

CIVIL ENGINEERING STUDIES

Transportation Engineering Series No. 8 Illinois Cooperative Highway Research Program Series No. 148



FAILURE MODES AND REQUIRED PROPERTIES IN ASPHALT-AGGREGATE COLD MIX BASES

Metz Reference Room
Civil Englishing Department
Blo6 C. E. Dulling
University of Llinois
Urbana, Illinois 61801

by
ILAN ISHAI
MORELAND HERRIN
DAVID G. LEVERENZ

A Report of the Investigation of
Structural Evaluation of Asphalt-Aggregate
Cold Mix Bases
Project IHR-505
Illinois Cooperative Highway Research Program

conducted by the

TRANSPORTATION RESEARCH LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

in cooperation with the
STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION

and

THE U.S. DEPARTMENT OF TRANSPORTATION FEDERAL HIGHWAY ADMINISTRATION

UNIVERSITY OF ILLINOIS URBANA, ILLINOIS AUGUST, 1973

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle		5. Report Date
FAILURE MODES AND REQUIRE	D PROPERTIES IN ASPHALT-	August, 1973
AGGREGATE COLD MIX BASES		6. Performing Organization Code
7. Author(s) Ilan Ishai		8. Performing Organization Report No.
Moreland Herrin		
David G. Leverenz		
9. Performing Organization Name and Address		10. Work Unit No.
Department of Civil Engin		
Engineering Experimental	Station	11. Contract or Grant No.
University of Illinois at	Urbana-Champaign	IHR-505
Urbana, Illinois 61801		13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address		Intorim Poport
Illinois Department of Tr	Interim Report	
2300 South 31 Street	amb p o r cae ross	July, 1972 - June, 1973
	6.1.	14. Sponsoring Agency Code
Springfield, Illinois 627	04	

15. Supplementary Notes

Study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract

This interim report summarizes the first part of phase 1.1 of the research project. The report introduces the objectives, scope and basic approach of the research, and describes the analytical study and actual field survey. The study and analysis described include:

- 1. Identification and classification of different types of failure and distress frequently occurring in actual cold mix bases.
- 2. Analysis of the failure modes to identify factors that cause the various types of distress and the properties needed in the mixture (required properties).
- 3. Quantitative determination of a) the relative significance of a given required property as related to the performance of actual cold mix bases and b) the local frequency of occurrence of the given failure group in actual service performance of the base.

The analysis was based on data collected from a) comprehensive and critical literature review, b) survey study of local county roads, c) field visits and interviews.

A foundation thus has been established for identifying feasible test methods and relating them to the major required properties which affect the behavior of actual cold mixes.

17. Key Words Cold mix bases, failure modes	, distress,	16. Distribution Statement	$U_{\mathcal{I}}$	Meta Palacan Liversity of Table	
required properties, feasible methods			Irl Url	C8 M. Romine S	1
19. Security Classif. (of this report)	20. Security Clas	sif. (of this page)	21- No. of Pages	22. Price	
Unclassified	Unclassif	ied	69		

FAILURE MODES AND REQUIRED PROPERTIES IN ASPHALT-AGGREGATE COLD MIX BASES

Ьу

Ilan Ishai Moreland Herrin David G. Leverenz

RESEARCH REPORT 505-1

A Report of the Investigation of Structural Evaluation of Asphalt-Aggregate Cold Mix Bases

> Project IHR-505 Illinois Cooperative Highway Research Program

> > conducted by the

TRANSPORTATION RESEARCH LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
at URBANA-CHAMPAIGN

in cooperation with the STATE OF ILLINOIS DEPARTMENT OF TRANSPORTATION

and the

U. S. DEPARTMENT OF TRANSPORTATION FEDERAL HIGHWAY ADMINISTRATION

UNIVERSITY OF ILLINOIS URBANA, ILLINOIS

August, 1973

Acknowledgments

This report was prepared as a part of the Illinois Cooperative
Highway Research Program, Project IHR-505 - Structural Evaluation of
Asphalt-Aggregate Cold Mix Bases, by the Department of Civil Engineering,
in the Engineering Experiment Station, University of Illinois at UrbanaChampaign, in cooperation with the Illinois Department of Transportation
and the United States Department of Transportation, Federal Highway
Administration.

