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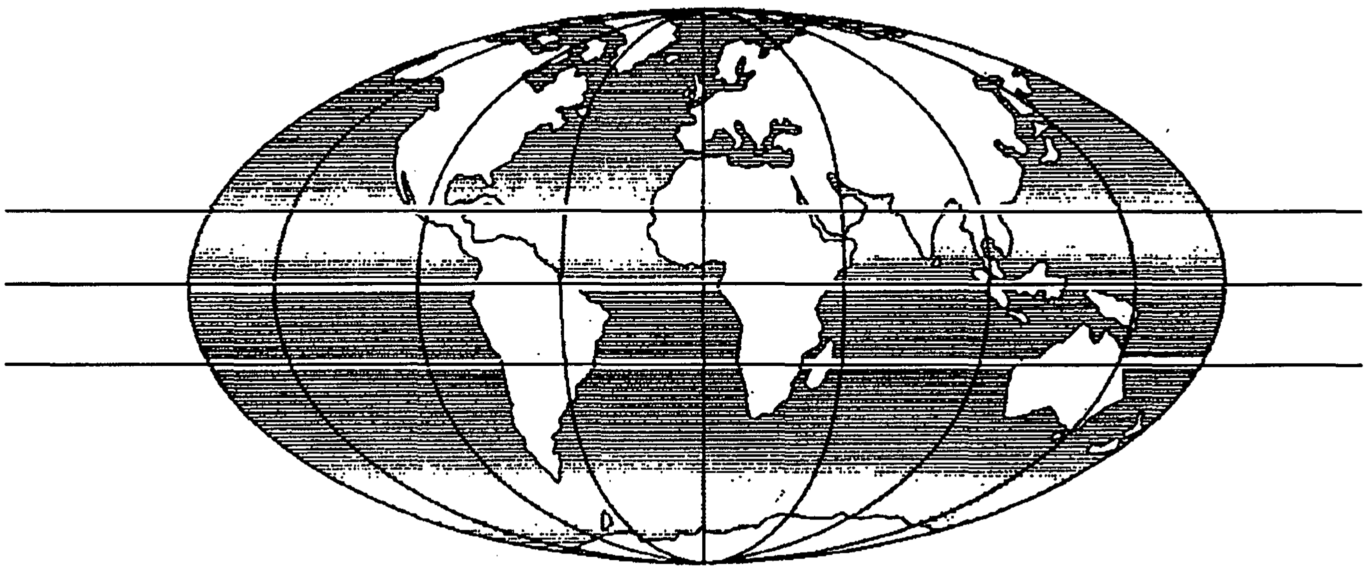

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RESEARCH ON HOT ROLLED SHEET OVERLAYS IN INDONESIA

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RESEARCH ON HOT ROLLED SHEET OVERLAYS IN INDONESIA

PREFACE

A better understanding of the behaviour of bituminous materials, their mode of failure and the optimisation of both the mixes and the structural design are of prime importance to Indonesia's Directorate General of Highways (DGH).

Over the past five years many thousands kilometres of road have been subjected to a road betterment programme which includes an asphaltic overlay composed of Asphalt Treated Base (ATB) and a thin wearing course of Hot Rolled Sheet (HRS). The overlay materials are designed to accomodate a greater amount of binder than the traditional, alternative asphaltic concrete (AC) mixes. The aim is to impart greater flexibility and durability to the pavement surface so that it can tolerate the high deflections common in Indonesia and to reduce the rate at which embrittlement of the bituminous material takes place, thus reducing the development of cracking. The HRS mixes are more similar to the UK gap-graded-hot-rolled asphalts than the continuously-graded asphaltic concretes of America origin. The adoption of the HRS technology followed studies in the early eighties in Indonesia.

In order to develop suitable performance prediction models for both HRS and AC mixes and improvements to mix specifications and thickness design, in-depth road performance and laboratory studies have been implemented as part of a joint programme of research involving the Institute of Road Engineering (IRE) and the UK's Transport and Road Research Laboratory (TRRL). The project has been underway since 1988.

This report summarises the design and implementation of the research and describes the analysis of the results of the initial field condition surveys and laboratory investigations which provide a broad picture of the behaviour of the overlays which had been constructed prior to the start of the project.

A comprehensive description of the design and implementation of the research and of the measurement, sampling and test methods used is contained in a separate report.

Subsequent reports will be issued which contain the results of the detailed performance studies and analysis.

Bandung, January 1991
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RESEARCH ON HOT ROLLED SHEET OVERLAYS IN INDONESIA

ABSTRACT

A comprehensive research programme has been established to develop performance prediction models for the alternative structural road surfacings in Indonesia and to improve specifications and thickness design. For this purpose detailed observations have commenced on 25 monitoring sections selected from a 360 km sample of the road network which was subject to a general condition survey. The road links and sections cover a wide range of design parameters and performance.

This report describes the design and implementation of the research on existing bituminous overlays and contains some early results and details of the pavement structures and overlay mixes.

In general, the performance of the mixes made to a hot rolled sheet specification is very variable. Although mean values for the rate of rutting and crack development can be low 90 percentile values are high with critical conditions being reached within a few years.

Correspondingly, the properties of the mixes manufactured to a common specification are variable, ranging from gap-graded to continuously-graded and covering a wide range of bitumen content and other properties.

Given the degree of variability it is not possible to make conclusive recommendations at this stage. Further observation of the monitoring sections and at a network level is required.

1. INTRODUCTION

In tropical areas of the world bituminous road surfacings are required to tolerate harsh climatic conditions and heavy axle loads. In addition, in many areas, deflections are high because of weak subgrades. These conditions impose severe demands on the design of mixes which must possess good load spreading properties to protect the lower pavement layers and the subgrade, good flexibility to withstand the high strains imposed by heavy traffic, good fatigue properties to carry traffic for as long as possible and good durability so that their properties do not deteriorate (degrade) rapidly.

Prior to about 1983 the predominant type of premix used in Indonesia for structural strengthening and overlaying was a continuously graded asphaltic concrete (AC) to American specifications. This material is relatively stiff and can perform well if it is made properly. Unfortunately its properties are extremely sensitive to its composition and very small changes produce mixes which are unsatisfactory.

Experience in Indonesia and elsewhere has shown that the most likely problem is poor durability and flexibility giving rise to premature cracking.

In 1983 Corne described an alternative composite overlay system comprising an asphalt treated base (ATB) and a wearing course of hot-rolled sheet (HRS). These materials were designed to accommodate a relatively high bitumen content to provide better flexibility and improve durability. The HRS is based on the gap-graded hot-rolled asphalt used in the UK (BSI, 1985). This material is more tolerant of minor changes in mix proportions and is therefore easier to make successfully. It is also easier to compact than AC and is therefore potentially more reliable.

Despite these advantages gap-graded mixes have not been used extensively in the tropics because of the fear that they will deform under the combined effects of high temperatures and heavy wheel loads. However, experiments carried out in the tropics (SMITH and JONES, 1982) and experience in Southern Africa indicated that gap-graded mixes could be designed to overcome this problem. Corne's paper (CORNE, 1983) showed that such mixes performed reasonably well in Indonesia and the method was adopted by the Directorate General of Highways for use in the road betterment programme.

Over the past five years several thousand kilometres of road have been upgraded with composite overlays of ATB and HRS. The investment in HRS technology has been large and ensuring its successful performance is therefore of high priority to DGH. Quantification of its performance in comparison with alternative materials, refinements in the design method and in the specifications and improvements in construction practice are necessary if HRS is to achieve its full potential for road rehabilitation and to remain an important option for road strengthening. To undertake this study a cooperative research project was established in 1988 between the Institute of Road Engineering in Bandung (IRE) and the Transport and Road Research Laboratory of the UK (TRRL).

This report describes the design and implementation of the research and the analysis of the results of the initial field condition surveys and laboratory investigations which provide a broad picture of the behaviour of the overlays which had been constructed prior to the start of the project.

