking which re-appeared a few months after completion. However, it must be noted that similar reflective cracking was even worse on adjoining sections, treated at about the same time by conventional methods.

The overall cost of the work was less than 50 per cent of the usual cost for conventional removal and replacement of 50 mm, although it was apparently based on promotional pricing.

The remixing work on the Milan ring road consisted of several sections. On this contract 40 mm of the existing material, the full depth of the surface course, was heated, scarified and remixed with 10 to 15 per cent of new material. The general appearance and rideability were acceptable considering the frequent end-joints and the cold weather prevailing during the period of the contract in November. The last section of the work was unsatisfactory, reflecting the working conditions of -3 °C during its completion. Apparently, in an effort to counteract the cold conditions, the preheating unit was operated forward and backward rather than simply ahead of the main machine.

The road authorities were cautiously optimistic, recognising that it was too early to draw firm conclusions, but were quite prepared to

undertake further remixing work in 1980 on the basis of the 1979 experience.

Wirtgen Italiana had carried out certain modifications on their remixer, including:

- the strengthening of the back section by the incorporation of two hydraulic supports to prevent horizontal wobble,
- the incorporation of a bitumen tank and a spraying facility in the form of a cross-pipe, with four outlet sprays, behind the scarifiers. Apparently the addition of bitumen could be controlled with 95 per cent accuracy within the limits of 0,3 to 1 per cent.

In the spring of 1980, Wirtgen Italiana were undertaking promotional trials in the south, on various types of road, and were looking forward to a full programme fo work during the 1980 season.

9.6.3 Hot mix recycling

Marini had developed their recycling plant on the basis of modifications to existing batch plants and modified drum mixers. These modifications enabled existing mobile batch plants to produce mixes containing 30 to 35 per cent of reclaimed material. Naturally, the production rate was reduced while recycling. With 35 per cent reclaimed material, the virgin aggregate had to be superheated to about 250 to 260 °C for the production of mixes at a temperature of 160 °C, and therefore the production rate was reduced by some 30 to 40 per cent. At the time of my visit the company were about to sell their first mobile modifications for work in Italy.

The modified drum mixer, developed for export purposes only, was capable of producing mixes containing up to 50 per cent of reclaimed material. The modifications were based on the split-feed principle, with a second inlet for reclaimed material half-way down the drum.

Edilvie Road Contractors had done some hot mix recycling in one of their batch type plants. The modified plant produced a satisfactory

mix containing some 20 to 30 per cent reclaimed pavement material.

Asphaltic Nord were expected to purchase a Barber-Greene dual-zone recycling plant in 1980. Apparently their concern about the electronic controls of the mixing plant (ability to detect errors while recycling, etc.), coupled with fears regarding a likely hostile reception by the road authorities, increased sufficiently during a period of delays before delivery of the plant for Asphaltic Nord to reverse their purchase decision.

For their part, Sobrino, Barber-Greene's distributors, appeared equally sceptical about the ability of the drum-mixing plant to recycle as claimed. They were particularly doubtful about whether the plant could process mixes with reclaimed material contents in excess of 50 per cent, at specified temperatures of about 115 to 120 °C, without the emission of blue smoke. They foresaw a bleak future for recycling in Italy unless the road authorities were prepared to accept lower standards at lower prices and the contractors were prepared to accept lower prices for producing lower quality material.

9.7 Japan

9.7.1 Background

The total length of the road network in 1978 was 1 097 411 kilometres and consisted of:

Freeways	2 195 kilometres
Other main roads	40 279 kilometres
Regional roads	129 425 kilometres
Other roads	925 512 kilometres

40,2 per cent of the above network was paved.

The introduction of the toll road system, in 1956, has played a major role in the development of the freeway (national expressway) network in Japan. The construction and maintenance of toll roads, which include the freeways, are wholly undertaken by public

corporations or authorities set up by the Japanese Government or local public bodies.

The "Specification for Asphalt Pavements" lays down the technical standards for the design and construction of bituminous pavements in Japan. Following the 1972 revision of the specification, lime-stabilized bases and subbases came into common use.

At the time, the main problems with bituminous surface layers in Japan were the abrasive effects of studded tyres or tyre chains in icy regions, and bleeding of asphalt concrete in summer.

In the late seventies Japan produced about 70 million tons of coated materials annually. Commercial involvement in the recycling of pavement material began in 1976.

9.7.2 Cold mix recycling

9.7.2.1 Central-plant

Niigata Engineering company had developed a plant system which could manage both asphalt hot mix recycling and cold mix recycling of concrete pavement material. The steam method was used for the former and the latter was done by means of conventional methods of primary and secondary crushing.

The capacity of the plant was 70 tons per hour for hot mix recycling and 150 tons per hour for cold mix recycling. The resultant cold mix material was being used for the construction of subbases and base courses.

9.7.2.2 In-situ

Nippon Hodo had developed an in-place cold mix recycling process, 'Field Recycling Base Construction Method' or 'FRB Method', for the rehabilitation of deteriorated basecourses. In this method, the ripping, breaking and pulverization of the pavement and the mixing

with stabilizers were all performed by a purpose-build machine, the 'Base Preparizer'.

9.7.3 Hot mix recycling

In 1980 about one-half million tons of mixes containing reclaimed bituminous material were produced in Japan, where several companies operate hot mix recycling plant. Due to the incorporation of a pre-steaming process in the recycling operations, mixes containing 100 per cent reclaimed material were common.

Taiyu Road Construction company produced some 60 000 tons per annum of high-proportion reclaimed material mixes, using two drum mixers of 80 and 120 tons per hour capacity. Taiyu's drum recycling system operated on the basis of simultaneous entry of virgin and reclaimed material and was equipped with a special pollution-prevention unit. The company used material reclaimed by ripping, breaking and crushing. Softening agents were added only in exceptional circumstances. The resultant mix was generally used for the construction of basecourses, although, on occasion, it was used as a surface layer for lightly trafficked roads.

Nippon Hodo, following an abortive involvement with the Mendenhall process (see Netherland section, 9.8.5), developed its hot mix recycling system on the basis of indirect heating of the reclaimed material. This was accomplished by the introduction of hot combustion gases into a 'heat exchanger' section of the recycling plant.

In both Nippon Hodo and Taiyu's experience, the resultant mix had, in general, higher Marshall stability and flow values than those of conventionally produced hot mix asphalt.

Niigata Engineering company manufactured hot mix recycling modification equipment for conventional batch type plants. Ripped and broken reclaimed bituminous materials were heated to a high temperature inside a steam boiler. The steamed bituminous materials

were then dried, reduced in size and further heated in a drum drier before the screening and mixing operations. Apparently atmospheric pollution problems were greatly reduced by the use of the steam system.

9.8 The Netherlands

9.8.1 Background

The total length of the road network in 1978 was 90 631 kilometres and consisted of:

Freeways	2 120 kilometres
Other national and regional roads	52 557 kilometres
Secondary roads	38 054 kilometres

The whole of the above network was paved. In 1980 research projects were being undertaken to develop a rational pavement management system.

A combination of recipe and end-product specifications was being used. The recipe specification was normally used when contractors had to furnish evidence of the good quality of the aggregates and achieve required standards of stability, flow and other Marshall properties. If, due to local conditions, this was not possible, then deviations from the recipe could be authorized. In these cases acceptance control testing was performed on completion and it was linked to penalty conditions; in fact this was applicable on all major works.

Following the hot summer of 1976 and the resultant deformation and concern about early loss of skid resistance, a new specification was issued in 1978. The "Requirements for materials in road construction, 1978" was edited by the State Road Laboratory and was drawn up by a committee on which were represented contractors, state authorities, large local authorities, suppliers and others. The new specification introduced two fundamental changes relating to the deformation resistance of asphalt mixtures:

- the applicable Marshall requirements were related to traffic classes, and
- a new requirement was added for a maximum percentage of bitumen-filled voids in the mineral mixture of the Marshall test specimens.

With regard to skid resistance requirements, a new method of determining the content of rounded particle surfaces was introduced, rendering the commonly used crushed river gravel unsuitable for traffic class 4 usage.

All state roads had been constructed with bituminous surface layers. In fact, due to the geological conditions, until the late 1970s some 90 to 95 per cent of all road pavements were constructed with bituminous materials. The province of Noord Brabant was the only one with substantial experience in constructing concrete pavements. However, faced with a substantial reduction in the use of cement in the building industry, the cement manufacturers began to display a more aggressive attitude. Consequently, two agricultural roads in the state reallocation/rationalization programme, were changed from flexible to concrete construction. As the programme for the construction of new roads was more or less coming to an end, the pressure was expected to increase.

By 1980 some 100 mixing plants were being operated in the country, producing about 8 million tons of hot mix material annually. During the peak period, 1971, 120 plants produced about 12½ million tons. Mainly due to the strict specification requirements regarding moisture content, 0,1 per cent maximum, drum mixers were not used in the Netherlands.

Apart from political and environmental pressures, there were other reasons for reusing existing pavement material. These were the anticipated serious shortages of high-quality aggregates and the rapidly increasing price of bitumen. In 1979 suitable crushed stone was already difficult to obtain, partly due to the new polished stone value (psv) requirements of 53 for class 3 and 65 for class 4 roads. The traditional Rhine supply from West Germany, psv 50 to

53, was considered too risky. The best-quality aggregate was imported from Wales.

9.8.2 Repaving and reforming

Experience in these techniques was very limited. The processes were used mainly in trials and problems had been encountered with achieving the required temperature, compaction and, in particular, rideability. Apparently a repaving project on the A12 had to be conventionally overlaid soon after completion.

Three machines had been used:

- Cutler repaver by Repave BV, a Volker/Stevin consortium
- Wirtgen repaver by Wirtgen
- Vogelete reformer by Vissers.

9.8.3 Cold mix recycling

Investigations into the use of crushed bituminous pavement material as the mineral aggregate for the construction of bases involved three distinct approaches:

- (1) the use of reclaimed material untreated,
- (2) the use of reclaimed material mixed with bitumen emulsion, and
- (3) the production of crushed asphalt cement by the mixing of the reclaimed material with sand and cement.

The investigations showed that, due to residual creep even when the experimental sections had been very closely compacted, crushed asphalt, untreated or mixed with bitumen emulsion, was not very suitable as a construction material for bases.

On the other hand reclaimed asphaltic concrete pavement material was crushed and mixed with sand and cement to produce a satisfactory basecourse mixture.

In addition, concrete pavement recycling had also been carried out. In an airfield project, 20 000 tons of a concrete pavement 20 cm

thick were crushed and mixed, after resurfacing, with 20 per cent sand and 16 kilogramme of cement per square metre to produce a lean concrete base. A soil cement stabilizing machine, BROSS, was used.

9.8.4 Rubble recycling

Successful recycling work had been carried out using selected rubble from demolition sites as aggregate for basecourse mixes. The hardcore consisted of concrete, brick and other materials, and was mixed with bitumen. Extensive investigations had established performance equivalencies between the thicknesses of hardcore asphalt layers and those of conventional asphalt.

On a strict project basis, this form of recycling was not economical. However, considerable savings could be realised on a wider basis taking into account the disposal costs of this material. There was also strong political support for the process in cities such as Amsterdam and Rotterdam which were prepared to pay premium prices for the recycled product because it helped to clear waste.

9.8.5 Hot mix recycling

Hot mix recycling operations in the Netherlands started a few years ago when Stevin, with the aid of a 10 to 15 tons per hour pilot drum mixer plant, constructed two series of experimental road sections, for which thin anthracene oil, thick anthracene oil and Mexphalte RJ3 respectively were used to rejuvenate heated crushed asphaltic concrete.

The pilot plant was built under licence from RMI (Recycling Machinery Incorporated) and was based on Mendenhall's Heat-Exchanger Tubes System (described in Chapter 4 - Hot Mix Recycling). In order to achieve a satisfactory heat transfer, the reclaimed material was reduced to a particle size of 45 mm or less. The required content of rejuvenator was found to be 4 to 6 per cent for thin anthracene oil, and 9 to 14 per cent for thick anthracene oil and Mexphalte RJ3 (the percentages are in terms of the bitumen content of the

reclaimed material). However, use of the thin anthracene oil was soon discontinued due to the objectionable fumes arising during both the recycling operation and the laying of the resultant mix.

Mainly due to the difficulty in separating the different layers of asphalt during reclaiming, the recycling mix was considered suitable only for the production of base material. Nevertheless, it was established that the pilot plant could be used for the production of a good-quality asphalt mixture. At the time it was calculated that savings of approximately 30 per cent could be realised through recycling, on the basis of using a mixing plant of about 100 tons per hour capacity.

Stevin were subsequently joined by HWZ and other contractors in forming Renofalt and entering into a venture with the State involving the 100 per cent recycling of 300 000 tons of bituminous material on a deformed and cracked section of the A16 Freeway, Rotterdam to Dordrecht. The project was scheduled to start during the autumn of 1980.

During the pilot plant's recycling operations some problems (carbonisation, blockages, blue smoke, etc.) occurred but it was thought that this would not happen with the full-size plant. However, news of serious problems encountered in Nevada, USA, with this form of recycling caused the Consortium great concern. The pilot drum was cut open and it was discovered that complete blockage would have been imminent if production had continued.

Urgent investigations into possible solutions included a visit to NOMA, a Japanese contractor who also had the RMI licence for the plant. It was found that NOMA had changed everything on the plant including the shape, number and size of the hot gas pipes. After many unsuccessful trials they appeared to be near a solution with the development of a system incorporating six sets of pipes on the outer part of the drum. When this system failed, three big sets were tried, with no success. Eventually the system was replaced by a semi-indirect heating approach. This created other problems with

part of the binder feedpipe becoming red hot, and the binder heating to 600 °C with consequent carbonisation, blue smoke emissions, etc.

Renofalt finally decided that the RMI system would not work. A competition was held within the consortium to find a solution other than the obvious one of recycling with a smaller proportion of reclaimed material. The state authority remained adamant on the 100 per cent reclaimed mix, reminding Renofalt of their original strong assurances of success.

Eventually a potential solution was found in the form of combining several approaches including the Japanese method of preheating the reclaimed material by steaming, indirect heating and direct heating. However, a few months before the scheduled start of the project, the situation was still viewed with considerable pessimism. At the time it was felt that the highway authority would eventually relax their insistence on 100 per cent recycled material. In fact the plant under construction was designed for a variety of reclaimed material/new aggregate mix ratios.

An indication of the lack of confidence in the derived recycling plant was the fact that in the spring of 1980 Zanen, one of the companies in Renofalt, purchased a Standard Havens drum mixer asphalt plant equipped with the coneflight recycling system. Apparently it was planned to introduce this drum in three stages: as a dryer, a mixing plant and a recycling plant.

In parallel to Renofalt, another recycling consortium was formed in the Netherlands. This consortium, Aduco (Association of Dutch Contractors), was made up by Bruil Arnhem, Bruil Apeldoorn, Schagen Zwolle, Ooms Avenhorn and Nelis Haarlem. The first four were also producers of hot mix material. The consortium, which was originally formed to undertake overseas work, owned a PR750 CMI profiler and had the use of smaller planers belonging to the parent companies.

In March 1980, Aduco was preparing to carry out hot mix recycling trials on the basis of the Minnesota method. Their plant in Zwolle

was being modified for recycling operations containing 15 to 25 per cent of reclaimed material. At that time, the possibility of recycling with 50 per cent reclaimed material was also considered. It was felt that this could be made possible by incorporating cascade systems, with the material falling downwards while the hot gases moved upwards, by extension of the mixing time to possibly 5 minutes, and by other modifications.

9.9 New Zealand

9.9.1 Background

The total length of the road network in 1976 was 96 034 kilometres and consisted of:

Freeways	108 kilometres
Other main roads	11 179 kilometres
Regional roads	72 308 kilometres
Other roads	12 439 kilometres

of which 46 000 kilometres were paved or sealed, 43 000 kilometres gravel, and 7 000 kilometres were earth roads.

Bituminous materials were used solely in and around the main cities. Most on the inter-city road network consisted of surface-dressed granular roads.

9.9.2 Recycling

There was growing interest in recycling, although neither hot mix recycling nor hot surface recycling had been attempted at that stage. With regard to repaving, Shell Oil considered the possibility of some involvement in this process. However, a study of the market potential indicated that there was unlikely to be sufficient work for a repaver even if it was bought in conjunction with Australia.

In view of the predominantly non-asphaltic surfaces, cold mix recycling appeared to offer much more scope.

9.10 Norway

9.10.1 Background

The total length of the road network in 1978 was 79 817 kilometres and consisted of:

Freeways	60 kilometres
Other national roads	25 099 kilometres
Regional roads	31 120 kilometres
Other roads	23 538 kilometres

53 per cent of the above network was paved, and the rest consisted of gravel roads with a low bearing capacity and small traffic volumes.

At the end of the War, 95 per cent of the road network was unpaved. Due to their low bearing capacity, these roads had to be completely reconstructed before they could be conventionally surfaced and consequently paving took place slowly. The paving programme included:

- A few hundred kilometres of concrete pavements. These were found to be far too costly because the climate necessitated thick bases and subbases.
- Thinner bituminous pavements (20 to 30 mm), which in general performed satisfactorily. These were preceded by the application of a hot binder coat acting as a sealer and penetrator.
- Oil-gravel pavements. In 1980 a special oil (mixture of oil and asphalt components) was used, replacing the traditional 'lubricating' oil. Apparently, oil-gravel and bituminous pavements look much alike. In many cases oil-gravel wearing layers became base or binder courses under subsequent overlays.

Some years ago, in an effort to expedite the paving programme, the road authorities initiated a large low-cost surfacing programme for rural roads. The Otta Surfacing Method used in this programme was developed by the Norwegian Road Research Laboratory in the mid-1960s, and is a special kind of surface treatment applied directly onto the unstrengthened gravel road.

The procedure involves the 'penetration' of the existing gravel by asphaltic solutions, followed by several courses of surface treatment using graded aggregate. It is an inexpensive, simple approach and has the added advantage of allowing the traffic flow to continue uninterrupted during construction (in rural Norway there are no detours!).

On the heavily trafficked roads, the design criteria met the axle load requirements so well that axle load restrictions were not required during the spring thaw period. Consequently, pavement thicknesses of 0,8 to 1,0 metres were common. The commonest problems with bituminous surface layers were alligator cracking and severe wear by studded tyres. The extensive use of studded tyres had reduced the service life of wearing courses on heavily trafficked roads to three to four years.

9.10.2 Hot surface recycling

9.10.2.1 Heater resurfacing

In order to withstand the effect of studded tyres, the paving mixes for urban roads contained the highest possible quantity of coarse aggregate. Consequently these mixes had to be applied in thick layers and expenditure on urban road maintenance was accordingly very high.

The Norwegian Road Research Laboratory had developed a relatively low-cost method which was based on the use of infrared heaters and the application of a thin overlay while the existing surfacing was still hot and soft. The amount of material used was just sufficient to fill the ruts. The thickness of the overlay was decided on independently of the maximum stone size as on the thin parts of the overlay the coarse aggregate was partly embedded in the existing layer.

The Heater Surfacing Method had been used since 1968 had reduced the resurfacing costs to less than 40 per cent of the cost of

traditional resurfacing while still giving the same service life.

9.10.2.2 Repaving

This surfacing method was also being used in Norway.

9.11 Sweden

9.11.1 Background

The total length of the public network in 1978 was 128 973 kilometres and consisted of:

Freeways	799 kilometres
Other main roads	12 623 kilometres
Regional roads	84 849 kilometres
Other roads	31 500 kilometres

56 per cent of the above network was paved, but the unpaved gravel roads carried only 10 per cent of the total traffic flow.

Nevertheless, the pressure for an increase in the proportion of surfaced roads was growing and had led to the development of simple and cheap wearing courses with a moderate service life.

Surface treatment with graded aggregate, YIG, was one such surfacing, the first of which was constructed in 1967. By 1978, the total length of YIG roads was 370 kilometres.

The increase in traffic loading and the use of studded tyres had, in many cases, reduced the life expectancy of pavements to less than half of what it was 15 years ago. This, in conjunction with the sharp rises in the cost of conventional surfacings, had led to a tendency to use simpler and less expensive maintenance procedures.

9.11.2 Hot surface recycling

9.11.2.1 Reshaping (Preheating methods)

Two methods were used:

- Overlaying by a conventional paver fitted with side heaters which preheated the existing surface and provided a soft layer for the partial embedment of the overlay at the edges.
- Heating the whole surface and then overlaying.

The above procedures had the advantages of limiting the maintenance to the damaged part of the pavement and providing sufficient material to fill the ruts, while using a thin overall overlay. The average thickness of the new surface layers was 20 mm.

9.11.2.2 Repaving

About 500 000 square metres per annum were repaved by the Swedish ABV company with Cutler repavers. Wirtgen had also carried out some repaving in Sweden (about 120 000 square metres during the period 1977 to 1979).

9.11.3 Hot mix recycling

This process had not been undertaken up to 1980. However, following the visit of a study group to the USA in 1979, it was anticipated that hot mix recycling would be introduced in the near future.

9.12 Switzerland

9.12.1 Background

The total length of the road network in 1978 was 62 628 kilometres and consisted of:

Freeways	737 kilometres
Other main roads	17 892 kilometres
Secondary roads	43 999 kilometres

Wearing course deformation appeared to be the main problem. This may be due to the softer binders used in the past. After 1972, in efforts to counteract the effect of studded tyres, harder penetration binders, 60 - 70 pen, were used.

Concern with rutting problems led to a programme of research into the sensitivity of bituminous surfacing materials to permanent deformation. It was found that the deformation of layers in practice is related to their behaviour in the creep test.

More recently attempts were made to use thermal insulating materials to counteract the effects of frost and thaw on mountain roads. Due to the high costs involved this practice was confined to special cases.

The end-product specification system was in use. In 1974 a system of penalties for not conforming to the specification was introduced in the canton of Berne. The penalties ranged from 2 to 8 per cent of the contract price and took into consideration the following factors:

- grading
- bitumen content
- percentage of voids
- layer thickness
- rideability (applicable to freeways only).

Apparently the introduction of this system was followed by a considerable improvement in compaction.

The specification for asphaltic concrete wearing courses was changed in 1973/74:

	<u>Previous</u>	<u>New</u>
Maximum size stone	10 mm	16 mm
Binder content	6 % plus	5,2 %
Penetration	120 - 150 (180 - 200)	60 - 70
Layer thickness	30 mm	40 mm

About 280 000 tons of bitumen were used annually by the road industry. There was a tendency to use tar-bitumen binders (e.g. in the canton of Zurich) due to their better bonding quality. In fact about 25 to 30 per cent of binder used was tar-bitumen.

Increasing use was being made of hot rolled asphalt material with precoated chippings. Although more expensive than the traditional asphaltic concrete, it was used for its better resistance to deformation and skidding in many mountainous areas, such as the canton of Grison.

9.12.2 Hot surface recycling

9.12.2.1 Repaving

This process was about 30 per cent cheaper than conventional resurfacing and five times cheaper than reconstruction. In the early repaving days some problems with inadequate compaction were encountered. Apparently these were due to the large daily outputs of about 6 000 square metres. The compaction problems were subsequently overcome. No other problems were experienced and the rideability was considered quite acceptable.

The canton of Berne had undertaken repaving, using both the Cutler and the Wirtgen machines, since 1973 when the process was carried out for the first time in Europe. Since then some 70 kilometres of freeway slow lane had been repaved. In 1980 repaving was the standard procedure on freeways in Berne, where conventional resurfacing was last undertaken in 1974.

The canton of Zurich was more sceptical. Experience there was limited to one freeway project. The road authority believed that the cost savings that could be achieved, compared with the loss in thickness of new mix material, did not justify the process.

Repave AG, a consortium of Losinger, Atag and Frutiger, bought a Cutler machine in 1972 and undertook repaving in several cantons during the 1973-74 period. In 1975 they did not operate due to problems involved in the administration of the company and limitations on the availability of work as a result of the inability of the original Cutler repaver to deal with street furniture. During 1976, the machine was used in West Germany for a while until

a serious breakdown necessitated the return of the repaver to Switzerland.

In 1977, Repave AG stopped all operations when liquidation of the company was seriously considered. However in 1978, after failing to sell the repaver, they sought further work. A 60 000 square metres freeway project, canton of Berne, was successfully completed before the machine and the key operators were hired to a Colas-SCR consortium in France for use on a 90 000 square metres project on the autoroute A10 near Paris.

In 1979 Repave AG and Colas attempted to form a new consortium. However, Colas bought a Wirtgen repaver instead. Bourdin e Chausse became interested and hired the repaver and key operators for use on a 28 000 square metres project A10 near Orleans, a 30 000 square metres project, A10 near Tours and a 30 000 square metres project, A8 near Aix en Provence. The last project was undertaken during December when a preheater was used. Rehabilitation was necessary mainly because of cracking. The surface also had a very dry appearance with the binder content about 4 per cent (original pen 40 - 50).

Several problems arose. These included insufficient scarification, lumps in the scarified material, burned binder and extensive damage to the repaver caused by the flames. Furthermore, two months after completion, potholes started to appear on the repaved pavement surface. Subsequently, Bourdin e Chausse bought a new Cutler repaver.

Wirtgen AG started their repaving activities in 1976, in the face of strong opposition from the asphalt lobby. According to the company the 1978 season was almost lost to politics. However Wirtgen AG completed some 100 000 square metres during 1979 in some seven or eight cantons, and were confident about future prospects. The company bought a new repaver/remixer in 1980 for use solely in Switzerland, where the total repaving market was estimated to be between 600 000 and 800 000 square metres per annum.

9.12.2.2 Kemma Bau process

During 1976 this process of heating and filling the ruts was tried on a one kilometre section of the N1 freeway in the canton of Berne.

9.12.3 Hot mix recycling

Some hot planed materials was used in the construction and maintenance of forest roads, footpaths, car parks and for other purposes. However it was becoming increasingly difficult to dispose of removed pavement material because of concern about environmental pollution.

Walo had attempted to recycle hot planed pavement material in modified batch plants, using the Minnesota approach. The reclaimed material was fed into a specially provided bin from where it was conveyed directly to the pugmill, where it joined the superheated new aggregate. The proportions of reclaimed material used ranged from 10 to 15 per cent. On arrival at the mixing plant site, the reclaimed material was mixed with sand, in a 5:1 ratio, to prevent congealment. Nevertheless considerable problems were experienced during processing.

In 1980, Amman, the largest plant manufacturer in the country, was developing both drum mixer recycling plants and modifications, for recycling, to existing batch plants. However, official hot mix recycling trials had not yet been undertaken in Switzerland.

9.13 United Kingdom

9.13.1 Background

9.13.1.1 New construction

By 1980 the motorway^{*} network in the UK extended to some 1 400 miles. Restrictions on public expenditure, national policy and the

^{*}The British term "motorway" is equivalent to the South African "freeway".

influence of public opinion were by then combining to bring the programme of major motorway construction to an end.

Of course, eventually, the remaining inter-urban gaps in the system were to be filled and other projects, such as routes to the major ports and some important orbitals, were to be completed. But, in the short term, new construction on major routes was unlikely to extend much beyond the completion of industrial routes, such as the M25 London orbital motorway and specific by-passes.

Other projects in this period may well have included improvements resulting from planning decisions, which could have a critical effect by further overloading busy sections of the existing network. For example, it was possible that the new link connecting London's third airport at Stansted to the M11 would be constructed as a priority scheme.

However, there could be little doubt that, apart from some individual projects, there was not going to be much new road building during the first half of the 1980s.

9.13.1.2 Effect of traffic loading

Road Note 29 contains guidance on the structural design of road pavements for traffic loadings of up to a cumulative number of 100 million standard axles (the 8 200 kg axle having been chosen as the standard axle).

Contrary to earlier expectations, it was becoming apparent that actual cumulative loadings, in a twenty-year design life for heavily trafficked routes, would most certainly exceed 100 million standard axles and could well approach 200 million standard axles.

Contributing factors had been the increased efficiency in loading, brought about by the rapid increases in fuel prices since 1973, and the need to conserve energy. As the loading factors progressively increased, the corresponding damaging effect on pavements, related

as it is to the fourth power of axle loads, also increased sharply.

Recent research (Transport and Road Research Laboratory report LR910) indicated that the vehicle damage factor, based on average commercial vehicle standard axles, on heavily trafficked roads had increased from 1,08 to 2,9. This meant that, even without the effect of the underestimated forecast of commercial vehicle flows, the damage factor had increased by about 270 per cent.

This could mean that major route reconstruction would be needed at more frequent intervals than had been hitherto envisaged, and it did explain, at least partly, the 'premature' failures on certain roads.

A national computerized system for picking up loads had been advocated for some time. In theory this could further rationalize haulage operations and could reduce the number of empty lorries on the roads. Although this measure would benefit the environment and should save money and energy, the saving in the damaging effect by the reduction in the number of empty heavy vehicles could be negligible unless the extra damaging effect of increased speed on the part of these vehicles was found to be significant. Conversely, if adoption of this proposal was to lead to even more efficiency in loading, it could even increase the damaging effect.

The Government-appointed Armitage Committee could ultimately recommend an increase in the then 32 ton maximum lorry weight limit, to bring it in line with the EEC 40 ton limit. This decision could be of less consequence than a decision to raise the 10 ton maximum axle load, because well-designed large lorries with the proper number of axles are less damaging than smaller overloaded lorries.

In 1980, I considered that, apart from the construction of new roads or the reconstruction of pavements to stronger standards, remedial measures in the next few years could well have included enforceable legislation and regulations to control the impact of heavy commercial vehicles, and possible changes in the road taxation system, to ensure that the 'culprit' vehicles would pay for the

amount of damage they caused.

9.13.1.3 Maintenance

One effect of the reduction in new construction was to focus attention on maintenance. In 1980 the then Minister of Transport, stressing the newly acquired importance of maintenance, stated that "Britain needs a programme of major strengthening and renovation on priority roads".

The prevailing political viewpoint was that sufficient funds ought to be spent on the existing primary network at least to prevent further deterioration. In view of the increasing loading factors on the major routes, considerably larger amounts than before would have to be spent if this aim was to be achieved. It was possible that, despite assurances, the existing infrastructure might begin to deteriorate.

Since there had already been mention of substantial cuts in the overall maintenance funds, the situation regarding the rest of the network was particularly bleak.

Experience has shown that economic restrictions tend to lead to more ingenious technology, more competitive prices and conservation and reuse of resources. It is therefore possible that more work may be undertaken than would seem to be indicated by the percentage cut in funds. In fact, only in the short term is there a direct linear relationship between the percentage cut and the reduction in the volume of work executed.

However, the fact remained that, despite any softening of the effect, a substantial reduction in the availability of funds for maintenance would lead to a considerable reduction in the amount of work undertaken, and to necessary remedial work remaining undone.

It appeared that the local road authorities had to accept a situation where they would need to be even more selective about

where to devote their shrinking funds. It was likely that expediency would necessitate a diversion of funds to major local routes despite signs of serious deterioration on minor roads.

With regard to the maintenance of motorways and trunk roads, the need for a forward planning programme longer than one year ahead had been felt for some time. Many advantages could be gained from a programme covering a longer period which could well incorporate a fixed part, becoming increasingly fixed as it approached execution, and a flexible part, to enable adequate forward planning.

This programme should be based on scientific data (deflectograph, SCRIM, CHART, current and projected traffic loadings, etc.) which would give a sound grasp of existing conditions and enable likely deterioration rates to be estimated.

Furthermore, I believed that the policy on the management of maintenance funds ought to be reconsidered. A small staff managing quite a large expenditure under increasing pressure from competitive needs was no longer appropriate. A computerized system allowing overall programming and fund allocation in accordance with available resources (funds, investigation and design staff, contract management, manpower, plant and material), and road needs, was well worth considering.

Major contractors, for their part, had to become more maintenance-orientated. As maintenance operations, unlike new construction, had to take existing traffic into account, it would be advisable to consider working over weekends and at night.

Traffic management during maintenance operations was becoming a major consideration. Current Health and Safety regulations had already had a major effect on maintenance operations by restricting previous practices. Much was done to reduce or prevent congestion on site. So far the use of signs, cones and ad hoc radio announcements had tended to be site-specific. In the next few years efforts were likely to become more route, or network, orientated

with a systematic approach incorporating radio/GPO/RAC/AA information services, in-car communication systems, etc.

9.13.1.4 Mechanistic design

The guidance on pavement design contained in Road Note 29 is based on the performance of full-scale experiments and on empirical findings. Although the recipe approach is simple and time-tested in most situations, it can be inadequate when conditions are atypical because of the use of new materials, non-standard construction methods, new developments in plant methodology and because of an unusual environment.

The establishment of a theoretical approach, based on a better understanding and knowledge of the fundamental behaviour of pavement structures and the materials used, had been advocated for some years. The basic philosophy of this approach is to compare, through simplifying assumptions, the anticipated loading and environmental conditions with the critical strains and stresses that the pavement, as a structure, can safely withstand, and to adjust either the layer thicknesses or the materials until a satisfactory design emerges.

Although research was still continuing, several design procedures were already available which were similar in approach but differed with regard to implementation. These procedures had been criticized quite extensively because they lacked validating evidence.

It was unlikely that theoretical methods would be adopted for new design purposes before they had been substantially validated in practice. The use of the Transport and Road Research Laboratory's heavy vehicle simulator when this became available, was thought to be the best way of linking the fundamentally laboratory-based approach to actual road conditions. This facility, when combined with a deflectograph-based analysis of existing pavements, should produce the required validating evidence or at least identify what modifications were needed.

It was envisaged that, within the next few years, analytical methods would enable the engineer to correlate the destructive effect of traffic with the known performance of materials and pavements, and to design more efficient pavement structures.

9.13.1.5 "End-result" specifications

In general, in the United Kingdom, road pavement materials were produced and laid in accordance with 'method-type' specifications. The specification for road and bridge works was under increasing criticism for being restrictive, leading to uneconomical procedures, preventing innovations, and so on.

Furthermore, increasing traffic demands on pavements had brought to light certain inherent weaknesses within the specification. For example there was no compaction requirement for bituminous pavement layers. Neither the number of passes, nor the percentage of voids, nor the density of the pavement mixes was specified.

The improved understanding of the behaviour of materials and pavements, achieved during the research for a theoretical approach to design, had helped to focus interest on 'end-result' specifications and had increased the support for their adoption in preference to 'method-type' specifications.

At least in theory, 'end-result' specifications appeared very attractive and their use beneficial in various ways. The benefits were likely to include encouraging manufacturers and contractors to do further research, greater freedom to introduce worthwhile innovations, greater energy savings, focusing on results rather than on the means of achieving them, the use of alternative, cheaper and more readily available materials, and a general orientation towards product testing.

At the time, it was feared that incorporation of this approach into contracts could create problems regarding adequate testing and control of the end-product. However, such difficulties could easily

have been overcome by statistically-based control procedures, a common quality control practice in many industries.

"End-result" specifications were being used successfully in many countries. In 1980 the Department of Transport was cautiously moving towards adoption of these methods to some extent. It was likely that, within the next few years, benefits from at least their partial incorporation would have been realised in the road industry.

9.13.1.6 Shortages of resources

The annual United Kingdom expenditure on road maintenance was well in excess of £500 million. About 20 million tons of asphalt mix and over 1,5 million tons of bitumen and tar binders were used each year. About a tenfold price increase in bitumen was experienced during the seventies. Apparently the bitumen portion alone was already responsible for more than half the total cost of hot mix material. Since, so far, the North Sea crudes were mainly paraffinic and lacked asphalt fractions, the great majority of these hydrocarbons had to be imported and their availability continued to be subject to unstable factors.

The high polished stone value requirements of pre-coated chippings had reduced the number of suitable material sources so drastically that, during 1979, surfacing contractors were experiencing considerable difficulties in securing adequate supplies to meet their operational needs. The inherent congealment characteristics of this material, with the resulting limitations on storage had further aggravated the situation and made supplies vulnerable to plant breakdowns at source. So far, artificial stone alternatives had proved prohibitively expensive. With the possibility of polished stone value requirements becoming even more stringent, shortages were likely to become increasingly severe.

Since 1973, due to economic restrictions and uncertainties, the industry had tended to reduce its investment in training. Potential workmen, for their part, were finding working conditions in the road

industry less attractive. The resulting shortage of quality labour was becoming progressively worse and there were no signs that the situation would improve.

The shortage of money was of course expected to continue to be the predominant adverse factor. Lack of funds was already resulting in substantial cuts in the programmes. Firms in the road industry were experiencing serious cash flow problems. There were increasing demands for additional funds from many other competing sectors. In the light of the Government's firm policy on reducing public expenditure, there was no basis for optimism regarding road investment in the near future.

9.13.1.7 Road network

The total length of the road network in Great Britain in 1978 was 349 344 kilometres. This network consisted of:

Trunk motorways	2 307 kilometres
Other trunk roads	12 558 kilometres
Local authority motorways	108 kilometres
Other principal roads	34 141 kilometres
Other paved roads	287 358 kilometres
Unsurfaced roads	12 872 kilometres

Guidance on the design and construction of road pavements is provided in the Specification for Road and Bridge Works, Road Note 29, British Standards, and Technical Memoranda issued by the Department of Transport.

Hot rolled asphalt with 50 pen. lake asphalt/bitumen or pitch bitumen was used as a wearing course for roads carrying 11 million standard axles or more. Dense bitumen macadam, cold asphalt, open-textured bitumen macadam, and other materials could be used as wearing courses on lower categories of road.

Plastic deformation was the normal type of failure experienced with flexible pavements. Fatigue cracking was quite rare and was

generally associated with subbase failures.

However, concern about the degree of permanent deformation in wearing courses due to the effects of higher traffic loadings and temperature (experienced during the uncommonly hot summers in the mid seventies) had led to the introduction of binders with a high penetration index in hot rolled asphalt. Design mixes, rather than the traditional recipe specifications, were becoming standard for the most heavily trafficked roads.

There was therefore a move towards stiffer pavements in which the contradictory requirements of wearing courses to resist both permanent deformation and fatigue cracking failures would have to be optimized.

An annual national survey on road condition, based on inspecting sample lengths, had been undertaken since 1976. The purpose of this survey was to provide a year-by-year record of the current condition of the road network and enable the effects of changes in the level of maintenance expenditure to be monitored. After four years some national trends could be identified. The 1979 survey report concluded that the overall picture did not support the claim that the nation's roads were getting worse.

9.13.2 Hot surface recycling

9.13.2.1 Repaving

9.13.2.1.1 Background

Colas introduced repaving (Cutler repaver) in the United Kingdom in the autumn of 1975 with projects on county roads in the Birmingham area and on the A74 trunk road in Scotland.

Following some sporadic work, with varying success, the repaver was substantially modified to enable the machine to cope adequately with hot rolled asphalt material. These modifications resulted in a

considerable improvement in the work undertaken on the A1 trunk road in Hertfordshire, in the autumn of 1977.

In mid-1978 the Department of Transport became sufficiently interested in the process to:

- (1) authorise the undertaking of official repaving trials on four trunk road sites, and
- (2) second me to industry to assist in the assessment and development of repaving.

Trunk road trials were successfully completed in the autumn of 1980 and confirmed the validity of the process. Furthermore, they demonstrated the potential for savings in hydrocarbons and good quality aggregate and for reducing the traffic disturbance caused by conventional resurfacing.

At that stage of development we recognised that the benefits of the repaving process were not immediately going to result in large cost savings for the road authority using the process. The reasons were first, the high capital cost of the machinery and secondly, the necessity to obtain large volumes of work in order to maintain high productivity.

A repaver can cope with some 500 000 square metres annually on open roads and, if even half of this figure can be assured, then undoubtedly large reductions in cost should be forthcoming.

After the trunk road trials, increasing interest was shown in the repaving activities and the Department of Transport continued to monitor the process with a view to include repaving as an option for surface maintenance. Understanding of and confidence in the process grew sufficiently to enable the road authorities to suggest a substantial number of sites for repaving, subject to suitability and cost considerations, which ensured a full programme of work during the spring of 1979. In fact, the volume of work necessitated the introduction of a second repaver (Wirtgen).

Acceptance of repaving increased through the season, so that after a first-ever motorway trial in the UK in April 1979, on the M1, the process was repeatedly selected for further motorway work. Over 100 000 square metres of repaving work were undertaken by Colas in the spring of 1979, with contracts on the A580, M1, A423(M) and M3.

The M1 contract, junctions 6 to 7 in Hertfordshire, was an overlay on the existing hot rolled asphalt wearing course which consisted of a 30 per cent stone content recipe mix with rubberised binder and 20 mm precoated chippings. The existing layer was scarified and then overlaid with 20 mm hot rolled asphalt of 40 per cent stone content and 4,5 kN stability.