Disclaimer

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

,					
				·	
					·

TABLE OF CONTENTS

е
7
3
3
)
l
1
3
7
)
2
4
6
7
9
6
3
5
6

		:

INTRODUCTION

The utilization of substandard (currently out of specification) aggregates in bases of low-traffic local roads is an essential need to lessen the rising demand for the rapidly depleting well-graded, quality granular materials, and to reduce the construction cost of these roads. Substandard aggregates usually can be upgraded by stabilization with bituminous binders to the point where they can perform satisfactorily as bases for local roads. The stabilization of these granular materials with asphalt cements is not economical for such roads. However, cold stabilization with emulsified or cutback asphalts, whether by plant or road mix methods, has been performed economically and has provided satisfactory bases.

Unfortunately, and despite the many years of use, the research in this area has been accomplished primarily by laboratory investigation. Little research has been done in the field or in relating mixture properties to field performance. Therefore, information is not available that 1) permits a critical evaluation of the actual field behavior and failure modes of mixtures stabilized with liquid asphalts, 2) establishes all mixture properties necessary for proper performance in the field,

3) allows the determination of testing procedures and criteria that can be used to evaluate all the required properties, and (4) relates these properties to the structural response (i.e. relative layer coefficients) of the compacted base in the pavement. This information is needed in order that liquid asphalt-stabilized mixtures can be designed so they will perform satisfactorily when proper design and construction techniques are used.

It is within the objectives and scope of IHR-505 research project to bridge this gap and to provide a more quantitative, systematic, and reliable procedure of testing methods, mixture design, quality criteria, and structural evaluation of cold mix bases.

This interim report summarizes the basic research approach and the preliminary analytical study which were utilized in the analysis of failure modes and related required properties in asphalt-aggregate cold mix bases.

RESEARCH APPROACH

The general suggested approach used in this study is illustrated in Figure 1. Based on this approach, the research is partitioned into three distinct but interrelated phases. Phase 1.1 and Phase 1.2 are designed to combine basic conceptual and analytical studies, while Phase 2 will consist of experimental laboratory studies for implementing the findings of the previous phases to a practical quantitative procedure for reliable utilization of cold mix bases.

The first preliminary work in this study was to develop a basic concept for future utilization of asphalt-treated cold mix bases. This concept, as illustrated in Figure 2, provides a logical sequence of factors

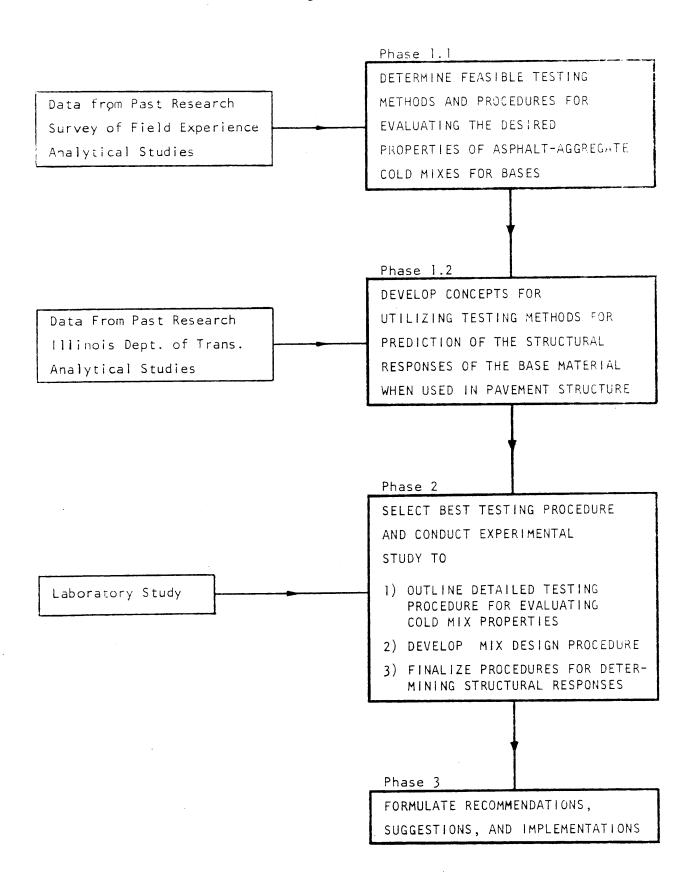
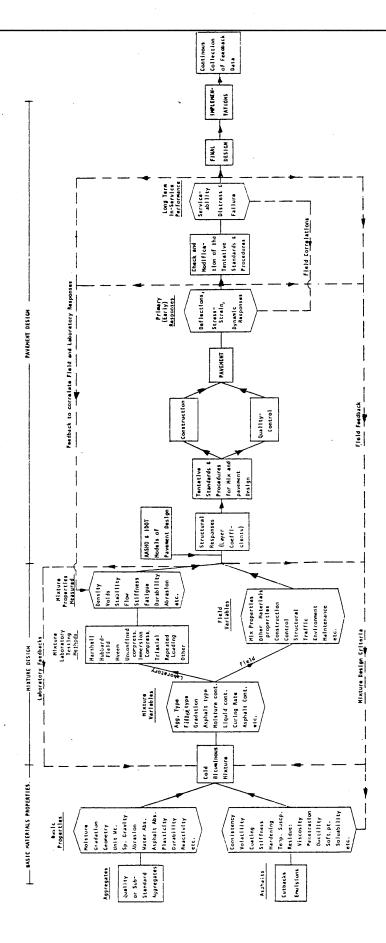