2. OBJECTIVES OF THE RESEARCH

At the outset of the research the following objectives and output were described:

Objective :
To evaluate the performance of structural road surfacings and rehabilitation methods in Indonesia.

Output :
An established research programme leading to sound performance predictions and improved specifications for hot-mix surfacings together with a calibrated analytical structural design method for thickness design.

3. DESIGN OF THE RESEARCH

Ideally the objectives of the research could be achieved by constructing a series of experimental overlays in which the key variables affecting performance were varied in a controlled way so that their effect on performance could be quantified. Such an approach would be scientifically correct but would be very difficult to carry out because of the large number of important performance related variables which would need to be controlled and varied systematically. Fortunately the scale of the betterment programme meant that a wide variety of roads had been overlayed under a wide range of conditions. Recognising that the nature of road making materials and mix production processes are such that quite wide variations in mix composition occur within any project, it was anticipated that the range of conditions encountered on the roads which had been rehabilitated by 1988 would cover the ranges of most of the key variables which were required for the study. Any factors which could not be assessed by studying the completed overlays could be taken into account by studying overlays which are under construction at the present time. Thus the scope of the research included the following principal components:

(a) A desk study of the design and construction procedures and problems encountered.

(b) Condition survey of a sample of the roads to identify general performance trends and mechanisms of failure.

(c) Selection of a sample of the roads for detailed investigation, including sample extraction, laboratory testing and performance monitoring over time.

(d) Analysis of behaviour to quantify the effects of key variables such as traffic level, traffic speed and mix properties.

(e) Identification of components missing from the sample and selection of additional samples of road from ongoing rehabilitation projects to provide the extra data.

(f) Evaluation of problems associated with the HRS techniques from the design stage through to construction.

(g) Theoretical analysis. The present structural design approach suffers from a number of difficulties concerned primarily with the analytical/ mechanistic principles rather than the mix design method itself. If the theoretical approach is to be of value in extending the design method to a wider range of conditions, these problems need to be resolved and a theoretical model developed, verified and calibrated to describe the observed performance and modes of failure.

(k) Defining the limitations of the method based on field experience and theoretical analysis.

(l) Refinement of the design method, improvement in specifications and construction procedures and publication of results.

The research design is illustrated in the form of a flow chart in Figure 1.

This report is concerned with the results of the condition survey, (c) above, the selection of sections of road for detailed testing and longer term performance monitoring and finally with the initial results of the laboratory test programme.

A comprehensive description of the design and implementation of the research and of the performance measurements, sampling and test methods used is contained in a separate report (TOOLE et al 1991).

4. FACTORS AFFECTING PERFORMANCE

The main factors which influence the performance of overlays are :

(1) Type of overlay and its mix properties including the properties of the individual components.

(2) The condition of the existing road on which the overlay is placed. Both structural condition and surface condition are important and therefore the type of road structure will also be important.

(3) Overlay thickness and the combined structural properties of the pavement after overlay.

(4) Climate. Average temperatures and temperature range are important as well as rainfall.

(5) Time. The materials deteriorate with time.

(6) Traffic characteristics. Both volume and axle loads are important.

(7) Road geometry. This affects the speed of vehicles, the degree of channelisation or wheeltracking and the tractive forces at the road surface.

In order to derive the interrelationships between performance and the main variables, the selection of sections for detailed monitoring should cover the widest possible range of all of the variables. However, at the time of the general condition survey when sections had to be selected, details of mix properties were not available. Visual inspection indicated that the inherent variability of mix properties along a site appeared to be too high for research purposes and therefore suitable information was not obtained until the laboratory analysis of site samples was completed.

To take the above problem into account, the selection of sections was made using apparent overlay performance as an additional variable. In this way sections of road which were similar in all respects as far as all the other variables were concerned but which displayed different degrees of deterioration were selected in the belief that the differential performance could be explained by the differences in the mix properties.

5. IMPLEMENTATION

A sample of 360 km of overlays, from a total of 3250 km built between 1985 and 1989, were selected and subjected to a network level condition survey, known as Pavement Condition Survey Level 1 (PCS 1). Brief details of the roads surveyed are contained in Table 1.

Measurements were recorded for each lane and each 100m length of road between successive Kilometre posts.

Finally, twenty five representative sections, most of which were 500 m in length, were established for detailed studies. Each of these, so called monitoring sections, is being surveyed at 10 m intervals on a regular basis to determine the rates of change in surface and structural condition and of the hardness of the bitumen in the overlays. Block and core samples of the asphalt mix and samples of unbound layers have been tested in the laboratory.

6. THE NETWORK LEVEL CONDITION SURVEY

6.1 Measurements

Representative rut depths were calculated from three measurements taken at equally spaced intervals in both the outer and inner wheeltracks (IWT and OWT) for each 100m length of road. The maximum rut depth was determined by visually selecting areas of deepest rutting. A note was made of the type of rutting; either as deformation (D), where the movement of the pavement surface is vertically downwards, or as pushing (P), where evidence of heave in the surfacing (as a ridge) on either side of a wheeltrack is apparent.

The extent of cracking was recorded as the length of roadway parallel to the road edge which was affected by cracking.

During the survey the road was subdivided into the following five areas: the road edge (E), OWT and IWT, the mid-lane (ML) and the centreline (CL). The intensity of cracking was recorded as the most severe cracking in each 100m length of road in one of the following 6 classes: none (0), single crack (1), more than one crack, not connected (2), more than one crack interconnected, not closed (3), interconnected cracks forming closed polygons (4) and interconnected cracking with loose blocks (5). The type of cracking was also recorded as longitudinal (L), transverse (T), block (B), crocodile (C), irregular (I) or parabolic (P). The areas of patching, potholing and depressions were also recorded as well as conditions such as slippage, bleeding and ravelling.

6.2 Results

The main results of the survey are presented below, and discussed later, in terms of wheelpath rutting and cracking. Summary statistics of the representative rut depth for each road surveyed are given in Table 2.

A typical distribution of rut depth data related to the type of rutting is illustrated in Figure 2.

Summary statistics of the linear extent of all wheelpath cracking are given in Table 3.

The mean distribution of cracking for all roads studied related to roadway position is given in Table 4.

The percentage of 100m subsections occupying different performance categories, in terms of the representative rut depth and the linear extent and intensity of cracking, are given in Tables 5, 6, and 7 respectively.

Tentative performance categories have been chosen from two sources; those recommended by TRRL for use in assessing overlay performance in the United Kingdom (KENNEDY and LISTER 1978) and those recommended by TRRL's Overseas Unit (1987) for use as maintenance intervention levels.

The TRRL UK divide overlay performance into three categories of sound, critical and failed. The onset of critical conditions has been defined as rutting in the wheeltracks of 10mm or the beginning of wheelpath cracking and is the preferred timing for a strengthening overlay to be applied. Structural failure is said to occur when rutting has reached 20-25mm or the appearance of severe wheeltrack cracking.

The recommended intervention levels defined by TRRL's Overseas Unit are as follows : an extent of cracking of 5-10 per cent usually triggers resurfacing using a spray and chip surface treatment whilst values of greater than 10 per cent indicate more serious deterioration and warrant detailed investigation. In the latter case this is because strict prescriptive measures are not usually generally applicable in the tropics since the principal failure mechanisms and associated causes are often different to those in temperate climates and design and construction conditions are much more variable.

The above criteria provide a benchmark for assessing the observed performance although they need not be directly applicable to Indonesian conditions given possible differences in the types and modes of failure which actually occur and the prevailing traffic, climatic and economic conditions.

6.3 Discussion

As indicated in Table 2, the average rate of rut development varied from virtually zero to 4mm per year. This is under conditions of both light and heavy traffic, in a variety of geometric situations and for three different specified mixes. The distribution of rut depth is also considerable as indicated in Table 2. For the representative rut depth statistic, the 90 percentile value is approximately twice the median value indicating that for a number of the roads the rate of rutting is more than 8mm per year over 10 per cent of their length.