The work was undertaken during March/April with the site available only between 8 p.m. and 6 a.m. every day. Although the process was considerably hindered by very bad weather, it soon became apparent that repaving could be carried out under conditions in which conventional resurfacing would be impossible. The use of an extra heater bank preceding the repaver ensured that during part of the contract progress was maintained at a reasonable rate despite the continuing bad weather.

The A423(M) project, although in theory an overlay contract, was in fact preceded by planing off of the surface dressing layer. This work was carried out during normal working hours with the motorway closed to traffic for the duration of the contract. The 11 000 square metres contract was completed in three days, achieving considerable savings in traffic delays on this busy London commuter artery.

The speed of the repaving process and consequent savings in traffic disturbance were again demonstrated on the M3 contract, where the operational speed averaged five metres per minute, enabling the completion of 1,5 kilometre sections daily. This contract consisted of inlay work on six sections of deformed slow lane with 20 mm of the existing pavement removed before repaving.

One of the most significant developments during 1979 had been the direct involvement in repaving of two important surfacing contractors. Both companies, following initial association with Colas on specific contracts, developed their own independent repaving operations. Redland bought a Colas repaver in August, and were active in the Essex area for the rest of the season. During the same period, Associated Asphalt, using a new Wirtgen repaver/remixer, on hire through Colas with an option to buy, completed some 80 000 square metres of repaving with contracts on the M4, Wiltshire and Berkshire, and on trunk roads in Oxfordshire.

On the basis of the 1978 series of repaving trials and subsequent experience, repaving was provisionally specified by the Department of Transport, in February 1980, as an alternative to conventional resurfacing.

A lot had been learned. Improvements ranging from the method for establishing suitability to operational techniques and reliability, had been incorporated in the process. In view of the benefits associated with repaving, the future of the process was viewed with optimism.

9.13.2.1.2 Cost savings

Until 1980 no significant direct savings were realised by repaving on any maintenance contract. In fairness, while the process was still in the development stages large savings could not be expected. In general, during 1979, under a limited single-tender arrangement, repaving rates were considered acceptable provided they were below typical local conventional resurfacing rates.

In the past repaving rates were adversely affected by numerous factors.

Colas incurred, apart from the high capital cost of the machine and the undertaking of the substantial modifications necessary in adapting the Cutler repaver to United Kingdom materials and specifications, the total development and marketing costs until the summer of 1979, when by selling the repaver to Redlands they withdrew from direct contracting involvement.

During the development years, 1975 to 1979, Colas operated without the benefits of either having a large parallel surfacing organisation or producing their own flexible surfacing material. For most of this period repaving was done on a limited scale, on small contracts, so that the high productivity rates necessary if the use of such a machine was to be economical, could not be achieved.

Furthermore, at times because of a lean programme, repaving work was undertaken well outside Colas' normal operational areas, which involved the firm in additional costs including having to pay premium rates for asphaltic material.

The introduction and development of repaving in the UK was not an easy task and credit is due to Colas for recognizing the potential of this process at an early stage and for their continuous belief in the validity of reusing bituminous material. In fact, Colas bought repaving to the stage where other surfacing contractors felt justified in becoming directly involved in the process, and where the Department of Transport and other road authorities participated in trials and considered accepting this method as an alternative to conventional resurfacing.

Both Redlands, with the original Colas repaver, and Associated Asphalt, using a Wirtgen machine, had entered the field of repaving too late in 1979 for any significant change in repaving prices to become apparent. Repaving, with the added complexities of preheating, scarifying and reprofiling the existing material before laying a new carpet layer, requires considerably greater skills

than does conventional resurfacing. Experience is also essential both in establishing the suitability of various sites and existing bituminous material for repaving, and in controlling the whole operation.

The involvement of both contractors in repaving during the autumn of 1979, when over 100 000 square metres of pavement were repaved, has been of great benefit in terms of experience gained in the above aspects and it was expected to have a significant effect on repaving prices during the 1980 season.

The importance to a road authority of direct cost savings arising from the use of repaving, must not be underestimated. However, in examining the overall validity of the process, additional factors have to be taken into account.

In repaving, because at least part of the existing wearing course is reused, the need for new materials is limited to no more than half the amount necessary for conventional work. Thus there is a direct and significant saving on aggregates and imported hydrocarbons. The rapidly increasing prices of imported raw materials alone constitutes a valid economic argument for repaving. Moreover, in a period of environmental concern, the conservation aspects of repaving cannot be overlooked. Another indirect saving associated with repaving is the minimization of traffic disturbance. Traffic benefits in various ways: from the actual speed of the operation; from the fact that the road is reopened to traffic soon after the repaving train has progressed along it; and from the reduction, by at least 50 per cent, in the quantity of material that has to be hauled to and from the site by truck.

All of these are important factors in a complete economic evaluation of the repaving process. Nevertheless, if repaving is to be readily accepted by employing authorities, a reasonable direct cost saving must be realised. This is as important as the

need for contractors to profit financially from repaving in order to justify their commitment to the process.

Savings of the order of those achieved when repaving asphaltic concrete, reportedly 30 to 40 per cent of the cost of conventional processes, are not achievable when repaving hot rolled asphalt material. This is due to the thinner new layer applicable on asphaltic concrete (12 mm) since this layer does not have to allow for the partial embedment of precoated chippings. However, an assessment indicated that a saving of the order of at least some 10 per cent of the conventional cost had to be realised before repaving became acceptable to road authorities.

After the 1979 season, I anticipated that repaving rates in 1980 would have been influenced by various changes in the prevailing conditions. Repaving was to be undertaken by at least two surfacing contractors, with the backing of their surfacing and material-producing organizations and relying on the experience gained during 1979.

If the repaving process had been specified as an alternative to conventional resurfacing, it could have competed directly with resurfacing, but instead rates based on single-tender arrangements had to be negotiated. Furthermore, official specification would have enabled work to be sought on larger and more suitable sites, making higher productivity rates possible.

The dramatic increases in the price of bitumen, and consequently of hot mix material, were expected to make repaving, with its inherent savings in new material, increasingly attractive.

Although it had been practice to apply a 20 mm thick new layer, trials strongly indicated that in most cases a 15 mm thick overlay would be sufficient on hot rolled asphalt material. It was therefore expected that thinner overlays would soon be used which would further reduce the cost of repaving.

However, in 1980, although most of what was expected had materialized, repaving rates did not show the expected savings, with the notable exception of the M4/A423(M) project in Berkshire. Furthermore, the anticipated substantial programmes of repaving work also did not materialize. It appeared that this last factor had the most significant influence on pricing and that it was likely that significant savings could not be achieved until full programmes were established. On the other hand, projects were unlikely to be forthcoming unless cost savings were ensured.

9.13.2.1.3 Position in 1980

During 1980 the two contractors together undertook less than 100 000 square metres of repaving. Redland, having completed their outstanding 1979 commitments, in Essex, in the spring, did not repave until they started the M4/A423(M) project in mid-August. Associated Asphalt started repaving in late July, on county roads in Cheshire, had a gap before undertaking the A5 trial in mid-September, and then another gap before starting work on the A38, in Devon, in October.

There were many reasons for the lack of substantial programmes. However, the main explanation for the lack of development must have been that neither of the two companies was in a position to seek and establish programmes of work before the start of the 1980/81 financial year. During the 'dead' season, Redland were fully occupied in resolving various mechanical problems with their machine. These problems were serious enough to interrupt their programme in Essex in 1979 and to cause some anxiety about the future of their repaver. Associated Asphalt, for their part, did not commit themselves to purchasing the Wirtgen repaver and thus to further involvement in the process until the spring.

It was therefore understandable that substantial repaving programmes were not achieved. In fact, it would have been surprising had this been so.

Nevertheless, the work undertaken was successfully completed. In particular the rideability of the repaved sections of the M4 provided further proof that high standards are achievable with repaving on hot rolled asphalt material. Incidentally, this was the only project where competitive rates were sought by direct tendering from the two companies. This resulted in substantial savings to the road authority.

9.13.2.2 Reforming

Jobling-Purser built their first machine, under licence from Jim Jackson USA, in 1974 and had been actively engaged in reforming mainly in the north and in Scotland.

The Jim Jackson reformers have a distinctly Heath Robinson appearance. The road surface is heated by direct-fire burners and scarified to a depth of about 20 mm by spring-loaded tines. The scarified material is agitated and reshaped by an oscillating tamping screed and a thin wearing course overlay is applied by a conventional paver which follows the reformer. In fact Jobling-Purser operated the reformer, and a surfacing contractor, or a county's direct labour force, undertook the thin overlay part of the operation.

Reportedly the first road project, undertaken in 1974 on a county road in Durham, proved a disaster due to lack of experience regarding the operation of the machine. Consequently Jobling-Purser did not reform again until May 1976, when they successfully completed a project for the South Tyneside District Council in Jarrow.

Between 1976 and 1980, the company's output was as follows:

1976	40 000	square metres		
1977	60 000	"	"	
1978	140 000	"	"	
1979	80 000	"	"	
1980	180 000	"	"	

In 1978 a second reformer was produced to meet the logistic needs brought about by high demand for the process during limited periods.

The process produced savings in the region of 20 to 30 per cent of the cost of conventional resurfacing, depending on the location and size of the contract.

9.13.2.3 Remixing

9.13.2.3.1 Hot Rolled Asphalt Considerations

Although repaving had been carried out fairly extensively on hot rolled asphalt surfaces prior to 1980, apart from trials, remixing had only been carried out on asphaltic concrete material. In the United Kingdom, where hot rolled asphalt is the normal surfacing material for trunk roads and motorways, the application of remixing is quite complex. This is mainly due to the use of precoated chippings with hot rolled asphalt wearing courses, although it should be possible in most cases to incorporate the existing precoated chippings in the mix and produce an acceptable material.

Before it can be decided whether remixing will be suitable, the existing material must be tested. These tests (normally one core per about 100 metres is needed) will determine the thickness of the reusable material, Marshall properties, binder content, penetration of the recovered binder, aggregate gradation and the uniformity of the mix. Based on these findings, an assessment can be made as to whether it is possible to produce a desirable mix by mixing the existing material with an economical amount of new material.

9.13.2.3.2 First remixing trial

During 1979 some consideration was given to the possibility of a remixing trial on a trunk road. Sites were considered and some preliminary testing was undertaken. In the event I considered it prudent to opt for full-scale off-road trials on a disused airfield in Cheshire, on a hot rolled asphalt wearing course.

The trial was carried out in September 1979 on Appleton Airfield.

In particular, the effectiveness of mixing the old and new asphalts and the uniformity attained were studied by analysing a large number of samples, nearly 100 in all. A length of taxiway, approximately 100 metres wide and 160 metres long, was used for the trials. This had been overlaid some two years previously with unchipped, 30 per cent stone content, hot rolled asphalt as part of another series of trials. A preliminary investigation showed that the bitumen content of this asphalt varied from 7,0 to 8,5 per cent, and the bitumen penetration from 31 to 40. The Marshall stability of cores taken from this asphalt ranged from 1,4 to 7 kN.

After an inspection of the site, it was decided that the area available was large enough to lay six test strips, each approximately 80 metres long and 3 metres wide (see Figure 19).

(A) + Mix 2 = High stone content, normal bitumen	(C) + Mix 4 = Normal stone content, polymer bitumen	(E) + Mix 4 = High stone content, polymer bitumen
(B) + Mix 1 = Low stone content, normal bitumen	(D) + Mix 3 = Normal stone content, soft bitumen	(F) + Mix 3 = High stone content, soft bitumen

FIGURE 19 Layout of Appleton Airfield Remixing Trial

In order to obtain more variation in the asphalt being treated, a depth of 30 mm was planed out from areas E and F, and replaced by

new hot rolled asphalt of 30 per cent stone content plus precoated chippings. The bitumens were 50 pen and 25 pen in E and F, respectively. It was also found, during a second, more detailed investigation of the existing surface material, that in areas A and B the asphalt had only been lightly compacted. The composition of all six test areas before the test began is given in Table 9 below.

Table 9 : Properties of asphalt in surface layer, prior to trial

Area	A	B	C	D	E	F
Composition (% W)						
Stone	29	28	29	32	36	38
Sand	54	53	53	48	48	46
Filler	9,5	10,9	10,6	12,9	9,3	8,9
Bitumen	7,4	7,8	7,3	7,0	7,2	6,8
Bitumen grade	50	50	50	50	50	35

The new asphalt mixes used in the trials were designed with the following considerations in mind:

- (a) New asphalt of approximately 15 per cent stone content is needed when remixing a typical surfacing of 30 per cent stone content asphalt plus precoated chippings, in order to produce a final mix of 30 per cent stone content.
- (b) New asphalt of approximately 50 per cent stone content is needed when remixing an old, lightly chipped surfacing, in order to produce a final mix of 40 per cent stone content.
- (c) Bitumen of 50 pen will probably be used for much of the new asphalt, but 100 pen could be used if it was required to soften an existing binder that was unduly hard.
- (d) A new mix in which the bitumen contained a polymer might be used to increase the stability of an existing soft mix.

Based on these considerations, the mixes used in the remixing were as follows:

Mix 1 : 15 % stone, 11,1 % filler, 9,1 % 50 pen bitumen

Mix 2 : 50 % stone, 6,1 % filler, 6,3 % 100 pen bitumen

Mix 3 : 15 % stone, 11,0 % filler, 9,1 % 100 pen bitumen

Mix 4 : 15 % stone, 11,0 % filler, 9,1 % bitumen & polymer

These were laid in the test areas as shown in Figure 19, with the object of producing:

Area A : a high stone content mix, normal bitumen

Area B : a low stone content mix, normal bitumen

Area C : a normal stone content mix, polymer bitumen

Area D : a normal stone content mix, softened bitumen

Area E : a high stone content mix, polymer bitumen

Area F : a high stone content mix, softened bitumen

The asphalt laid in each test area was examined for its uniformity by analysing five samples taken at 10 metre intervals. A typical set of results, taken from area A, is shown in Table 10.

Table 10 : Uniformity of asphalt composition (percentages)

Sample	Stone	Sand	Filler	Bitumen
1	40,1	45,2	8,1	6,6
2	37,0	48,0	8,6	6,4
3	38,0	46,0	9,6	6,4
4	44,8	42,8	7,2	5,8
5	40,0	45,0	8,8	6,2
Average	40,0	45,3	8,5	6,3

The results show the final mix to be of acceptable uniformity, the stone, filler and bitumen contents being within 5 per cent, 1,3 per cent and 1,5 per cent of their respective averages.

At two positions in each test area samples were taken of the existing surface prior to scarification, and of the new asphalt. From the analysis of these, and assuming that a 1:1 mix of the two was made by remixing, the composition of the final asphalt can be predicted.

Table 11 shows a comparison of the predicted and actual composition of area A.

Table 11 : Comparison of predicted and actual composition - Area A (percentages)

Component	Predicted	Actual
Stone	41,0	40,1
Sand	44,8	45,2
Filler	7,7	8,1
Bitumen	6,5	6,6

The results show that the actual mix composition achieved was very close to the predicted composition.

Marshall test properties were determined on the existing mix prior to treatment (cored samples), on the new asphalt (normal compacted samples) and on the final asphalt (cored samples). Comparison of the results was made difficult by the two types of sample that were taken, but by applying an empirical correction factor of 0,7 to the normally compacted samples to make them equivalent to the cored samples, the values in Table 12 were obtained.

Table 12 : Marshall stability of mixes

Test area	Marshall Stability (kN)		
	Old surface	New asphalt	Final asphalt
A	1,4	5,6	4,8
B	1,7	5,2	4,7
C	4,5	9,2	4,0
D	3,8	2,9	4,7
E	4,2	10,9	4,6
F	7,0	3,1	3,4

There is clearly no simple relationship between the properties of the final asphalt and of its component mixes. It is probable that differences in the degree of compaction achieved more than outweighed the differences in the mixes themselves.

A disappointing feature of the results was the lack of improvement given by the polymer mixes in areas C and E. An inspection of the samples during their analysis suggests that, although the polymer was well dispersed in the bitumen of the new asphalt samples, this asphalt did not get equally well dispersed in the old scarified asphalt when the final mix was produced. Hence a non-homogeneous mix was formed, having the properties of the original material only.

The results confirmed the expected hardening of the existing bitumen caused by heating and indicated that the final asphalt was a consistent product, with penetration varying by only a few units in any one area.

9.13.2.3.3 Trunk road trial

After the Appleton trial, a road trial on the A5 Trunk Road, in Buckinghamshire, was undertaken in September 1980 following consultations between the Departments of Transport and Energy, the agent authority, the Transport and Road Research Laboratory and me. Shell Thornton Research Centre were also involved in consultations on the mix design.

The trial had two main functions. Firstly it served as a first-ever remixing trial on a road in the United Kingdom, and secondly it provided a basis on which to compare the energy requirements of conventional, repaving and **remixing resurfacing** methods. For this reason the Department of Energy appointed consultants to monitor the energy outputs during the project and report on their findings.

The project involved three adjoining 450 metre long sections of the 9.2 metre wide three-lane carriageway. The first section was

conventionally resurfaced. After removal of the existing surface dressing layers, the second section was repaved and the last section remixed.

The existing wearing course material was a 40 per cent stone content hot rolled asphalt with precoated chippings. Preliminary testing established the uniformity of the mix, necessary for undertaking a practicable remixing operation, and the applicability of repaving to the relevant section. Analysis of the cores taken showed that the penetration of the recovered bitumen ranged between 70 and 75 and that the bitumen content varied between 7,4 and 8,2 per cent.

The work was undertaken by Associated Asphalt, using their Wirtgen repaver/remixer. Although the results of the monitoring and analysis were not available in 1980, the initial impressions were generally favourable, with the exception of adherence to the required ratio of existing to new mix material: the proportion of new mix was considerably less than the 50 per cent specified.

The energy report was also still awaited, but I anticipated that the energy requirements of the three processes may well show only marginal differences and the actual life of the resultant layers may be the main factor influencing energy comparisons.

9.13.2.3.4 Costs

On the European continent, working on asphaltic concrete surfaces, substantial savings have been achieved through the use of the remixing and repaving processes.

However, mainly due to the added complexities of working with hot rolled asphalt materials, one aspect of remixing that was causing some anxiety in the United Kingdom, was the question of cost. The pricing for repaving work had not as yet made the process particularly attractive compared with conventional resurfacing and there was every indication that remixing, in its standard form,

would prove more expensive than repaving.

On the other hand, the possible use on hot rolled asphalt wearing courses of remixing with no, or very little, new material, except precoated chippings, was expected to prove economically very attractive.

9.13.3 Cold mix recycling

9.13.3.1 Retreading

This cold recycling process saved on average some 15 to 20 per cent of the cost of conventional overlay resurfacing.

In 1980, Colas, operating four retread units, had been alone in this field for over twenty years. However, Jobling Purser, having entered into retreading in the late seventies and operating mainly in the north and Scotland, had during 1980 captured about 60 per cent of the total market.

Two other companies, BRF and Bearing Macadam, started retreading during 1980. Bearing Macadam, however, operated for only one season.

9.13.3.2 Central plant

There was increasing interest in this process which, although it limits the product to secondary uses, provides a less complicated and cheaper recycling option.

Following an analysis of material availability, logistics, cost of production and market potential, Allmacadams were taking the first steps towards cold, central-plant recycling at their Chertsey Depot.

9.13.4 Hot mix recycling

Until 1980, apart from unofficial off-road trials, this process had not been undertaken in the United Kingdom. However, for some time a number of surfacing contractors and hot mix producers had been carefully monitoring the developments in recycling overseas, and, particularly in the USA, the general attitudes in the industry, and had, to at least some extent, been waiting for some lead from the Department of Transport.

Many companies considering involvement in hot mix central-plant recycling were examining the available options of investing in drum mixing recycling plant or modifying their batch-type plants. The material removed from reconstruction and other resurfacing projects was increasingly scrutinized for its suitability for reuse in producing desirable hot mix material. The effects of the different reclaiming processes on the grading and other characteristics of pavement material were compared. To this effect planning contractors were monitoring the effects of various cold milling techniques on hot rolled asphalt material.

During the preceding few years, Barber-Greene, CMI and other USA plant manufacturers, had been actively engaged in numerous discussions and consultations with road authorities, surfacing contractors and producers of hot mix material in efforts to introduce their own brands of recycling systems into the United Kingdom.

Although the importance of the Department of Transport's role in the development of the process could not be over-emphasized, most parties were prepared to accept the principle that during the development stages in recycling hot rolled asphalt and other UK material, trunk roads and motorways could only be involved as a source of reclaimed material. Nevertheless, in 1980 Tarmac Roadstone (Southern) offered recycling as an option in a tender for an M1 motorway reconstruction project. However, as the recycling option was not the lowest bid, it was not considered.

By far the most significant occurrence was the joint development of a recycling system by Parker Plant and Tarmac Roadstone (Northern).

Since 1979 the two companies had been undertaking off-road trials and experiments with their prototype plant. This was a drum mixer recycling plant based on the centre-feed principle. In the autumn of 1979 it was expected that the plant, in Renishaw, Derbyshire, would be available for road trials in the spring of 1980. However due to the need for further modifications and development work, this was delayed.

During a visit to the Renishaw plant, in September 1980, I found that the trials and modifications had not as yet resolved the environmental pollution problem. Paradoxically, pollution appeared to decrease as the proportion of reclaimed material increased. However, closer scrutiny showed that these improvements in the emission of pollutants were associated with the substantially lower temperatures achieved when recycling with higher proportions of reclaimed material.

The ratios of reclaimed material to virgin aggregate attempted were 60:40, 70:30 and 80:20. A heavy flux oil (PM88) was added in producing a recycled mix which apparently conformed to the specification for 20 mm dense bituminous basecourse material.

The reclaimed material used in the trials derived from the A38 Trunk Road, Allestree Bypass. Material from a reconstruction project on the M1, in the vicinity of the M18 junction, was being stockpiled for future use.

The effect on the penetration of the binder on recycling with the addition of a heavy flux oil had been monitored. Analysis indicated that the penetration values of the recovered bitumen in the reclaimed material reduced in hardness from about 25-30 to 65-88. However there was also a significant loss in the bitumen content. Typically, an existing content of 7 per cent was supplemented by about 1.5 to 2 per cent flux oil in a 70:30 recycling ratio.

At the time of my visit, a road trial was planned on local roads in Derbyshire. The recycled material was to be used as a basecourse with the wearing course delayed for at least a year. No publicity was envisaged for this low-profile trial.

In Northern Ireland the position was somewhat different. The Department of Environment for Northern Ireland operated mixing plants, had its own substantial labour forces, and was keen to develop and introduce recycling activities through, at least initially direct involvement. To this effect, I was involved in a number of consultations with the road authority during 1979 and 1980.

After preliminary discussions in July 1980, about 6 000 tons of material, deriving from an M1 reconstruction project, were stockpiled by the Down Road Service at one of their quarry/mixing plant sites.

The stored reclaimed material had been partially separated, providing a stockpile containing only hot rolled asphalt wearing course material, as well as stockpiles containing a mixture of wearing and basecourse materials. Moreover a large stockpile was kept under cover to protect the reclaimed material from weathering and dust.

Preliminary testing indicated that the penetration of the recovered bitumen was around 20 for the wearing course and lower for the basecourse materials. However a full analysis, which was to form the basis of the hot mix recycling operations, was being carried out.

It was planned to use an existing batch plant for recycling, subsequent, of course, to the undertaking of the modifications then under consideration. Initially modest proportions of reclaimed material were to be used in producing mixes for tests on secondary roads. It was anticipated that, on the basis of the early trials, the proportions of reclaimed material would increase and more

important routes would be used for trial sites.

9.13.5 Other developments and general considerations

For several years recycling had been either the theme of, or one of the main topics at a number of seminars and conferences. Examples included the 1979 annual conference of the Institute of Asphalt Technology, and the 1980 annual seminar of the Asphalt and Coated Macadam Association. There was also an increasing tendency for the subject of recycling to crop up in conferences during discussions on road maintenance topics and other related topics.

Following the establishment of the government-sponsored working party on reconstruction of motorways and trunk roads, a sub-committee on recycling of material was set up under the chairmanship of the Engineering Intelligence division of the Department of Transport. I addressed a meeting of the sub-committee on 14th August 1980, on the topic of central-plant recycling systems. It became very clear that the road authorities would consider any controlled and properly monitored hot mix recycling trial as highly desirable.

Some progress was made in a project involving the reclaiming of type 1 subbase and lean mix material from an M1, Buckinghamshire, reconstruction site and its use for the production of a fairly consistent lean concrete material. The existing layers were to be ripped, broken and crushed. No screening was anticipated due to the known homogeneity of the original material. The trials were to be undertaken by Hartigan at their site some three miles from junction 14 of the M1. It was planned to market the product on a normal commercial basis.

In the summer of 1980, Dr A F Stock's research project entitled 'Recycling bituminous material' became fully active with the appointment of a research assistant. The project, the first major investigation into the recycling of bituminous materials in a university in the United Kingdom, was being carried out at the

University of Dundee and was mainly sponsored by the Science Research Council, with some financial support from Kings, Scotland.

The project was divided into the following three parts:

"Firstly, an investigation of the raw material. This part will involve sampling and testing material from the road, by coring, before it is removed, and subsequently sampling of milled material.

Secondly, to investigate restoration of this material to something which meets current specifications. Also to undertake comparative tests between recycled and virgin materials.

Finally, if the progress in stages one and two is sufficient, to undertake full-scale trials of mixing and laying recycled materials."

For some time petroleum companies had been considering the possible repercussions of recycling on their sales of bitumen business and the new opportunities that could be created as a result of developments in the recycling of bituminous materials. In fact, recycling was being assessed in order to decide whether it presented a threat or an opportunity. Shell (UK) Oil, for their part, were developing a bitumen additive for recycling.

Witco Chemical Limited, a subsidiary of the USA-based chemical company, had been recruiting professional engineers to fill technical sales positions arising from the company's involvement in road maintenance chemicals. These chemicals were intended for use in the surfacing, maintenance and rejuvenation of roadways.

9.14 United States of America

9.14.1 Background

In 1977 the USA road network consisted of:

Freeways	78 289	kilometres
Other main roads	773 709	"

Secondary roads	468 139 kilometres
Other roads	5 000 799 "

82 per cent of the above roads were paved.

About 375 million tons of hot mix asphalt were produced annually, including a small percentage of mixes containing varying proportions of reclaimed bituminous pavement material. The recycling outputs from 1974 to 1977 were:

1974	5 000 tons
1975	25 000 tons
1976	150 000 tons
1977	500 000 tons plus

Figures for the last few years vary. One source estimated that the production of 'recycled' mixes for 1978 and 1979 was 3 and 7 million tons respectively. It was also estimated that there were 15 billion tons of recyclable pavement materials already in place having a value of some \$50 billion at 1980 prices.

A movement away from using the penetration values of bitumen started some fifteen years ago. In 1980 the change was almost complete, with viscosity being the main criterion for binders. In the West (Pacific coast states), the viscosity was measured after exposing the binder to conditions representing those encountered in the hot mix process. Consequently two viscosity values were used, AC values in most states and AR values in the Pacific coast states.

Table 13 below gives the equivalent AC, AR and penetration values, and shows that there is a constant factor of 4 between the AC and AR values.

Table 13 : AC and AR viscosity and equivalent penetration values

Viscosity at 60 °C (values plus or minus 10 %)(poises)				Penetration at 25 °C
AC2,5	250	AR10	1000	200
AC5	500	AR20	2000	120
AC10	1000	AR40	4000	70
AC20	2000	AR80	8000	40
AC40	4000	AR160	16000	20

9.14.2 Recycling situation in 1980

Before 1980, by far the greatest proportion of hot mix recycling in the USA had been carried out using modified batch-type plants. Most of the modifications were undertaken directly by the producers of material and were based on the heat transfer method.

However, many plant manufacturers had developed their own individual systems based on the drum mixer plant. These manufacturers included Boeing, Barber-Greene, IMC (Cedarapids), Standard Havens, CMI, Astec, RMI, and Stansteel Asphalt Plants.

It falls outside the scope of this work to make direct comparisons between the drum mixer recycling systems developed by the various USA plant manufacturers. All these systems had their relative advantages and disadvantages, some had obvious similarities and others were based on distinctly individual approaches. One common characteristic of these systems was their ability to produce mixes containing much larger proportions of reclaimed material than was possible with batch plant recycling.

Nevertheless, a high proportion of reclaimed material in a mix is not by any means the sole criterion for successful recycling operations. The proportion of reclaimed material is, or should be, dictated by mix design considerations and not by the mixing capability of plants. The availability of reclaimed material, in

itself, is another important factor.

There is plenty of room and need for both types of central-plant recycling. Their individual development has helped to make hot mix recycling commercially viable and acceptable with regard to the quality of the product and compliance with environmental regulations.

In the field of surface recycling, Cutler, producing the first-ever repaver in the Sixties, and Jim Jackson, with their reformers, led the way in developing equipment and methods. Their two methods, providing distinct but very similar approaches to surface recycling, set the scene for a period of strong competition between the two companies. During the Seventies the antagonism between them led to considerable controversies including attempts to get road authorities to adopt exclusive proprietary specifications.

Cold mix recycling was seen by many authorities as having the greatest potential. In the USA, this process was not limited to the production of basecourses: on numerous occasions, cold recycled mixes were used successfully as wearing courses, with or without surface dressing. Although this type of recycling had been somewhat neglected in comparison with the other types, in 1980 leading manufacturers were attempting to exploit its potential by developing in-place systems comparable to the equipment available for hot surface recycling.

9.14.3 National Asphalt Pavement Association (NAPA)

NAPA is the national trade association for hot mix asphalt producers and paving contractors. In 1980 it had 650 full members (hot-mix asphalt producers), 210 associated members (paving contractors, asphalt plant manufacturers, quarries, laboratories, etc.) and 80 to 90 international members (from 24 countries). The Association exists to serve the needs of its members and to promote the production and use of high-quality hot mix asphalt.

NAPA is very active in promoting the reuse of bituminous pavement

materials and had produced several publications of a technical, managerial and promotional nature on the subject. Naturally it is particularly involved in the development and acceptance of hot mix recycling and strongly supports the following principles:

- deteriorated pavements provide a source of high-quality materials
- materials need not be reused on the project from which they are removed
- contractors should take over the ownership of reclaimed materials removed from a project
- contractors should be permitted to add any percentage of salvaged asphalt pavement to a mix as long as that mix complies with the stated test properties
- use of a low percentage of reclaimed material (50 per cent or less) in a mix will result in the most economical use of reclaimed asphalt material
- the recycled end product must meet the conventional design standards and performance criteria
- the undertaking of 100 per cent reclaimed material recycling is ludicrous and detrimental to the progress of hot mix recycling.

In 1980 NAPA conveyed to me that in their opinion the major thrust behind the development of central-plant recycling had come from the Federal Highway Administration's projects. These projects had led to several States using recycling as part of their regular programmes. Some States had already specified recycling as an option. Minnesota's specification set 50 per cent as the maximum content of reclaimed material and Illinois was expected to specify on similar lines. On the other hand, other States appeared to be encouraging the use of drum mixers by limiting the content of reclaimed material to different figures depending on the type of recycling (e.g. 60 per cent for drum mixers and 40 per cent for batch plant recycling). Wisconsin's draft specification set the reclaimed material content at between 50 and 70 per cent, with 45 per cent being the absolute minimum before the imposition of non-compliance penalties. NAPA stood firmly against any specification

which either excluded or put at a disadvantage hot mix recycling through modified batch-type plants.

While in the USA, I was invited to attend one of the quarterly meetings of NAPA's Recycling Committee. This session, held on 6 May at St Louis, Missouri, included discussion on various aspects:

- Recycling specifications already issued and those expected: Concern was expressed about the implications of setting minimum limits for reclaimed material content in the specifications of West Virginia and Wisconsin. It appeared that some States were moving towards a drum-mixers-only situation, due to their policy of making the maximum use of reclaimed material on the project from which the material originated. The feasibility of issuing a model specification document was considered.
- Current and forthcoming recycling projects: The projects mentioned included:
 - a I 94, Illinois, reconstruction project (visited 5th May);
 - a 'combination' project in Minnesota (starting in June), involving the removal of $4\frac{1}{2}$ inches of the slow lane and recycling in a 50:50 (reclaimed:virgin material) ratio, and the reforming of the fast lane;
 - an Arkansas resurfacing project (visited 2nd May);
 - a project on the US2, Michigan, involving the hot mix recycling of previously reclaimed surplus material.Information on current projects was to be submitted for inclusion in NAPA recycling reports.
- Ownership of reclaimed pavement material: The Committee expressed its absolute belief in and commitment to the principle of allowing contractors to assume ownership of reclaimed material. However, it was conceded that exceptional circumstances could arise, as for example in Arizona, where the State has a definite further use for this material.

- Recycling additives: A whole range of specifications for modifiers developed on the West Coast appeared to be making its way through the ASTM in an effort to gain national acceptance. So far, these modifiers, which are very expensive, had been tested only on artificially aged asphalt. In any case, softer binders could be used instead at a much lower cost. Unfortunately there appeared to be a strong bias towards modifiers on the part of the foremost investigators (e.g. Professors Terrel and Epps). It was decided to do nothing much, for the time being, other than to express the Recycling Committee's concern.
- Minnesota Asphalt Pavement Association's recycling advert: This recent advertisement was considered impressive and worthwhile. The Recycling Committee decided to recommend consideration of further advertisements under the name of NAPA.
- Reuse of reclaimed material as a subbase: Strong opposition was expressed, by a hot-mix producer member, to NAPA's promotion, or even support, of this form of recycling. It was agreed that, in view of the interests of members who produced only hot mixes, NAPA's support would be confined to hot mix recycling.
- Federal Highway Administration and hot mix recycling: The FHWA was apparently disappointed in the current situation considering the work that had been undertaken during its three years of active support. Nevertheless, the FHWA had decided not to issue its intended circular stating that recycling should be considered by highway authorities in preparing tender documents and that explanations should be furnished if it was not included as an option. Apparently such a circular would have been politically unacceptable. Instead, the FHWA was planning a big new drive to promote recycling.
- Further action to promote hot mix recycling: The current

resistance to recycling was viewed as similar to the storm over the introduction of hot storage bins. It was agreed: "NAPA must at least encourage its own members towards a greater commitment to recycling, perhaps through another attempt to emphasize the economic benefits. The industry ought to be less sensitive about mentioning profits. The publication of simple case histories, indicating the realisation of worthwhile savings, to be further considered".

Donald Gallagher, vice-president of the Gallagher Asphalt Corporation, was the chairman of NAPA's Recycling Committee. Three of the corporation's five batch-type hot mix plants had been modified for recycling. About 50 000 tons of hot mix, containing 23 to 50 per cent of reclaimed bituminous material, were produced during 1979 for sale to their commercial customers. The recycling output was expected to double in 1980.

9.14.4 The Asphalt Institute

The Asphalt Institute is an international, non-profit association sponsored by members of the petroleum asphalt industry to serve both the users and producers of asphaltic materials through programmes of engineering service, research and education.

In the spring of 1980 the Institute was preparing a manual on hot mix recycling, and hoping to publish it at the end of 1980. Cold mix and hot surface recycling were to be dealt with in separate future publications. The hot mix recycling manual was being based on the principle of restoring aged binders to their original condition or even further improving them by the incorporation of special additives.

The feasibility of 100 per cent recycling was considered unlikely. The Asphalt Institute believed that, mainly due to environmental regulations regarding pollution, 70 per cent would prove to be the upper limit of the reclaimed material content in central-plant hot mix recycling.

The claim that recycling can produce better mixes than conventional hot mix asphalt was viewed as unlikely. On the other hand, it was recognised that recycling can improve original mixes.

The Asphalt Institute's willingness to accept the validity of modifying agents was tempered by a number of unanswered questions. These included:

- how intimately does the small amount of additive mix with the existing aged, stiff and brittle binder? Once it gets into close contact, how does it restore? Is the process time-dependent? Are individual modifying agents compatible only with certain binders?

One of the problems was that laboratory tests on the mixing of extracted binders with additives did not represent actual operational conditions, and the results of these tests were not readily accepted as validating evidence.

The Institute believed that cold mix recycling was likely to become increasingly important. "There are some 800 000 miles of secondary roads that have to assume a larger responsibility with the increase in traffic volumes and axle loading. In general, these roads are seal coated or have a minimum bituminous paving on some 6 to 12 inches of granular base."

With regard to cold mix in situ recycling, the Asphalt Institute had found that:

- apparently it was not essential for all the aggregate to be coated;
- authorities were saving up to 75 per cent of maintenance expenditure (e.g. Clark County, Illinois);
- preliminary testing was always essential;
- the process had appeared messy and not practicable until the numerous initial difficulties had been ironed out;
- plant manufacturers were developing in situ cold mix recycling equipment on the basis of cold-milling machines.

9.14.5 Asphalt Recycling and Reclaiming Association (ARRA)

The ARRA was formed, in 1976, to promote the collective interests of those individuals, firms or corporations who are engaged in the asphalt recycling industry as contractors, owners or manufacturers of equipment, as well as engineers and suppliers.

The Association, which was apparently gaining a new member every day, believed that recycling would be mandatory in a few years. In the spring of 1980, the ARRA was busy setting up committees to compile recycling manuals. Some progress had already been made with the production of a cold mix recycling manual.

9.14.6 The Transportation Research Board (TRB)

The Transportation Research Board is a unit of the Commission of Sociotechnical Systems of the National Research Council, which in turn serves both the National Academy of Sciences and the National Academy of Engineering.

As part of its activities, the TRB had organised a national seminar on asphalt pavement recycling, held in October 1980 in Dallas, Texas, under the sponsorship of the Federal Highway Administration. The seminar covered all aspects of asphalt pavement recycling, including surface, hot and cold recycling in both rural and urban situations.

The mixing ratios and the ownership of reclaimed material were seen as the two most controversial topics in hot mix recycling. The TRB viewed the proportion of reclaimed material in a recycled mix as a question of economics. On the other hand, NAPA was supporting lower percentages and encouraging recycling through batch-type plants (its members owned predominantly this type of plant). On the other hand, the state highway authorities, as the owners of existing pavements, wanted to maximize the benefits of reusing their own material. A compromise was needed. Of course, the TRB accepted that the fundamental factor in deciding the percentage of

reclaimed material must be the blend needed to produce a desired mix.

9.14.7 Universities

9.14.7.1 Iowa State University

The FHWA recently sponsored a research project, 'Data bank for recycled bituminous concrete pavements', involving the collection of all available information on recycling projects that had been carried out in USA during the past few years.

Professor Dah-Yinn Lee was the principal investigator for this project which was being undertaken by the State University with the co-operation of the Iowa Department of Transportion. It was intended to collect data from completed recycling projects, to determine additional essential material properties where needed, and to establish a comprehensive cross-reference data bank. Ultimately, the data bank would provide comprehensive information for assessing the performance of recycled bituminous pavements and related material requirements.

A very comprehensive questionnaire had been prepared and circulated during the summer of 1980. Professor Dah-Yinn Lee had some misgivings regarding the preparedness and ability of some highway authorities to complete the questionnaire fully. It would have been better if the project had been started a few years before to coincide with the large programme of FHWA-financed recycling projects, when completion of the questionnaire could have been treated as part of those projects. On balance, it was deemed preferable to obtain full information on a smaller number of projects, than to risk devaluing the project.

The project was scheduled for completion in September 1982, when the data bank would be handed over to the FHWA.

Regarding recycling in general, Professor Dah-Yinn Lee was not as

yet satisfied that the actual performance of recycled mixes would stand up to time, traffic, weathering, etc. He believed that most technique problems had been resolved although various technical questions, such as the percentage of reclaimed material, the need for increasing structural capacity, the homogeneity of mixes of aged and new binders, still remained unanswered.

9.14.7.2 Texas A & M University

Professor Jon A Epps was the principal investigator for the Texas Transportation Institute's report, "Guidelines for recycling pavement materials" (prepared for the Transportation Research Board's National Co-operative Highway research project entitled "Softening or rejuvenating agents for recycled bituminous binders" (undertaken by Texas A & M University)).

He firmly believed in the validity of using special additives, when these were required, in hot mix recycling operations. However, he recognised that in some cases their inclusion could tip the economic balance away from recycling and also that, in appropriate situations, soft binders could be used instead. Nevertheless, in certain circumstances, if a modifier was not used it would be pointless to recycle.

The opposition to modifiers was viewed as being based on prejudice and short-sighted economic views. Economic considerations in hot mix recycling, which vary from one project to another, must take into account a wide range of other factors as well as the actual cost of reprocessing.

With regard to the energy savings associated with recycling, it was recognised that any measurable benefits ought to be reflected in a project's costs and prices. However, he felt that it would be politic in advocating recycling to continue to mention energy savings for some time yet.