A similar picture emerges from Table 5 where the percentage of 100 m sub-sections in each performance category related to rutting is given. On average 10-15 per cent of all sub-sections on the most heavily trafficked roads were in a critical condition after two years. On a linear projection approximately 50% of the sub-sections roads could be expected to be in a critical condition at the end of their 10-year design life.

The rutting behaviour of roads carrying more lightly loaded vehicles is generally satisfactory. The roads included in this category include Ciamis-Cikijing, Cikijing-Cirebon, Ciawi-Cianjur, Kopo-Rancabali and Sadang-Subang. Exceptions to this are expected to be in areas of severe geometry. This has yet to be confirmed by further analysis.

Although the actual cause(s) of the rutting could not be determined with certainty during the surveys it was possible to assess likely causes by noting whether any pushing (or heave) was apparent at the edge of the ruts. Whereas the former is a surfacing problem only the latter is usually indicative of structural weakness or secondary compaction. However, the measures for controlling them may need to be quite different and would depend on the primary type of distress.

The percentage of rut depths where heave or pushing was apparent has been determined for each road link. However, as illustrated by the example in Figure 2, the existence of pushing is only apparent if substantial rutting has taken place (10 percentile = 6mm). In cases where the type of rutting was recorded as vertical deformation the distribution of the representative rut depths is less (90 percentile = 6 mm). This therefore suggests that only where serious rutting takes place can heave be identified and in such circumstances the rutting is likely to be a result of failure in the mix rather than structural deterioration. To investigate this the deformation within individual layers is being determined by digging trenches across the width of the road and measuring the profile of successive layers.

As indicated in Table 3 the average extent of cracking is relatively low, with a few exceptions. However, it is clear from the range of values that the variability is high with maximum values between 20 and 100 per cent, and an overall mean maximum value of approximately 60 per cent. The 90 percentile values range from less than 1 (5 cases) to 15 per cent.

The sites which are badly cracked include three out of the five lightly trafficked routes, namely: Ciamis-Cikijing, Cikijing-Cirebon and part of Ciawi-Cianjur. The mixes used on these roads are to different target specifications; namely HRS A, HRS B and AC respectively (BINA MARGA 1986). However, in the case of Ciawi-Cianjur a deliberate change to the specification for surfacing material was made for a substantial length of roadway. This has enabled the effect of nominal mix type to be identified under reasonably similar design conditions.

The data in Table 6 indicates that greater than 20 per cent of the length of Ciawi-Cianjur surfaced by AC was cracked to a degree that would warrant resealing after 2 years whilst 10 per cent was more severely affected. Only 2 per cent of the HRS B surfacing was found to be in a similar condition.

The above discussion on cracking has been related to the linear extent of all cracking irrespective of intensity or type. The definition of pavement condition from TRRL UK is in terms of intensity of cracking. For this study the percentage of 100m sub-sections in each category of crack intensity is shown in Table 7. This shows that of the three most badly cracked roads two of them, namely Cikijing-Cirebon and Ciawi-Cianjur, are more severely cracked with 11% and 18% respectively in a critical/failed condition. The corresponding value for Ciamis-Cikijing is 5%, and in this case most of the cracking is in classes 1 and 2 which is indicative of line (or longitudinal) cracking possibly as a result of road widening.

By illustrating performance by intensity of cracking, as opposed to linear extent, the presence of localised failures can be detected. For the more heavily trafficked routes of Tangerang-Merak and Dawuan-Cirebon-Kalijaga the percentage of 100m sub-sections in a critical/failed condition is between 7 and 17. The HRS B on part of Ciawi-Cianjur, Cirebon-Losari, Kopo-Rancabali and Sadang-Subang have less than one per cent in a critical/failed condition.

The data in Table 4 which quantifies the distribution of cracking with respect to roadway position indicates that in most cases a greater amount of cracking occurred in the OWT and road edge areas. These are normally recognised as the weakest positions in a road structure. The causes of cracking in these areas can, however, vary and may be a result of fatigue in the bound layers due to inadequate structural design, a lack of side support, poor road widening practice or moisture ingress into the unbound layers. Swelling and shrinkage of the lower layers as a result of seasonal moisture changes may also occur.

In summary, the data obtained during PCS1 allowed a general assessment to be made of the performance of the overlays. More importantly for the purposes of this research, the results of PCS1 enabled sections of road with widely different performance characteristics to be identified.

In the future, repeat surveys at intervals of two to three years are planned to further quantify performance at the network level.

7. THE MONITORING SECTIONS

7.1 Pavement composition

The mean and range of overlay thickness, the type of supporting layers and the subgrade strength on each section are given in Table 8.

As indicated in Table 8 considerable variation in thickness of the overlay occurs within several sections. In a number of cases the variation is sufficiently large, and consistent with chainage, to warrant further sub-division of these sections. This will be considered in later analysis following further sampling and the grouping of all core, block and test pit data. It will lead to an increase in the number of sections and the range of overlay thicknesses covered.

The overall range of overlay thicknesses covered is, however, considerable, ranging from approximately 50 mm to more than 200mm.

Penetration Macadam (PM) is the most common upper base layer, and is present in 21 of the 25 sections. It would also have been the original pre-overlay surface. Unbound granular materials have been used as bases in the upper layer of the remaining 4 sections. This is a result of grade-raising or localised reconstruction.

The lower base layers comprise unbound granular materials (6 sections), PM (1 section) or Telford stone layers (10 sections). In a number of cases there are two lower base layers of PM/Telford (1 section) or Telford/Unbound (5 sections). In a further example a single base layer exists lying directly on a weak subgrade.

As indicated in Table 8, subgrade strengths are predominantly weak and twenty of the sections possess subgrades with CBR values in the range 1-6 per cent.

7.2 Properties of the bituminous overlay materials

Samples of bituminous mixes taken from the monitoring sections have been analysed and the results are summarised in Table 9. In most cases the overlays comprised three layers; namely the hot-rolled sheet surfacing (HRS), the asphalt treated base (ATB) and the asphalt treated base levelling layer (ATBL) (BINA MARGA, 1986).

The mean gradation of typical bituminous surfacings are plotted in Figures 3 and 4 and are compared with appropriate grading envelopes conforming to a hot-rolled asphalt (HRA) (BSI, 1985) or asphaltic concrete (AC) (TRRL, 1977).

It is clear from Table 9 and Figures 3 and 4 that a significant variation in mix properties exist.

In order to distinguish between HRA and AC-type mixes, a method of classifying mixes into gap-graded or continuously graded types has been devised and involves identifying the per cent gap in the mix. The method is based on the BS 594 (BSI 1985) specification for hot rolled asphalts in which an upper limit is placed on the allowable percentage retained between the 2.36mm (No. 8) and 0.6mm (No. 30) sieves, particularly for Type F wearing courses which include natural fine aggregate. The limit is set according to stone content (per cent material retained on 2.36 mm sieve) and ranges from 9 to 14 per cent for stone contents of 55 and 30 per cent respectively. For this study three classes of mix were defined as follows: Gap-graded (G) - where the per cent retained is less than the upper limit for Type F surfacings, Intermediate (I) - where the amount retained is up to 5 per cent above the upper limit and Continuous (C) - where the amount retained is more than 5 per cent above the limit.

On the above basis 15 per cent of the mixes have been classified as gap-graded, 40 per cent fall into the intermediate class and 45 per cent are continuously-graded. In circumstances where the specified mix type was HRS, either class A or B, 17 per cent are gap-graded, 43 per cent are intermediate and the remaining 40 per cent are continuously graded. In addition all sections located on lightly-trafficked roads have continuously graded mixes (40 per cent of all sites) whilst on heavily trafficked roads the division between gap-graded, intermediate and continuously graded is 15, 35 and 10 per cent respectively.

The specified minimum effective bitumen content for most of the sampled mixes was 6.8 per cent and 6.2 per cent for HRS A and HRS B respectively. In comparison with these limits, approximately 75 per cent of the mixes have mean effective bitumen contents which are less that the specified minimum value. The distribution of the mean effective and total bitumen content of all mixes is illustrated in Figure 5. The reported values each represent the arithmetic mean of up to eight samples.