Professor Epps also considered that cold mix recycling provided the

greatest potential for further developments in the field of bituminous pavement material recycling.

9.14.7.3 University of Washington

Professor Ron Terrel and Assistant Professor Mahoney were the principal investigators for the Federal Highway Administration's research project entitled "Tests for the efficiency of mixing recycled asphalt pavements", which was being undertaken by the University of Washington.

The objective of the project was to:

"Develop a technique and necessary testing equipment to establish a mixing operation's ability to produce an intimate mixture consisting of reclaimed bituminous materials, modifying agent, new bitumen, and new and reclaimed aggregates."

The technique and associated testing equipment was to be applicable on a macro-scale, i.e. the dispersion of recycling agents was to be measured throughout the recycled mixture and not the distribution on an individual aggregate particle.

A method for measuring the dispersion of the recycling agent in the aged binder film, in the mixture being recycled, was not to be developed. Although desirable, it was not considered a practical proposition, due to the associated costs and the level of expertise that would be required by the users of such a testing technique.

Terrel and Mahoney believed that additives had a role in recycling, as indeed had the inclusion of soft bitumen. Cost considerations were very important and each case should be judged on its merit. On the question of the 'a recycled mix is better than new' theory, they considered that some foundation for it was provided by the unpredictability of new binders. These were viewed as inferior to the old types.

9.14.8 Departments of Transportation

9.14.8.1 Iowa

Most of the State's hot mix recycling experience was gained from the projects undertaken in Kossuth County. The Iowa DOT was not at all happy with the advocacy of recycling with a high percentage of reclaimed material. In Iowa the ratio of reclaimed to new material was based on considerations of grading and usable bitumen content in the reclaimed material. Apparently degrading of existing mixes by milling was forcing the reclaimed material content to under 50 per cent.

Cold mix, in-place recycling had been carried out on many projects over the past thirty years. On the other hand, Iowa had had limited experience with hot surface recycling. Cutler had done some work in Iowa in the past but not very successfully. However, following a reasonably successful reforming project on Interstate 80 with Jim Jackson equipment, further projects were planned for 1980.

9.14.8.2 Michigan

Michigan had considerable experience with hot mix recycling with outputs of 500, 60 000 and 300 000 tons in 1977, 1978 and 1979 respectively. As yet a general specification had not been produced and each project had been treated individually. However, there were plans for a preliminary specification in 1980 which was intended to provide a general recycling option for the production of basecourses containing up to 20 per cent of reclaimed material.

Three wearing course recycling projects had been carried out since the State first became involved in recycling operations in 1975. Milling had always been used for reclaiming. There had not been any failures although some projects had been more successful than others.

Experience showed that both drum mixer and batch plant recycling could produce a satisfactory mix. With batch plants a 50-50 reclaimed-new material ratio was normally used, although successful trials had been undertaken with 55 per cent of reclaimed material (and 60 per cent on a private airfield project). With regard to drum mixers, opacity requirements had not been complied with at reclaimed material proportions above 70 per cent. In 1979 all recycling was kept to a 50-50 reclaimed-new material ratio in order to allow both batch plant and drum mixer systems to be used and to satisfy the requirements of the environmental agencies.

The State planned to introduce an asphalt recycling additive in 1981. This, a much cheaper version of the currently available modifiers, was being developed in conjunction with Amoco and was intended for the production of mixes containing up to 70 per cent of reclaimed material.

Michigan was probably the State with the most experience in cold mix recycling. The work carried out on state highways had always been treated as a basecourse. The climatic conditions would have had a detrimental effect on any basically open-textured surface course. The State recognised that cold recycling would never produce as good a mix as hot mix recycling. However it was firmly believed that, despite the lesser uniformity, inconsistent stability, etc., cold recycling, due to the cost savings, had an important role in the maintenance of appropriate sections of state highways.

During the discussions, several examples of the use of cold mix in-place recycling were quoted, including the following operations:

- An existing pavement, 4 inches thick and 20 feet wide, had been used to provide a cold mix basecourse layer, $2\frac{1}{2}$ inches thick and 24 feet wide.
- An excessive crown had been corrected by trimming to desirable slopes, and the surplus material had been used to produce a cold mix basecourse, extending the carriageway width by 10 feet. Thereafter the whole carriageway had been covered by a

new mix wearing course.

In 1980, Michigan was using contractors to reclaim pavement material and take possession of it free of charges on either side. The State believed that the maintenance engineer should use his ingenuity to save money.

9.14.9 Plant manufacturers

9.14.9.1 Iowa Manufacturing Company (IMC), Cedarapids

IMC developed and produced a drum-within-a-drum recycling system in 1977, following some pioneering recycling work on county roads in Kossuth County, Iowa, which was undertaken by Everds Bros Inc using a Barber-Greene drum mixer.

The first project, 5 000 tons, was carried out in 1975 using a modified drum mixer (burner moved back) and led to considerable pollution problems. In 1976 a further project was undertaken, involving the production of 80 000 tons of hot mix containing 60 per cent reclaimed material. For this project the drum was further modified by drawing excess air into a combustion chamber placed between the burner and the drum. Again considerable environmental problems were encountered although a satisfactory mix was produced. In 1977 Iowa let a further recycling contract involving 9 000 tons, with provision for a further 10 000 tons depending on the results achieved on the first section. This last contract was let, with many stipulations regarding environmental control, to Rohling Construction Company.

IMC modified the contractor's drum mixer by installing a second drum and a feed chute to the existing drum. The reclaimed material was heated in the space between the two drums and protected from direct flame and high gas temperatures, thus preventing blue smoke emission. The virgin aggregate was heated in the inner drum. The heavy curtain effect in this drum allowed maximum heat exchange between the burner flame, hot gases and material, so that the

material discharging into the outer drum was elevated above normal mix temperatures. Two mixing percentages of reclaimed material were used on the project, 65 and 70 per cent.

The operation met both the opacity and particulate pollution requirements adequately, and led to further recycling work (24 000 tons) in Kossuth County during 1977.

The advantages claimed for the drum-within-a-drum system were:

- no excess air
- no excess moisture
- use of the whole length of the main drum by both the virgin and reclaimed materials
- possibility of a wide range of reclaimed-virgin material ratios
- complete compliance with environmental regulations.

The disadvantages were:

- about 10 per cent more costly than comparable systems
- six to seven hours needed to convert plant from normal production to recycling and vice versa
- capacity was substantially lower than the maximum achievable with 70 per cent reclaimed material if this percentage was lowered significantly. Some compensation could be achieved by feeding some of the virgin material through the reclaimed material inlet in these circumstances.

The drum-within-a-drum system was not used during 1979. However, IMC was expecting to use it in six or seven projects in the USA and Canada during 1980.

9.14.9.2 Standard Havens

The Standard Havens' split-feed recycling system utilized a coneflight attached inside the drum under the reclaimed material inlets and extending past these openings as the cone diameter decreased. The cone served three purposes. Firstly, virgin aggregate moved through the cone passing the openings in the drum

shell. Secondly, as reclaimed material fell through the openings it was directed, by the cone, towards the discharge end of the drum. Finally, the cone's internal flights promoted a heavy veil of material in a reduced cross-sectional area, which protected the reclaimed material further on in the drum.

A steel collar assembly was mounted on the outside of the drum shell. This varied significantly from the designs of other manufacturers by being welded to the drum. Use of a rotating collar prevented wear and eliminated the possibility of seizure of the drum on the collar during the mixing operation.

The coneflight system could produce hot mix asphalt containing up to 70 per cent of reclaimed material at mix temperatures between 250 and 300 °F. The stack temperatures were between 25 and 50 °F higher than the discharge mix temperature. This effective heat transfer was attributed to the length of the drum (the longest in the industry) and to the use of the cone.

At the time of the survey Standard Havens' recycling experience was limited to tests and off-road trials over a period of 18 months. However, projects were envisaged in:

- Michigan: Ace Asphalt, Flint, had been stockpiling reclaimed material for about two years.
- Canada: a 25 000 ton project in Quebec.
- Delaware: George & Lynch, Newcastle, had been stockpiling reclaimed material.
- Iowa: a 60 000 tons project scheduled for September 1980.

Standard Havens were planning to use the opportunity presented by the sale of their recycling system to HWZ, Netherlands, to encourage a more 'positive' attitude in Europe.

9.14.9.3 CMI Corporation

In the autumn of 1975, CMI (Consolidated Machinery Incorporated) produced the PR375 roto-mill (the first-ever machine for fine

grading of pavements) and introduced it in the Oklahoma area. By the summer of 1976, ten roto-mills had been leased to contractors. In 1977, CMI began selling these machines and developed the PR225, PR575 and PR750 models.

In their early hot mix recycling trials, CMI tried various approaches in attempts to produce a mix containing 100 per cent of reclaimed material. When this did not prove practicable, CMI tried several other methods involving various ratios of reclaimed-virgin material before introducing their split-feed system. This system, the Roto-Cycler, was developed under licence from Mendenhall and is capable of producing hot mixes from either all new material or a blend of up to 70 per cent of reclaimed material.

The Roto-Cycler incorporated a flight design called Vari-Flight which maximized the heat transfer from the burner to the new material and from the new material to the reclaimed material. The variations in the flight design and arrangements throughout the length of the drum created several distinct zones with varying material densities and heat transfer properties.

Several recycling projects were carried out using the Roto-Cycler system.

Over one million tons of recycled asphalt was produced in CMI plants during 1980. Twenty-one portable and eight stationary drum mixers, and a batch plant were used in 40 projects including:

- Oklahoma: a 20 000 ton project on the I 40, near Weatherford, by Brooks & McConnel Construction Corporation, Oklahoma City.
- Nebraska: a 6 000 ton project in Omaha, by Mid-Con Construction Company, Omaha, Nebraska.
- Kansas: a 38 000 ton project on US 283, near Phillipsburg, by Western Engineering Company, Harlan, Iowa.
- Arkansas: a 17 mile, 55 000 ton, single-carriageway project on State Highway 79 near Magnolia, by R M Courson Construction Co. Inc, Hamburg, Arkansas.
- Oklahoma: a 23 mile, 83 000 ton, project on the Turner

Turnpike, between Tulsa and Oklahoma City, by Western Engineering Co, Harlan, Iowa.

I visited the Arkansas project on 3 May 1980. The contract involved the recycling of an 18-month-old overlay with 40 per cent of new material. This overlay had been contaminated during production by diesel in the mixing drum. Tests showed that the contamination had been successfully removed during reprocessing.

During the recycling operation, blue smoke was emitted and the opacity was estimated to be about 50 to 60. This was blamed on the inadequate size of the settling pond. Apparently environmental pollution controls were not very strict in the area. The plant was operating at some 120 tons per hour, using 2,3 per cent new bitumen. The moisture contents of the reclaimed material and the virgin aggregate were 2,5 and 6 per cent respectively. The mix discharge temperature was 279 °F (137 °C).

The contractor appeared quite content with the profits and the highway authority was reportedly saving about 17 per cent or \$5 per ton. The resultant mix appeared to be laying satisfactorily, although it had been applied on a very wet surface following a rainstorm.

Bill Swisher, president of CMI, discussed with me some of the company's earlier problems and future plans, including:

- Earlier difficulties with the roto-mills: The shearing of the drum shafts due to sonic vibrations - overcome by using special steel (250-260 000 psi). Shearing of the welded flanges - resolved by bolting. Steering of the rubber-tyred model - solved by differential revolving of left and right wheels depending on the forward or backward direction.
- Concern about pollution: The centre-feed process had not resolved all the blue smoke problems. A supplementary unit was being developed involving the after-heating and burning of the exhaust gas impurities.
- 100 per cent recycling: In conjunction with Mendenhall, CMI

were developing optional supplementary equipment enabling their existing recycling system to produce mixes containing as much as 100 per cent reclaimed material.

9.14.9.4 Barber-Greene

Barber-Greene's drum mixer recycling evolved from early simple modifications, involving moving the burner back and installing a combustion chamber with provision for excess air, to their current Dual-Zone recycling system with provision for a cooling air system. In 1980, the company was also experimenting with twin-drum recycling systems.

Barber-Greene believed that although all the pollution problems had not yet been resolved, they were ahead of the other split-feed recycling system manufacturers due to their advanced flighting systems. However they viewed this advantage as marginal and likely to disappear in due course.

Batch plant recycling was actively supported. It was seen as an important step in the development of hot mix recycling, encouraging involvement by hot mix producers, due to the low capital investment requirements, and subsequent acceptance by highway authorities. Barber-Greene were producing the equipment necessary for carrying out modifications to batch plants, thus enabling the production of hot mix asphalt containing up to 50 per cent of reclaimed bituminous pavement materials.

By the end of 1979, well over one million tons of hot mix asphalt, containing varying percentages of reclaimed material, had been produced using Barber-Greene equipment. In the spring of 1980, a Dual-Zone recycling system was sold to Strimont-Enrobes in Belgium. The company was hoping to follow up this, the first-ever USA drum mixer recycling system in Europe, by the sale of further plants to potential customers in the United Kingdom, France, Belgium and Italy.

With regard to the above market, Barber-Greene considered that the RX40 dynaplane was ideally suited to European conditions. Already there were three dynaplanes in France.

They had also developed a prototype cold mix, in-place recycling unit. This machine was based on the RX40 dynaplane. Apparently initial trials showed sufficient promise and have led to further trials and modification of details in the design.

9.14.9.5 Boeing Construction Equipment Company

Boeing was the first manufacturer to produce, in 1973, a drum mixer (based on Shearer's patent). The company, which also introduced the blast shield and the pyrocone recycling system, holds the patent for the early introduction of binder into the mixing drum.^z

The pyrocone system consisted of three sections: a combustion chamber; a nose-cone heat shield; and a combustion chamber extension.

The combustion chamber was a cylindrical tube constructed from high-alloy stainless steel, with slots in the chamber wall to allow the entry of excess air. It was installed between the burner and the drum mixer fire-wall. It was left in place when the plant was operating conventionally, thus increasing overall plant efficiency.

The nose-cone heat shield was used for processing recycled material and was normally removed for the production of standard mixes. However, as it prevented radiation heating and ensured that heat was transferred by convection only, its incorporation could prove to be of economical benefit even when not recycling. (Recent reports from Canada indicated the fuel savings associated with the use of the shield to be about 8 per cent.) The heat shield was constructed from a special alloy designed to withstand the extreme temperatures of the burner flame. Close-tolerance holes perforated the nose-cone to allow hot gases to enter the drum. The nose-cone section bolted onto the slotted combustion chamber and extended inside the drum.

The combustion chamber extension was constructed from heavy stainless steel and bolted directly into the slotted combustion chamber to replace the heat shield when the system was operating conventionally.

The exact place at which binder was introduced was considered critical within plus or minus 1 foot. Binder was introduced just after the second flight, some 12 to 15 feet inside a drum 30 to 36 feet long. Experience had shown that if the binder was introduced too early, it would cause blue smoke but produce no particulate matter, whereas the reverse would occur if it was introduced too late.

Boeing did not believe in 100 per cent recycling, although it claimed to be the only manufacturer capable of it. From the mix design point of view, Boeing considered that recycling with a content of 50 to 70 per cent of reclaimed material represented the optimum range.

In the opinion of the company, the pyrocone system had major advantages over the recycling systems of their competitors. These included:

- it did not alter the basic simplicity of the drum mixing process;
- very high percentages of reclaimed material could be recycled;
- initial costs were low due to the single-feed system;
- changing from recycling to conventional production was simple.

A summary of recycling operations undertaken using Boeing plant over the period 1977 to 1979 is given in Table 14.

Table 14 : Boeing - recycling output

Year	Projects	Total tonnage	Recycled material tonnage	Reclaimed-new material ratios
1977	4	178 000	124 000	70 - 30
				80 - 20
				100 - 0
1978	7	296 000	249 000	50 - 50
				70 - 30
				85 - 15
				100 - 0
				50 - 50
1979	9	510 000	355 000	70 - 30
				75 - 25
				100 - 0

9.14.10 Ashland-Warren Inc

The Company operated 140 mixing plants (10 drum mixers) in twenty States, producing some 12 million tons of hot mix asphalt annually, of which about 0,5 per cent contained recycled material. Ashland-Warren, having sold off part of the original Warren Bros company (40 plants in Canada to Kaiser, Toronto, and 40 plants in the north USA to Tilcon), no longer manufactured their own mixing plants. They used modified batch plants for recycling. The company was considering the development of a mobile transferable modification unit.

Regarding hot mix recycling, Ashland-Warren believed that:

- There had been considerably less progress in recent years than anticipated. The future development of the process was tied to the availability of reclaimed material, processing economics and general official attitudes. There were more opportunities for recycling in the north-east, where there were thicker pavements, than in the south, where the bituminous pavements were generally thin (3 to 4 inches).

- The economics of recycling depended on whether removal of material was to be undertaken by milling in any case.
- Contractors and hot mix asphalt producers would not commit themselves to recycling unless they were assured of a parallel commitment on the part of highway authorities.
- 100 per cent of reclaimed material was undesirable, mainly due to the problem of changes in grading after reclaiming. The quantity of fines could double.
- Although 40 per cent reclaimed material content was possible when recycling through batch plants, the optimum ratio was considered to be a 30-70 reclaimed material-virgin aggregate mix. This ratio would allow the mix design to take full account of variations in the existing material and of the excess of fines produced in reclaiming this material.

In the spring of 1980, Ashland-Warren were considering the following recycling projects:

- Mississippi airfield project. Following a resurfacing project, where on technical and economic grounds recycling was not undertaken, 10 000 tons of milled bituminous material became available. Tests indicated that 3,5 per cent of bitumen could be recovered by reprocessing. The cost of virgin aggregate in the area was about \$3 per ton. The inherent value of the stockpile was calculated to be \$72 000. At the time Ashland-Warren were thinking in terms of using this material, with a MC 250 asphalt modifier, to produce a cold mix. The market value of the recycled mix was expected to be about \$20 per ton.
- Involvement in urban hot mix recycling operations producing secondary mixes.
- A 50 000 tons project on the Georgia-Miami turnpike in Florida.

9.14.11 I 94, (Eden's Expressway) Reconstruction Project

The recycling alternative offered by the successful contractor was \$18 million cheaper than the lowest conventional tender price of

\$131 million for the reconstruction of 15 miles of the I 94. The existing pavement consisted of an asphaltic concrete overlay 3 inches thick on the original concrete pavement.

The project entailed the recycling of two-thirds of the existing overlay (30 000 tons), in a 30-70 reclaimed material-new aggregate ratio, for the production of a bituminous aggregate material basecourse. The rest of the existing overlay material was to be used with the bituminous shoulder material to construct the subbase.

During my visit two dynaplanes (RX75 and RX40) were milling the bituminous pavement, operating at speeds of about 20 and 25 feet per minute. The machines belonged to Monarch Asphalt Co., the subcontractor for the reclaiming, recycling and paving operations. The reclaimed material was windrowed on adjoining lanes and picked up by caterpillar scrapers for use as subbase material. It appeared exceptionally soft with a considerable amount of degrading caused by milling.

Having just bought the two dynaplanes operating on the I 94, Monarch Asphalt Co appeared committed to recycling, adopting a policy of stockpiling all reclaimed material for further use. The company planned to undertake further recycling projects in the near future and had just been awarded a 12 000 tons project in Lincolnwood.

9.14.12 Cutler Repaving Inc

Earl Cutler, President of Cutler Repaving Inc, Lawrence, Kansas, developed the repaving single-pass hot surface recycling system in 1965. The complexity of the machine and the need for specialist experience in its maintenance, forced Cutler to introduce it to the road industry by the direct undertaking of contracting work.

The first Cutler repaver was initially used in Kansas, Illinois, New Mexico and Missouri, and by 1970 four other machines had been produced. By that time the direct-heating system had been replaced

by infra-red heaters.

In the early Seventies, repaving was introduced into Europe and three additional machines were produced and sold by Cutler to companies in Switzerland, Sweden and the United Kingdom.

In 1980 Cutler was operating in many parts of the country.

9.14.13 Jim Jackson, Contractor

Jim Jackson, Little Rock, Arkansas, first built a planer in 1936. The machine used chisels to cut the asphalt while cold in a slow, expensive operation. In 1950, the company produced a diesel-fueled hot-planer which subsequently formed the basis for the development of the Jackson heater-scarifier and the reforming process.

By 1980, Jackson was also operating, through affiliates, in Canada, Venezuela and the United Kingdom.

9.14.14 Las Vegas Paving Corporation

Robert L Mendenhall, President of Las Vegas Paving Corp. and Asphalt Products Corp., was a pioneer in the field of bituminous material recycling, starting his central-plant experimental work in 1970.

In 1974 a Mendenhall-designed system was used by Las Vegas Corp. for a recycling trial on a one-mile section of the I 15, south of Las Vegas. Since then the company has undertaken several recycling projects.

The Mendenhall system was licenced to CMI Corp. and formed the basis of the Roto-Cycler system.

9.15 West Germany

9.15.1 Background

The total length of the road network in 1978 was 479 658 kilometres and consisted of:

Bundesautobahnen (State freeways)	7 029	kilometres
Bundesstrassen (Federal main roads)	32 252	"
Landstrassen ("Provincial" roads)	65 377	"
Other roads	375 000	"

97 per cent of the above network was paved.

The "Instructions for road pavements - Standard structures" ("Richtlinien für den Strassenoberbau - Standardausführungen" RSt075), published in 1975, introduced classes of construction (I to V) for both bituminous and concrete pavements, which are determined by the volume of traffic (number of trucks with payloads of more than 5 tons and of buses in 24 hours) at the time the road is opened to traffic.

Both suitability testing and behavioural assessments were used in a comprehensive system of control for aggregates. With regard to hot mix bituminous material, a distinction was made between suitability testing, factory control testing and quality control testing. Quality control testing was carried out exclusively by recognised test establishments. In the acceptance of construction work, the results of the quality control tests were used, and if these were not within the permissible tolerances, a deduction from the price was made, or other measures were taken.

9.15.2 Hot surface recycling

9.15.2.1 Repaving

There had been considerable use of this process since 1976. The output of the Wirtgen repavers alone over this period had been 240 000, 571 000, 1 000 000 and 1 050 000 square metres in 1976,

77, 78 and 1979 respectively. This work had been carried out by three contractors owning repavers and by Wirtgen directly.

By the end of 1979 Wirtgen had manufactured 15 repaving machines, which were being used in twelve countries in Europe, as well as in Mexico. Since 1979 most new models had been built as repaver/remixers.

Strabag had also produced two repavers. These machines were operated solely in West Germany.

9.15.2.2 Reforming

This process had also been used considerably over the past few years. Vogeles-Scholkopf manufactured their reformers for work in West Germany and other European countries.

9.15.2.3 Remixing

After the first remixing trial in 1978, further work in West Germany included a 30 000 square metre project on the Federal Main Road B516, Mohne-Dam. This project was undertaken during June 1979 and involved the remixing of 40 mm of the existing pavement with 50 per cent additional new material. The operation was carried out at the normal speed of 2 to 3 metres per minute, enabling the completion of 3 000 to 5 000 square metres daily.

9.15.3 Cold mix recycling

In 1979, Hessisches Landesamt für Straßenbau, carried out an experiment involving the cold mix, in-place recycling of the basecourse of a 150-metre-long temporary road. The 200-mm-thick basecourse was constructed using reclaimed bituminous material mixed (by a Merkt machine) with 6 per cent of cement.

In the summer of 1979, following the successful undertaking of this experiment, the road authority was planning cold mix recycling

trials in conjunction with the widening project of the A3 Autobahn, Frankfurt to Munich, between the Offenbach and Hanau junctions.

The trials were to involve various sections of the widening project where conventional pavement layers were to be replaced by:

- (a) a mixture of reclaimed bituminous material and 5 to 7 per cent cement (replacing the normal lean concrete layer);
- (b) reclaimed bituminous material (replacing the normal granular subbase layer);
- (c) a combination of these two operations.

In planning these trials, the road authority was influenced by reports on the Netherlands' recycling trials with cement. However, Hessisches Landesamt für Strassenbau was also prepared to undertake cold mix, in-place recycling trials using an emulsion as an additive, provided the proper emulsion, methods and equipment were available.

9.15.4 Hot mix recycling

Before 1980 two hot mix recycling projects had been carried out on German Autobahnen, in 1978 and 1979, as part of official drum mixer recycling trials and development. In both cases the recycling option was about 15 per cent more expensive than the conventional method. The contractor (Teerbau) attributed this to the relatively small sizes of the projects.

The 1978 project was undertaken on the A48 Autobahn, Frankfurt to Kassel, near Reiskirchen and the 1979 project on the same Autobahn, near Reinhardshain. The 1978 trial involved the recycling of material reclaimed by ripping, breaking and crushing operations, whereas in the 1979 trial cold milling was used. Specially manufactured recycling drum mixers (Wibau) were used for the production of mixes containing 65 per cent reclaimed material.

The Wibau mixers were the only ones operated in West Germany, where there was still considerable resistance to the use of drum mixers

for producing hot mix material. The reclaimed material was fed into the drum, together with the new material, at the burner end and was, at least in theory, protected from the flame by special 'shadow' flights. For the second trial, an elaborate arrangement called a 'Rieselfilter' was used for filtering the exhaust gases. This entailed the introduction of virgin aggregate into the drum mixer after using the aggregate for the filtering operation.

The resultant mix was used in two trial projects for constructing a basecourse and a binder course, except that on a 100 metre experimental section, of the 1979 project, it was used as a surfacing. In the summer of 1979, some eight months after the trials, the recycled wearing course appeared to be in a satisfactory condition.

The main problems encountered during the 1978 trial were:

- (a) The ripping and breaking reclaiming operations caused considerable disturbance of the subbase and involved additional expenditure for the removal and replacement of light columns and the longitudinal cutting of the pavement structure.
- (b) The crushing process caused environmental problems (dust) and difficulties associated with the tendency of the reclaimed material to congeal during the operation.
- (c) The existing and new (0,5 per cent) binders did not combine satisfactorily. Globules of binder were observed in the resultant mix. This was attributed partly to insufficient mixing time.
- (d) Considerable pollution was caused by emissions of both blue smoke and dust particles during the recycling operation.
- (e) The production rate of the drum mixer when recycling was substantially below its capacity rating for conventional operations.

Overall improvements were made in the 1979 trial by:

- reclaiming by milling, thus avoiding the 1978 (a) and (b) problems;
- using a longer and larger drum, resulting in improved mixing

- and higher production rates;
- incorporating the 'Rieselfilter', thus alleviating, to some extent, the 1978 pollution problems.

Nevertheless, in the summer of 1980 Wibau informed me that the company had abandoned the recycling system used in the above trials. Their reasons included the realisation that the system was reducing the plant's capacity by 30 per cent, that pollution remained a problem, that the 'Rieselfilter' was causing mobility problems, and that the shadow flights did not provide adequate protection for the reclaimed material.

Wibau was developing a centre-feed recycling system with baghouse filtering. In conjunction with Albert Cochery, Paris, they were planning to set up a drum mixer plant (2,2 metres diameter x 9 metres long, with a capacity of 150 tons per hour) in the Dieppe area. Recycling trials were due to commence in September 1980.

If the above method did not prove successful, Wibau planned to develop a special dryer, modified for the production of recycled mixes, while normal mixes would still be produced in a batch plant. In Wibau's opinion this approach would combine the batch plant's flexibility and ability to produce high-quality material with the drum mixer's superior range of recycling ratios.

During 1979, Teerbau, using modified batch plant, produced some 3 000 tons of hot mix material containing proportions of reclaimed material of 15 to 20 per cent. This material was used for the construction of bases on projects carried out by the company. The reclaimed material was obtained by ripping, breaking and crushing to 35 mm maximum size. 5 per cent of sand was mixed with the reclaimed material in special equipment which constituted part of Teerbau's modifications to batch plants for recycling. Three of the company's twenty-four batch plants had already been modified for this operation.

10. SOME SIGNIFICANT RECENT DEVELOPMENTS IN THE RECYCLING OF PAVEMENT MATERIALS

- 10.1 Introduction
- 10.2 Recycling plant
- 10.3 Recycling agents
- 10.4 Sulphur-asphalt
- 10.5 Research
- 10.6 Selected bibliography

10.1 Introduction

Since the completion of my survey in 1980, interest and involvement in recycling have continued to grow and a number of road authorities have come to accept recycling processes as part of their normally available rehabilitation options. During this time, research into various aspects of recycling has continued, further innovations in plant and methods have been made, and asphalt associations and institutes have become more active in promoting the recycling of pavement materials.

In 1981, the Asphalt Recycling and Reclaiming Association (ARRA) in the USA reported, on the basis of a national survey, a significant increase in asphaltic pavement material recycling. The Association predicted that between 1981 and 1986 some 31,5 million tons of material would be produced through hot mix recycling alone. Cold mix and hot surface recycling were also expected to account for several million tons during the same period. In 1982, ARRA published guidelines for hotmix and in-place cold recycling, and recommended specifications for hot surface recycling.

In 1981, the USA National Asphalt Pavement Association (NAPA) published "Recycling asphalt pavements - stretching taxpayer dollars while conserving materials and energy". In line with NAPA's support, declared over the last few years, for central-plant hot mix recycling, this document promotes and encourages commercial involvement in the process.

Also in 1981, Shell International Petroleum Company published "Asphalt recycling - the state of the art, 1980". This document summarized my final report on the project sponsored by Shell IPC and the UK Department of Transport.

Since 1980, the Asphalt Institute have been devoting considerable effort to recycling. In August 1981, the Institute published a manual on hot mix recycling, and a manual on cold mix recycling is currently being prepared. In May 1982, the Institute released a

film entitled "Recycling roads with asphalt emulsions". The film features methods used in the USA to recycle material from low-volume roads to construct asphalt-strengthened pavement bases. It also illustrates recycling as a uniquely cost-effective method of rehabilitating and improving roads.

In 1981 the UK Department of Transport issued a specification for repaving and thus accepted this hot surface recycling process as an alternative to the conventional methods of rehabilitating wearing courses.

A committee, formed under the auspices of the Danish State Road Administration, published a document in 1981, entitled "Recommendations concerning recycling of asphalt materials in Denmark". The Association of Danish Asphalt Industries reported that during 1981 recycled materials were used in a number of basecourses and on 14 wearing course projects on state freeways and main roads, covering a total area of some 600 000 square metres.

10.2 Recycling plant

Since 1980 there has been a great increase in the availability of recycling plant outside the USA. With regard to hot mix recycling, most drum-mixer manufacturers have produced their own particular models, in most of which the reclaimed material is fed into the centre of the drum. During this period, the general availability of cold milling machines has had the greatest impact on cold mix recycling methods and the effectiveness of reclaiming pavement material.

In August 1980, a high-speed 'slinger-belt' was used, in Iowa USA, to feed reclaimed material through an opening in the back of a conventional drum mixer. Reportedly some 12 000 tons of reclaimed asphaltic material were recycled successfully, in a 50/50 reclaimed/new ratio, using this simple and economical approach.

In 1981, the CMI Corporation produced a prototype '100 per cent

recycling' drum mixer. This plant was first used commercially in Iowa during the summer of 1981. CMI reported that it performed satisfactorily.

Also in 1981, the Iowa Manufacturing Company (IMC) abandoned their drum-within-a-drum concept and adopted the centre-feed approach. According to IMC, one of the main disadvantages of the drum-within-a-drum system was that when the plant was used for conventional operations (100 per cent new material) the production rate was significantly reduced. Naturally, this disbenefit could be remedied by the removal of the inner drum for conventional operations. However, asphalt producers, engaged in switching back and forth from recycling to conventional operations, were not prepared to spend the time and effort involved in carrying out continual alterations to their plant. Following the abandonment of the drum-within-a-drum system, IMC converted all their existing recycling drum mixers to the centre-feed system.

In the autumn of 1981 an in-place cold mix recycling project in Colorado, USA, involved adding the bitumen emulsion to the tumbling reclaimed material through a spray-bar mounted on a Barber-Greene cold milling machine near the cutting drum. Water, normally sprayed to cool the picks of the milling machine, improved the coating and spreading properties of the recycled mix.

In 1982, Wirtgen, West Germany, reported that they had successfully undertaken preliminary hot surface recycling trials using a modified cold milling machine. The modifications included the attachment of a heater-mixer unit, to the tail end of the milling machine, for the reprocessing of the milled asphaltic material and for the addition of virgin material and new bitumen or recycling agents.

10.3 Recycling agents

During the last few years, the increasing use of recycling agents and the wide range of products available have forced many road

authorities to examine closely the applicability and potential of individual agents and to define their own specification requirements.

The revised Bituminous Materials Specifications of the Arizona Department of Transportation published in 1981, includes specifications for recycling agents and emulsified recycling agents.

The specification for recycling agents shown in Table 15, is largely based on that proposed by the Pacific Coast User-Producer Committee (see section 6.5), but includes requirements for asphaltene content, chemical composition and compatibility.

Table 15 : Specification for recycling agents - Arizona DOT

Test on recycling agent	Test method	Requirement							
		RA-1		RA-5		RA-25		RA-75	
		Min	Max	Min	Max	Min	Max	Min	Max
Viscosity, 140°F Centistokes	*T201	100	200	200	800	1000	4000	5000	10000
Flash Point, Pansky Martens closed tester, degrees F	*T73	340		375		425		450	
Saturate, by weight, per cent	D2007		30		30		30		30
Asphaltenes, per cent (1)	D2006-70		1.0		5.0		10.0		17.0
Chemical composition N+A1 (2) P+A2	D2006-70	0.2	1.0	0.2	1.2	0.2	1.4	0.2	1.6
Compatibility: N (2) P	D2006-70	0.5		0.5		0.5		0.5	
Test on residue (3)									
Weight change, per cent		6.5		4		3		2	
Viscosity ratio (4)		3		3		3		3	

*are AASHTO; others are ASTM

- Note (1) Asphaltenes for Ra-1 may be determined in accordance with the requirements of Arizona Test Method 505; however, in case of dispute, ASTM D2006-70 shall be used.
- Note (2) N = nitrogen bases; P = paraffins; A1 = first acidaffins; A2 = second acidaffins.
- Note (3) Residue will be obtained in accordance with the requirements of AASHTO T240.
- Note (4) Viscosity ratio:

$$\frac{\text{Viscosity of residue at } 140^{\circ}\text{F centistokes}}{\text{Viscosity of recycling agent at } 140^{\circ}\text{F centistokes}}$$

The specification for emulsified recycling agents is shown in Table 16. An additional requirement is that within 30 days of delivery, and provided separation has not been caused by freezing, the emulsified recycling agent shall be homogeneous after thorough mixing.

Table 16 : Specification for emulsified recycling agents -
Arizona DOT

Test on emulsified recycling agent	AASHTO test method except as shown	Requirement			
		ERA-1	ERA-5	ERA-25	ERA-75
Viscosity, Saybolt, Furol, 77°F Seconds, range	Ariz. 508	15 - 40	15 - 100	15 - 100	15 - 100
Miscibility	T 59	Passes	Passes	Passes	Passes
Sieve test, per cent, maximum	T 59 (1)	0.10	0.10	0.10	0.10
Particle charge	T 59	Positive	Positive	Positive	Positive
Residue (2) Residue, per cent minimum(3)		60	60	60	60

- Note (1) Distilled water will be used instead of the two per cent sodium oleate solution
- Note (2) Residue will be obtained in accordance with the requirements of Arizona Test Method 504 and shall conform to all the requirements specified in Table 705-3.

Note (3) Residue by evaporation may be determined in accordance with the requirements of Arizona Test Method 512; however, in case of dispute, AASHTO T 59 will be used.

10.4 Sulphur

Field trials undertaken in 1980 on Highway II, Ontario, Canada, proved that sulphur-asphalt pavement material can be recycled without significant SO_2 and H_2S emissions.

Since 1975, the Ontario Ministry of Transportation and Communications had been using sulphur-asphalt blends (liquified sulphur emulsified in bitumen) increasingly often in their paving operations and were concerned about possible adverse effects on the future ability to recycle these mixes.

In the trials, although fairly high concentrations of SO_2 and H_2S were detected within the skirt of the milling machine during reclaiming, readings fell to almost nil at the roadside. The reclaimed material was recycled, in ratios of 25/75 and 40/60 with new material, in a batch plant where mixing temperatures were kept below 300 °C. Detection meters showed no concentration of either H_2S or SO_2 in the emissions from the pugmill and there was no significant odour during the paving operations.

10.5 Research

As in the preceding period, most of the recent research into recycling has been undertaken in the United States of America.

The Federal Highway Administration (FHWA), USA Department of Transportation, remaining fully committed to the principle of recycling road pavement materials, has initiated new research projects to address outstanding problems in recycling, such as the variability in the reclaimed material and the physical and chemical compatibility between old and new binders and recycling agents. Another current FHWA project examines energy, economics and the

environmental and material conservation associated with the recycling of asphaltic pavement materials.

The Asphalt Institute are carrying out, under a contract with the Federal Highway Administration, a research project entitled "Flexible pavement mixture design using reclaimed asphaltic concrete". It is a thirty-month project whose objectives are to develop statistically sound sampling procedures, test methods to characterize the reclaimed binder, and mix design criteria for recycled mixtures, and to select tests for evaluating the susceptibility to moisture damage of recycled mixtures.

Several other road authorities and universities in the USA have continued their research, or have become involved in new projects. Current activities include research on:

- mix design criteria, energy and cost data, and structural designs (Connecticut Department of Transportation)
- time-dependency of performance (University of Illinois)
- properties of in-place cold mix recycling mixtures (Purdue University)
- relationships between the physical properties of aged bitumens and the quantity of recycling agents needed (Louisiana Department of Transportation and Development)
- characterization of recycled mixtures (Ohio State and University of Texas).

In the Republic of South Africa, the National Institute for Transport and Road Research, became actively involved in research into recycling. This involvement led to the development of a prototype drum mixer test unit, the Servacycler, during 1982. (See Chapter 12.)

10.6 Selected bibliography

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11. PAVEMENT MATERIAL RECYCLING IN THE REPUBLIC OF SOUTH AFRICA

11.1 Background

11.2 Cold mix recycling

11.2.1 Cemented bases

11.2.2 Bituminous surface seals

11.2.3 Gravel roads

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11.3.1 Plattekloof project

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11.3.3 Other developments

11.3.3.1 Roadmix recycling at Knights

11.3.3.2 N3, Pietermaritzburg bypass

11.3.3.3 Durban City Corporation

11.3.3.4 Johannesburg City Engineer's Department

11.4 Rejuvenating

11.4.1 Tar rejuvenator

11.4.2 Mobil Sol 30

11.4.3 Reclamite and Cyclogen

11.4.4 RJ0 2 rejuvenating oil

11.4.5 Spramex RJ55 and RJ110

11.5 Selected bibliography

11.1 Background

The main road transport network in the Republic of South Africa has been established over the last half century and has been planned, constructed and maintained with a high degree of technological sophistication. The level of service provided is comparable with that in most developed countries.

Pavement material has been reused in the RSA for many years, long before the term "recycling" came into general use. Cold-mix recycling, in particular, has numerous applications and a number of processes have been in use for many years. Hot mix recycling was relatively untried until 1981 when the undertaking of the Van Reenen's pass project focused considerable attention on the process. Since then there has been increasing interest in hot mix recycling, which is reflected in the current rehabilitation planning procedures used by road authorities and consultants, in the introduction and marketing of recycling additives by oil and chemical companies, in the acquisition of recycling plant by the industry, and in the numerous symposia, seminars and papers on the subject.

Hot surface recycling has not been used in this country as yet. Nevertheless, despite the predominance of thin surfacings, it should provide a worthwhile alternative to the conventional resurfacing techniques, especially on freeways and the main urban network.

11.2 Cold mix recycling

In South Africa, cold mix recycling has been widely used for pavement rehabilitation to:

- (i) reuse material from cracked cemented bases,
- (ii) upgrade unstabilized bases,
- (iii) reuse asphaltic surfacings,
- (iv) maintain gravel roads.

11.2.1 Cemented bases

The upgrading of natural or crushed gravel to meet the demands of heavier traffic loads led to the stabilization of base materials, in particular with cement. The use of well cemented base layers under thin bituminous surfacings has resulted in widespread block cracking and the need for costly maintenance.

Experience has shown that, provided traffic volumes are not too high, various ways of crack sealing or pre-treatment prior to surface sealing or overlaying can significantly extend the serviceable life of the pavement. However, replacement or reworking of these bases becomes necessary when serious secondary cracking and/or pumping of fines to the surface and rocking of the cemented slabs occur. This has been the case on a number of projects in various parts of the country.