Typical within-section distributions of bitumen content are illustrated in Figure 6 for a number of sections located on Tangerang-Merak. These indicate a true difference in the bitumen contents between most sites rather than heterogeneous variability. Within each site the standard deviation of bitumen content is between 0.2 and 0.4 per cent, with the exception of Section 8. The distribution of bitumen content shown in Figure 5 represents a number of reasonably homogeneous mixes. The causes of such widespread variation between sites is, however, unclear.

The range of filler to binder (f/b) ratios is high (see Table 9) and although they conform with the specified value of greater than 0.7, past experience by TRRL in the tropics (ROLT et al, 1986 and SMITH and JONES, 1982) has shown that values of 1.6-1.7 and above lead to early cracking. In this study approximately 35 per cent of all mixes have f/b ratios greater than or equal to 1.6. It remains to be confirmed whether this is of similar importance with the types of surfacing mixes used in Indonesia.

Although only a limited number of pavements have been sampled during this study and therefore may not be totally representative of as-laid mix properties, compliance with the specification for HRS A and HRS B has been checked. The results are given in Table 10 and, in particular, these indicate problems with obtaining the specified effective bitumen content and satisfactory filler contents. In cases where the filler content criteria was not satisfied, too high a value was obtained.

Table 10

Percentage of samples passing specification requirements

Specified Mix type	Bitumen content		Bitumen absorption	Stone Content	Filler Content	Filler/binder ratio
	Total	Effective				
HRS A	50	0	0	50	75	100
HRS B	92	36	100	60	16	100

The properties of the recovered bitumens are being determined on thin slices of overlay and on complete layers. Early results indicate a wide range in the recovered penetration. Further comment will need to await the completion of the laboratory programme.

7.3 Compaction characteristics of the overlay materials

The per cent air voids in surfacing samples taken from the road were determined using Rice's method (RICE 1953). The distribution of typical results are presented in Figure 7 and represent the grouping of all tests on samples taken from positions between and within wheeltracks. The specified range at the time of construction was 3-6%.

The results indicate a substantial range in values, particularly for samples taken from Ciawi-Cianjur (CWI-CIA). For the three road links, between 60 and 95 per cent of all results are below the specified minimum. Although this may have occurred through additional compaction by traffic, ie. since completion of construction, the values are very low and can be expected to contribute to the occurrence of deformation (or pushing) within the mix. Conversely, the instances of high air voids may contribute to the reduction in bitumen penetration and, therefore, the embrittlement of the mixes. This in turn can lead to premature surface cracking.

Further analysis of the data is being carried out to determine a relationship between air voids and other mix and physical properties.

8. SUMMARY AND CONCLUSIONS

1) A comprehensive research programme has been established to develop performance prediction models for the alternative structural road surfacings used in Indonesia and to improve mix specifications and thickness design.

   For this purpose, detailed 6 monthly surveys have commenced on twenty five monitoring sections located on existing roads. These sections were chosen from a general survey of a 360 km sample of the road network.

2) The road-links and monitoring sections cover a wide range of variables including design traffic, ADT, age, pre-overlay deflection, overlay thickness, performance, terrain, geometry and mix type. To date the variables of age and mix type are not covered as comprehensively or as uniformly as desired and further sections need to be identified and included in the study. In addition, insufficient detail is available on the condition of the existing surface prior to overlay and this has led to the research being extended to include roads on which new overlays are being applied.

3) The results from the network level condition survey indicates that substantial variations in the performance of the roads exist in terms of the accumulation of permanent deformation (rutting) and cracking after only two years. The key conclusions from the survey are as follows:

(a) Average rates of rutting can vary from zero to 4mm per year under conditions of light or heavy traffic, in a variety of geometric situations and for each of the three mix types investigated.

(b) The 90 percentile value of rut depth is approximately twice the median value, indicating that in 10 per cent of the road length rates of rutting of twice the mean can be expected.

(c) Where severe rutting occurs this is accompanied by pushing in the mix, indicating low surfacing stiffness. This is being confirmed by digging trenches across the road.

(d) On average, rates of cracking are low although high variability exists. The 90 percentile values range from less than one per cent to 15 per cent and are highest on the more lightly loaded pavements. More severe localised failures do, however, occur on the heavily loaded roads.

(e) Extensive cracking was found on all mix types although in the case of one road, where substantial lengths were surfaced with two different mixes, the section overlaid with asphaltic concrete was more severely cracked; to an extent which would warrant resealing within 2 years. A higher bitumen content mix laid on other sections is performing satisfactory.

(f) On average a greater amount of cracking existed in the road edge and outer wheeltrack areas. Likely contributing factors include inadequate side support and, possibly, poor road widening practices.

4) The range of overlay thickness covered in the monitoring section varies between 50 and 200mm. Penetration macadams comprise the dominant pre-overlay surface and upper base layer (21 sections) whilst unbound granular materials are used as bases in the remaining sections. Lower base layers comprise combinations of the latter two materials and Telford bases. Subgrades are predominantly weak, twenty of the sections have CBR values between 1 and 6 per cent.

5) A substantial variation of mix properties are covered in the monitoring sections. The results indicate that the mixes produced under current specifications can vary from gap-graded Hot Rolled Asphalt-type mixes to continuously graded Asphaltic Concrete-type Mixes.

In relation to mix properties the main findings are:

(a) 15 and 45 per cent of all sampled mixes have been classified as gap-graded or continuously graded mixes respectively. The remaining 40 per cent are of an intermediate gradation.

(b) Where the specified mix type was to the specification for Hot Rolled Sheet (HRS), 17 per cent were gap-graded, 43 per cent were intermediate and 40 per cent continuously graded.

(c) The range of total and effective bitumen contents in the surfacing mixes are between 5.5 to 8.4 per cent and 4.2 to 7.0 per cent respectively. The within-section variation of binder content is however acceptable.

The range of filler to binder ratios and the air voids of samples recovered from the road are large varying between 1:1 and 2:1 and from virtually zero to seven per cent respectively.

(d) The results indicate that the specification requirements for effective bitumen and filler contents are met least often.

9. ACKNOWLEDGEMENTS

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Table 1

Details of roads surveyed in the network level condition survey

Road Link Name	Length (km)	Age of Surfacing (*)	Surfacing Type	Design ADT	Design ESA (millions)	Design Overlay Thickness (mm x 10^{-2})	Terrain
Ciamis-Cikijing	50	21 months	HRS A	7500	3.8	65-125	Mountainous
Cikijing-Kuningan	20.6	24 months	HRS A	6600	2.1	65-105	Mountanious
Kuningan-Cirebon	30	24 months	HRS B	10400	5.2	70-120	Flat/Hilly
Cirebon-Losari	30	24 months	HRS B	15300	11.3	70-155	Flat
Ciawi-Cianjur	33.6	21 months	HRS B	) 23100	) 2.2	) 70-145	Mountainous
Ciawi-Cianjur	14.7	18 months	AC	)	)	)	Mountainous
Tangerang-Ciujung	48.6	15 months	HRS B	9900	10.1	60-100	Flat/rolling
Ciujung-Serang	14.8	17 months	HRS B	9900	10.1	65-130	Flat/rolling
Serang-Cilegon	22.4	19 months	HRS B	11600	10.1	75-150	Flat/rolling
Cilegon-Merak	12	21 months	HRS A	7700	5.8	60- 85	Flat/rolling
Kopo-Rancabali	13.9	8 months	HRS B	12100	2.6	60-170	Flat
Kopo-Rancabali	11	8 months	HRS A	8000	1.8	85-165	Hilly/mountainous
Kopo-Rancabali	16.1	8 months	HRS A	3000	0.7	65-155	Hilly/mountainous
Sadang-Subang	41.6	9 months	HRS A	5300	2.0	60-110	Rolling/Hilly