Material has been reclaimed from cemented bases with plant such as bulldozers, scarifiers, milling machines, self-propelled vibratory or steel-tyred tandem and pneumatic-tyred rollers and many other items of equipment.

The recycling operations have been undertaken in-situ and at central plant. Although central-plant operations have proved more costly, they have offered advantages such as high quality product on projects such as sections of the S12 Freeway between Johannesburg and Witbank and the N1 Freeway between Springfontein and Trompsburg.

Bitumen emulsions at low contents have been used to modify reclaimed material. This application has shown several advantages over the use of water alone to facilitate compaction. However, it was found important to keep the compaction moisture approximately 2 per cent above optimum moisture content, to facilitate the mixing and coating of the emulsion through the material. It was also found beneficial to allow a slightly richer final application of diluted emulsion to produce a slush on the surface, giving a fairly tight surface texture after compaction. On a recent project on the

N2 Freeway near East London, this type of procedure allowed the road to carry fairly heavy traffic for up to six weeks before being overlaid.

11.2.2 Bituminous surface seals

The major portion of South Africa's surfaced roads consists of "spray and chip" seals. Roads built prior to the late 1940s have been found to have little or no salvage value at the end of their service life, whereas those constructed in the 1950s and later, when materials of higher quality were used, have been found to provide adequate material for stabilized bases. Where required, new material is added to improve the grading and quality of the reclaimed materials or for improvements to the road geometry.

In the rural areas of South Africa where traffic volumes are below 5 000 vpd, many old national roads have been upgraded in this fashion. Costs vary from R100 000 to R300 000 per kilometre, depending on locality and other factors.

11.2.3 Gravel roads

By far the largest part of a road network in any developing country is usually gravel surfaced or earth and proper maintenance of the riding surface is often more an art than a technological process although in some countries (e.g. RSA) computer-based maintenance systems are being introduced to optimize the maintenance strategy.

The surface can be destroyed by injudicious use of motor graders and in many areas the scarcity of good sources of gravel for resurfacing is becoming a problem. The reworking of gravel surfaces with the minimum of gravel replenishment can provide considerable savings.

In the Orange Free State it has become almost standard practice to scarify and reshape a gravel road when required, which is approximately halfway through its service life usually after three

to four years. The cost of this work has been found to be approximately ten per cent of the cost of a full regravelling operation. The process involves a minimum of plant and only nominal compaction after scarification to 150 mm. The actual cost of this process was found to vary from R700 to R1 000 (1981) per kilometre in the Vrede district of the Orange Free State.

Prior to establishing a gravel road network's maintenance programme, the following factors need to be determined:

- Traffic volume: roads should be ranked according to their respective traffic volumes.
- Topography: this has an important effect on the rate of wear of the gravel wearing course. In hilly country it may be difficult to move the surface material about during grader maintenance.
- Geology: a thorough knowledge of local geology is essential to make the best possible use of natural materials.
- Drainage: bad drainage will necessitate more maintenance. Ideally, gravel roads should be aligned for minimum run-off, and the cross-section of the road must be free-draining at all times.
- Material properties: The selection of the correct gravel material for optimum life is very important.

How frequently maintenance is required is usually dictated by traffic considerations and availability of funds, plant and trained operators. The maintenance programme is established by:

- identification of criteria and needs for each particular area
- regular inspection
- processing of relevant data
- determination of a provisional programme
- testing the provisional programme and adjusting it as required.

In most areas in South Africa road superintendents are finding that bi-monthly programme adjustments are needed.

11.3 Hot mix recycling

It is generally recognized that hot mix recycling has been undertaken for some time by contractors and producers of asphaltic mixes in unofficial, unpublicized, limited-scale operations. However, experience with formal full-scale hot mix recycling has been limited.

The advent of modern cold milling machines in South Africa has drawn further attention to the potential of reclaimed bituminous material. These machines have been used effectively in recent hot mix recycling projects.

11.3.1 Plattekloof project

In 1981, hot mix recycling was carried out as part of the Plattekloof reclamation and recycling project in the Cape Province. The project consisted of three trial sections and involved the in-situ reuse of material reclaimed from the existing 200 mm thick cemented base as a granular base, as well as the hot mix recycling of the 35 mm thick asphaltic layer.

The reclaimed asphaltic material was recycled in a 40/60 ratio with virgin aggregates by Much Asphalt in their Eerste River plant, which was suitably modified. A Mobil recycling additive, Mobil Sol 30, was used. The plant, a Wibau batch plant with a production capacity of 150 tons per hour, was already equipped with an additional elevator and spare post-screening storage facilities. Consequently, a minimum of modifications was needed and these consisted of a cold bin and conveyor to handle the reclaimed material. During the recycling operation the production rate was reduced to between 100 and 120 tons per hour. The virgin material was heated to 250 °C, the exhaust temperature was about 120 °C, and the final mix temperature 140 to 150 °C. The resultant premix appeared satisfactory, although it was contaminated to some extent by the isolated presence of Malmesbury shale basecourse aggregate. Furthermore, reportedly due to inadequate compaction, the premix

layer was more permeable than was desirable. However, these defects reflect on operational control and not on the validity of the process or the use of an additive.

The trial showed that, with a modified batch plant, it is possible to reuse asphaltic material complying with standard RSA specifications, in this particular case a typical Cape mix.

However, the cost-benefit analysis showed that savings were adversely affected by two important factors:

- the limited size of the project
- the costs involved in transporting the reclaimed material to and from a central plant.

11.3.2 Van Reenen's pass project

11.3.2.1 Background

In 1981, Savage and Lovemore undertook, as the main contractor, the National Route 2, Van Reenen's Pass, rehabilitation contract in Natal. The project involved the re-use of the existing asphaltic pavement material to produce the base mix, based on an alternative proposal by the contractor.

The accepted alternative called for two 50 mm layers of "recycled" basecourse premix, containing 70 per cent of reclaimed material, and a 40 mm conventional premix wearing course.

The recycling part of the contract, involving the reuse of some 45 000 tons of existing asphaltic material and therefore by far the biggest recycling venture in the Republic of South Africa to date, was carried out by Rand Roads, as a specialist subcontractor.

11.3.2.2 Method

The existing pavement was removed by using both the traditional ripping and breaking method and cold milling for which a Wirtgen

machine was used to remove layers of the existing pavement and produce sized material ready for reprocessing. The ripped and broken pavement was sized to the required grading by subsequent primary and secondary crushing operations at the central plant site. The crushed and milled materials were stockpiled separately.

The reprocessing was done by using an existing drum mixer plant, modified for recycling on the dual-feed principle: the virgin material being fed in at the burner end and the reclaimed material at a point midway down the drum. New binder was added further down the drum after the reclaimed material has been introduced. Before modification this plant was rated at 100 ton/hour when material of 2½ to 3 per cent moisture content was used.

The drum mixer used coal/tar fuel. When not discharging directly into a truck, the discharge chute was connected to the storage silo via an exceptionally steep conveyor. Only primary dust extraction equipment was fitted owing to the water supply requirements of wet collectors and the mobility problems of dry collectors.

During recycling an asphalt plant's production rate normally falls well below its conventional capacity. However, at the Van Reenen's Pass project the plant was run at an increased production rate 100 - 110 tons/hour, even at times when the reclaimed material had a high moisture content. Naturally, this practice had adverse effects on the quality of the resultant mix and emissions and led to rates of fuel consumption about 50 per cent above normal. On one occasion it caused the combustion chamber to burn out.

At the early stages of the contract two per cent of a 400 penetration bitumen binder was added to the virgin and reclaimed material mix during reprocessing. This soft binder resulted in high flow values of about 4 mm, and marginal creep characteristics (creep modulus about 50 MPa). Concern about these results led to the replacement of the original binder with a 150 - 200 penetration bitumen which resulted in the reduction of the flow values to between 2,5 mm and 3,5 mm, and the increase of the creep modulus to over 100 MPa.

Cyclogen was also used as a recycling additive on a trial section when 0,4 per cent of cyclogen was added to 1,6 per cent of the 150 - 200 penetration binder.

At the end of September 1981, the NITRR became involved in testing samples taken from the recycled layers. Tests for creep, fatigue and recovered binder properties were included in the programme. The use of the Heavy Vehicle Simulator (HVS) was also suggested.

11.3.2.3 Comments on procedures adopted

Opportunities to visit the site arose on a number of occasions during the latter stages of the recycling operations. Observations of the construction procedures and controls adopted led me to the conclusion that a wide variability in the resultant mix was to be expected. This gave rise to misgivings regarding the validity of undertaking elaborate testing of the resultant mixes, and in particular, the proposed use of the HVS appeared to be of limited, if any, merit.

The numerous irregularities involved in reclaiming, stockpiling and reprocessing procedures (all detrimental to the quality and uniformity of the product) included:

- considerable variation in the moisture content and type of reclaimed material, including quantities of unmilled material in the stockpile of milled pavement;
- size segregation in the milled and crushed material as a result of the steep slopes of the stockpiles;
- contamination, such as grass, clay, fencing poles, wood and rejected premix, in the ripped and broken pavement stockpile which included oversized pavement pieces and large stones;
- contamination of virgin material;
- the crusher was adjusted to a correct position late in the contract by which time most of the crushed reclaimed material had been produced with an excess of fines;
- size segregation in the resultant mix arising from the steepness of the conveyor connecting the outlet chute to the storage silo.

The above highlighted the difficulty of monitoring and controlling the quality of hot mix material produced on the basis of a broad recipe specification and containing a very high predetermined proportion of reclaimed material. Experience has shown that in these circumstances neither the contractor nor the employing authority has direct and clear responsibility for the quality of the product.

11.3.2.4 Air pollution

During the recycling operations the problem of pollution, caused by dirty emissions from the plant, remained unsolved and, in fact, the Directorate of Land Transport (DLT) expressed concern that this could prove a general and inherent problem of hot mix recycling in South Africa.

However, in my opinion there were more than enough local factors to account for the pollution problems encountered at the project. Observations indicated that the problem was due to a variety of reasons, including:

- the mixing plant was not fitted with secondary dust-collecting equipment;
- the production rate normally exceeded the design capacity of the drum mixer;
- the burner, fired with coal/tar fuel, presented frequent operational problems;
- the moisture content of the reclaimed milled material was often unacceptably high;
- substantial moisture content variations in successive portions of reclaimed material greatly aggravated the pollution problem;
- portions of the reclaimed material contained tar and/or other surface treatments;
- there was a high ratio of reclaimed material to virgin aggregate.

If the above factors are examined and procedural modifications implemented where possible, the pollution problems encountered during the Van Reenen's Pass project need not recur at other central-plant recycling sites.

11.3.2.5. NITRR test results and recommendations

Some of the NITRR test results are shown in Tables 17 to 22. Despite the limitations imposed by the small number of samples tested, the results served to verify the earlier misgivings, arising from observation of the procedures adopted and the controls exercised, regarding the uniformity of the resultant mixes.

The lack of uniformity in the resultant mix highlighted the need for adequate preliminary testing, adoption of appropriate reclaimed/new material ratios, and the establishment of clear lines of control and responsibility for the production of mixes complying with normal specification requirements.

The road authority was advised that any further testing on this project was not likely to further the understanding of the requirements for successful hot mix recycling operations.

11.3.3 Other developments

11.3.3.1 Roadmix recycling

In 1981, Roadmix modified their Wibau drum mixer at their Knights asphalt depot to enable the plant to be used for hot mix recycling. The modifications were mainly based on the Barber-Greene dual-zone principle and involved some interesting innovations such as an additional screening process for the reclaimed material prior to its entry into the drum, and the preliminary introduction of binder to suppress the generation of dust from the superheated virgin material.

Apart from the normal contractual interest of the company in the recycling process, an additional reason for their involvement was

Table 17 : Binder and voids content and binder characteristics of 'recycled' layer in sections where 150/200 Pen binder and cyclogen were added - Van Reenen's Pass project - NITRR tests December 1981

Added binder	Sample number	Voids (%)	Binder content	Penetration	Ductility (mm)	Softening point (°C)	Thin Film Oven Test				Absolute Viscosity	
							Loss in mass (%)	Ductility (mm)	Penetration 1/10 mm	% of original	100 °C (cp)	135 °C (cp)
1,6% 150/200 Pen bitumen + 0,4% cyclogen	A1 (top layer)	8,78	4,39	47	1400 ⁺	55,5	1,400	270	30	63,8	4237	506
	A2 (top layer)	10,80	3,50	38	1350	54,5	1,097	155	25	65,8	5416	491
	A3 (top layer)	8,47	4,85	56	1375	51,3	2,347	170	31	55,4	2301	321
	A1 (bottom layer)	1,24	5,61	51	1400 ⁺	56,4	1,309	165	33	64,7	3735	454
	A2 (bottom layer)	7,15	6,26	38	820	59,2	0,606	155	30	78,9	9070	702
	A3 (bottom layer)	3,17	6,45	35	525	60,0	0,651	145	27	77,1	9072	737
Mean		6,60	5,18	44	-	56,2	1,235	177	29	67,6	5638	535
Standard Deviation		3,65	1,14	8,42	-	3,2	0,64	46,5	2,9	8,9	2840	157

Table 18 : Binder and voids content and binder characteristics of 'recycled' layer in sections where 150/200 Pen binder was added - Van Reenen's Pass project - NITRR tests December 1981

Added binder	Sample number	Voids (%)	Binder content	Penetration	Ductility (mm)	Softening point (°C)	Thin Film Oven Test				Absolute Viscosity	
							Loss in mass (%)	Ductility (mm)	Penetration 1/10 mm	% of original	100 °C (cp)	135 °C (cp)
2% 150/200 Pen bitumen	B1 (top layer)	7,41	5,58	40	1400 ⁺	55,5	1,164	185	27	67,5	5043	481
	B2 (top layer)	6,97	5,82	47	1400 ⁺	52,9	1,365	365	30	63,8	3217	410
	B3 (top layer)	13,49	5,50	61	1400 ⁺	50,5	1,913	360	32	52,4	2608	332
	B1 (bottom layer)	6,94	5,78	44	1400 ⁺	55,6	1,416	220	26	59,1	4179	459
	B2 (bottom layer)	8,26	6,60	43	1400 ⁺	54,6	1,508	210	27	62,8	3445	416
	B3 (bottom layer)	7,44	5,75	74	1400 ⁺	48,7	2,448	180	28	37,8	2520	332
Mean		8,42	5,84	51,5	1400 ⁺	53,0	1,64	253	28	57,2	3502	405
Standard Deviation		2,53	0,39	13,25	0,0	2,84	0,47	85,9	2,25	10,8	967	62

Table 19 : Binder and voids content and binder characteristics of 'recycled' layer in section where 400 Pen. bitumen was added - Van Reenen's Pass rehabilitation project - NITRR tests December 1981

Added binder	Sample number	Voids (%)	Binder content	Penetration	Ductility (mm)	Softening point (°C)	Thin Film Oven Test				Absolute Viscosity	
							Loss in mass (%)	Ductility (mm)	Penetration 1/10 mm	% of original	100 °C (cp)	135 °C (cp)
2% 400 Pen. bitumen	C1	0,65	6,60	44	1400 ⁺	53,8	0,243	1310	39	88,6	5506	545
	C2	2,23	6,40	38	1400 ⁺	56,7	0,180	1005	33	86,8	6345	679
	C3	4,56	6,76	36	1400 ⁺	56,5	0,410	770	33	91,7	7305	748

Table 20 : Binder content and characteristics of reclaimed material - Van Reenen's Pass rehabilitation project - NITRR tests December 1981

	Binder content (%)	Penetration (1/10 mm)	Ductility (mm)	Softening point (°C)	Thin Film Oven Test				Absolute Viscosity	
					Loss in mass (%)	Ductility (mm)	Penetration 1/10 mm	% of original	100 °C (cp)	135 °C (cp)
Crushed material	5,01	27	315	60,9	0,842	90	20	74,1	8315	803
Milled	4,61	37	845	56,8	2,229	90	22	50,1	1000	1000

Table 21 : Creep modulus - Van Reenen's Pass rehabilitation project - NITRR tests December 1981

Recycling additive	Sample No	Creep modulus (MPa)
1,6% 150/200 Pen. bitumen + 0,4% Cyclogen	A1	95
	A2	43
	A3	82
2% 150/200 Pen. bitumen	B1	59
	B2	37
	B3	56

Table 22 : Elastic modulus values obtained from Instron fatigue testing - Van Reenen's Pass rehabilitation project - NITRR tests December 1981

Recycling additive	Sample No	E Modulus (MPa)
1,6% 150/200 Pen. bitumen + 0,4% Cyclogen	A1 (top layer)	1310
	A2 (top layer)	1490
	A3 (top layer)	-
	A1 (bottom layer)	1850
	A2 (bottom layer)	1510
	A3 (bottom layer)	1980
2% 150/200 Pen. bitumen	B1 (top layer)	1420
	B2 (top layer)	1370
	B3 (top layer)	-
	B1 (bottom layer)	1630
	B2 (bottom layer)	1610
	B3 (bottom layer)	1960
2% 400 Pen. bitumen	C1	2440
	C2	2610
	C3	2560

Note: Samples A3 (top layer) and B3 (top layer) failed prematurely

the existence of supposedly redundant stockpiles of asphaltic material occupying large areas of the plant site. These stockpiles consisted of unused material accumulated over the years and included many different types of asphaltic mixture. In view of this variability in the reclaimed material, it was planned to limit the use of the resultant mixtures to base layers on secondary roads and to the construction of car parks and other commercial undertakings. The reuse of this material in recycling was viewed as an attractive proposition which would save new material and clear useful space.

I attended the start of the recycling trials in mid-January 1982, and found the first results encouraging, although the level of emission was unsatisfactory. The asphaltic material produced was laid in the yard at the back of Roadmix's main offices at Boksburg so that it could be subjected to trafficking by heavy construction equipment. On a subsequent visit, June 1982, it was observed that the condition of the pavement containing the recycled material was comparable to that of adjoining conventional pavements of similar age.

In June 1982, Roadmix was offering a recycled mixture, conforming to the TPA specification for bituminous basecourse material, at 17,5 per cent less than the price of conventional material.

11.3.3.2 N3, Pietermaritzburg bypass

In January 1980, a 150 metre experimental section was constructed on the Pietermaritzburg bypass, as part of the investigation into alternative measures for its rehabilitation. In the experimental section various types of pavement layers were used, including premix wearing courses containing reclaimed asphaltic material, (with and without recycling agents), lime, emulsion or foamed bitumen-treated dolorite crushed stone bases, and lime-stabilized shale subbases. The Heavy Vehicle Simulator was used to assess the relative performance of these sections.

In a meeting on 23 November 1981 with the DOT (Natal), NPA and NITRR, Scott & de Waal outlined the background investigations and the two favoured alternatives which were based on cold mix and hot mix recycling approaches respectively and consisted of:

Pavement Alternative A

- 30 mm of new continuous graded asphalt wearing course.
- 150 mm of a mixture of existing asphalt and existing crushed stone modified with 2 per cent lime and stabilized with 1½ per cent bitumen emulsion.
- 150 mm of a mixture of existing asphalt and existing crushed stone stabilized with 4 per cent lime.
- 150 mm of existing shale stabilized with 4 per cent lime.
- 150 mm of in-situ shale.

Pavement Alternative B

- 100 mm of recycled asphalt (65/35 reclaimed/new ratio).
- 200 mm of existing crushed stone modified with 2 per cent by mass of slaked road lime.
- 150 mm of existing shale stabilized with 4 per cent lime.
- 150 mm of in-situ shale.

During the ensuing discussions, I supported the initiative to reuse the existing pavement material but emphasized the importance of adopting a proper approach and of exercising caution during the early applications of hot mix recycling in the country. Recent experience in South Africa, (Van Reenen's Pass rehabilitation project) highlighted the difficulties of monitoring and controlling the quality of hot mix recycling material produced on the basis of a broad recipe specification and containing a high pre-determined proportion of reclaimed material selected for economic reasons alone.

Following the above meeting, new trials were undertaken in January 1982, using the recycling plant at Van Reenen's Pass to produce mixes containing higher proportions of virgin aggregate than were previously used and without recycling agents.

On the basis of the new trials, the consequent testing of the resultant mixes, and indications that the proposed pavement had to support E4 class traffic and not E3 as originally envisaged, the following pavement alternatives were selected, in June 1982, for inclusion in the contract documents for the rehabilitation of the bypass:

Pavement Alternative A

- 40 mm semi gap-graded asphalt
- 150 mm of a mixture of existing asphalt (\pm 100 mm) and a combination of existing cement treated and untreated crushed stone (\pm 50 mm) modified with 1 to 2 per cent lime and treated with approximately 1½ per cent of anionic stable grade bitumen emulsion.
- 150 mm of a mixture of existing cement-treated crushed stone and untreated crushed stone stabilized with 3 to 4 per cent lime or milled slag and lime or Portland blast furnace cement (PBFC).
- 150 mm of existing shale or tillite stabilized with approximately 4 per cent lime.
- Approximately 150 mm of in situ shale or tillite shaped and recompacted as necessary.

Pavement Alternative B

- 40 mm semi gap-graded asphalt (containing a maximum of 20 per cent existing asphalt)
- 100 mm recycled continuously graded asphalt (containing a maximum of 45 per cent existing asphalt).
- 150 mm of a mixture of existing cement-treated crushed stone and untreated crushed stone stabilized with approximately 4 to 5 per cent of lime or milled slag and lime or PBFC.
- 150 mm of existing shale or tillite stabilized with approximately 4 per cent lime.
- Approximately 200 mm of in-situ shale or tillite shaped and recompacted as necessary.

The contract specified that all asphalt removed from the existing pavement became the property of the Contractor. With regard to the hot mix recycling process, it was specified that the actual composition of the mix had to be determined by the Contractor and approved by the Engineer, and that the results of tests performed had to comply with:

	Maximum	Minimum
Marshall Stability (kN)	15	7
Marshall Flow (mm)	4	2
Voids in mix (%)	6	3
Stability/Flow ratio (kN/mm)	-	2,5
Ductility of bitumen (mm)	-	800
Residual penetration of bitumen ($\times 10^{-1}$ mm)	45	30

The following tenders were received on 16 July 1982:

	<u>Amount (R)</u>	<u>Contract Period</u>
Grinaker Construction	A 15 854 320,16	24 months
	B 19 101 839,16	24 "
Clifford Harris	A 15 869 429,50	24 "
Carlton Construction	A 13 700 239,30	18 "
	B 17 154 079,30	Not stated
Savage & Lovemore	A 14 981 431,50	" "
	B 17 202 001,50	" "
LTA	A 16 512 697,51	20 months
	B 17 051 010,16	19 "
	C 16 566 643,56	15 "
Labor	A 14 823 815,62	24 "
	B 15 474 303,72	24 "
Peter Faber	A 15 437 780,74	24 "
	B 17 777 237,44	24 "
	C 15 354 893,74	21 "
	D 17 585 544,44	21 "

Due to subsequent lack of funds, the Department of Transport did not award the contract. However, a great deal was learned from this involvement.

It was significant that, although some contractors put forward alternative recycling designs, none tendered a conventional design using only new materials. This showed that recycling offered the cheapest solution.

The five lowest prices in the above list were based on cold mix recycling, whereas the lowest hot mix tender was R1 774 064,42 more expensive than the lowest cold mix tender. Nevertheless, the cold mix alternative would not necessarily have been the most economical option.

In practice, there is little difficulty in achieving specification requirements in hot mix, central-plant operations, since, if the reclaimed material has fairly poor properties, its proportion in the mix can be reduced until the specification requirements are met. However, in cold mix, in situ operations, reclaimed material of poor or variable quality, would present problems in meeting the specification requirements.

On the bypass, carrying E4 traffic, a satisfactory cold mix recycling basecourse could only be obtained if the reclaimed material had satisfactory grading, if variability was low and if an above-average density could be achieved. Taking all factors into account, it was likely that the performance of the hot mix alternatively would have been significantly better than that of the cold mix. The inclusion of the cold mix recycling alternative proved useful in testing the market for a process with considerable potential in situations where the traffic demands on the pavement are lower.

11.3.3.3 Durban City Corporation

Towards the end of 1981, the Durban City Corporation was considering recycling of the road material reclaimed during road maintenance and improvement activities in the city. At that time the Corporation was also planning to set up a new mixing plant site and the relative merits of either buying a new drum mixer equipped for

recycling or re-siting and modifying an existing batch plant were considered.

For these reasons, the Corporation has asked the NITRR for information on methods of reclaiming, stockpiling and re-processing and on the economics of hot mix recycling and are basing their investigations and deliberations on the advice received.

11.3.3.4 Johannesburg City Engineer's Department

In July 1982, taking advantage of the recent availability in South Africa of the Wirtgen cold milling machines, the Johannesburg City Engineer's Department embarked on what is intended to be a yearly programme of milling prior to resurfacing operations. Some 20 000 tons of asphaltic reclaimed material were expected to be produced during 1982.

In order to use this material, they consulted the NITRR regarding the possibility of modifying the City's asphalt plant at Ophirton for hot mix operations. This plant, a Wibau batch plant of 60 tons per hour capacity, is used for the annual production of some 100 000 tons.

Subsequent investigations showed that the area in which the plant operates is too congested to allow easy and economical modifications to be made. The City therefore decided to use the reclaimed material on footways, placing, profiling and compacting the milled material cold and producing a surfacing that is just about acceptable. The future use of rejuvenating agents is being envisaged.

11.4 Rejuvenating

11.4.1 Tar rejuvenator

Since 1978 SATCHEM have promoted the use of a tar-based product designed for surface application and subsequent penetration into a

distressed bituminous wearing course, so that with time it would rejuvenate the existing hard bitumen and, with the aid of trafficking, close up cracks. The rejuvenator consists of a blend of aromatic tar oils and conforms to the specification given in Table 23. In November 1981 the price of the rejuvenator was 44 cents per litre.

The chemical action that takes place during the rejuvenating process is the replacement of oxidized fractions. This helps to redisperse the asphaltene fraction.

According to the manufacturer: "The rejuvenator can be applied at ambient temperatures with the aid of a binder distributor, brushes, watering cans, handspray, or even paint rollers. Application rates will depend on the porosity of the surface being treated and are normally designed to allow not more than six hours to reach surface dry condition. Material can be re-applied intermittently until sufficient softening is obtained. Cracks in the surface allow concentration of oils right there where it is needed and the oils can migrate from cracks into the layer. As the plasticizing oils are of a low volatile nature exhibiting high boiling points, the softening effects can take months to work through a few centimetres. When sufficient softening has however been obtained, the action of traffic on this surface and with the help of heavy pneumatic rollers, are able to close up cracks to the extent that water will not penetrate the layer. The pavement acquires a fresh black colour and better flexibility".

Experience has shown that inappropriately high application rates can lead to serious problems. Moreover, to date, use of the rejuvenator has not proved effective when the degree of cracking is serious.

Tar rejuvenator has been used in the following projects, inter alia:

- o Jan Smuts Airport - July 1978

This was the first application of the rejuvenator in the

Table 23 : Specification for tar rejuvenator

Property	Specification	Test method
Relative Density at 25 °C g/ml min	1,08	ASTM D287
Water content, % (m/m) max	2,0	ASTM D95
<u>Distillation,</u> * Fractions % (m/m)		ASTM D86
IBP °C	180	
180 °C	1,0 max	
190 °C	2,0 max	
200 °C	3,0 max	
210 °C	4,0 max	
220 °C	5,0 max	
230 °C	6,0 max	
240 °C	10,0 max	
250 °C	2 - 18	
260 °C	5 - 30	
270 °C	15 - 40	
280 °C	20 - 45	
290 °C	25 - 55	
300 °C	30 - 60	
Relative Density at 25 °C/25 °C of distillate to 300 °C, g/ml min	1,023	ASTM D287
<u>Viscosity</u>		
Engler at 40 °C	2,5	ASTM D1665
Saybolt Furol at 50 °C, of residue above 300 °C, max	100	ASTM D88
Flash point, COC, °C min	93	ASTM D92

*The volume of sample for this test is 200 ml and the flask is specified in ASTM E133 (Flask D).

country and was basically done on a trial basis of 30 000 m² of a taxiway with a surfacing of 40 mm continuously graded asphalt on a stabilized basecourse. Following an application at a rate of 0,4 l/m² at 60 to 65 °C and at a surface temperature of 35 °C, some of the rejuvenator penetrated within approximately one hour. However, there were problems associated with:

- too high an application rate;
- bitumen contamination of the rejuvenator due to a dirty distributor; and
- the spray overlapping at the sides of adjoining sections resulting in a certain amount of contaminated rejuvenator flowing over the surface.

Attempts to remedy the situation included the spraying of sand over the whole area.

o N4, near Witbank - November 1978

A small-scale trial was done on 10 m sections of the eastbound fast lane, on extensively cracked gap-graded asphalt surfacing. The application rates ranged between 0,2 and 0,4 l/m².

Although no compaction was attempted, one week after the application the appearance of the surface improved. The cracks were not only filled with rejuvenator but had actually closed up to some extent. No major differences were apparent between the sections on which different application rates had been used, although the appearance of the surface was markedly better in the wheelpaths, highlighting the importance of compacting after applications of rejuvenator.

o Louis Botha Airport - March 1979

The purpose was to treat fine cracks on the runways. Some 14 000 m² were treated at application rates of about 0,4 l/m² during the first night. However, by morning only a very small amount of the rejuvenator had penetrated and as the situation was further aggravated by rain, cement was applied to the surface to allow the movement of aeroplanes. Further work was stopped. Subsequent analysis of the rejuvenator showed it to be contaminated with asphaltic material.

- o Wonderboom Airport (Pretoria) - October 1979
Rejuvenator was applied to 84 000 m² of a badly cracked runway. Although not an ideal treatment considering the extent of the cracking, rejuvenating was considered the only economically acceptable remedial measure. Some of the cracks remained open despite further selective applications of rejuvenator.

The manufacturer has serious misgivings about the validity of the control and monitoring procedures used in tar rejuvenator trials to date. Reportedly, problems have been experienced with regard to the correct use of the product because of the different viewpoints of the supplier and users. I believe that independently monitored trials will prove of great benefit in fully evaluating the rejuvenator and establishing the following:

- type of surfacing for which the rejuvenator is the appropriate treatment;
- optimum application time for curing or prevention of cracks; and
- best application procedures to prevent subsequent problems such as poor skid resistance.

11.4.2 Mobil Sol 30

In 1981, a Mobil recycling additive, Mobil Sol 30, was used on the Plattekloof reclamation and recycling project in the Cape Province.

Preliminary laboratory testing by Mobil indicated that the binder in the reclaimed material could be restored from 23 Pen at 25 °C to 60/70 Pen by adding Mobil Sol 30 in a blend with a conventional 150/200 Pen bitumen. The blend, 36 per cent of the existing binder, was made up in a ratio 15 per cent Mobil Sol 30 to 85 per cent 150/200 Pen bitumen.

The road authority reported that the resultant mix appeared satisfactory.

11.4.3 Reclamite and Cyclogen

Protea Chemical Services are marketing the Witco Reclamite and Cyclogen products in South Africa. To date the use of these additives in this country has been very limited and inconclusive.

Reclamite is a surface-applied asphalt rejuvenator agent. According to the manufacturers: ".... It is fine-particle size, cationic, oil-in-water emulsion of a selected blend of maltene components, tailored to facilitate and assure the desired mode of incorporation of the added maltene fractions into asphalt pavements". Its significant properties are summarized below:

Intrinsic properties of maltenes emulsion:

Average particle size, 1:4 dilution (μ)	1,8
Polarity, by electrophoresis	Cationic
Stability, in 1:7 dilution*	---
Maltenes content (%)	60 \pm 3

Typical properties of maltenes:

Relative Density	0,95
Viscosity at 210 °F, SSU	80 - 90
Loss on heating, 3 h at 325 °F (%)	1 max
Saturated Hydrocarbons, D-2006	24 - 28

Reclamite was used on one of the experimental sections in the preliminary trials for the rehabilitation of the Pietermaritzburg bypass. However, this trial was invalidated by the incorrect use of reclaimed material freshly treated with Reclamite in hot mix recycling. The price of reclamite in September 1982 was R1,20 per litre.

The Cyclogen series are one-component recycling agents, used as the sole additive in recycling. The product is available as Cyclogen L, M, H, 22 and 47, for hot mix recycling, and in three emulsified versions, Cyclogen LE, ME and HE, for cold mix recycling.

*No irreversible stratification; no coagulation on contact with sea water

Cyclogen was used on a trial section on the Van Reenen's Pass recycling project, when 0,4 per cent of this product was added to 1,6 per cent of conventional 150/200 Pen bitumen to form the modifier. This small-scale trial proved inconclusive.

11.4.4 RJ0 2 rejuvenating oil

Shell produced a recycling additive early in 1982. RJ0 2 is an aromatic oil designed to be used in ratios of 20 to 26 per cent by mass with new bitumen to raise the penetration of existing bitumen from about 20 to 80/100. It costs about one and a half times more than conventional binder. RJ0 2 has not as yet been used in South Africa.

11.4.5 Spramex RJ 55 and RJ 110

In November 1982 Shell introduced the rejuvenator Spramex RJ 55 and the hot mix recycling binder Spramex RJ 110. Both these products have been recently developed and marketed in West Germany.

11.5 Selected bibliography

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12. PAVEMENT MATERIAL RECYCLING RESEARCH IN THE NITRR

- 12.1 Background
- 12.2 Scope and objectives of research programme
 - 12.2.1 Surfacing rejuvenators
 - 12.2.2 Hot mix recycling
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12.1 Background

Since 1981 the general growth of interest, in the RSA, in the recycling of pavement materials has warranted increasing involvement by the NITRR in this subject and in particular in hot mix recycling and in-situ rejuvenating methods. When I joined the NITRR, in October 1981, the expertise I had gained during my secondment to Colas and the undertaking of the project sponsored by the UK Department of Transport, Shell International Petroleum Company, and Colas, added considerable impetus to the Institute's activities.

Until the middle of 1982, these activities involved monitoring of recycling operations and developments, and advising road authorities, consultants, and the industry on various aspects of pavement material recycling. During this period it became increasingly apparent that it would be appropriate for the NITRR to focus attention on research aimed at resolving at least some of the outstanding problems in the field of pavement material recycling, e.g. life-cycle comparabilities and mix efficiency. This opinion was reinforced by requests from other organisations, including the Department of Transport who requested that, in view of the importance of recycling of bituminous and other pavement materials, this topic be treated as a research project with special priority.

12.2 Scope and objectives of research programme

In the Republic of South Africa, most developments and current activities in pavement material recycling involve the use of surfacing rejuvenators and hot mix recycling operations and so, naturally, research directed at solving problems in these areas is likely to prove the most rewarding to the South African road industry.

12.2.1 Surfacing rejuvenators

The use of surface rejuvenators has been put forward as a solution to problems such as premature cracking, which are often associated

with the ageing of binder in asphalt surfacings.

As it is currently defined and understood premature cracking of surfacings is a distress phenomenon not necessarily associated with or caused by conditions in the underlying layers. In other words, the distress is supposedly non-structural as far as the rest of the pavement structure is concerned, and thus not associated with vehicular traffic. In fact, it appears at first glance that the less the traffic, the more severe the problem. An appropriate definition of the distress could well be: "Non-traffic-associated crack initiation on the surface of asphalt wearing courses and possible propagation to structural distress".

Although this distress is not limited to any particular type of asphalt, in the RSA it is most commonly found in gap-graded surfacings.

Gap-graded surfacings were first used in the United Kingdom and were strictly based on a recipe-type specification. This has changed recently and mix design procedures are now used for the more heavily trafficked roads. The greatest advantage of these mixes is their durability even under the most severe traffic conditions, and this fact has prompted South African engineers to use these mixes in surfacings, levelling courses and bases.

The gap-graded mix is characterized by the fact that its stability is derived from the mortar produced by the binder-sand-filler mixture. This in turn depends mainly on the viscosity of the bitumen and therefore fairly hard grades of bitumen are used for gap-graded asphalt. In South Africa the design of gap-graded asphalt was developed using Marshall criteria and the specifications had to be modified somewhat to accommodate locally available aggregate, sands and fillers. These modifications have mostly concerned adjustments to grading, binder/filler ratio, stability/flow ratio and permeability.

Gap-graded asphalt bases and surfacings have been generally used in rehabilitation and in new airport and road construction projects in

the RSA since about 1970. Mixes were designed to provide asphalt with greater fatigue resistance, although the designs also improved skid resistance through the addition of precoated chippings. However, subsequent monitoring indicated that the surfacings on some of these new gap-graded asphalt projects have tended to start cracking as early as four years after construction. The most prominent characteristic of the distress is that the cracks start at the top of the surfacing and propagate downwards.

Towards the end of 1981, the Transvaal Provincial Administration, viewing the problem with increasing concern, appointed consultants to investigate the cause of distress. The NITRR is participating in this study and is represented on its steering committee. A condition survey on some 800 km of asphalt surfaced roads (about 85 per cent of the total asphalt-surfaced network in the Province) showed that 30 per cent exhibited cracking of some sort.

Premature cracking is not confined to the Transvaal and it occurs, albeit to varying extents, throughout the country. In July 1982, I participated in extensive inspection tours of road sections in the Cape Province, Orange Free State and Natal, which showed that this type of distress was not uncommon. The identification of the cause of premature cracking and the establishment of preventive and curative measures form part of a current NITRR research project. Curative measures may well include applications of surfacing rejuvenators.

A number of **surfacing rejuvenators** are marketed currently and pressure on road authorities and consultants to use these products more extensively is increasing. However, I believe that before a surfacing rejuvenator is accepted for general use its field of applicability and economic effectiveness have to be demonstrated and the best method of using it must be determined. Accordingly, the following need to be established:

- applicability to particular asphalt mixture designs, to the current characteristics of the binder in a given existing surfacing, and to type and extent of the distress which the

rejuvenator is used to remedy;

- optimum methods, for particular situations, with regard to rates of rejuvenator application, rolling techniques and timing, and need for heating and scarifying the surfacing before applying the rejuvenator;
- confidence that the skid resistance (if the treated layer continues to serve as a surfacing) and the stability of the mixture will not be adversely affected by the application of the rejuvenator;
- need to surface-treat or overlay the rejuvenated surfacing;
- economic effectiveness of rejuvenating compared to that of conventional options.

The scope of the proposed research on rejuvenators embraces the above needs.

12.2.2 Hot mix recycling

In Section 1.3 the current relative obscurity of associated cost savings and the concern regarding the quality of the product were given as two of the main factors restraining the growth of recycling. When the cost savings model for hot mix recycling operations, Section 8.3 becomes generally available it may well give a positive reason for recycling involvement. In the example of cost saving calculations, given in Section 8.3.12, typical rural South African conditions and values were used to show a potential saving of 20,5 per cent of the average cost of conventional asphaltic mixtures for recycling with a 40:60 ratio of reclaimed to new material. The cost model, which has been computerized, was used to undertake an economic analysis by a team comprising staff members of both the NITRR and the Department of Transport. This analysis showed that if hot mix recycling is used in the 17 rehabilitation projects suitable for recycling in the Department's five-year forward programme, savings of R6,8 m can be expected. These results may encourage the Department to allow the industry to tender recycling alternatives. •

With regard to the quality of hot mix recycling products, a research programme has been formulated to examine the

- mix efficiency between old hardened and new bitumens, and/or recycling agents,
- recycling agents and their short and long-term effects on asphalt mixtures,
- penetration and viscosity parameters, e.g. optimum values in recycled mixtures, comparable ageing characteristics of binder in conventional and recycled mixtures,
- comparable life-cycles of conventional and recycled mixtures.

12.2.3 Current research activities

The preceding sections have identified two areas into which research could be usefully directed. Research activities have been initiated in each of these areas. The first concerns an experiment in which various rejuvenators are being tested in a field trial. The second concerns the development, construction, and use of a specialized mini recycling plant, which has been named the "Servacycler". The following sections describe these activities in more detail.

12.3 Surfacing rehabilitation trials

In September 1982, following a series of preliminary discussions between the NITRR and the Department of Transport, the Transvaal Roads Department, consultants, and sectors of the road industry producing, marketing or using rejuvenators and other special surface treatments (such as rubberized bitumen, tar or emulsion), it was decided to proceed with road trials aimed at determining appropriate rehabilitation measures for prematurely cracked asphalt surfacings. The trials were scheduled for April/May 1983 and are to be undertaken on sections of the N3, Heidelberg to Alberton.

The Heidelberg-to-Alberton section of the national route N3 was constructed in the early Seventies and consists of two carriageways,

each with two 3,66 metre lanes, a fast shoulder of 1,22 metres and a slow shoulder of 2,44 metres. The gap-graded wearing course is exhibiting premature cracking with the distress being more pronounced in the shoulders and fast lanes.