* Average age of new surfacing up until mid-1988

** HRS A = Hot rolled sheet Class A

HRS B = Hot rolled sheet Class B

AC = Asphaltic concrete

Table 2

Summary statistics of representative rut depth

Road link	No. of 100 m sections	Representative rut depth (mm)			Specified mix type
		Median	Range	90 per-centile	
Ciamis-Cikijing	994	2	0-40	4	HRS A
Cikijing-Kuningan-Cirebon	1008	2	0-23	4	HRS A/HRS B
Cirebon-Losari-Pejagan	754	6	1-40	12	HRS B
Ciawi-Cianjur I	672	4	0-20	7	HRS B
Ciawi-Cianjur II	294	3	1-25	4	AC
Tangerang-Ciujung	972	5	0-33	12	HRS B
Ciujung-Cilegon	728	5	1-43	11	HRS B
Cilegon-Merak	252	6	1-22	12	HRS A
Dawuan-Cirebon-Kalijaga	192	5	1-23	9	HRS B
Kopo-Rancabali	816	2	0- 9	3	HRS A
Sadang-Subang	838	3	0-10	4	HRS A

Table 3

Summary statistics of the linear extent of all wheeltrack cracking

Road link	No. of 100 m Sections	Extent of all wheeltrack cracking (%)			Specified mix type
		Median	Range	90 percentile	
Ciamis-Cikijing	994	5	0-89	14	HRS A
Cikijing-Kuningan-Cirebon	1008	5	0-94	15	HRS A/HRS B
Cirebon-Losari-Pejagan	754	1	0-75	<1	HRS B
Ciawi-Cianjur I	672	<1	0-24	<1	HRS B
Ciawi-Cianjur II	294	3	0-39	11	AC
Tangerang-Ciujung	972	1	0-73	4	HRS B
Ciujung-Cilegon	728	1	0-100	1	HRS B
Cilegon-Merak	252	2	0-83	5	HRS A
Dawuan-Cirebon-Kalijaga	192	2	0-32	6	HRS B
Kopo-Rancabali	816	<1	0-20	<1	HRS A
Sadang-Subang	838	<1	0-50	<1	HRS A

Table 4

Mean distribution of cracking related to roadway position

Roadway Position	Linear extent of all cracks (%)		
	Median	Range	90 percentile
Edge	2	0-100	4
OWT	2	0-100	5
Mid-lane	1	0-100	2
IWT	0.5	0-100	1.5
Centreline	0.6	0-100	1.7

Table 5

Percentage of 100 m subsections in each performance category : Representative rut depth

Road link	Representative rut depth (mm)		
	<10	10-20	>20
	SOUND	CRITICAL	FAILED
Ciamis-Cikijing	98	2	0
Cikijing-Kuningan-Cirebon	99	<1	<1
Cirebon-Losari-Pejagan	86	11	3
Ciawi-Cianjur I	96	4	0
Ciawi-Cianjur II	98	1	1
Tangerang-Ciujung	88	10	2
Ciujung-Cilegon	85	12	3
Cilegon-Merak	83	15	2
Dawuan-Cirebon-Kalijaga	96	3	1
Kopo-Rancabali	100	0	0
Sadang-Subang	100	0	0

Table 6

Percentage of 100m subsections in each performance category : All wheelpath cracking

Road link	All wheelpath cracking (%)			
	<5	5-10	10-30	>30
Ciamis-Cikijing	77	9	12	2
Cikijing-Kuningan-Cirebon	83	6	7	4
Cirebon-Losari-Pejagan	97	1	1	1
Ciawi-Cianjur I	98	1	1	0
Ciawi-Cianjur II	80	10	8	2
Tangerang-Ciujung	92	3	4	1
Ciujung-Cilegon	94	3	2	1
Cilegon-Merak	88	6	4	2
Dawuan-Cirebon-Kalijaga	87	5	4	4
Kopo-Rancabali	99	1	0	0
Sadang-Subang	97	2	<1	<1

Table 7

Percentage of 100 m sub-sections in each performance category : Intensity of Wheeltrack cracking

Road link	Intensity of wheeltrack cracking			
	None	C1/C2	C3	>=C4
	SOUND	INTERMEDIATE	CRITICAL	FAILED
Ciamis-Cikijing	49	46	4	1
Cikijing-Kuningan-Cirebon	66	23	10	1
Cirebon-Losari-Pejagan	93	5	2	0
Ciawi-Cianjur I	92	5	2	<1
Ciawi-Cianjur II	51	26	18	5
Tangerang-Ciujung	79	14	5	2
Ciujung-Cilegon	84	9	5	2
Cilegon-Merak	70	13	8	9
Dawuan-Cirebon-Kalijaga	77	13	8	2
Kopo-Rancabali	96	3	1	0
Sadang-Subang	95	5	0	0

Table 8

Overlay thickness and pavement composition of the monitoring sections

SECTION	LANE	Overlay Thickness (mm)		Upper base (**)	Lower base (**)	Mean Subgrade CBR (%)
		Range	Mean			
CBN KNG 1	KNG	95-200	140(*)	PM	UB	3.5
CBN KNG 1	CBN	65-150	98(*)	PM	UB	3.5
CBN KNG 2	KNG	85- 95	91	PM	UB	>100
CBN KNG 2	CBN	110	110	PM	UB	-
CBN KNG 3	KNG	85-135	118	PM	UB	5.0
CBN KNG 4	KNG	80-100	87	PM	UB	4.2
CBN LOS 1	LOS	90-150	122	UB	PM	3.0
CBN LOS 2	LOS	80-100	95	UB	PM/T	6.0
CBN LOS 3	LOS	120-160	135(*)	PM	-	-
CBN LOS 4	LOS	75-255	166(*)	UB	UB	22.0
CWI CIA 1	CWI	170-210	190	PM	T	1.1
CWI CIA 2	CWI	160-210	185	PM	T	2.0
CWI CIA 2	CIA	140	140	PM	-	-
CWI CIA 3	CWI	140	140	PM	UB/T	2.0
CWI CIA 3	CIA	135	135	PM	-	-
CWI CIA 4	CWI	205	205	PM	T	4.0
CWI CIA 5	CWI	210	210	PM	T	2.5
CWI CIA 5	CIA	165-190	187	PM	-	-
CWI CIA 6	CIA	115-190	154(*)	PM	T	4.0
CWI CIA 7	CIA	180-200	187	PM	T	3.1
TNG MRK 1	MRK	90-165	127(*)	UB	UB	6.2
TNG MRK 2	MRK	110-190	152(*)	PM	UB/T	3.7
TNG MRK 3	MRK	65-70	69	PM	T	9.0
TNG MRK 4	MRK	50-65	56	PM	UB/T	1.9
TNG MRK 4	TNG	60-90	81	PM	T/UB	2.0
TNG MRK 5	MRK	80-270	154	PM	T	2.8
TNG MRK 6	MRK	100-170	134	PM	T	12.0
TNG MRK 7	TNG	100-155	133	PM	T/UB	5.0
TNG MRK 8	TNG	50-150	95(*)	PM	T/UB	12.0
KOP RAN 1	RAN	95-100	99	PM	-	4.1
KOP RAN 1	KOP	110	100	PM	-	-
KOP RAN 2	RAN	90-115	102	PM	T	6.2
KOP RAN 2	KOP	100	100	PM	-	-

* : Sections which may need to be sub-divided due to a consistent change in overlay thickness with chainage.