Although the 1983 trials will have to be tailored to the conditions and type of surfacing on the N3, they have a much wider application than the determination of the optimum rehabilitation option for this road. In view of the extent of the cracking problem, other road authorities and consultants are to be invited to observe the trials. In fact, it is envisaged that an inspection panel will be formed to undertake initial and subsequent inspections.

Trial sections are to be left untouched for a number of years to allow adequate monitoring, and where possible particular treatments are to be used on both 'bad' and 'better' sections of the N3. Final details are still to be decided but treatments are likely to include:

- heating and scarifying the surfacing, spraying rejuvenator, compacting and single sealing;
- heating and scarifying the surfacing, spraying rejuvenator, compacting and overlaying;
- spraying rejuvenator on shoulders only and rolling after a period of time (about one month);
- applying bitumen-rubber;
- applying tar-rubber;
- single sealing;
- overlaying;
- applying diluted emulsion, followed by very fine slurry sealing and single sealing;
- heating and scarifying the surfacing, compacting and single sealing;
- heating and scarifying the surfacing, compacting and overlaying.

Sections 200 metres long (full width of the carriageway) are to be used for all the treatments except those involving heating and scarification equipment. The latter will be restricted to one

metre sections due to the limited availability of such equipment in the RSA, where only a one-metre wide machine is available.

With regard to surfacing rejuvenators, three products will be tried. These are:

- a tar rejuvenator, marketed by Suprachem (previously Satchem);
- reclamite, a Witco product marketed in the RSA by Protea Chemical Services;
- RJ 55, introduced in the RSA in October 1982 by Shell.

The organisation and control of the trials will be undertaken by the NITRR.

12.4 Development of the Servacycler

While drawing up the programme of research into the quality of hot mix recycling products, I realised that, in view of our limited access to the small number of commercial recycling plants in the RSA, the NITRR needed to acquire or develop a recycling plant.

The Institute has a Wibau batch-plant at the Silverton test site which can be modified for recycling operations. I considered this option and decided that as the limitations on the proportions of reclaimed material, imposed by the use of a batch-plant for recycling, would have substantially restricted the scope of the research programme, it should be better to opt for a drum-mixer operation. However, in taking this decision, I bore in mind that the Silverton plant could be modified at a future date and be used for undertaking useful supplementary research.

In considering the relative merits of particular drum-mixer types, I realised that without exception, all currently operational or commercially available recycling drum mixers were plant which had been developed to produce conventional asphaltic mixes and which had been modified, during or after their manufacture, to cope with recycling as a secondary activity. Therefore, it was likely that a drum mixer designed specifically for recycling would have

advantages over modified conventional plant. I expected that these advantages would result from possible improvements in the control of operations such as heating and mixing, and the protection of reclaimed material from the effect of direct heating. With this in mind I considered various options, which are discussed below.

12.4.1 Dual-zone screw-fed, single-drum, recycling plant

This design, shown in Figure 20, had the following special characteristics:

- screw-feed for the reclaimed material which entered the drum from the discharge end, at an adjustable position;
- circular flame-shield attached to the screw-feed mechanism;
- single-speed drum;
- particle veil, mixing and retention times in each zone dependent on the configurations of the flights and the tilt (adjustable) of the drum.

Although an attractive, simple and cheap design, this possibility was abandoned mainly due to:

- the need for cumbersome adjustments to the position of the reclaimed material's entry point and to the flight configurations to enable the effective use of other ratios of new to reclaimed material and to take other variables, e.g. moisture, into account;
- fears of possible jamming within the screw-feed mechanism during operation;
- lack of obvious advantages of this design over modified conventional drum-mixers.

12.4.2 Tandem-drum recycling plant

The design, shown in Figure 21, had the following special characteristics:

- two drums in tandem with individually controlled rotational speeds
- variable tilt to the drums

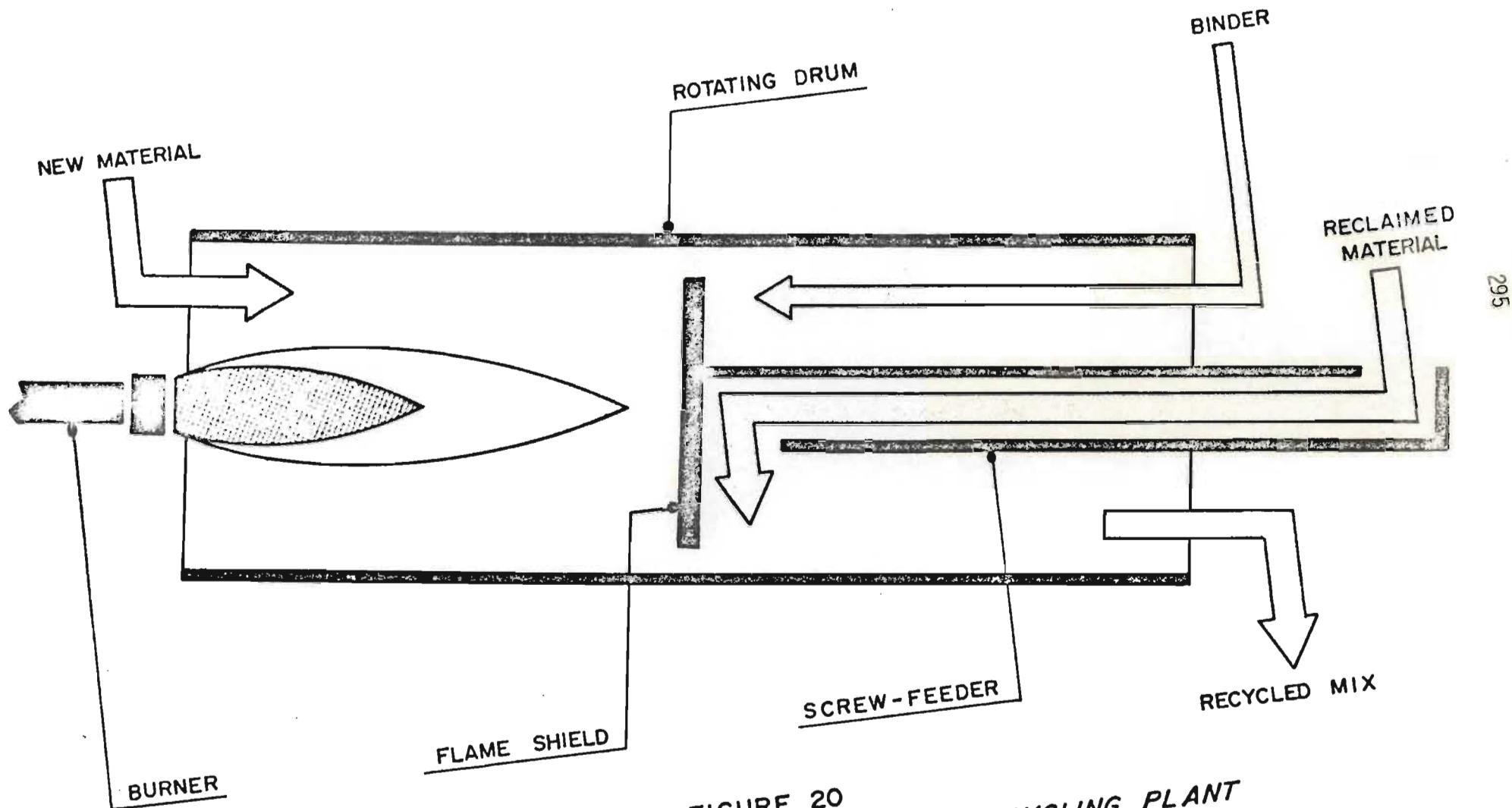


FIGURE 20
DUAL-ZONE, SCREW-FED, SINGLE-DRUM, RECYCLING PLANT

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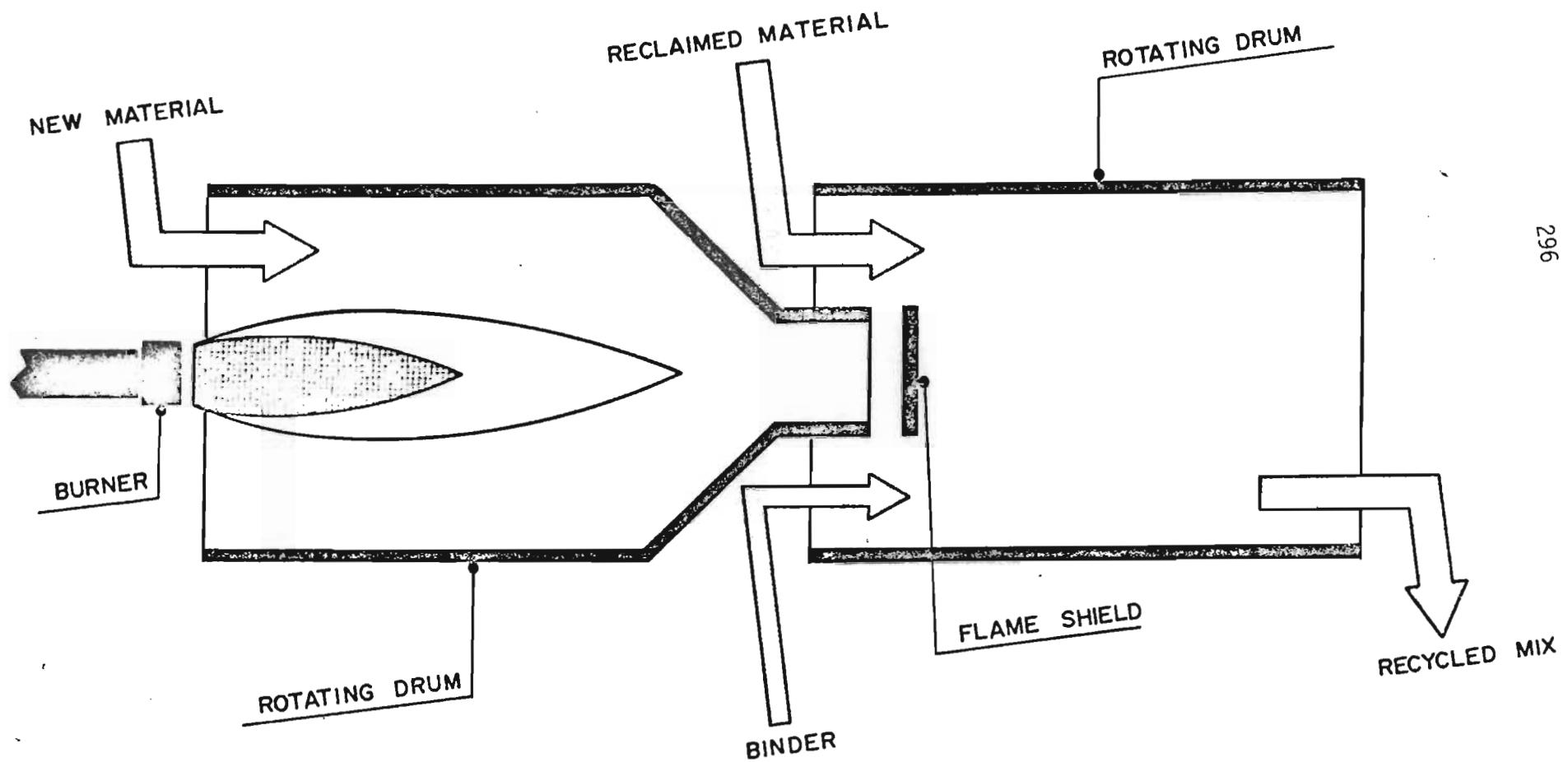


FIGURE 21
TANDEM-DRUM RECYCLING PLANT

- induced hot gases flowing through the system
- circular flame-shield attached to the heater drum.

The design made it possible to control the heating and mixing operations independently. It also obviated the need for adjustments to the flight configurations to enable the plant to be used effectively with various recycling ratios. However, the scale of the envisaged recycling plant made it difficult to provide adequate space for the passage of the superheated new material, and the introduction of the reclaimed material and new binder at the interface between the drums.

12.4.3 Servacycler

This design, shown in Figure 22, has all the advantages of the tandem-drum design while providing ample space for the introduction of reclaimed material and new binder into the mixing drum. A mini recycling plant (production capacity about 1,5 tons per hour) has been manufactured and is situated at the NITRR's Silverton test site. This recycling plant has become known as the Servacycler. It has the following special characteristics:

- two drums in tandem with individually controlled rotational speeds
- variable tilt to the drums
- induced hot gases flowing through the system.

The new material is fed into the heater drum, at the burner end, where it is superheated before it is discharged into the mixer drum. The retention time in the heater and the particles' flight and resultant veils are controlled by the rotational speed and tilt of the heater drum. The reclaimed material is fed into the mixer drum where it is heated through heat transfer from the superheated new material. New binder is introduced in the mixer. The mixing time and efficiency of heat transfer and mixing are controlled by the rotational speed and tilt of the mixer drum.

The development of this plant, jointly undertaken by the National

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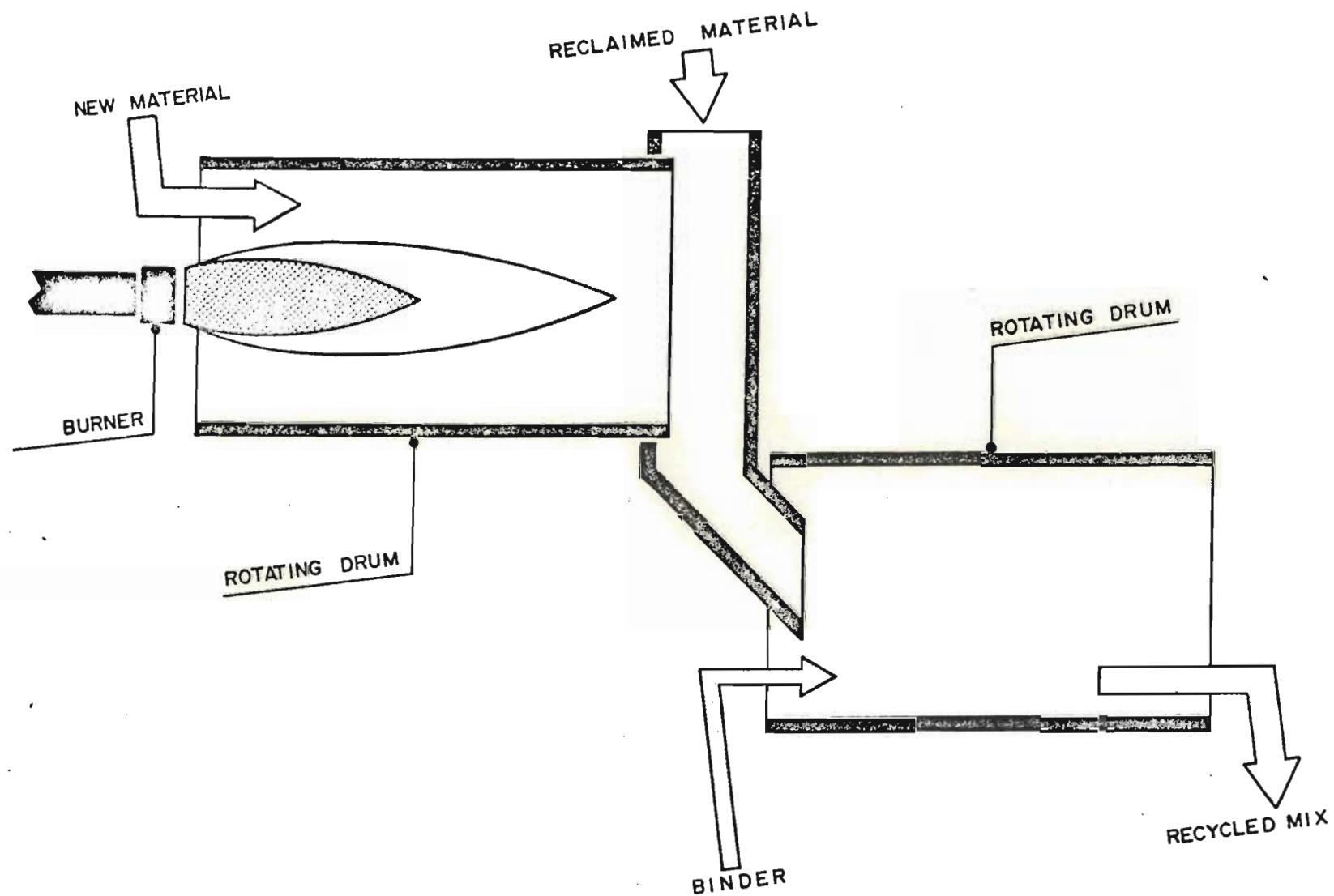
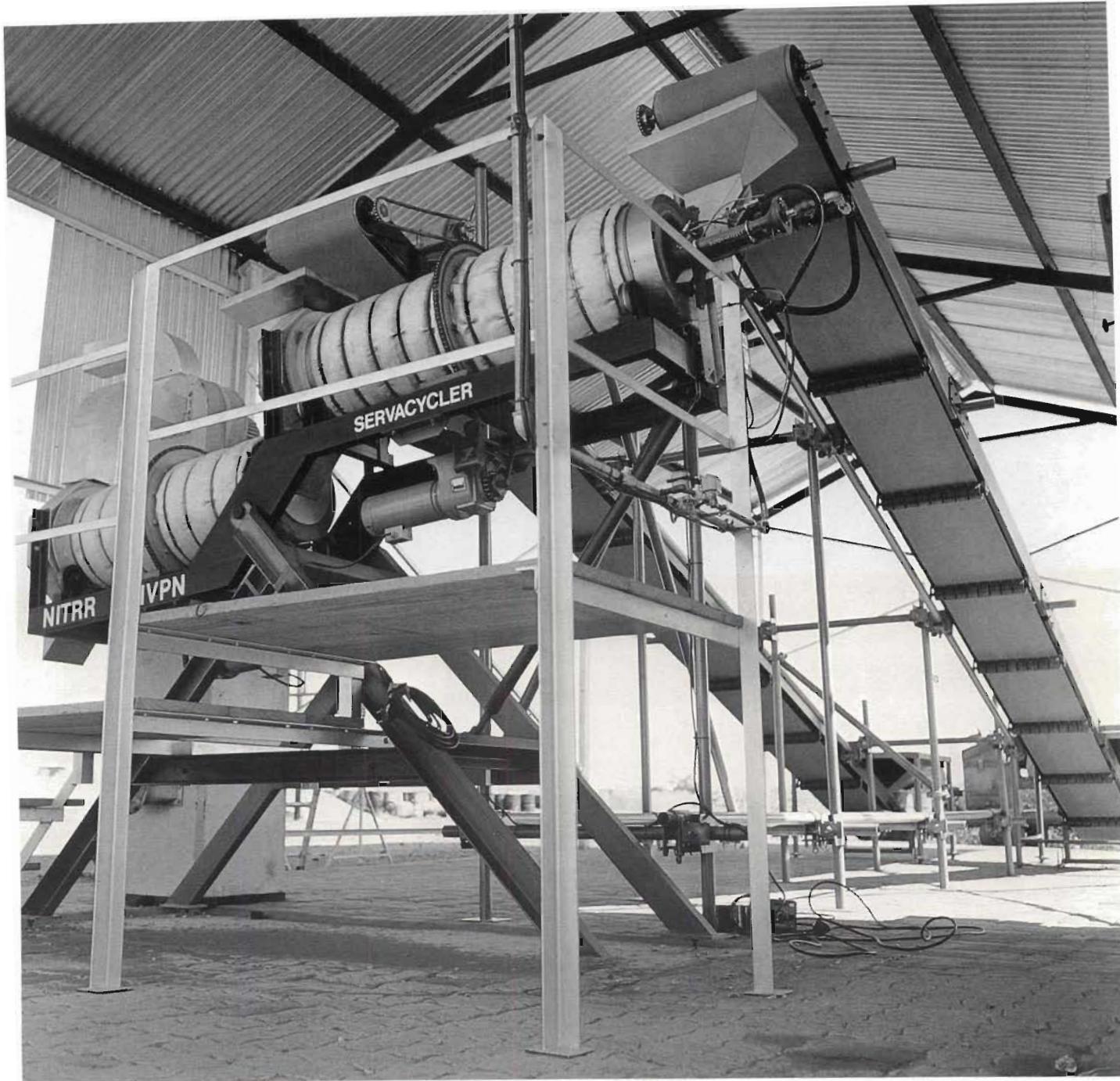


FIGURE 2
DIAGRAMMATIC LAYOUT OF SERVACYCLER



THE SERVACYCLER

The mini-recycling plant at the Silverton test-site of the National Institute for Transport and Road Research.

Institute for Transport and Road Research and the Technical Services Department of the CSIR, has aroused considerable interest among road authorities, consultants and the asphalt industry as well as among visitors involved in recycling. The Servacycler became operational early in 1983 and a series of demonstrations was given, including a presentation on 28 February which resulted in nation-wide press, technical journal, radio and television coverage.

Although the Servacycler has been designed and manufactured as a research tool, its advantages as a commercial-scale recycling plant in enabling more effective use to be made of reclaimed material were recognised. Accordingly, the NITRR lodged patent applications in 1982 and the first commercial-scale Servacycler should be operational in 1984.

It should be noted that the Servacycler can be used to produce traditional hot mix material. In fact it has advantages over conventional drum mixers as it undertakes the heating and mixing operations separately, providing full control over each operation. Furthermore the bitumen is introduced in the mixing drum and is thereby protected from direct exposure to the flame of the burner.

12.5 Calibration of the Servacycler

Before the Servacycler can be used to produce any particular mix, its feeding system has to be calibrated to allow adequate control of the rates of feed of reclaimed and new material, and added binder. In addition, the control settings of the plant have to be adjusted so that an adequately mixed material is produced at the required mix temperature.

The plant control settings involved in the calibration are:

- speeds of the reclaimed and new material conveyors,
- heights of the openings of the storage bins over the conveyor belts,
- intensity of the storage bins' vibrators,

- output rate of the new binder supply mechanism, and
- output of binder heater.

The adjustments involve:

- tilt and rotational speeds of the heater and mixer drums,
- output of the burner, and
- flow rate of combustion gases induced by means of an extractor fan.

In general these settings depend on:

- recycling ratio of new to reclaimed material,
- type and blend of the new material,
- grading, and binder content and characteristics of the reclaimed material,
- penetration grade of the added binder (bitumen), and
- specified temperature of resultant mix.

12.5.1 New and reclaimed material feed control

The rate of feed of material into the heater or mixer drum of the Servacycler depends on the:

- type and blend of material (to date the new material has been pre-mixed using a pan mixer),
- moisture content of the material,
- vibration intensity of the storage bin,
- height of the storage bin's opening over the conveyor belt, and
- speed of the conveyor.

In a rate of feed calibration, for a given material, the vibration intensity of the storage bin and the height of the bin opening above the conveyor belt are held constant at values (about 90 per cent of vibrator capacity and 35 mm height) which ensure free flow of material from the storage bin. Consequently, at any moisture content, a linear relation between conveyor belt speed and rate of feed can be established, as in Figure 23.

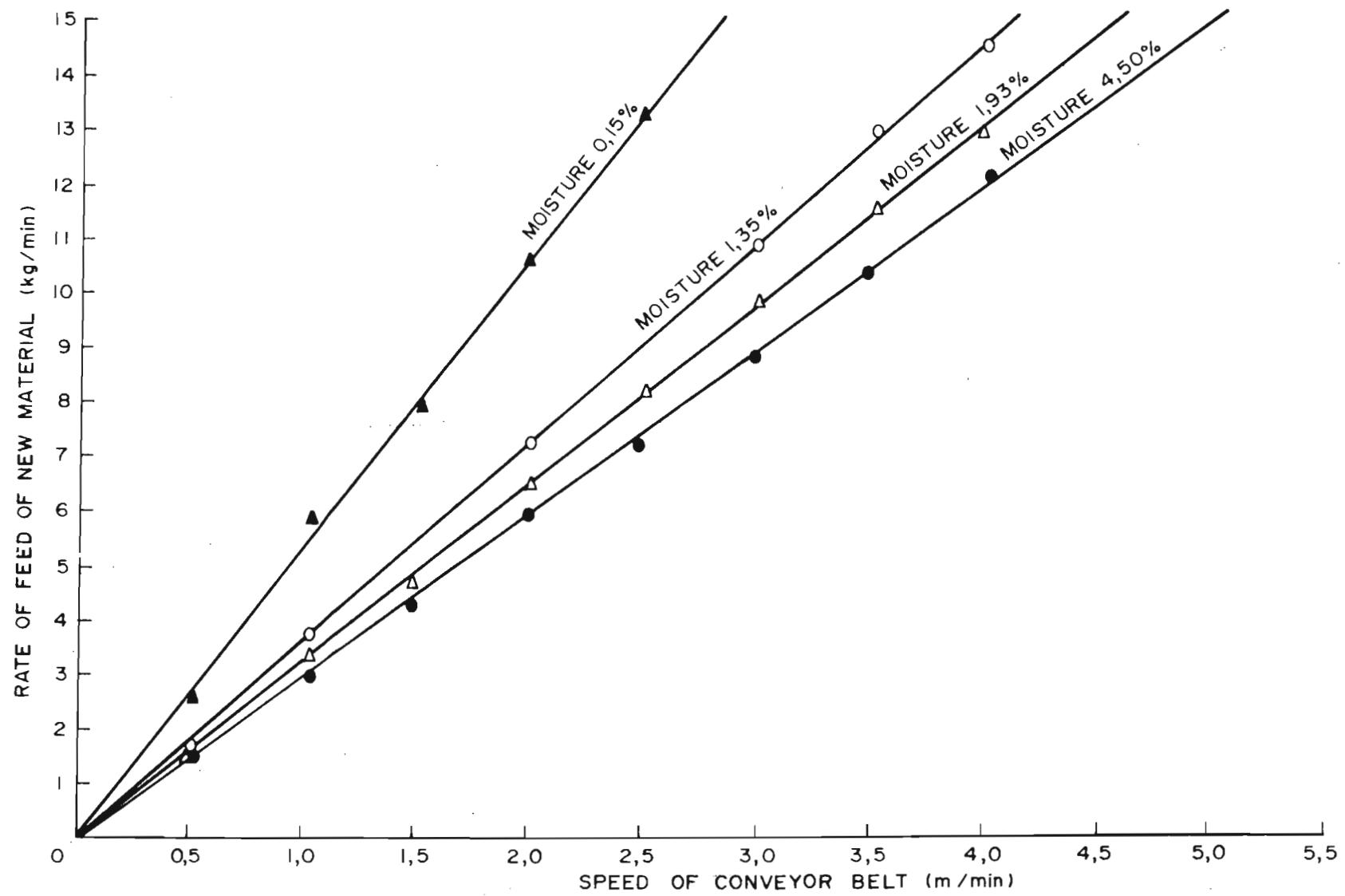


FIGURE 23

CONVEYOR SPEED - RATE OF FEED RELATIONS AT DIFFERENT MOISTURE CONTENTS

As shown in this Figure, moisture content has an important bearing on the rate of feed of new material. In addition to its direct influence on the material weight-volume relationship, moisture content affects the shape of the material stack on the conveyor belt. (Wet material stacks neatly on the conveyor belt, whereas dryer material spreads and thereby increases the amount deposited on the belt and hence the rate of feed.) Therefore the moisture content must be known to ensure effective control over the rate of feed. For this purpose a microwave oven was acquired and is used to dry material samples quickly (eight minutes for a 500 g sample). The moisture content is then calculated and the appropriate conveyor speed for the required rate of feed is determined using a relation such as the one shown in Figure 24 (for a rate of feed of 15 kg/min).

The results shown in Figures 23 and 24 are conveniently expressed by the following equation:

$$S = 0,197 R e^{0,144M}$$

where S = conveyor belt speed

 R = rate of feed of material

 M = moisture content

12.5.2 New binder feed control

Penetration grade bitumens are preheated to specified temperatures before they are introduced into the mixing drum. The binder heater has to be calibrated to determine the setting and time required to heat a given quantity and type of bitumen to the required temperature, and the setting which will then maintain this temperature.

The rate of feed of bitumen into the mixing drum is controlled by the setting of the metering valve. (The pump output is kept at a constant pressure and flow, which can accommodate the maximum supply requirements, i.e. the maximum metering valve setting.) This setting has to be determined for different penetration grade bitumens. The shape of the nozzle which produces a spray (to facilitate the coating and mixing) is determined by the rate of flow and type of bitumen.

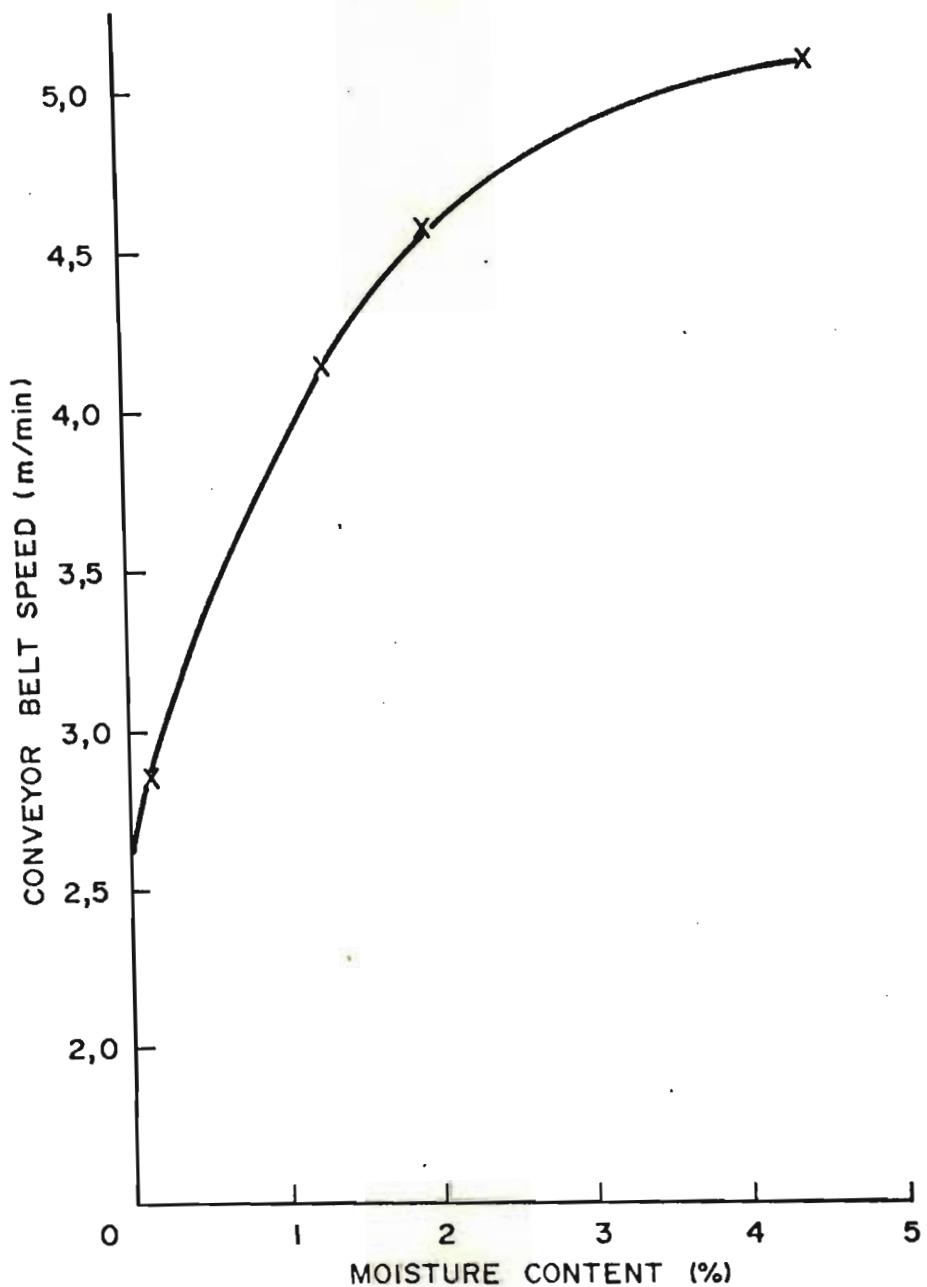


FIGURE 24

MOISTURE CONTENT - CONVEYOR SPEED
RELATIONSHIP AT A RATE OF FEED OF
15 kg / min

12.5.3 Temperature and mixing controls

An asphalt plant must be able to operate at its design capacity and produce an adequately mixed material at the required temperature. Furthermore its operational characteristics must be such as to ensure that at no stage are aggregate or binder subjected to damaging temperatures.

The throughput of the Servacycler is a function of the size of its drums and their tilt and rotational speeds. When the mini recycling plant became operational, its design capacity (1,5 tons per hour) was confirmed for a range of ratios of new to reclaimed material.

The available controls of the heater drum are the settings of the burner, tilt and rotational speed of the drum, and combustion gases extractor fan. The setting of the burner depends on the throughput, the moisture content of the new material and the recycling ratio. The tilt controls the flow of material through the drum. The rotational speed ensures an adequate material veil. The setting of the extractor fan is primarily based on the operational needs of the burner. The settings of these controls are interrelated.

Heat transfer and mixing take place in the mixer drum. These operations are controlled by the tilt and rotational speed of this drum.

To date, the need to adjust the above settings during a recycling operation has been determined by observing the temperature and mix adequacy of the resultant material. One can tell from the temperature whether it is necessary to adjust the control settings of the heater drum, and from the mix adequacy whether the mixer drum controls need to be adjusted.

However the interrelationships between the various controls still need to be fully established to enable efficient adjustments to be made to their settings. When this has been achieved, sensors will

be added which will provide accurate and readily available feedback for making these adjustments.

The design of the Servacycler provides much greater control over temperatures and mixing than has hitherto been possible in drum mixer recycling. The results of the on-going study into the operational characteristics of the mini recycling plant will be applied to commercial-scale plant to provide procedures for establishing the optimum control settings for particular recycling ratios and types of material.

12.6 Mix design for hot mix recycling

In hot mix recycling the specified requirements for a selected mix have to be met by a blend of reclaimed and new materials. The following need to be determined:

- the optimum (most economical) ratio of reclaimed to new material,
- the grading of the new aggregate, and
- the quantity and penetration grade of the new bitumen.

12.6.1 Determination of the recycling ratio and grading of new material

Analysis of the reclaimed material will determine its grading. This is used to calculate the maximum ratio of reclaimed material that can be used in a blend with new material to meet the grading requirements of the selected mix.

12.6.2 Determination of quantity and type of new bitumen

The percentage of new binder (B_N) required in the resultant mix, as a first approximation, is derived by:

$$B_N = B_F - W(B_R \times \frac{R}{T})$$

where B_F = percentage of binder in resultant mix

B_R = percentage of binder in reclaimed mix

$\frac{R}{T}$ = proportion of reclaimed material in resultant mix

W = wastage factor.

B_R is obtained by analysis of the reclaimed material,

B_F is determined by the mix design,

$\frac{R}{T}$ depends on reclaimed material availability and grading considerations, and

W depends on construction procedures (in general about a third of the binder in a bituminous pavement layer is wasted).

For given values of the design binder penetration, the percentage of new binder and the penetration of the binder in a reclaimed material, the required penetration of the new binder can be determined using a nomograph such as in Figure 25.

In the three examples illustrated in this Figure a design 50-60 pen grade binder and a 20 pen reclaimed material binder are used. The percentages of new binder in the asphalt mix are 90, 50 and 10 in each case.

In the first case a 60-70 penetration grade binder is required, in the second a 150 - 200 penetration grade binder, and in the third a recycling additive is needed.

12.7 First use of the Servacycler

The Servacycler was first used to produce a gap graded mix containing 30 per cent of a reclaimed material which had been milled during resurfacing operations in Johannesburg. Samples of the milled material were tested to determine its grading and a 4,8 per cent bitumen content (average recovered penetration 16) was found.

Table 24 shows the grading of the reclaimed material, the design envelope, the grading of the new aggregate, the designed blend, and the grading of the resultant mix. The grading of the resultant mix shows that the plant provides adequate control of the feeding and mixing operations.

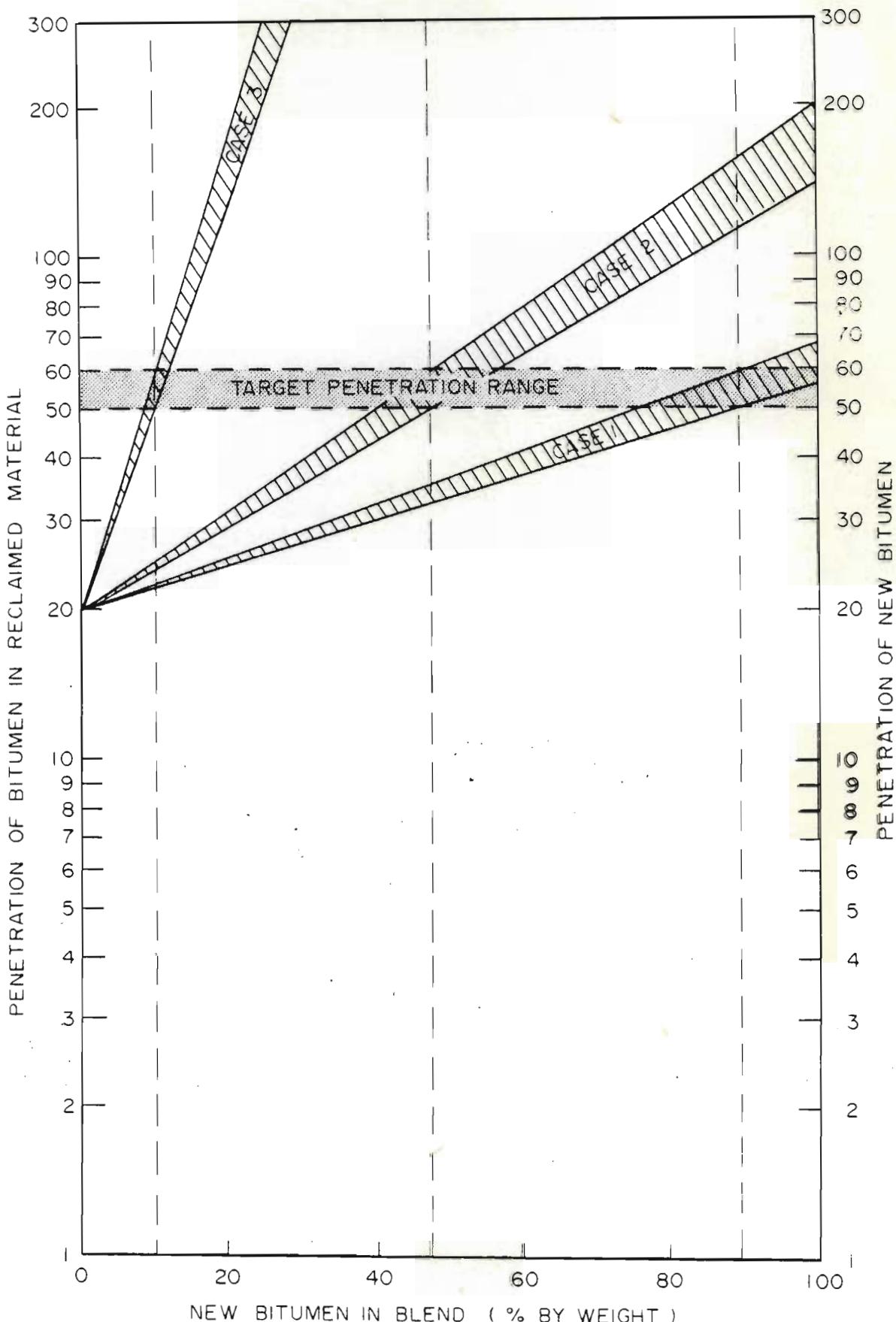


FIGURE 25

USE OF NOMOGRAPH FOR DETERMINING THE REQUIRED

Table 24 : Material gradings in the first operation with the Servacycler

Sieve size (mm)	Cumulative percentage by mass passing sieve				
	Reclaimed material	Design envelope	New material	Designed blend	Resultant mix
19,0	100	100 100	100	100	100
13,2	91,7	100 75	87,8	89	90,5
9,5	68,3	90 70	86,4	81	77,2
6,7	55,4	80 65	80,5	73	71,7
4,75	48,6	70 60	72,0	65	68,4
2,36	41,0	63 53	61,0	55	58,9
1,18	37,8	62,5 52	55,2	50	51,9
0,600	36,0	62 45	50,3	46	49,8
0,300	30,2	55 35	47,1	42	41,3
0,150	19,3	35 15	40,3	34	20,2
0,075	10,9	12 5	5,3	7	6,3

The new material, consisting of 19 mm stone, 9,5 mm stone, crusher dust and mine sand, was premixed and fed at a moisture content of 3 per cent.