** : PM - Penetration Macadam
T - Telford stone
UB - Unbound granular material

Table 9

Bituminous mix properties of surfacings from monitoring sections

SECTION	LANE	BITUMEN CONTENT TOTAL %	BITUMEN CONTENT EFF %	Stone content	Filler content	Percent retained between 2.36-0.6mm	Effective Filler/binder ratio	Specified Mix	Mix class
CBN KNG 1	KNG	7.6	6.2	46	7	14	1.1	HRS B	I
	CBN	7.4	6.2	40	7	15	1.1	HRS B	I
CBN KNG 2	KNG	7.5	6.3	37	9	20	1.4	HRS B	C
	CBN	7.7	6.3	35	9	17	1.4	HRS B	I
CBN KNG 3	KNG	7.2	5.7	38	9	13	1.6	HRS B	I
CBN KNG 4	KNG	7.0	5.3	41	9	13	1.7	HRS B	I
CBN LOS 1	LOS	7.5	6.1	53	8	11	1.3	HRS B	I
CBN LOS 2	LOS	7.8	6.3	50	9	11	1.4	HRS B	I
CBN LOS 3	LOS	7.8	6.2	51	8	10	1.3	HRS B	G
CBN LOS 4	LOS	7.5	6.0	49	8	10	1.3	HRS B	G
CWI CIA 1	CWI	7.1	6.1	50	8	18	1.3	HRS B	C
CWI CIA 2	CWI	6.7	5.7	53	9	17	1.6	HRS B	C
	CIA	6.9	5.7	50	8	16	1.4	HRS B	C
CWI CIA 3	CWI	7.1	6.0	46	8	19	1.3	HRS B	C
	CIA	6.8	5.5	50	8	17	1.4	HRS B	C
CWI CIA 4	CWI	5.8	4.7	56	9	16	1.9	HRS B	C
CWI CIA 5	CWI	6.0	4.8	53	9	16	1.9	AC	C
	CIA	6.1	4.7	58	9	15	1.9	AC	C
CWI CIA 6	CIA	6.1	4.9	54	8	18	1.6	AC	C
CWI CIA 7	CIA	5.5	4.2	56	8	15	1.9	AC	C
TNG MRK 1	MRK	7.7	6.4	49	9	8	1.4	HRS B	G
TNG MRK 2	MRK	7.4	5.9	51	7	9	1.2	HRS B	G
TNG MRK 3	MRK	7.4	6.1	53	7	10	1.1	HRS B	I
TNG MRK 4	MRK	6.8	5.5	60	9	13	1.6	HRS B	C
	TNG	6.5	5.3	50	11	14	2.1	HRS B	C
TNG MRK 5	MRK	7.2	5.8	48	10	10	1.7	HRS B	G
	TNG	7.0	-	60	10	12	-	HRS B	I
TNG MRK 6	MRK	7.2	5.1	52	11	11	2.1	HRS B	I
TNG MRK 7	TNG	7.4	-	52	9	12	-	HRS B	I
TNG MRK 8	TNG	8.4	7.0	49	9	11	1.3	HRS B	I
KOP RAN 1	RAN	6.8	5.8	52	10	15	1.7	HRS A	C
KOP RAN 1	KOP	7.1	5.8	49	9	12	1.5	HRS A	I
KOP RAN 2	RAN	7.4	5.8	50	9	15	1.5	HRS A	C
KOP RAN 2	KOP	7.4	5.6	52	8	16	1.4	HRS A	C