The operation was pollution-free and the resultant mix was discharged at a temperature of 150 °C. Its properties are compared below against the design requirements.

Property	Design requirement	Value obtained
Binder content (% by mass)	7	7,3
Penetration (at 25 °C)	35 - 40	44
Air voids (%)	2 - 12	6,5
Marshall Stability (kN)	3 - 12,5	3,5
Marshall Flow (mm)	2 - 6	2,7

The added binder was a 150 - 200 penetration grade bitumen and comprised 5,8 per cent by mass of the resultant material. This bitumen was selected to allow the use of a wide range of recycling ratios. However, it was obviously too soft for the first trial and

this is reflected in the values achieved for penetration, Marshall Stability and Flow. Suitable bitumen penetration grades would have been either 80 - 100 or 60 - 70 depending on the target penetration value. These grades will be used in future trials for recycling ratios of approximately 70 : 30, new to reclaimed material.

The results obtained have demonstrated that the design of the Servacycler is appropriate for its intended use. The target discharge temperature of 150 °C was achieved quite easily at maximum throughput. In fact, in testing the heater controls, discharge temperatures of over 200 °C were obtained without reaching the limits of the burner. Adequate mixing and coating of the material were also achieved while operating well within the available range of the mixer drum's rotational speeds.

12.8 Investigation into the economics of hot mix recycling

12.8.1 Quality seen in perspective

The cost savings model, developed in section 8.3, for estimating the savings that can be expected from using **hot mix** recycling rather than conventional methods, can also be used to determine the relative influence of various factors on expected savings. Furthermore it can be used to relate **risk** to cost savings and thereby determine the most economical design (1).

As an illustration, the sensitivity of the savings to the proportion of reclaimed material used in the mix and to the haul distance of the aggregate was determined, for the example given in Section 8.3.12. The results are illustrated in Figure 26. They show that the cost savings are much more sensitive to the proportion of reclaimed material used than to the haul distance.

In a similar way the sensitivity of other parameters can be calculated for particular recycling situations.

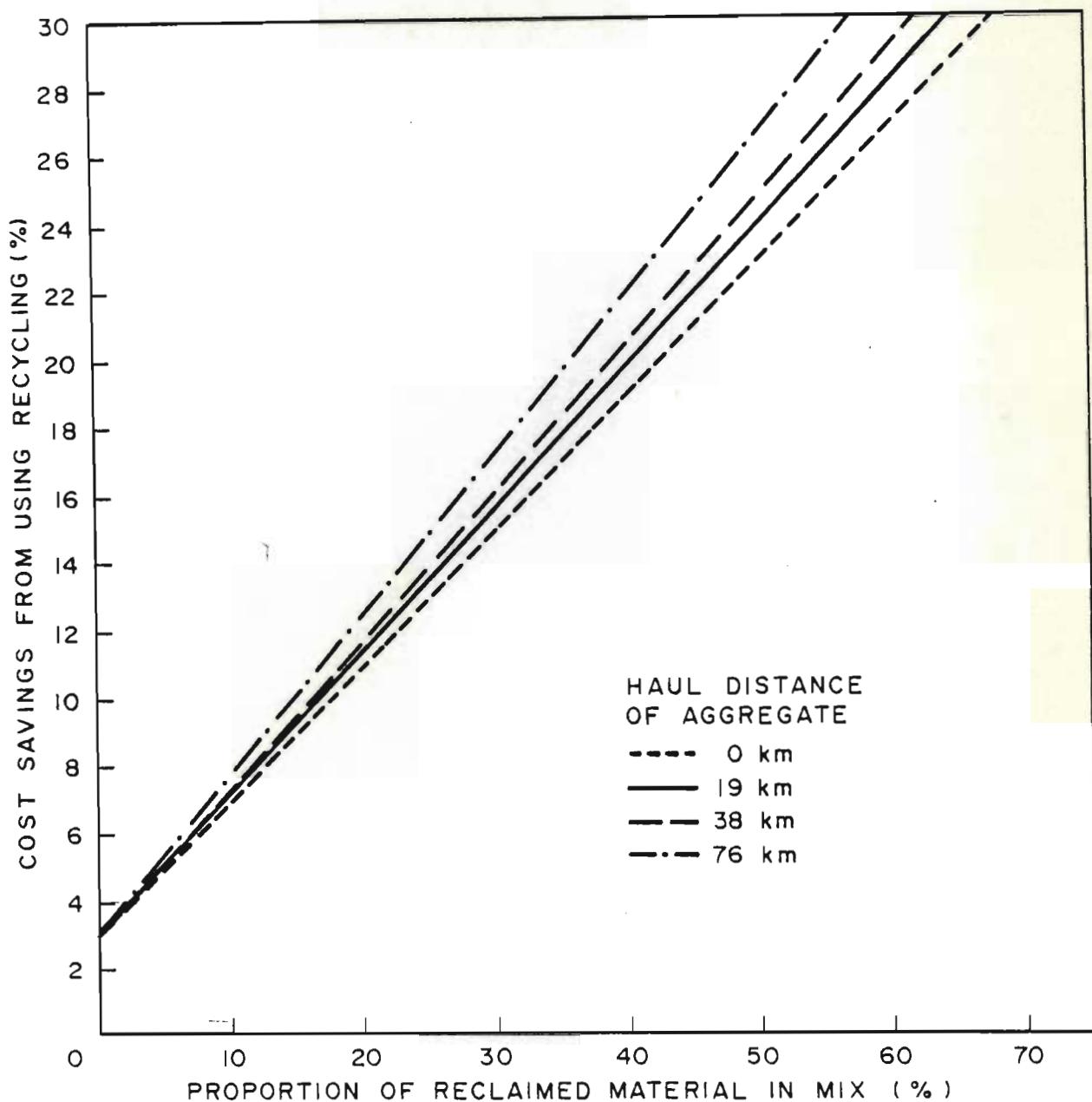


FIGURE 26

RELATION OF COST SAVINGS TO RECYCLING RATIOS FOR
DIFFERENT HAUL DISTANCES

Figure 26 shows that cost savings are obtained even at nil proportions of reclaimed material in the mix. These arise from the inherent value of reclaimed material when stockpiled for future use.

One of the factors inhibiting the use of recycling is uncertainty about the expected life of the resultant mix. Generally, the greater the proportion of reclaimed material in the mix, the greater the fear of an early failure. The model can be used to weigh up the potential cost savings against the consequences of the expected life of the mix.

As an illustration consider a hypothetical case in which the expected life of a mix containing certain proportions of reclaimed material is given by the curve in Figure 27 and for which the initial cost savings obtained by using this material are given by the solid line in Figure 26 (i.e. for a haul distance of 19 km).

The following additional assumptions are used to calculate the net benefits :

- cost of conventional mix = A
- expected life of conventional mix = T
- cost of recycled mix = B
- expected life of recycled mix = t
- end-of-life rehabilitation consists of conventional mix at cost A with life T
- discount rate = $r = e^\lambda - 1$

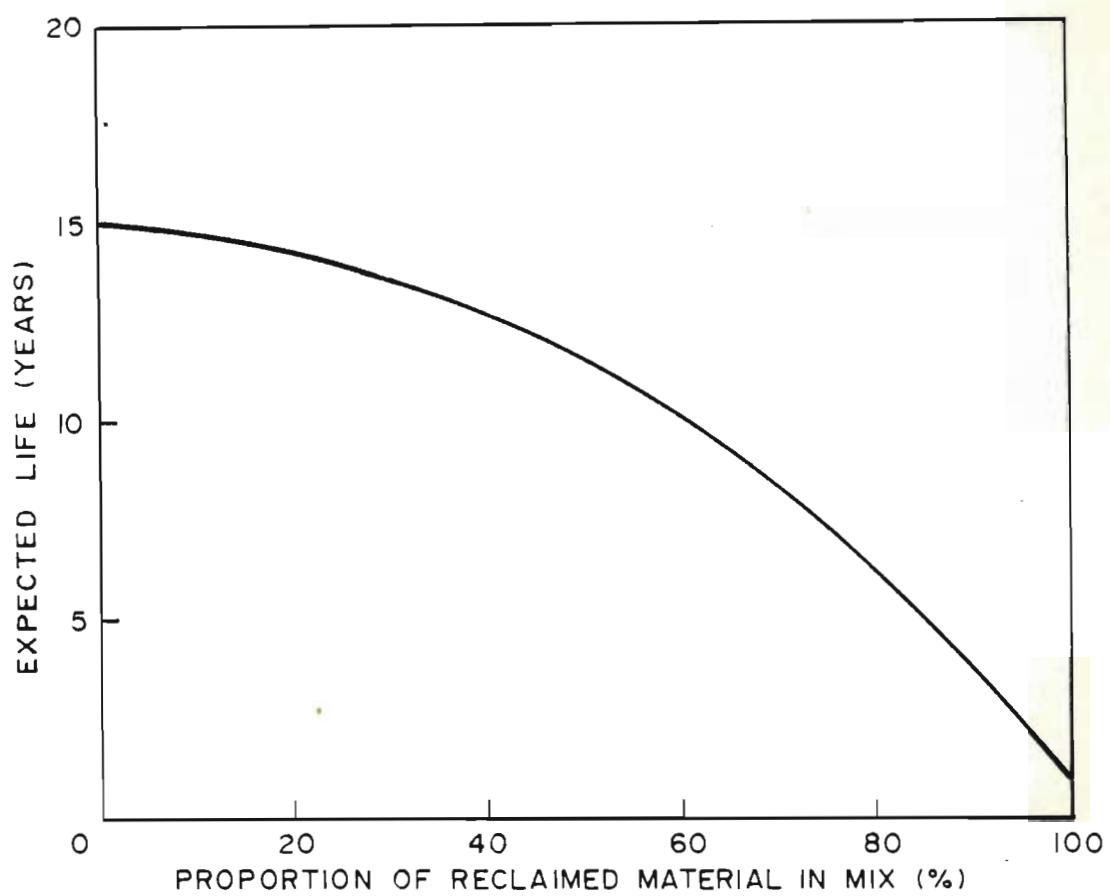


FIGURE 27

*EXPECTED LIFE OF RECYCLED ASPHALT
(HYPOTHETICAL)*

With these assumptions the conventional mix is rehabilitated at times T and 2T and the recycled mix at times t and T + t. Further rehabilitation is not considered. The net saving as a proportion of the cost of the conventional mix is given as

$$S = \frac{A - (B + V)}{A}$$

where V = net cost of rehabilitation at time t

$$= Ae^{-\lambda t} - Qe^{-\lambda T}$$

where Q = salvage value of rehabilitation at time T
= economic value of delaying rehabilitation at
time T to $T + t$

$$= Ae^{-T} (1 - e^{-\lambda t} + e^{-\lambda T})$$

Therefore

$$S = 1 - \alpha + e^{-\lambda T} (1 - e^{-\lambda t} + e^{-\lambda T} - e^{-\lambda(t-T)})$$

where $\alpha = \frac{B}{A}$

The results of this equation are given in Figure 28 for :

$$\lambda = \log_e 1,1 \quad (\text{i.e. } r = 10 \text{ per cent})$$

$$T = 15 \text{ years}$$

$$\alpha = 0,96 - 0,004x \quad (\text{derived from Figure 26})$$

$$t = 15 - 1,4 \times 10^{-3} x^2 \text{ years} \quad (\text{derived from Figure 27})$$

where x = proportion of reclaimed material in mix.

With these assumptions the optimum reclaimed to new material ratio is 40 : 60 with a net saving of 13 per cent. Savings are obtained for mixes containing up to 76 per cent reclaimed material despite the greatly reduced expected lives of mixes containing high proportions of reclaimed material.

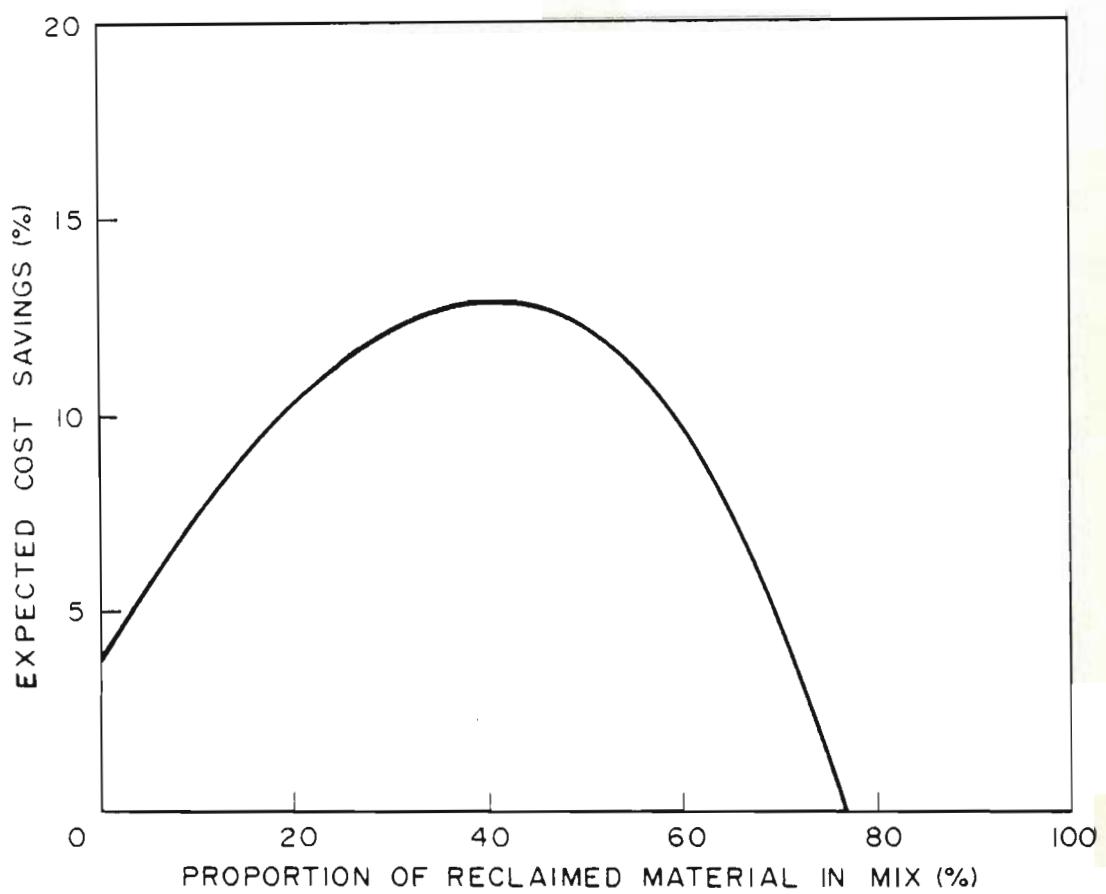


FIGURE 28

NET EXPECTED SAVINGS AFTER CONSIDERING LIFE
OF MIX

The above method may be considered simplistic but it has been used effectively in this example to put cost savings and fears about the quality of recycled mixes into perspective. However, the example has demonstrated the need for empirical data relating the performance of recycled material to factors such as the proportion of reclaimed material in the mix.

12.8.2 Factors contributing to the quality

The acceptable performance of an asphalt mix is essentially a balance between cracking resistance and deformation resistance and, for surfacings, also durability (weathering). The cracking and deformation resistance of particular layers are considered in terms of the whole pavement structure.

The above characteristics are affected by numerous factors. These include, inter alia: grading, aggregate shape and type, binder content and type, mix and compaction temperatures, and amount of voids in mix, as well as traffic loading and environmental conditions.

The effect of these factors is catered for in the design of conventional asphalt mixes in which the most suitable characteristics for their particular use in the pavement structure have been established.

However for hot mix recycling, with nominally the same composition as conventional mixes, additional factors need to be considered. These are related to the reclaimed material and are concerned with:

- (a) the difficulty in controlling the composition of the material
- (b) uncertainty about the properties of a mix containing significant proportions of reclaimed binder.

Reclaimed material may vary considerably both in grading and bitumen content according to the way it was originally

constructed. It may even comprise batches of asphalt with substantially different design characteristics. The process of ripping or milling the material and stockpiling it may introduce significant quantities of impurities. Furthermore variations in the milling or crushing processes may introduce differences in the grading, particularly the amount of fines. This variability will ultimately be reflected in the properties of the recycled material and adversely effect its quality, unless the properties of the reclaimed material are carefully controlled and frequently monitored.

Even when the new and reclaimed materials are correctly blended so as to produce the same characteristics as the design properties of conventional mixes (i.e. grading, binder penetration and Marshall properties) the quality of the mix is still in question, mainly with respect to the binder. This can be manifested in its initial engineering properties, i.e. fatigue and deformation resistance, and its longer term resistance to weathering (i.e. its durability). Reasons for this are:

- (a) the uncertainty of the binder mixing efficiency during the recycling process,
- (b) the possible remaining effects of the weathered nature of the reclaimed bitumen,
- (c) the uncertainty regarding the long-term effects of recycling additives when these are used.

Concerning durability, the effect can only be determined from long-term monitoring of the ageing characteristics of recycled binders. With regard to the initial engineering properties, the quality of the recycled mix can be compared with those of conventional mixes in terms of cracking and deformation resistance. This can be done by laboratory fatigue testing, such as repeated indirect tensile measurements (2 and 3), with regard to cracking resistance and by triaxial testing with regards to deformation resistance.

The above reservations will naturally be greater as the proportion of reclaimed material in the recycled mix increases.

Note further that there are certain practical limitations on the maximum proportion of reclaimed material imposed by factors such as:

- (a) meeting the required grading
- (b) achieving the specified bitumen properties (though this limitation can be overcome to some extent by the use of recycling agents)
- (c) heating and mixing constraints in the recycling operation.

The assessment of quality of recycled mixes will therefore have to consider:

- the effect of variability and methods for controlling it
- the effect of recycled binders in mixes meeting required specifications
- the practical limitations in providing mixes with specified properties.

The main concern of this study is the second of these considerations as it relates to the different requirements of base and surfacing layers.

12.3.3 Scope and objectives of study into the effect of proportion of reclaimed asphalt on quality

In section 12.8.1 it was shown that optimum benefits do not necessarily coincide with maximum proportions of reclaimed material in a recycled mix. It was further shown that it is important to establish the relationship, if it exists, between proportion of reclaimed asphalt and expected life.

A comprehensive study has been initiated which involves the use of reclaimed asphalt in various proportions to produce specified base layer and surfacing mixes and the subsequent comparison of these recycled mixes with each other and with conventional mixes, produced using the same specification. The study also involves the construction of trial sections at the NITRR's test site and the use of the Heavy Vehicle Simulator to test their performance. It is also planned to supplement the above activities with ad-hoc investigations on forthcoming rehabilitation projects where hot mix recycling is used. A diagrammatic layout of the planned investigatory programme is shown in Figure 29.

In view of the uncertainty regarding the ageing characteristics of recycled binders the effect of proportion of reclaimed asphalt on durability and hence expected life of surfacings can only be determined by long-term monitoring. This part of the study includes the production of surfacing mixes, placement of cores in different environmental conditions, and periodic testing of binder characteristics. It also includes chemical analyses to determine the appropriate type of recycling additive needed to rejuvenate the aged binder, when this cannot be accomplished using penetration-grade bitumens (Appendix 2).

The study reported here concerns the use of gap-graded reclaimed material in various proportions to produce continuous-graded base course mixes and the subsequent testing of these mixes to establish their engineering properties. In South Africa three main types of asphalt are used for bases and surfacings: continuously-graded, semi-gap-graded and gap-graded mixes. Therefore various combinations of reclaimed and new asphalt types need to be considered. However, gap-graded reclaimed surfacings are the most readily available asphalts in South Africa and continuously-graded mixes are most frequently used in bituminous bases nowadays. I viewed this combination of reclaimed and new types as most relevant to the needs of road authorities and accordingly I have selected it to produce the mixes shown in Figure 30. This study is an extention of the work previously reported by the University

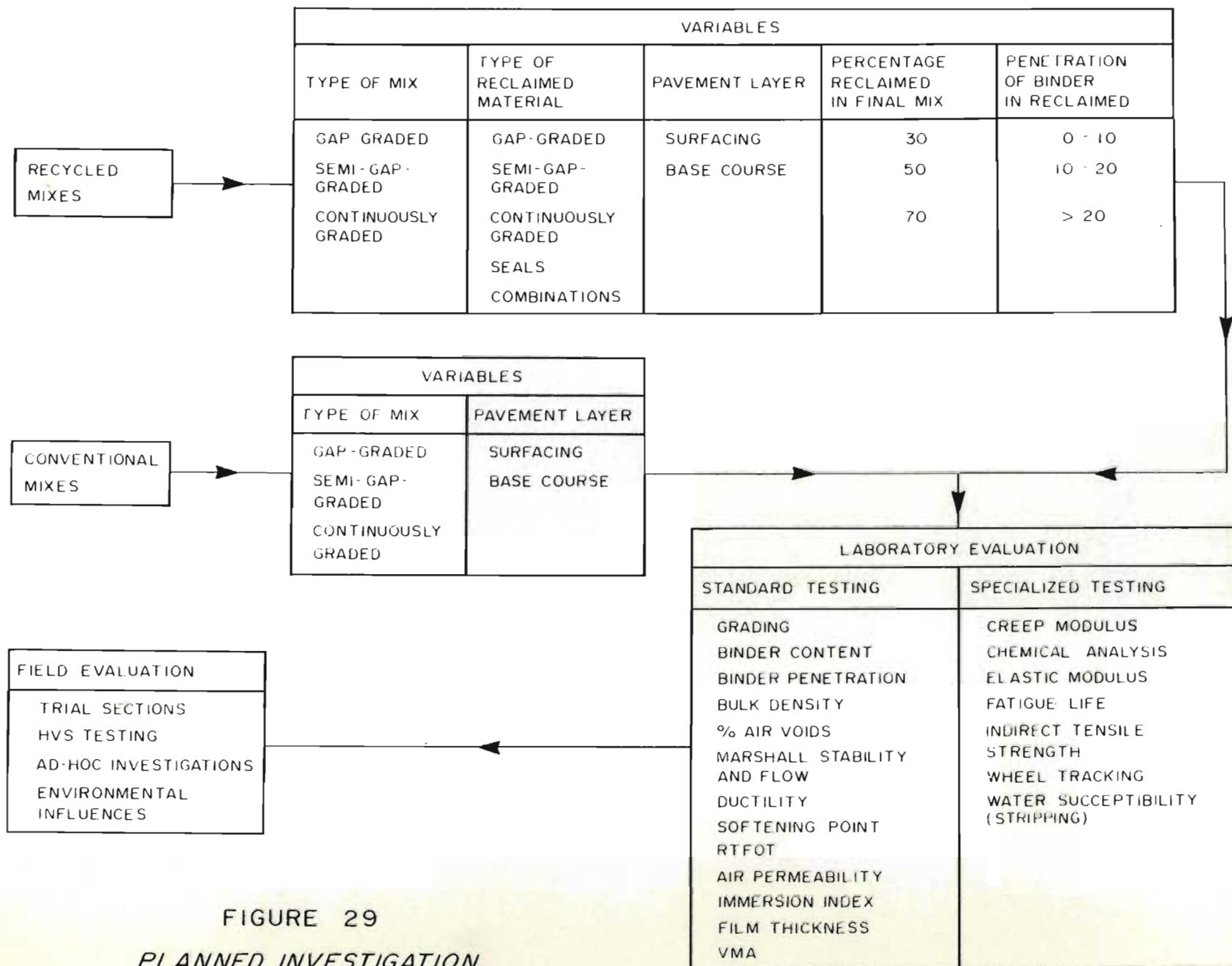


FIGURE 29
PLANNED INVESTIGATION

of Texas (3 and 4) in as much as it :

- examines and compares the properties of recycled and conventional base course mixes produced, according to the same specification, using a range of reclaimed material proportions, and
- considers South African materials and conditions.

The Servacycler provides effective control over the rates of feed of new and reclaimed material and it can heat and mix adequately. Therefore, the mini-recycling plant has been utilized usefully in this study to produce the designed mixes. The realistic simulation, albeit on a mini-scale, of actual drum mixer hot mix recycling operations enabled mixes to be produced with binder which had been subjected to the effects of plant heating, heat exchange, and mixing.

In this experiment the effect of varying the proportion of reclaimed to new material was examined by subjecting the mixes to :

- standard laboratory tests to examine their degree of compliance with standard requirements,
- the creep test to assess their resistance to permanent deformation, and
- repeated loading tests to determine their initial fatigue properties.

In this work I am indebted to my colleagues M A Ferreira for his assistance in the laboratory testing and data processing and P C Curtayne for his suggestions regarding the analysis.

12.8.4 Characteristics of materials used

12.8.4.1 Reclaimed material

The reclaimed material used was a 14 year old gap-graded asphalt which had been milled for the Johannesburg City Engineer's Department during resurfacing operations in 1982. The material was first screened through a 25 mm sieve. The resulting grading is shown in Figure 31. Tests on this material determined its binder content of 4,4 per cent and an average recovered binder penetration of 16 at 25°C.

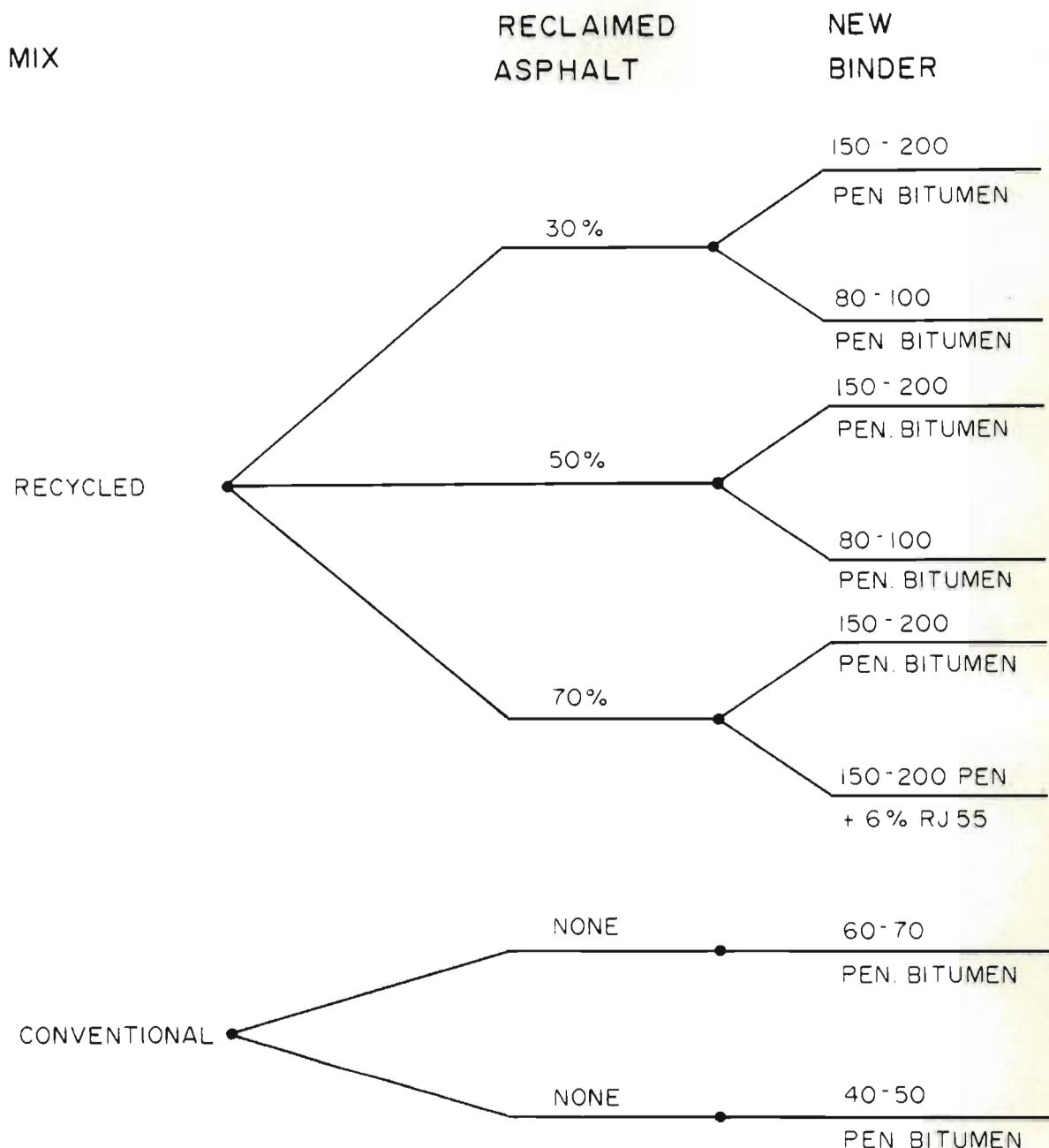


FIGURE 30

MIXES PRODUCED

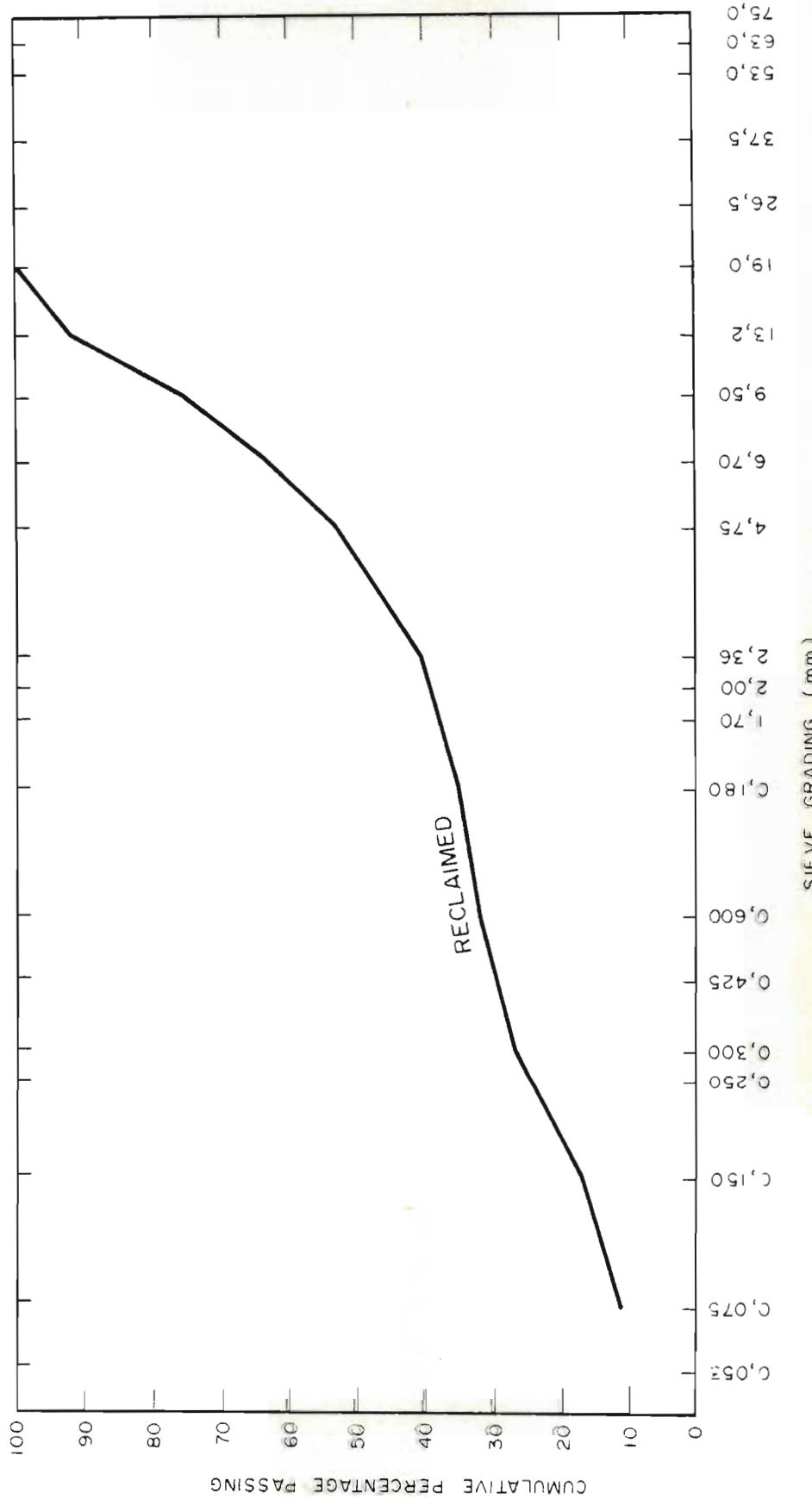


FIGURE 31
GRADING OF RECLAIMED MATERIAL

12.8.4.2 New aggregate

Four sizes (19 mm, 13,2 mm, 6,7 mm and crusher dust) were obtained from Ferro Quarries, East Lynn, Pretoria. The following characteristics were determined for this material:

- ACV: 19 per cent (maximum specified value^{*}: 29 per cent)
- Dry 10 per cent FACT: 183 kN (minimum specified value^{*}: 110 kN)
- Flakiness index: 24 and 25 per cent for the 19 mm and 13,2 mm respectively (maximum specified value^{*}: 35 per cent).

^{*}Technical Recommendations for Highways (TRH 14): Standards for Road Construction Materials, Pretoria, South Africa, 1980.

These materials were used in different proportions in each mix to meet the continuously-graded asphalt grading specification. For the conventional mixes, grading requirements necessitated the addition of minus 0,075 mm material. The gradings of the new aggregates are shown in Figure 32.

12.8.4.3 New binder

Conventional mixes were produced using 40-50 and 60-70 penetration-grade bitumens. For each reclaimed to new material ratio, the appropriate penetration-grades of new bitumen were determined using a nomograph (Figure 25) which relates the required penetration-grade to the reclaimed material's recovered binder penetration and the percentage of new bitumen in the final blend. Accordingly the mixes containing 30 and 50 per cent reclaimed material were produced using 80-100 and 150-200 penetration grade bitumens, and those containing 70 per cent reclaimed material using a 150-200 penetration-grade bitumen. Furthermore a recycling agent (Spramex RJ55) was used in one of the mixes containing 70 per cent of reclaimed material.

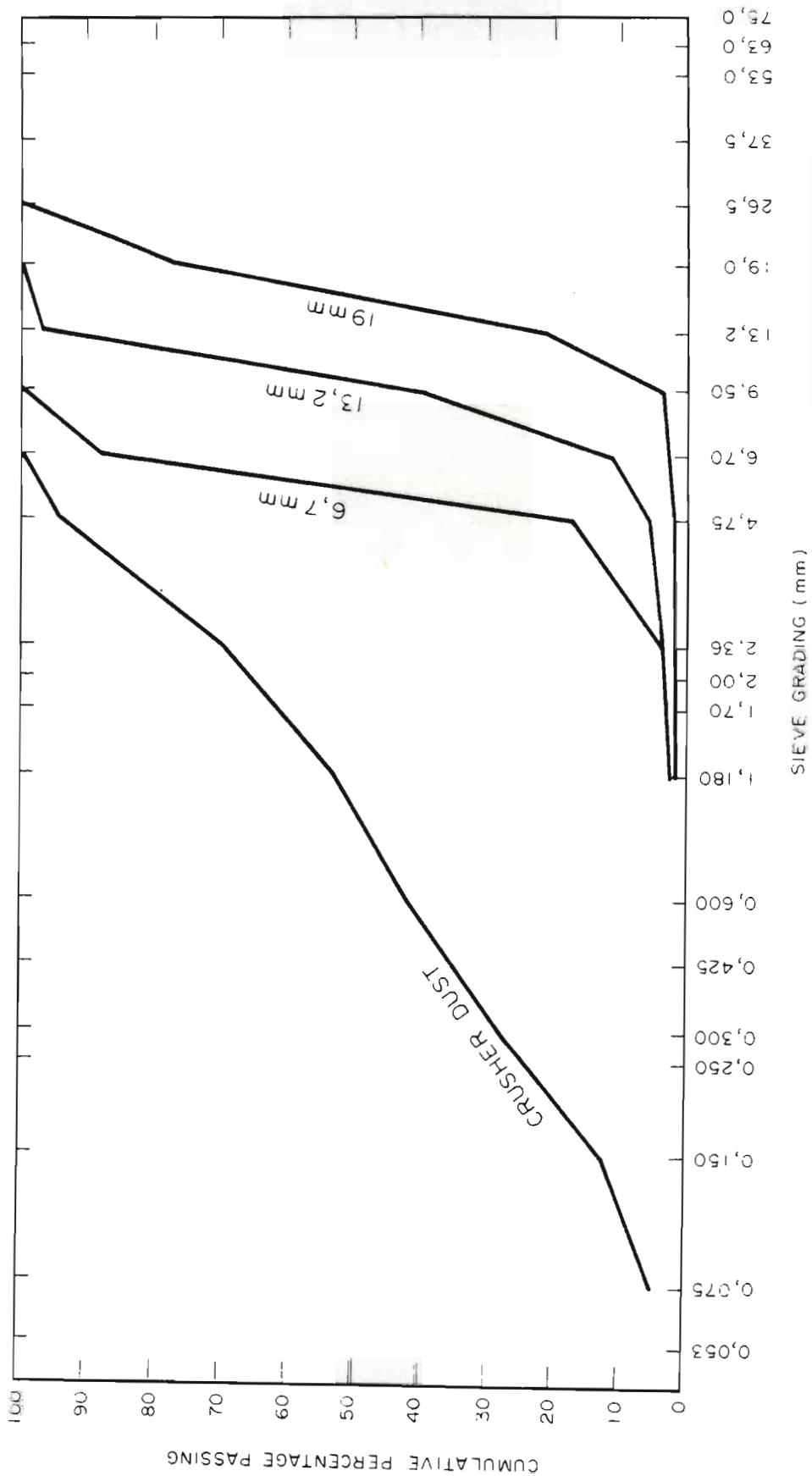


FIGURE 32
GRADINGS OF NEW MATERIALS

12.8.5 Mix specifications and compositions

The mixes were produced to conform to the continuously-graded asphalt grading specification shown in Figures 33 & 34. The binder content aimed-for in each case was $5,3 \pm 0,5$ per cent. All the mixes were produced within the desired range.

The compositions of the mixes are given in Table 25.

12.8.6 Test programme and methods

A comprehensive test programme was undertaken to determine the following for each mix:

- grading
- binder content
- recovered binder penetration, softening point and ductility
- bulk density
- air void content
- Marshall stability and flow
- creep modulus
- indirect tensile strength
- resilient elastic modulus
- fatigue life.

Marshall briquettes were produced from samples of the mixes at compaction temperatures of 140°C for the Marshall, creep and indirect tensile tests.

The standard tests were undertaken according to the procedures prescribed in the Technical Methods for Highways (TMH 1): Standard Methods of Testing Road Construction Materials, Pretoria, South Africa, 1979.

The creep test (4) determines the resistance of bituminous mixes to permanent deformation. A constant load of 200 kPa is applied to the horizontal planes of a cylindrical specimen and the vertical strain is measured. The creep modulus is

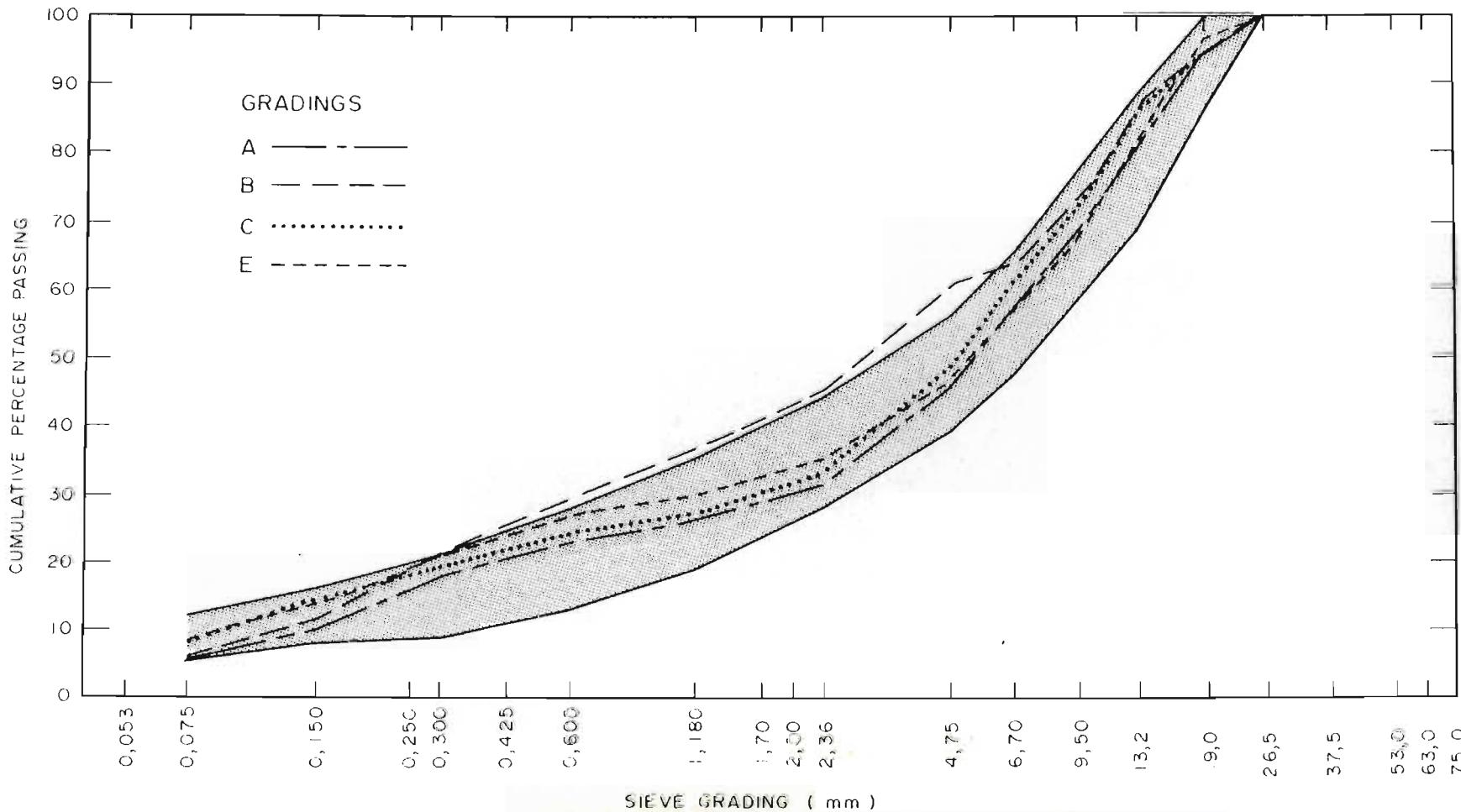


FIGURE 33

CONTINUOUSLY-GRADED ASPHALT ENVELOPE AND GRADINGS OF MIXES A,B,C & E

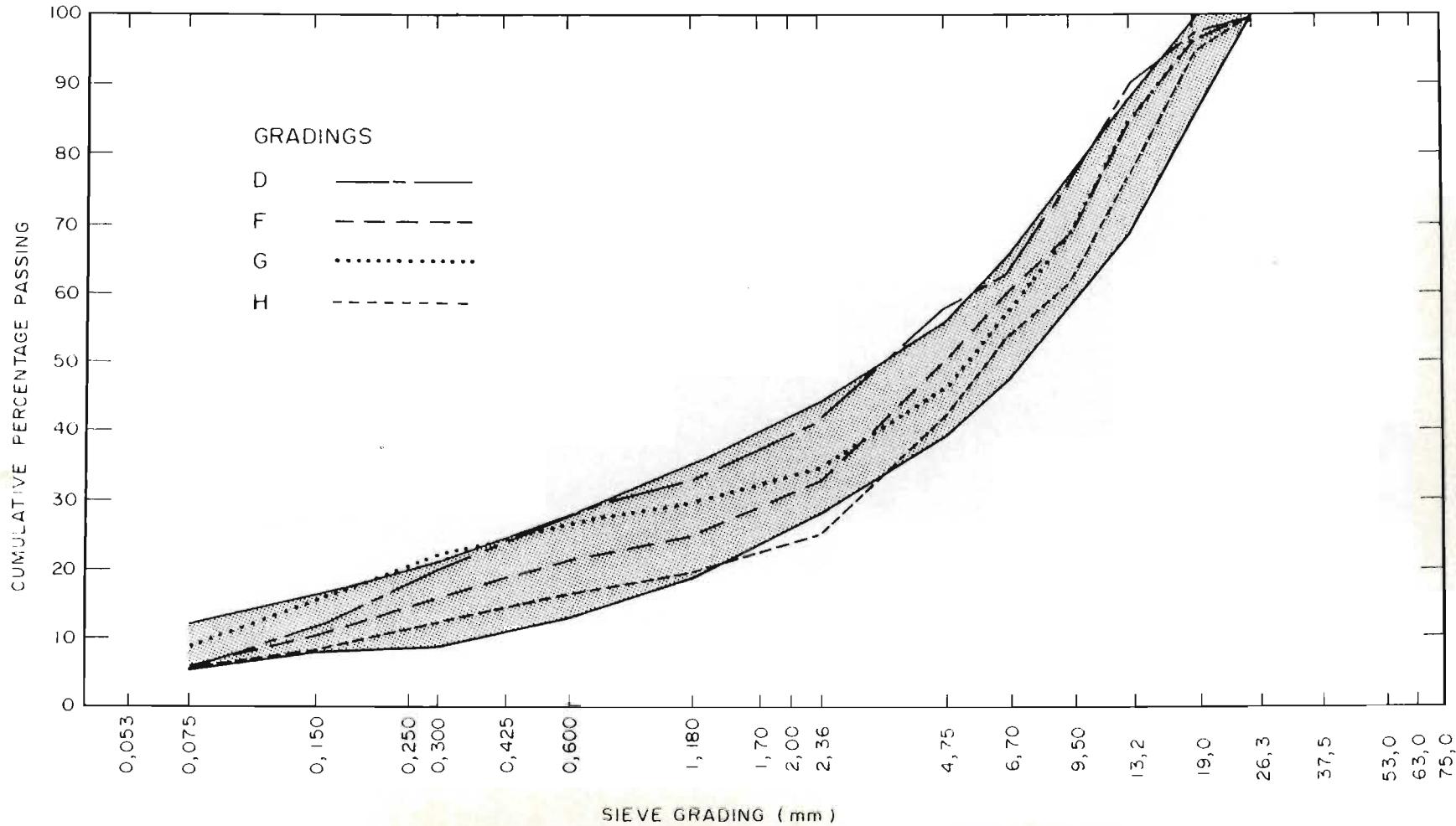


FIGURE 34

CONTINUOUSLY-GRADED ASPHALT ENVELOPE AND GRADINGS OF MIXES D, F, G & H

TABLE 25 : Mix compositions

MIX	PROPORTION OF RECLAIMED MATERIAL (%)	PROPORTIONS OF NEW MATERIAL (%)	TYPE OF NEW BINDER
B	30	15,4 (19 mm) 17,5 (13,2 mm) 37,1 (Crusher Dust)	150-200 PEN. BIT.
D	30	As for mix B	80-100 PEN. BIT.
A	50	17 (19 mm) 3 (13,2 mm) 14,5 (6,7 mm) 15,5 (Crusher Dust)	150-200 PEN. BIT.
E	50	As for mix A	80-100 PEN. BIT.
C	70	18,9 (19 mm) 6,6 (6,7 mm) 4,5 (Crusher Dust)	150-200 PEN. BIT.
G	70	As for mix C	150-200 PEN. BIT. +6% RJ55
F	NIL	25 (19 mm) 18 (13,2 mm) 12 (6,7 mm) 40 (Crusher Dust) 5 (-0,075 mm)	60-70 PEN. BIT.
H	NIL	As for mix F	40-50 PEN. BIT.

calculated by dividing the applied stress by the vertical strain measured after 100 minutes of loading. The creep moduli criteria given in Table 26 have been developed in South Africa following field studies (5) using the Heavy Vehicle Simulator.

Table 26 : Design criteria to limit permanent deformation of asphalt mixtures*

Traffic class	E80/Lane	Lower limit of creep modulus (MPa)
E4	$12-50 \times 10^6$	80
E3	$3-12 \times 10^6$	60
E2	$0,8-3 \times 10^6$	40
E1	$0,2-0,8 \times 10^6$	30

*Test temperature = 40°C

In the indirect tensile test (6) static or repeated (dynamic) compressive loads are applied along the vertical diametral plane of a cylindrical specimen. In this study, the static indirect tensile test is used to determine the tensile strength of the asphalt mixes at 20°C using a loading rate of 50 mm/minute. The dynamic indirect tensile test is used for the determination of resilient elastic moduli and fatigue lives. It is a constant stress-type fatigue test[†] done at a temperature of 24°C with the load applied in the form of a haversine. The loading time is 0,1 seconds with a rest period of 0,9 seconds.

12.8.7 Laboratory test results

The laboratory test results are given in Table 27. Figures 33 and 34 show the gradings obtained for the different mixes.

The results of the standard laboratory tests show that all the mixes would be generally acceptable with regard to the

[†] As the behaviour of thick asphalt base layers (130 mm with 40 mm surfacing) is investigated, controlled stress mode testing is appropriate rather than controlled strain testing which is applicable for thin (less than 50 mm) asphalt layers (7 and 8).

Table 27 : Laboratory test results

Mix	A	B	C	D	E	F	G	H
% Reclaimed	50	30	70	30	50	Nil	70	Nil
New Binder (Pen-grade bitumen)	150-200	150-200	150-200	80-100	80-100	60-70	150-200 + 6% RJ55	40-50
Penetration ^{1/10 mm at 25°C}	149	150	147	79	79	64	293	44
Discharge Temperature °C	146	151	160	155	147	156	160	160
Binder Content %	5,5	4,8	5,0	5,7	5,3	5,3	5,0	5,7
Bulk Density kg/m ³	2385	2323	2398	2348	2401	2318	2409	2319
Air Voids %	3,8	5,1	4,3	4,1	2,3	5,1	3,8	4,6
Stability kN	11,3	9,4	15,5	9,0	14,4	7,1	15,1	10,4
Flow mm	1,3	2,1	2,7	2,5	2,7	2,3	2,9	2,3
Stability/flow kN/mm	8,7	4,5	5,7	3,6	5,3	3,1	5,2	4,5
Recovered Binder Penetration ^X ^{1/10 mm at 25°C^{XX}}	47	58	19	36	22	45	24	33
28	48	18	20	15	27	15	25	
Ductility mm at 25°C ^{XX}	913	1400 ⁺	91	1400 ⁺	140	1400 ⁺	60	130
Softening Point °C ^{XX}	59,0	53,3	66,0	59,0	62,7	57,0	66,2	66,4
Creep Modulus MPa	128	172	115	123	106	148	119	186
Indirect Tensile Strength kPa	1650	1400	2100	1900	2300	1800	2200	1650
Resilient Elastic Modulus (Stiffness) (MPa)	3550	2500	4350	3800	4100	2850	3950	2900

^X ex uncompacted sample^{XX} ex Marshall specimen

criteria recommended in South Africa (9). Furthermore, these results show clearly that increasing proportions of reclaimed material have no detrimental effect on the properties measured.

The creep moduli values tend to decrease as the proportion of reclaimed material increases. However, as these values are well above the minima recommended in Table 26, it can be taken that all the mixes produced would have adequate resistance to permanent deformation.

The indirect tensile strength results show no correlation with the proportion of reclaimed material. It is noted that these results are above the design range (500 to 1400 kPa) suggested by Kennedy et al. (3). In general, higher resilient elastic moduli were obtained for the mixes containing higher proportions of reclaimed material. However, these results are within the range (1700 to 6500 MPa) suggested in (3).

The fatigue results are shown in Figure 35. The relationship between fatigue life and stress difference has been found (10) to have the form :

$$N = K (I/\Delta\sigma)^n$$

where N = number of repetitions to failure (fatigue life)

$\Delta\sigma$ = difference between horizontal and vertical stresses at centre of specimen

K & n = constants for a given mix and test conditions.

Best fit relationships were obtained by linear regression for $\log N$ against $\log \Delta\sigma$. The results are shown in Figure 35 and the corresponding values obtained for K and n are given in Table 28. With the exception of the K value of conventional mix F, these values are within the range given ($2 < n < 8$ and $10^{12} < K < 10^{25}$) by Kennedy et al. (3). However, because fatigue is characterized by two parameters

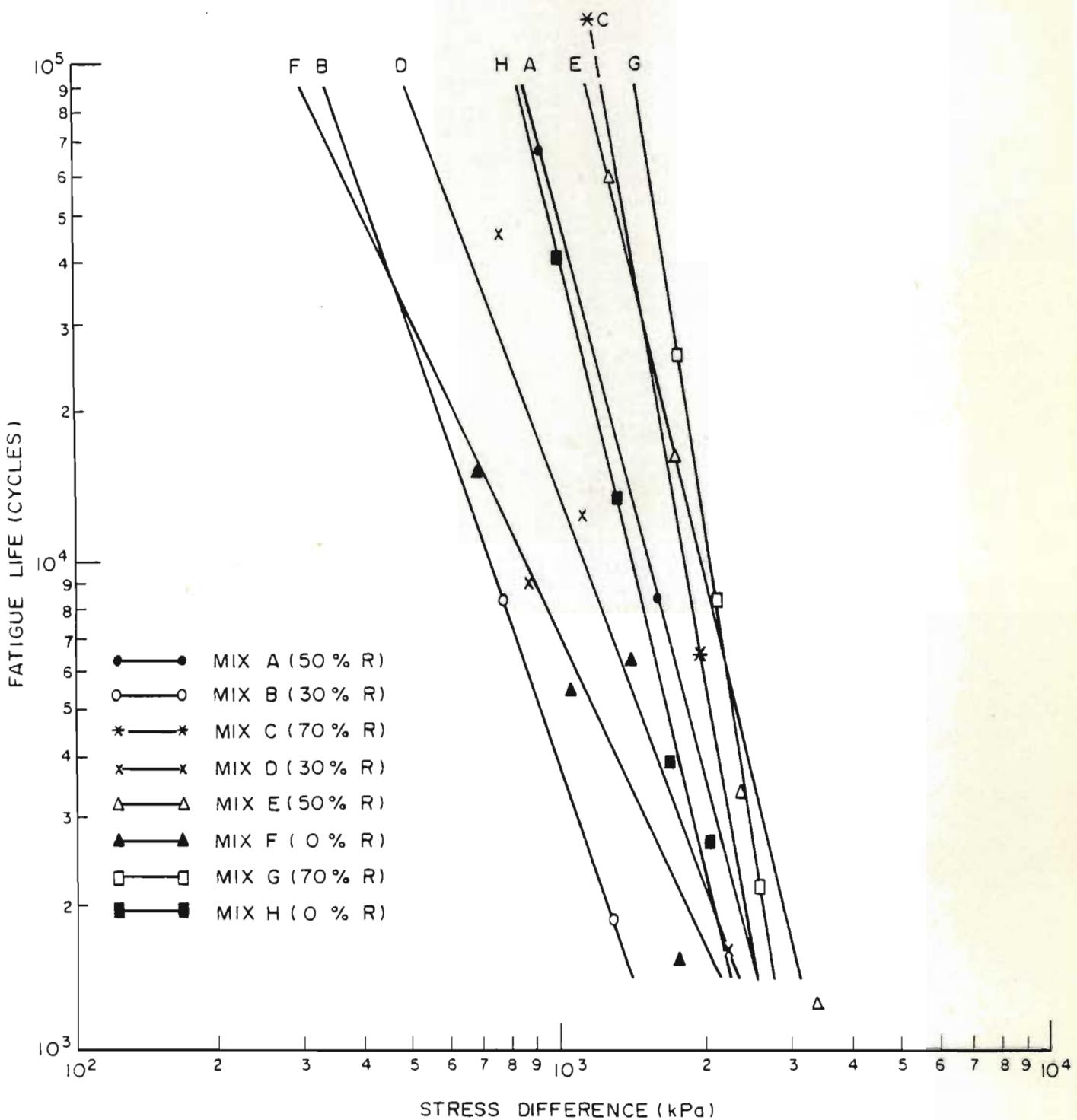


FIGURE 35

RELATIONSHIPS BETWEEN FATIGUE LIFE AND STRESS DIFFERENCE
FOR MIXES CONTAINING VARIOUS PROPORTIONS OF RECLAIMED MATERIAL

(n and K) it is difficult to relate it simply to the proportion of reclaimed material. This aspect is addressed further in the following section.

Table 28 : Fatigue parameters

MIX	% RECLAIMED	n	K
A	50	3,8	$1,1 \times 10^{16}$
B	30	2,9	$1,9 \times 10^{12}$
C	70	5,7	$5,1 \times 10^{22}$
D	30	2,6	$1,1 \times 10^{12}$
E	50	4,1	$2,3 \times 10^{17}$
F	Nil	2,1	$1,2 \times 10^{10}$
G	70	6,5	$3,4 \times 10^{25}$
H	Nil	4,1	$1,1 \times 10^{17}$

12.8.8 Analysis of fatigue results

The analysis would be greatly simplified if fatigue life can be expressed in terms of one varying parameter instead of two. Two simple approaches are possible :

- to assume that all the fatigue lines converge on a single point. This approach has been used to correct actual to predicted constant-strain testing fatigue lines by Nottingham University (II) and Monismith and McLean (12). The model will have the form :

$$\frac{N}{N_1} = \left(\frac{\Delta\sigma_1}{\Delta\sigma} \right)^n$$

where $(N_1, \Delta\sigma_1)$ is the focal point.

- to assume that all fatigue lines are parallel. In this case the model will be :

$$N = K \left(\frac{1}{\Delta\sigma} \right)^{n_1}$$

where n_1 is constant for all lines.

In the first case the fatigue lives are completely represented by the slopes, n , of the lines on a logarithmic plot and in the second case by the intercept $\log K$. Figure 35 indicates that the first model is likely to prove more appropriate.

The focal point (4750, 175) was obtained by finding the point for which the sum of the squared deviations of the measurements from the best fit new lines was minimum, i.e. :

Let :

$$\bar{N}_{ij} = \log N_{ij}/N_1$$

where N_{ij} = measured fatigue life for test i of mix j
 N_1 = ordinate of focal point

$$\Delta\sigma_{ij} = \log \Delta\sigma_1/\Delta\sigma_{ij}$$

where $\Delta\sigma_{ij}$ = stress difference for test i of mix j
 $\Delta\sigma_j$ = abscissa of focal point.

The model has the form :

$$\bar{N}_{ij} = n_j \Delta\sigma_{ij}$$

and the point $(\Delta\sigma_1/N_1)$ is obtained that minimizes

$$S_r = \sum_{ij} (\bar{N}_{ij} - n_j \Delta\sigma_{ij})^2$$

where for each j

$$\frac{\partial}{\partial n_j} \sum_i (\bar{N}_{ij} - n_j \Delta\sigma_{ij})^2 = 0$$

$$\text{or } n_j = \frac{\sum_i \bar{N}_{ij} \Delta\sigma_{ij}}{\sum_i \Delta\sigma_{ij}^2}$$

The results of using the focal point model are given in Figure 36 and the corresponding n values in Table 29. Inspection of Figure 36 suggests that the model fits the data satisfactorily. However, to test whether this model could be shown to fit the measurements less well than the two parameters model an analysis of variance of the residuals was undertaken. This is given in Table 30 which shows that the one parameter model cannot be considered inferior at the 5 per cent level of significance and it can thus be assumed to provide an equally good description of the results.

The model using the parallel line approach was also considered and, although not proven inferior, it did give greater deviations and since it was not expected to produce significantly different results for the ensuing analysis it was not taken further.

The values of n were expected to depend primarily on the stiffness of the mix (7). A good correlation was indeed obtained as shown in Figure 37. The next step was to determine to what extent the deviations from this relationship were determined by the proportion of reclaimed asphalt. The results of a stepwise regression analysis which considered the following variables :

n : slope
STIFF : stiffness
ITS : indirect tensile strength
CREEP : creep modulus
RECPEN : recovered penetration
STAB : Marshall stability
VOIDS : air voids
BC : binder content
RECLAIM : proportion of reclaimed asphalt

and which was forced to accept stiffness as the first variable, are given in Table 31.

Table 29 : Actual n values and those predicted assuming that fatigue lines converge on a single point

MIX	% RECLAIMED	ACTUAL n	PREDICTED n
A	50	3,8	3,6
B	30	2,9	2,0
C	70	5,7	4,6
D	30	2,6	2,8
E	50	4,1	4,6
F	Nil	2,1	2,4
G	70	6,5	4,9
H	Nil	4,1	3,4

Table 30 : Analysis of variance of regression for 25 observations concerning eight mixes

Variation	Sum of squares	Degrees of freedom	Mean square
About free lines	0,29	9	0,0322
About lines through focal point	0,46	16	0,0288
Reduction	0,17	7	0,0243

$$F = \frac{0,0243}{0,0322} = 0,75$$

$$F_{7;9;0,05} = 3,29$$

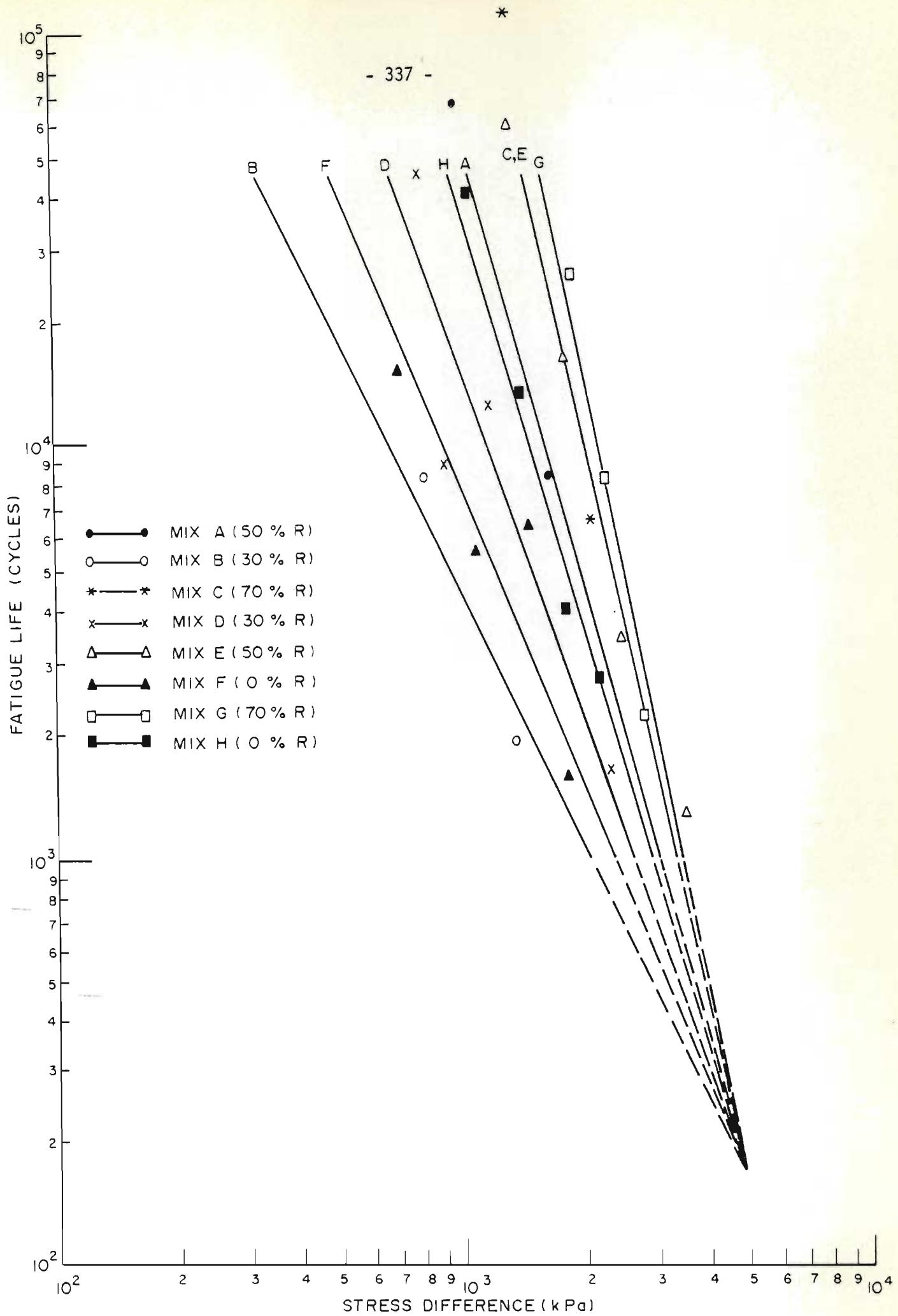


FIGURE 36
RELATIONSHIPS BETWEEN FATIGUE LIFE AND STRESS DIFFERENCE

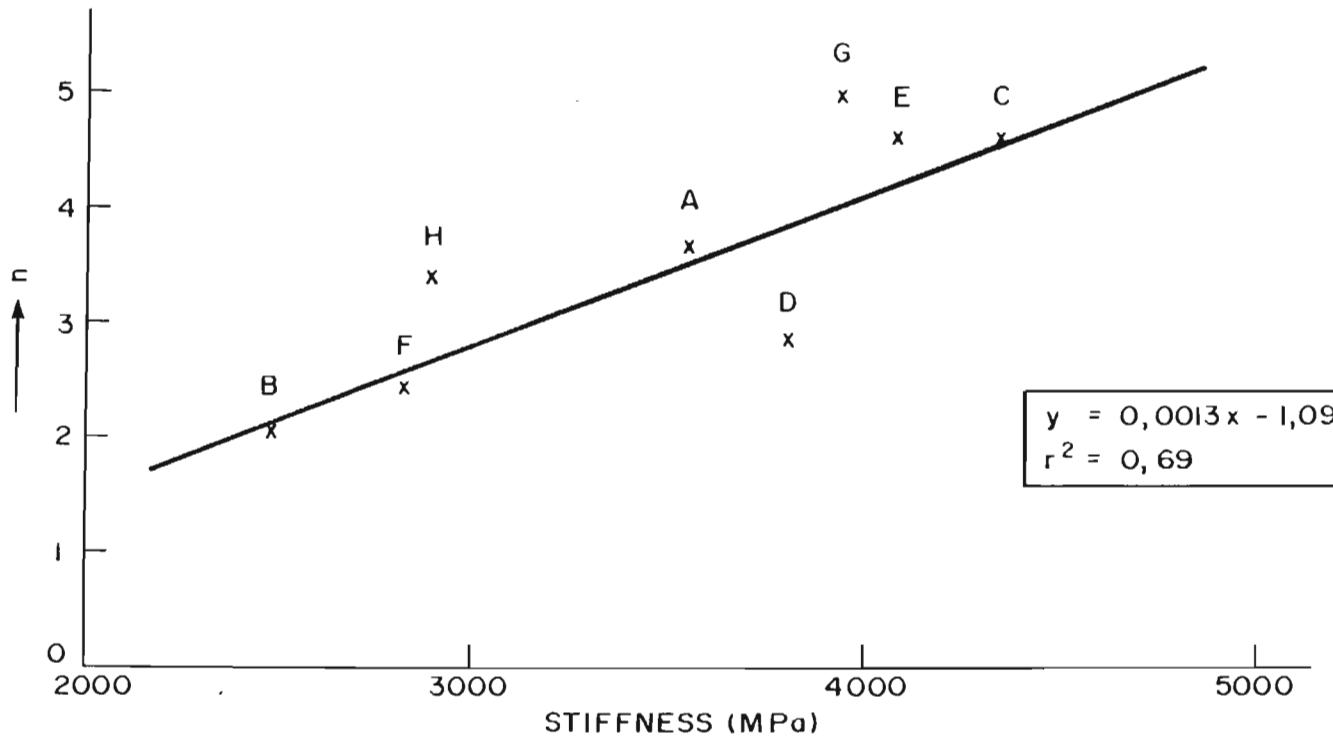


FIGURE 37

RELATIONSHIP BETWEEN FATIGUE COEFFICIENT n (calculated assuming fatigue lines converge on a single point) AND STIFFNESS

Table 31 : Results of stepwise regression forced to accept stiffness as first variable

Number of cases : 8

Step	Variable entered	F to enter	Significance	Multiple R	R Square	Standard error of estimate
1	STIFF	13,6	0,011	0,833	0,695	0,645
2	STAB	11,4	0,021	0,951	0,905	0,394
3	RECPEN	14,7	0,019	0,990	0,980	0,204
<u>Variable</u>		<u>Regression Coefficient</u>			<u>Std Error</u>	
STAB		0,288			0,041	
RECPEN		-0,0498			0,013	
STIFF		$-0,370 \times 10^{-3}$			$0,272 \times 10^{-3}$	
CONSTANT		2,74			1,01	

Note that virtually all the scatter is explained by the three variables : stiffness, stability and recovered penetration, whilst no significant effect of the proportion of reclaimed material per se was found.

The analysis was repeated without forcing the stiffness variable and the results given in Table 32 show that stability was found to be the primary variable.

Table 32 : Results of stepwise regression free to determine primary variable

Step	Variable entered	F to enter	Significance	Multiple R	R Square	Standard error of estimate
1	STAB	44,7	0,001	0,939	0,882	0,402
2	RECPEN	14,9	0,012	0,985	0,970	0,221
3	STIFF	1,8	0,244	0,990	0,980	0,204

The relationship between stability and n is shown in Figure 38. Note that in this analysis also the effect of the proportion of reclaimed material was found insignificant.

In the limited experiment undertaken the role of the various variables affecting fatigue life have not been necessarily determined. However for the mixes used and the test conditions obtaining it can be said that the proportion of reclaimed material had no effect on the fatigue life other than its effect on the stiffness and stability which tended to increase with increasing proportions.

12.8.9 Conclusions

The investigation concerned the determination of the effect, if any, of the proportion of reclaimed asphalt on the quality of the mix produced. It was based on an experiment involving the recycling of a gap-graded surfacing in various proportions with new material to produce continuously-graded base course mixes. These mixes were compared with conventional mixes, produced using the same specification, in terms of their compliance to standard requirements, their resistance to permanent deformation and their fatigue characteristics.

Standard laboratory testing showed that increasing proportions of reclaimed material have no detrimental effect on properties such as air voids, stability, flow and stability/flow ratio. The creep test determined that, although creep moduli tend to decrease with increased proportions of reclaimed material, all the recycled mixes had adequate resistance to permanent deformation. It was also shown that the proportion of reclaimed material had no effect on the fatigue life other than its effect on the stiffness and stability which tended to increase with increasing proportions.

Because of the limited data the results are only tentative. However, they suggest that gap-graded surfacings can be used in high proportions to produce continuous-graded base course

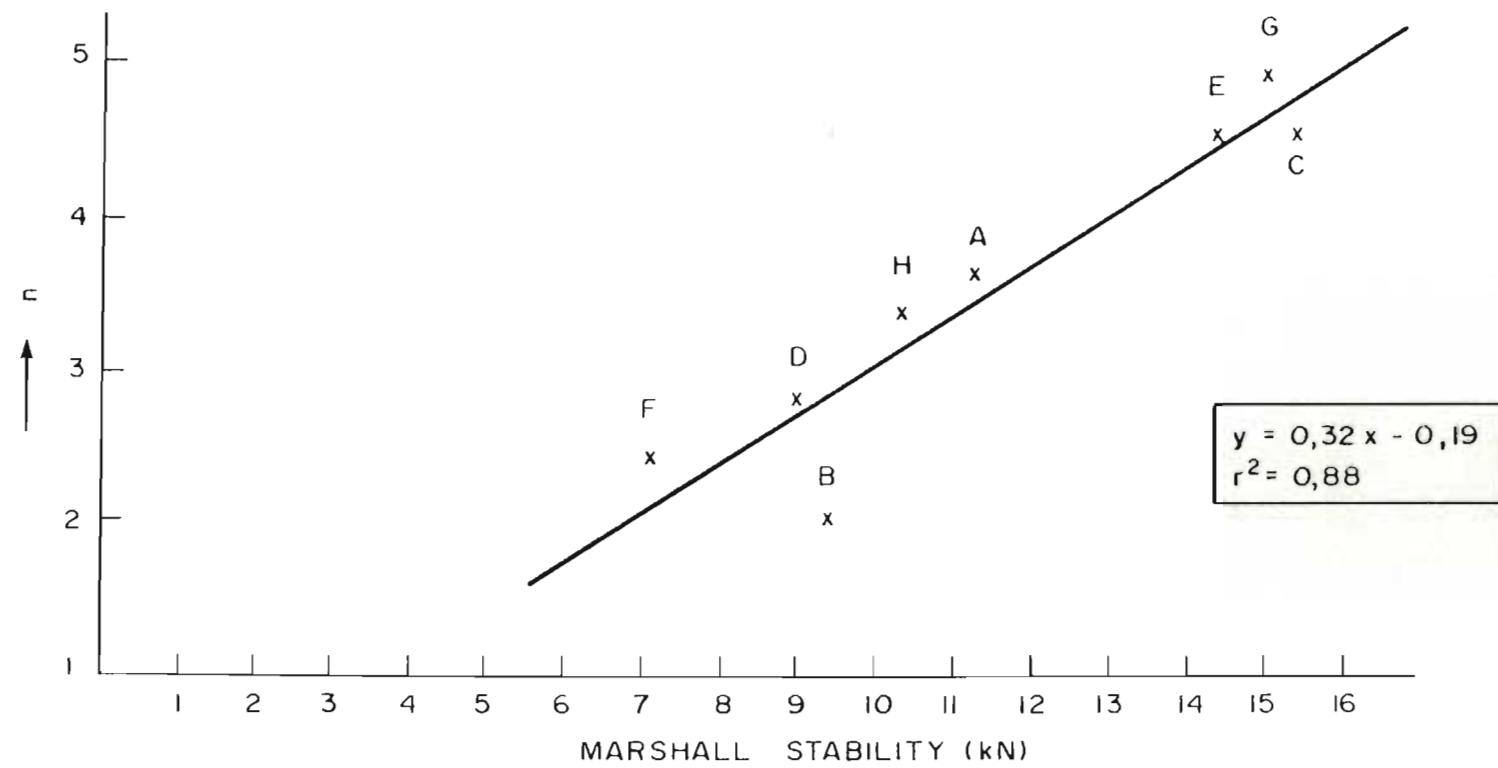


FIGURE 38

RELATIONSHIP BETWEEN FATIGUE COEFFICIENT n (calculated assuming fatigue lines converge on single point) AND STABILITY

mixes without detriment to the initial engineering properties of these mixes provided the following criteria are met :

- grading specification
- mix design
- heating and mixing controls.

It must be noted that the experiment specifically excluded aspects relating to :

- durability considerations,
- variability inherent in commercial-scale recycling operations,
- other types of reclaimed material and mix designs, and
- effect of variations in the gradings of the mixes produced.

It is intended to study the above factors as part of the NITRR's planned investigation into hot mix recycling (Figure 29).

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13. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

- 13.1 State of the art in 1983
- 13.2 Factors inhibiting the use of recycling
- 13.3 Results of research into inhibiting factors
- 13.4 Recommendations

13.1 State of the art in 1983

Recycling can provide an economical alternative to conventional construction methods. Technology has developed that enables existing pavement material to be readily reused in hot or cold processes, which can be undertaken in situ or at a central plant. Although the required technology exists, difficulties often arise in practice due to limited knowledge on the part of the users.

Fairly recent developments in planing and milling equipment have resulted in new rehabilitation methods, such as levelling and bonding, surface refinishing, surface retexturing, and in-situ cold recycling. Existing pavement material can be reclaimed for central-plant recycling by either ripping, breaking and crushing, or milling. Both methods have their merits and the choice will depend on local circumstances.

Hot mix recycling can be undertaken using modified plant of either the batch or drum mixer type. The latter allows higher proportions of reclaimed material to be used. However, the maximum ratio of reclaimed to new material must not be determined by the capabilities of a particular plant but by the aggregate grading, binder content and binder characteristics.

Cold mix recycling includes in-situ and central-plant operations. The in-situ process is undertaken using a wide range of methods and equipment and is particularly economical. Current developments in plant are likely to make in situ cold recycling even more attractive.

Hot surface recycling embraces processes such as reforming, rejuvenating, repaving and remixing. These processes offer significant benefits associated with reduced haulage costs, both for the disposal of existing pavement material and for the provision of new material. However, they are only applicable to wearing courses and their use should be strictly limited to pavements with sound underlayers and foundations.

Special additives have been used in recycling for some time and they are particularly applicable with high ratios of reclaimed to new material. However, there is still much controversy regarding their use and their medium to long-term effects on the resultant mix need to be established.

Although recycling can conserve energy, there has been a tendency to overestimate this aspect. Energy conservation arises mainly from savings in new material and haulage requirements. These savings can be quantified and are realised as cost savings in recycling contracts.

Cost savings through recycling were not significant when new techniques or equipment were being developed or introduced. However where proven processes were used on large projects, substantial savings have been reported.

Economic considerations since the 1973/74 oil crisis, coupled with technological developments, have resulted in recycling gaining international acceptance as an alternative to the traditional resurfacing and reconstruction methods. Although recycling is currently practised, to various extents, worldwide, the most significant developments and involvement have taken place in the USA, Europe and Japan.

In the RSA cold mix recycling has been used for some time and its applications have included the rehabilitation of cement-treated basecourses, the upgrading of roads with bituminous surface seals, and the maintenance of gravel roads. Hot mix recycling was first used in 1981 on the Van Reenen's pass rehabilitation project in Natal. Surfacing rejuvenating additives have been available for the last few years although their use has been sporadic and at times problematic.

13.2 Factors inhibiting the use of recycling

In most countries, including the USA, the extent of current

involvement in recycling is not nearly as high as that envisaged some ten years ago. There appears to be still a reluctance to adopt recycling methods on a meaningful scale. This points to the following drawbacks in these methods that must be evident to road authorities:

- current obscurity of cost savings,
- concern regarding quality of product, and
- complexities in contractual procedures.

The numerous options and factors that need to be considered make it difficult to obtain a clear picture of the economic advantages of choosing to recycle rather than to employ conventional methods. This problem is aggravated by the fact that there is currently little evidence as to the relative long-term quality of recycled mixes as compared with conventional mixes. In spite of the fact that mixes can be produced to comply with all conventional specifications, there are still misgivings that the reprocessed binder would be inferior to and not as durable as fresh binder. There has been no clear answer to these doubts.

A further difficulty lies in the design and specification of the recycled mix. First there is the doubt as to what would constitute the most desirable and economical product. Secondly a recycled mix specification, based on a fixed ratio of reclaimed to new material will not be equitable to contractors for whom this ratio is above the capabilities of their plant. There is also the complementary problem of ensuring that the specified product is in fact supplied. These problems make it difficult for road authorities to organize and control a recycling contract.

13.3 Results of research into inhibiting factors

Considerable attention has been given in this thesis to finding ways of overcoming the above inhibiting factors. Although much remains to be accomplished, various techniques have been developed which should substantially improve the acceptance of recycling by road authorities.

A cost savings model has been developed for estimating the savings that can be expected from using hot mix recycling rather than conventional methods. This model has shown that savings of about 20 per cent of the average cost of conventional asphalt mixes can be expected by adopting hot mix recycling in rural projects in the Republic of South Africa. The Department of Transport is currently using this model to evaluate expected benefits on individual rehabilitation projects. This model was also used to determine the relative influence of various factors on expected savings. Furthermore it was used to relate risks to cost savings and thereby determine the most economical design.

Because of the concern regarding the quality of hot mix recycling products, a mini recycling plant, the Servacycler, has been developed as a research tool. This plant provides the controls necessary to enable specified mixes to be produced. Research with the Servacycler is expected to contribute significantly to knowledge of the characteristics and relative performance of recycled mixes and thereby to the improvement of the quality of these mixes. I anticipate that the controls incorporated in the Servacycler can be used to advantage in commercial-scale plant. Currently, the NITRR is involved with manufacturers in the production of prototype plant of 15 to 20 tons per hour operational capacity.

A comprehensive study has been initiated which involves the use of reclaimed asphalt in various proportions to produce specified base layer and surfacing mixes and the subsequent comparison of these recycled mixes with each other and with conventional mixes produced to the same specification. The study reported in this thesis concerned the use of gap-graded reclaimed material in various proportions to produce continuous-graded base course mixes and the subsequent testing of these mixes to establish their engineering properties. The results, although tentative as they are based on limited data, suggest that gap-graded surfacing reclaimed material can be used in high proportions with new material to produce continuous-graded base course mixes without detriment to the initial engineering properties of these mixes.

The many different types of hot surface recycling equipment and methods have created considerable problems for road authorities faced with the need to assess the relative economic effectiveness of these options. As a first step in providing a structured procedure for choosing the most suitable option, the various hot surface recycling methods have been categorised into the broad groups of reshaping, regripping, reforming, rejuvenating, repaving, and remixing. The next step will be to determine the relative effectiveness of each group in terms of thickness of conventional overlays.