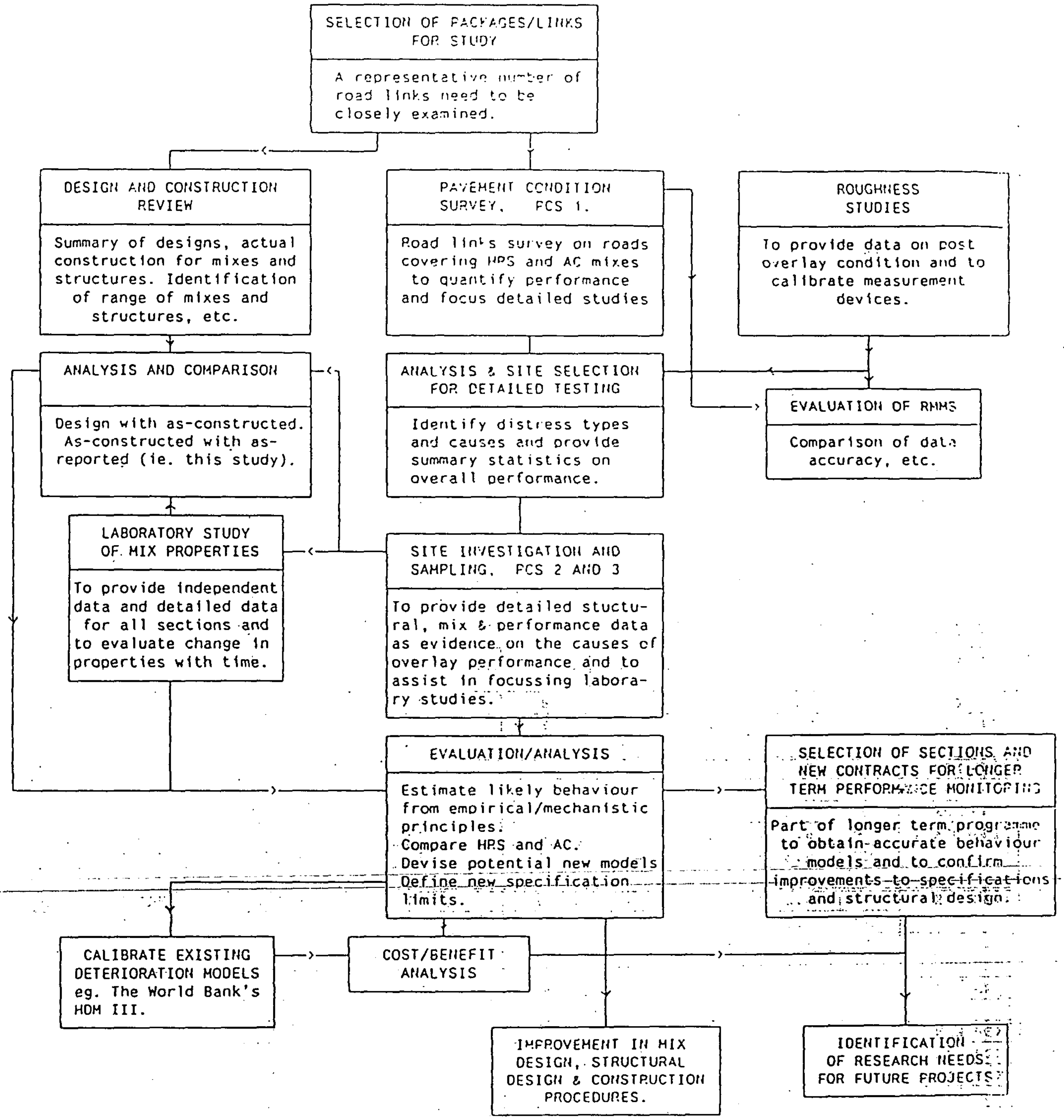

Figure 1 Research design flow chart

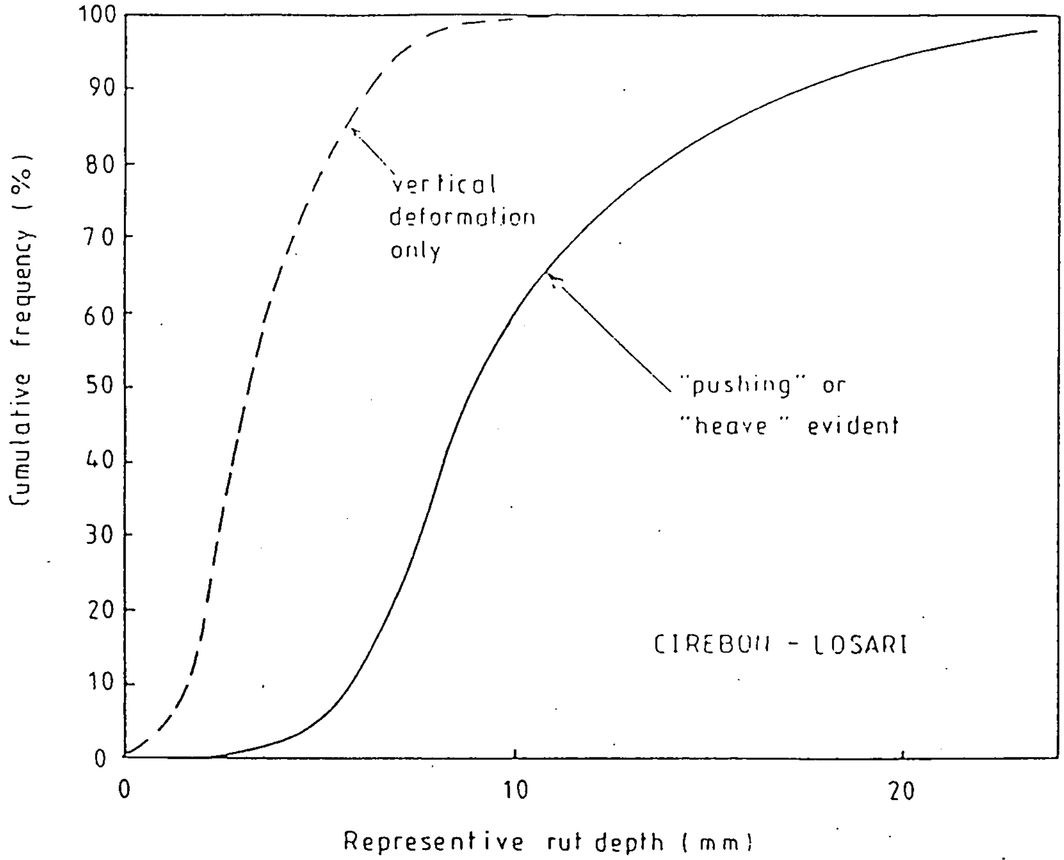

Figure 2 Typical distribution of rut depth for sections where "pushing in the mix" is evident or absent.

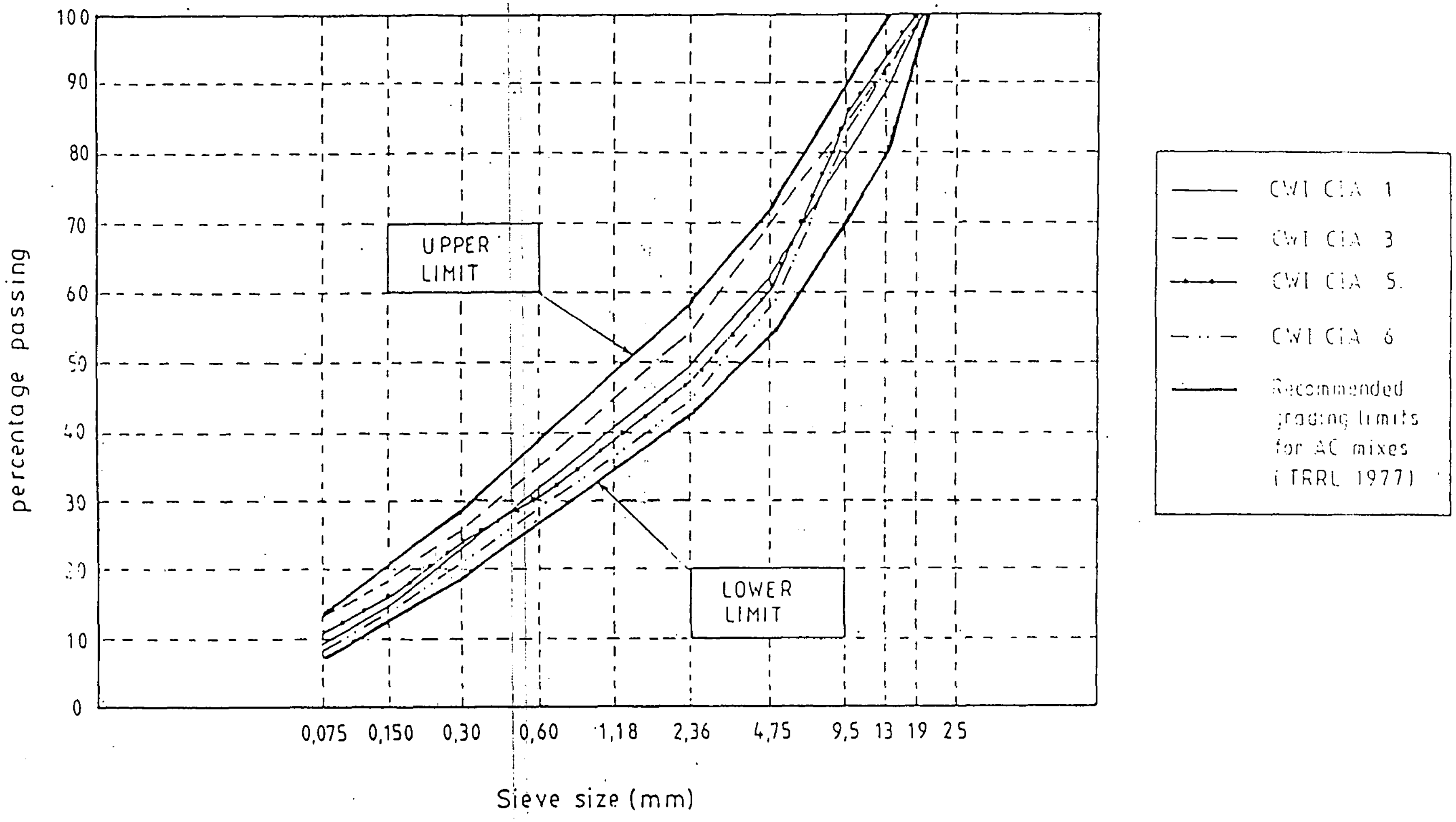

Figure 3 Mean gradation of bituminous surfacings from selected monitoring sections on Ciawi - Cianjur