In general, attempts by road authorities to predetermine the use of central-plant recycling on individual rehabilitation projects lead to contractual complexities and, often, to failure to proceed with a recycling option. Investigations have shown that contractual procedures are much simplified when road authorities encourage the reuse of existing pavement material by stating that they would accept recycled mixes provided these comply with end-product specification requirements.

13.4 Recommendations

The fact that, in general, material is reclaimed from and reused on pavements which belong to road authorities is often overlooked in the complex arguments for and against recycling. In theory, road authorities should be the main beneficiaries of recycling operations. In practice, this has only occurred in cases where a road authority has taken the initiative by creating conditions to enable the effective and economical reuse of pavement material. I believe that it would be appropriate for road authorities to assume the responsibility for maximizing the potential economic benefits of recycling, by establishing the necessary procedures and specification requirements.

It has been amply demonstrated that, provided proper contractual procedures are adopted, substantial savings can arise from undertaking recycling rather than conventional operations. It must also be accepted that the economic benefits of recycling

will depend on the long-term performance of recycled material compared with that of new material. Although a lot of the required knowledge and techniques are already available, research is needed to fill remaining gaps. Priority should be given to determining the following :

- methods for calculating the cost savings that can be expected from cold mix and hot surface recycling;
- the effect of recycling additives on the behaviour of asphalt mixes;
- the durability of recycled material compared with conventional material.

APPENDIX 1

SERVACYCLER-AIDED RECYCLING DESIGN : N3, PIETERMARITZBURG BYPASS

1. INTRODUCTION

In parallel with research activities the Servacycler has been used to provide a design input for the recycling options of a number of forthcoming rehabilitation projects. This has assisted road authorities and consultants to determine appropriate mix designs and reclaimed to new material ratios for inclusion in the tender documents of those projects as guidelines to the contractors. Such an example was the involvement in the proposed Pietermaritzburg bypass rehabilitation project. The design consisted of two distinct rehabilitation measures which included either concrete or asphalt overlays. In order to utilize as much of the existing bituminous material as possible, three uses of this material were envisaged

- up to 20 per cent of reclaimed material in the asphalt overlay;
- up to 50 per cent of reclaimed material in the bituminous base course under the asphalt overlay; and
- up to 75 per cent of reclaimed material in the bituminous layer under the concrete overlay.

The Servacycler was utilized to produce trial mixes of the two bituminous base course layers using reclaimed materials from the bypass and new local materials supplied by the consultants. These mixes were needed to check the results obtained from testing laboratory mixes, and to establish whether any detrimental effects could be expected in practice from the use of reclaimed material containing tar binder or PVC-tar reseals.

2. MATERIALS AND MIX COMPOSITIONS USED

The gradings of the reclaimed and new materials used are given in Table A1 and Figure A1. The binder contents and penetrations of the reclaimed materials were :

	Binder content (%)	Penetration of recovered binder at 25°C (1/10 mm)
- asphalt (ex south-bound carriageway)	4,38	17
- asphalt (ex north-bound carriageway)	4,26	22

The design included two rehabilitation measures based on the use of either concrete or asphalt overlays.

- asphalt containing PVC-tar reseal	4,63	18
- asphalt with tar binder (assumed 85% soluble)	3,97	-

TABLE A1 : Gradings* of the reclaimed and new materials

Sieve size mm	Milled asphalt (1)	Milled asphalt (2)	Milled asphalt & PVC-tar	Milled asphalt with tar	13,2 mm dolerite	Crusher dust	Pit sand
26,5	-	-	-	100,0	-	-	-
19,0	100,0	100,0	100,0	94,1	100,0	-	-
13,2	95,4	94,0	96,9	83,4	80,4	-	-
9,5	84,5	80,5	75,8	70,6	14,6	100,0	-
6,7	74,1	64,0	61,5	58,4	4,9	98,8	-
4,75	66,0	54,8	56,0	48,6	-	92,4	100,0
2,36	54,1	46,4	51,5	36,6	-	74,1	99,9
1,18	45,8	42,5	48,3	28,7	-	53,0	99,6
0,600	38,4	38,6	42,3	23,2	-	37,1	96,5
0,300	27,5	24,1	28,3	15,3	-	25,8	72,1
0,150	15,1	11,6	14,1	7,7	-	18,3	28,5
0,075	9,8	7,8	9,5	4,8	-	13,3	13,2

*Cumulative percentages passing

(1): North-bound carriageway

(2): South-bound carriageway

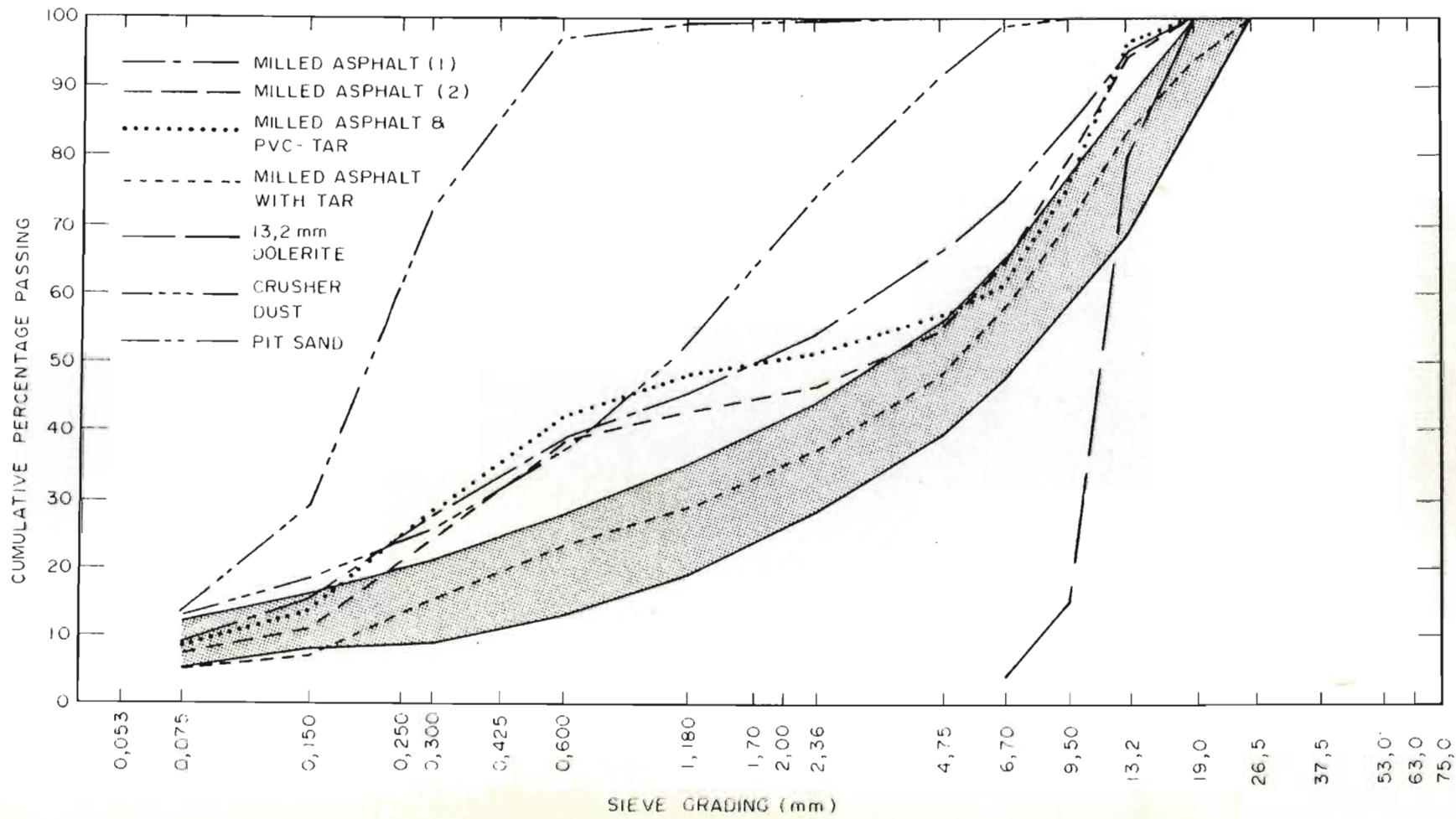


FIGURE AI

CONTINUOUSLY-GRADED ASPHALT ENVELOPE AND GRADINGS OF RECLAIMED AND
NEW MATERIAL

The compositions of the six mixes produced are given in Table A2. Table A3 shows that the achieved ratios of reclaimed to new material were close to the specified values. This table shows also that the discharge temperatures were within the desired range of 140⁰C to 160⁰C. It is noted that heavy smoke emissions occurred during the production of mixes containing reclaimed asphalt with tar binder.

TABLE A2 : Composition of mixes

Mix number	Reclaimed material	New material	Type of new binder	Binder content aimed for
1	50% (1)	18% (5) 12% (6) 20% (7)	80 - 100 Penetration grade bitumen	5,3% <u>±</u> 0,5%
2	50% (1)	As for mix 1	150 - 200 Penetration grade bitumen	5,3% <u>±</u> 0,5%
3	75% (1)	25% (7)	150 - 200 Penetration grade bitumen	6,3% <u>±</u> 0,5%
4	25% (1) 25% (2)	As for mix 1	150 - 200 Penetration grade bitumen	5,3% <u>±</u> 0,5%
5	25% (3) 25% (4)	As for mix 1	150 - 200 Penetration grade bitumen	5,3% <u>±</u> 0,5%
6	37,5% (3) 37,5% (4)	As for mix 3	150 - 200 Penetration grade bitumen	6,3% <u>±</u> 0,5%

(1): milled asphalt (ex north-bound carriageway)

(2): milled asphalt containing PVC-tar reseal

(3): milled asphalt (ex south-bound carriageway)

(4): milled asphalt with tar binder

(5): 13,2 mm dolerite aggregate

(6): crusher dust (dolerite)

(7): pit sand.

TABLE A3 : Mix proportions and discharge temperatures

Mix	Reclaimed/new ratio		Discharge Temperature oC
	Specified	Achieved	
1	50/50	51/49	145
2	50/50	54/46	150
3	75/25	76/24	145
4	50/50	53/47	155
5	50/50	53/47	145
6	75/25	76/24	145

3. LABORATORY RESULTS

The test results are given in Tables A4 and A5.

3.1 Gradings

The gradings of the mixes produced are given in Table A4 and Figure A2. These gradings are not within the intended continuously-graded specification.

TABLE A4 : Gradings of the mixes produced

Sieve size mm	Cumulative percentages passing					
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
26,5	100,0		100,0		100,0	
19,0	98,9	100,0	98,6	100,0	98,6	100,0
13,2	92,2	95,1	90,9	93,3	91,6	94,8
9,5	74,9	79,8	83,5	70,1	81,3	84,8
6,7	68,9	75,1	77,1	59,5	77,1	79,7
4,75	61,6	68,1	68,8	54,7	71,2	73,6
2,36	53,1	59,8	59,7	48,7	64,0	69,6
1,18	46,8	52,3	54,3	43,8	56,6	66,6
0,600	40,4	44,9	48,6	39,1	48,9	61,7
0,300	27,8	29,8	34,1	29,7	27,9	39,3
0,150	13,0	13,8	14,3	14,8	12,3	15,1
0,075	8,5	8,4	9,3	8,2	8,7	9,6

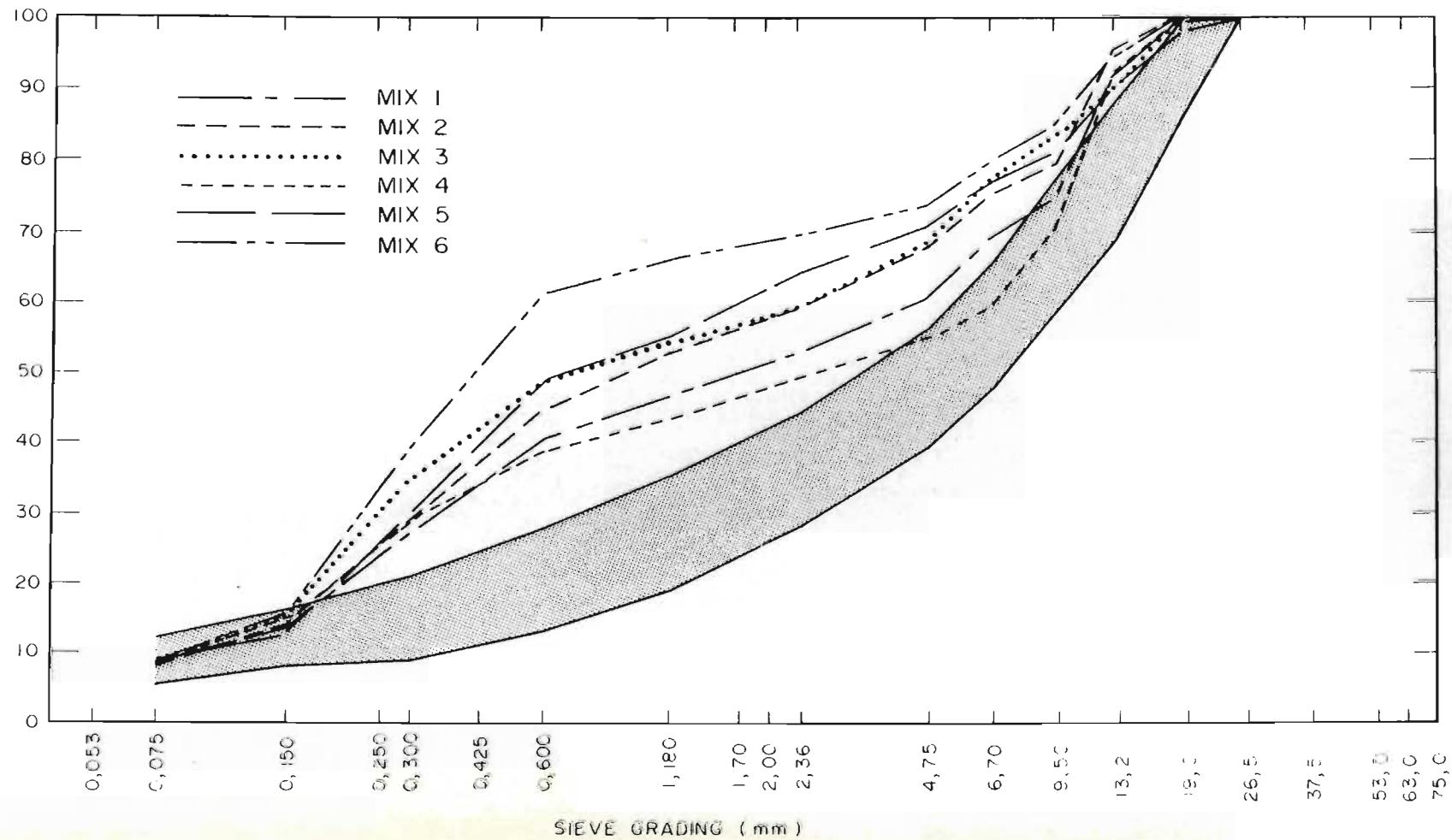


FIGURE A2

CONTINUOUSLY-GRADED ASPHALT ENVELOPE AND GRADINGS OF MIXES 1,2,3,4,5 & 6

TABLE A5 : Summary of laboratory test results

MIX	BINDER CONTENT (%)	RECOVERED PENETRATION AT 25°C (1/10 mm)	MAXIMUM DENSITY OF MIX (kg/m ³)	BULK DENSITY OF MIX (kg/m ³)	VOIDS IN MIX (%)	MARSHALL STABILITY (kN)	FLOW (mm)	INDIRECT TENSILE STRENGTH ^X (kPa)	E- MODULUS ^X (MPa)	CREEP MODULUS ^{XX} (MPa)
1	6,19	31	2514	2468	1,8	9,7	2,5	1969	4474	108
2	6,21	64	2513	2449	2,5	8,0	2,1	1320	3414	88
3	6,61	44	2477	2399	3,1	8,6	2,3	1498	5477	48
4	5,87	58	2537	2494	1,7	7,9	2,2	1705	5588	184
5	5,88	90	2510	2379	5,2	7,7	1,5	745	2765	127
6	6,78	72	2445	2324	5,0	4,6	0,8	807	2001	FAILED

^X Determined at 20°C.

^X The dynamic indirect tensile test was used for the determination of the elastic modulus. This test was done at 20°C with a repeated load of 20% of the static indirect tensile strengths. The loading time was 0,1 seconds and the test was done up to 2000 repetitions.

^{XX} Determined at 40°C with a constant load of 200 kPa. (3) (NITRR Report TP/54/82).

Difficulties in conforming with grading specifications have been experienced often when large quantities (50 per cent or more) of semi-gap-graded or gap-graded reclaimed asphalts are used to produce a continuously-graded recycled mix. I believe that inadequate control of the milling operation tends to aggravate the problem. Two options are available in such cases:

- either to reduce the percentage of reclaimed asphalt in the mix, or
- to change the grading specification.

3.2 Binder penetration

The penetration values indicate that a 80-100 penetration grade bitumen is appropriate for mixes containing 50 per cent reclaimed material when the latter consists of either asphalt or a 50/50 mixture of asphalt and asphalt with a PVC-tar reseal. A 150-200 penetration grade bitumen appears suitable for mixes containing 75 per cent reclaimed material.

Unacceptably high penetrations were obtained for mixes 5 and 6 which had tar binder in 50 per cent of the reclaimed material.

3.3 Marshall characteristics

It is noted that the Marshall stability of mix 6 and Marshall flow of mixes 5 and 6 are low. In general, the rest of the Marshall results are satisfactory.

3.4 Elastic, indirect tensile strength and creep characteristics

The dynamic moduli of elasticity and indirect tensile strengths obtained appear to be satisfactory, with the exception of the mixes containing tar binder (mixes 5 and 6). It is worth noting that the PVC-tar reseal (mix 4) did not seem to have any adverse effect.

As regards the creep moduli, acceptable values (above 80 MPa for E4 traffic) can be expected for mixes containing 50 per cent reclaimed material and which have a binder content of about 5,3 per cent. In contrast, the creep moduli of the mixes containing 75 per cent reclaimed material were lower (mix 6 failed). However, I believe that the creep modulus of mix 3 is likely to prove adequate for a layer under a concrete overlay. The relation between indirect tensile strength and recovered penetration is shown in Figure A3, whilst Figure A4 shows the relation between creep modulus and binder content. Both indicate fairly strong linear relationships. Deformation is a major concern in Natal and it is worth noting that the steepness of the regression line in Figure A4 shows that a small decrease in binder content can lead to a significant increase in the value of the creep modulus.

4. CONCLUSIONS

Some worthwhile findings were derived from the above work. These include:

- it seems unlikely that the grading specification limits of a continuously-graded mix will be met using 50 per cent or more of the reclaimed material. Consideration will have to be given to either reducing the percentage of the reclaimed material or adopting a different grading specification
- limited amounts of the PVC-tar reseal in the reclaimed material do not appear to have detrimental effects on the characteristics examined; this is probably due to the ageing of the tar binder in the surface treatment
- the reclaimed asphalt containing tar binder should not be used in any significant proportions in hot mix recycling
- a 80-100 penetration grade bitumen should prove satisfactory for mixes containing 50 per cent reclaimed material, and a 150-200 penetration grade bitumen for those containing 75 per cent reclaimed material.

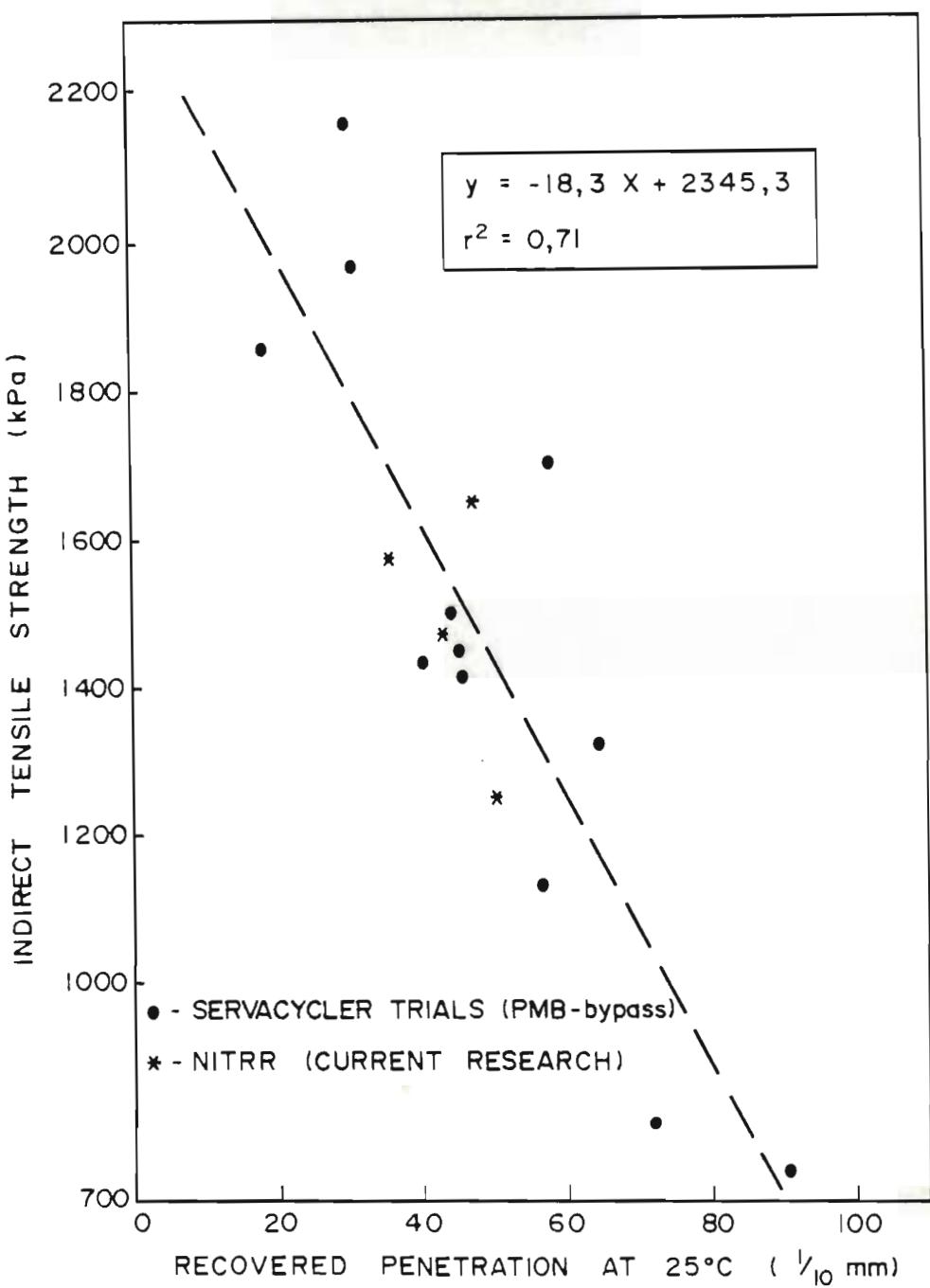


FIGURE A3

RELATION BETWEEN INDIRECT TENSILE STRENGTH AND
RECOVERED PENETRATION

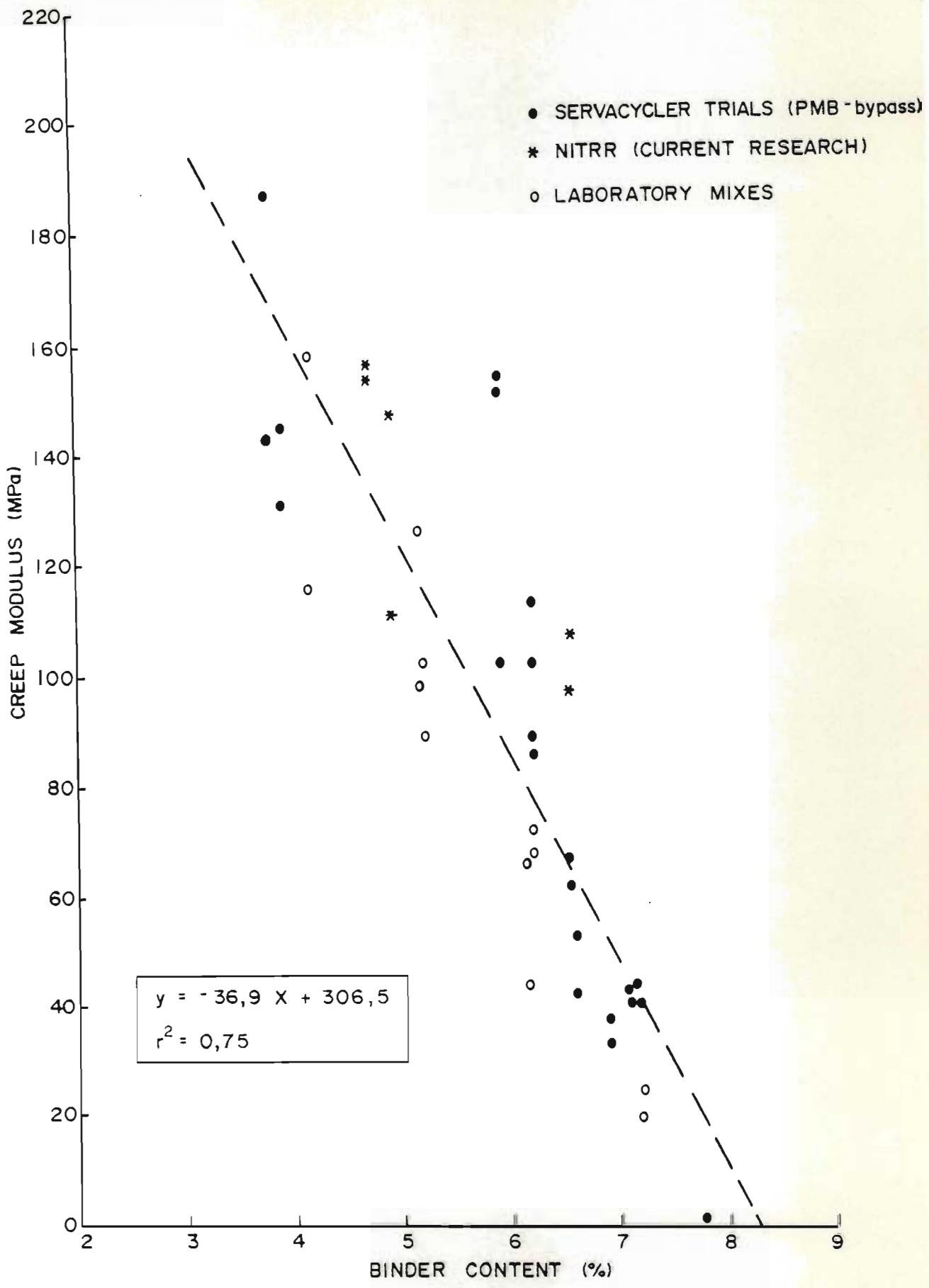


FIGURE A4

RELATION BETWEEN CREEP MODULUS AND BINDER CONTENT

The use of the Servacycler as a design aid proved useful. Apart from the logistic advantages over traditional methods (laboratory mixes) in the production of the quantities of mixes needed for testing, the operation simulated realistically drum-mixer hot mix recycling. Of course, this simulation had no effect on the obtained gradings. However, it meant that the selection of appropriate grades of new bitumen could take into account the effects of plant heating, heat exchange and mixing, albeit in a mini-scale, on the resultant binder characteristics. Furthermore, it gave a good indication of the likelihood, or not, of pollution problems occurring, during the actual recycling operations, because of the use of reclaimed material containing tar binder or PVC-tar reseals.

APPENDIX 2

DETERMINATION OF TYPE AND AMOUNT OF RECYCLING ADDITIVE

1. INTRODUCTION

Section 6, Recycling Additives, concluded posing a number of questions about the use and effect of additives in recycling. The issues raised by these questions need to be resolved before recycling additives can be used effectively.

The study into the effect of the proportion of reclaimed asphalt on the quality of the recycled product (section 12.8) includes the production of mixes containing additives. Additives are used when commercially available penetration-grade bitumens cannot rejuvenate the existing binder. This happens when using high reclaimed to new material ratios and/or reclaimed materials containing particularly hard binder.

In the above cases it is essential to use the correct type and amount of a recycling additive. Both these requirements could be met easily by establishing fluxing power plots of recycling additives if penetration (or viscosity) was the sole criterion of a rejuvenated binder's performance. However, binders are more complicated than that and their chemical composition balance needs also to be taken into account.

In the study a chemical analysis is used to determine the composition of the reclaimed bitumen and thus to establish the composition of recycling additives needed to produce an acceptable final binder. This analysis is used, as suggested by Marvillet (1), in conjunction with the bitumen penetration and content in the reclaimed material, the solvent power of recycling additives, the reclaimed to new material ratio, and the required binder content in the recycled mix, to determine the appropriate type and amount of recycling additive.

2. CHEMICAL ANALYSIS

The reclaimed binder is analysed using a solvent extraction method (2) to determine its composition and the fractions are plotted on a triangular graph, Figure A5. There should be an area on the graph into which satisfactory bitumens fall and bitumens that have performed adequately are being analysed in order to define its parameters. Aged bitumens may well fall outside this area and, in recycling, it is the function of recycling additives (when the use of penetration grade bitumens will not suffice) to bring them into this area.

In the example shown in Figure A5, X represents an aged bitumen having 30 per cent asphaltenes, 50 per cent aromatics and resins and 20 per cent saturates and Y a recycling additive with 5 per cent asphaltenes, 70 per cent aromatics and resins and 25 per cent saturates. Their blending will result in a binder with fractions along the XY line.

3. RECYCLING ADDITIVE'S EFFECT ON PENETRATION

Following the determination of the desired composition and hence the type of recycling additive needed, the relative effect of suitable additives on the penetration of the reclaimed binder need to be assessed. This is done by combining these additives in various proportions with the reclaimed binder and measuring the penetration of the blend. The results will be plotted as shown in Figure A6.

The examples given in Figure A6 show that additive A has a greater fluxing power than additive B. An aged binder with penetration of 20 needs to be combined with 40 per cent of additive A or 53 per cent of additive B to produce a blend with penetration of 60 to 70. The selection between additive A and B is based on the required quantity of new binder in the final blend.

Plots of this type are used to choose between suitable additives, the most applicable for particular reclaimed materials and reclaimed to new material ratios.

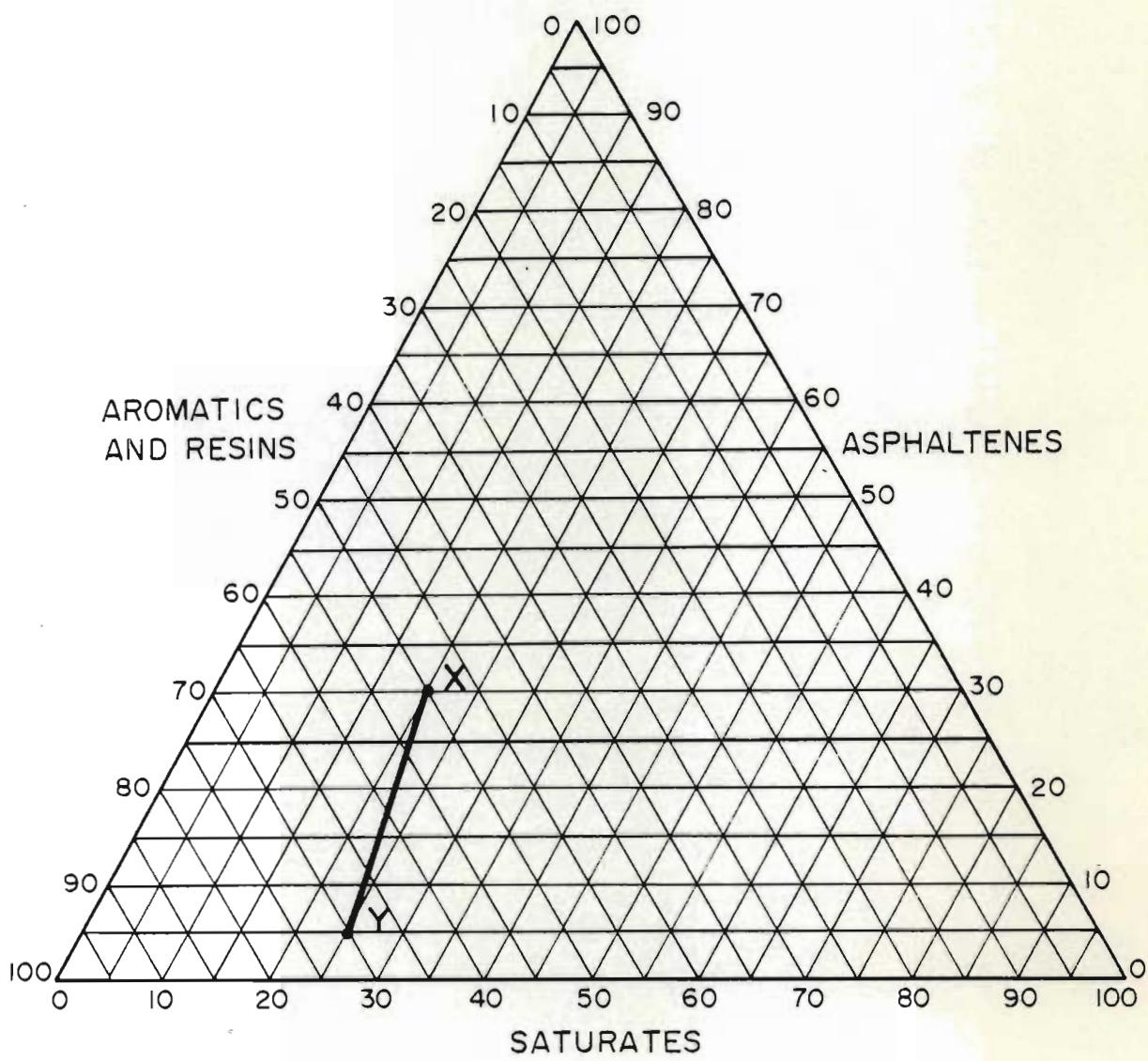
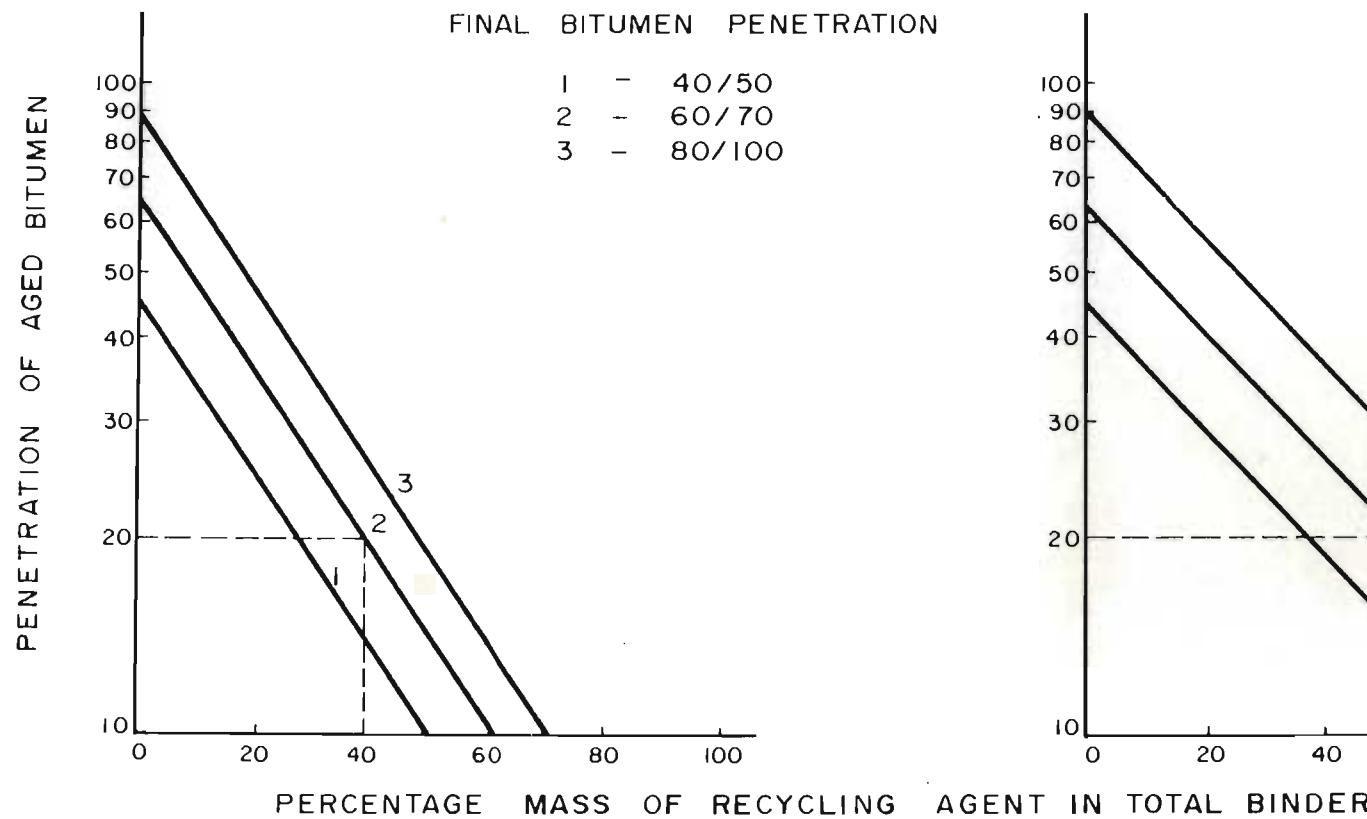
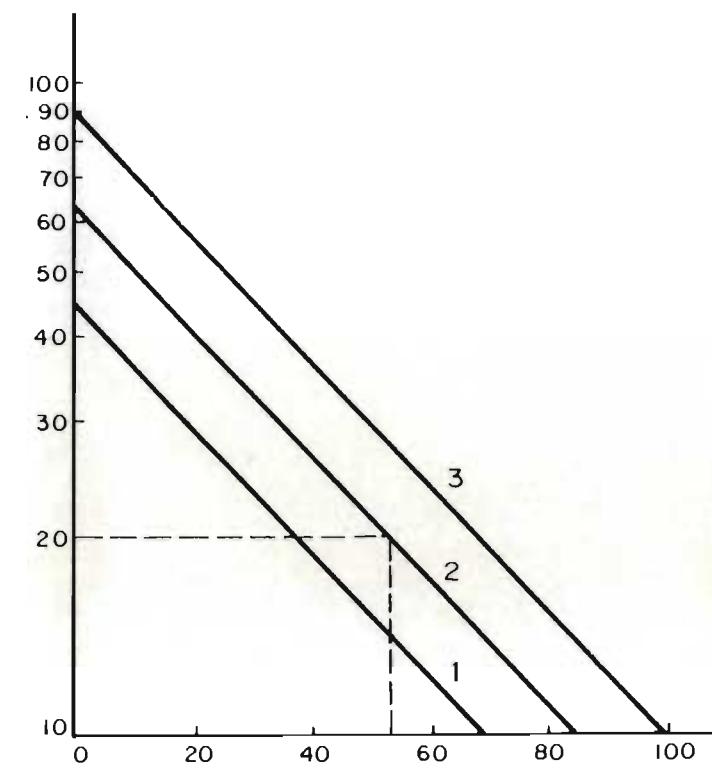


FIGURE A5
BITUMINOUS BINDER COMPOSITION CHART

RECYCLING AGENT A



RECYCLING AGENT B



A2 - 4

FIGURE A6
THE FLUXING POWERS OF TWO RECYCLING AGENTS

4. DISCUSSION

For simplicity, the above sections illustrated the procedure followed in cases where a recycling additive is used alone to rejuvenate an aged binder. However, in general, recycling additives are used in conjunction with new penetration grade bitumens. The approach remains basically the same, albeit more involved.

The chemical analysis in these cases includes the new bitumen whose composition is plotted in Figure A5 and taken into account. Similarly its fluxing power is considered together with that of the suitable recycling additives in determining the most appropriate combination for particular blends and reclaimed binders.

The above procedure enables the determination of the need, type and amount of recycling additive for a given recycling situation. Therefore, mixes containing additives can be correctly designed and produced to investigate outstanding issues such as mix efficiency and time dependant effects.

REFERENCES

1. MARVILLET, J. Characterization and field testing of recycling agents. Proceedings of the Fourth Conference on Asphalt Pavements for Southern Africa, Cape Town, South Africa, March 1984.
2. 1983 Annual Book of ASTM Standards, Part 15, D4124-82, "Standard test method for separation of asphalt into four fractions" pp 676-680.