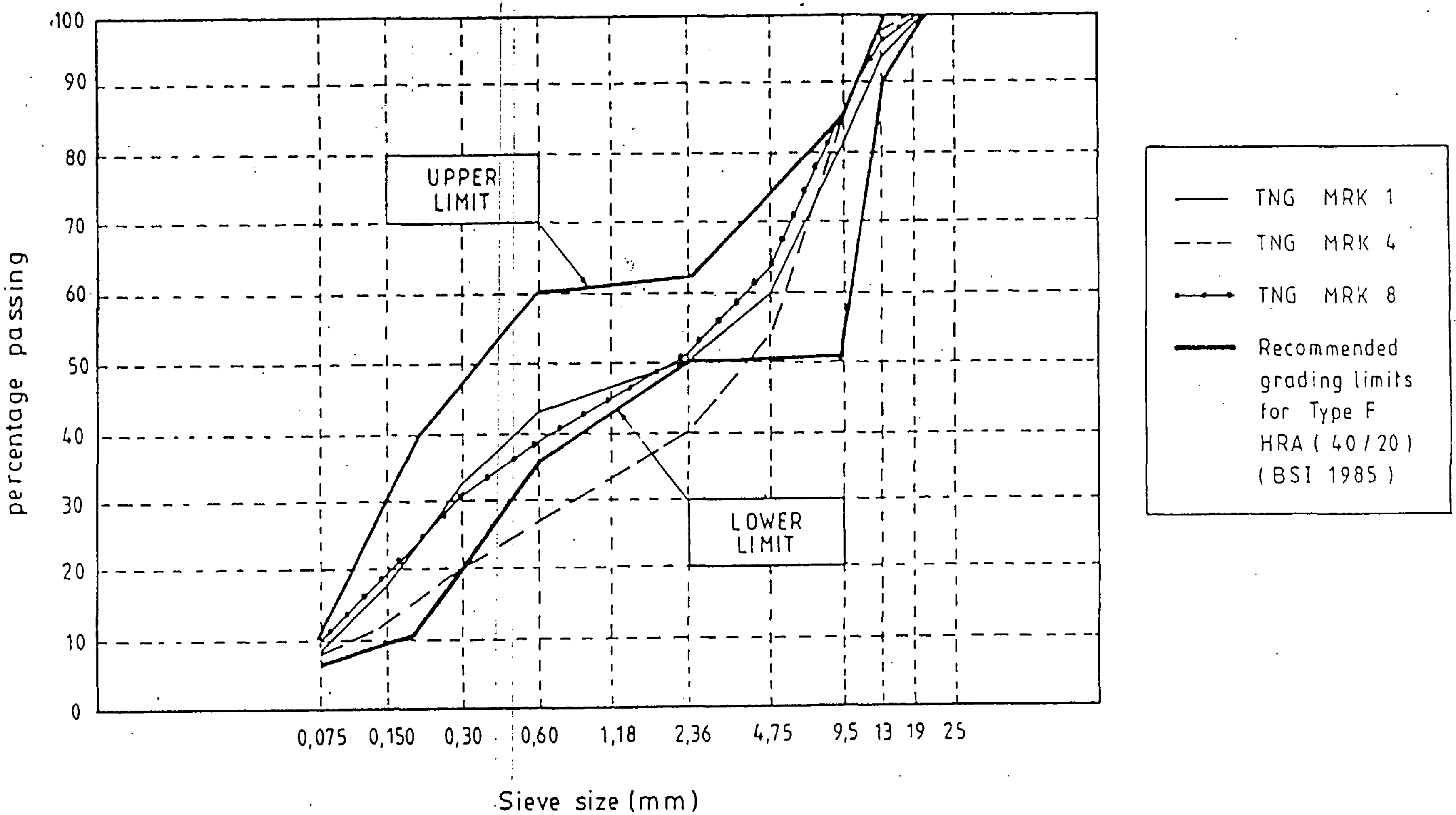

Figure 4 Typical range of gradations of bituminous surfacings from monitoring sections on Tangerang – Merak

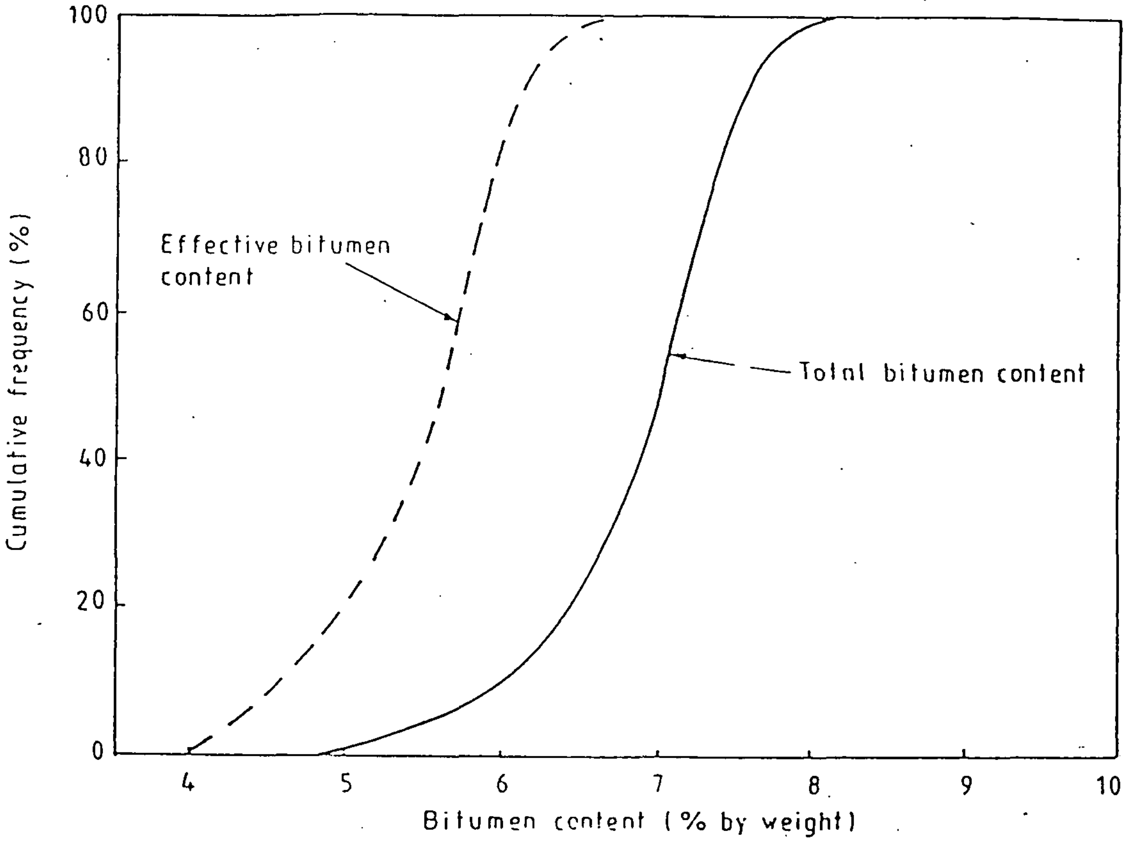

Figure 5 Cumulative frequency distribution of mean total and effective bitumen contents for all monitoring sections

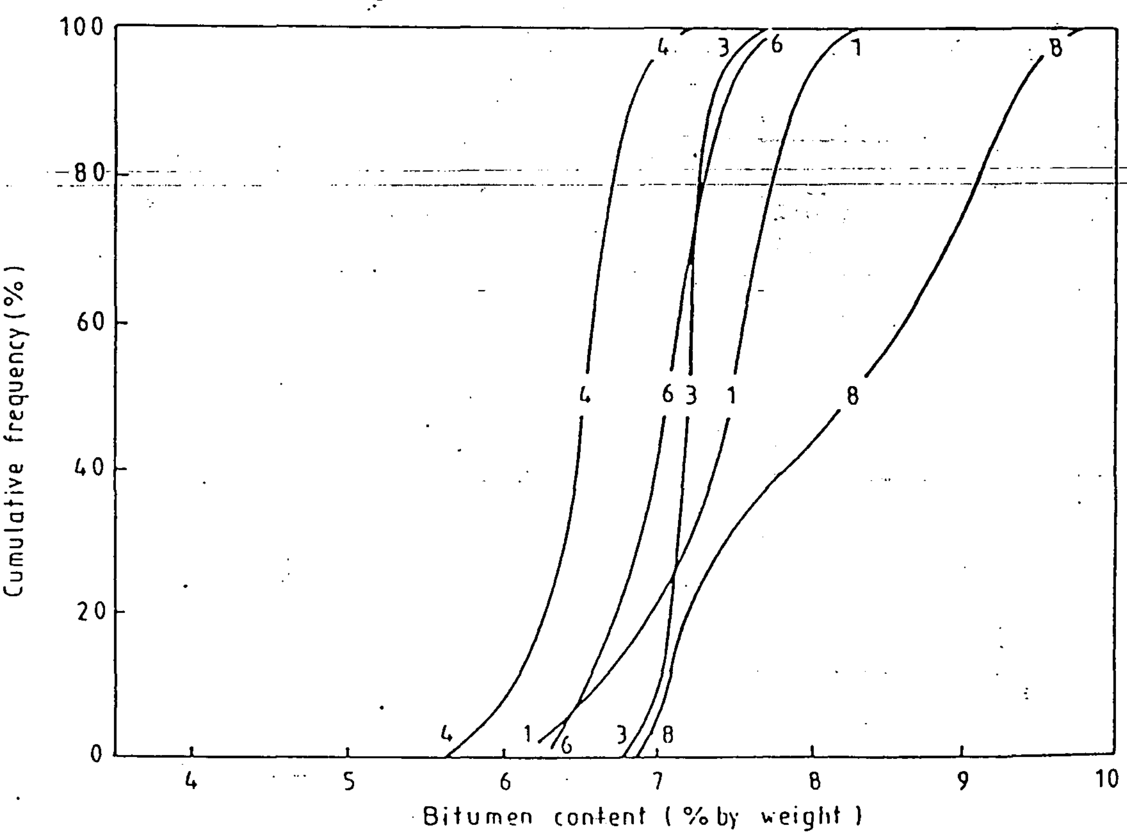

Figure 6 Cumulative frequency distribution of total bitumen contents of selected monitoring sections on Tangerang-Merak