Figure 1. Basic Research Approach to "Structural Evaluation of Asphalt-Aggregate Cold Mix Bases" (IHR-505).



Basic Concept for Utilization of Asphalt-Aggregate Cold Mix Bases Figure 2.

and operations needed for a satisfactory and rational cold mix and pavement design for bases of local and low traffic roads. At the same time, the development of this concept was meant to provide a tool for better understanding of the problem, and a basis for a systematic design of the various phases of the research.

The basic requirement in the first phase of the study was to determine a complete series of feasible testing methods and procedures for evaluating the desired properties of cold mix bases. These methods and procedures are to be related both to laboratory and field variables affecting the performance of actual cold mix bases. The optimal solution would have been to adopt the basic concept shown in Figure 2 as the work plan for the research; namely, to conduct a full program of laboratory and road tests in order to correlate primary and long term pavement responses to the desired properties which are to be measured in the laboratory.

Since the scope of the research is limited, a different practical solution was desired. It was, therefore, decided to obtain the primary and long-term pavement response from available sources, namely from actual cold mix technology, from existing pavements performance, and from data of past research. In that way, the basic concept suggested by Figure 2 is still valid but with a different and more practical starting point.

Figure 3 illustrates the work plan as adopted for the first phase of the research. Specifically, it is a combination of the following steps:

- Identification of types of failure and distress which frequently occur in actual cold mix bases.
- 2. Analysis of the failure modes to identify the factors that cause the various types of distress and the properties needed in the mixture (required properties).

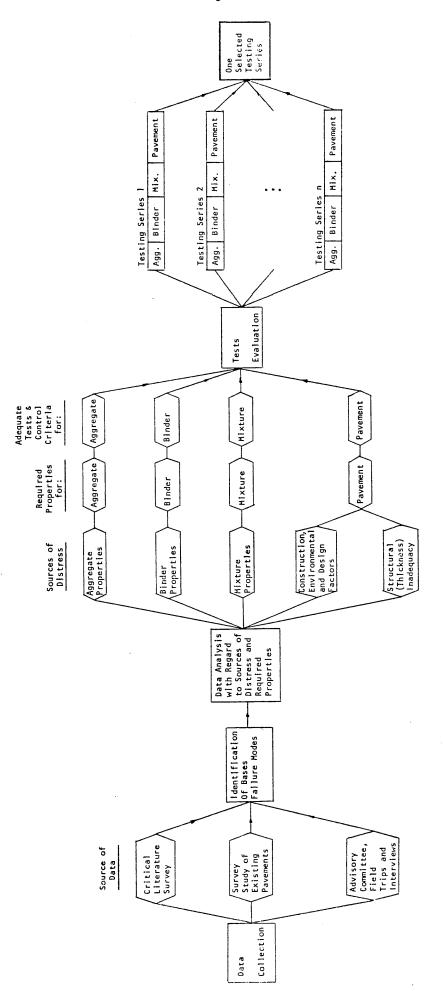


Figure 3. Concept and Work Plan for the First Phase of the Research.

- 3. Identification of the tests that measure the required properties and grouping of the criteria used with each test for control of the specific properties.
- 4. Evaluation of the tests and establishment of several alternate series of tests that will measure all desired properties of the base material.
- 5. Selection of the best test series.

The analylitical study and data discussed in this report are limited to the first two steps indicated above.

DATA COLLECTION

As shown in Figure 3, the data for this phase were collected from three major sources:

Literature Survey

A comprehensive literature survey, which covered about 150 references, was conducted. The collection of data was oriented to evaluate the performance, frequent failure modes, required physical properties, and various testing procedures used in asphalt-treated cold mix bases. The data were critically reviewed and grouped by failure modes.

Survey Study of Actual Field Technology

The evaluation of the actual utilization of cold mix bases was carried out by a systematic survey study of local roads at the county level. A detailed questionnaire was composed and sent to about 200 county engineers (of eight midwestern states) who were known to have considerable experience with cold mix bases. The questionnaire was designed to provide information about basic

materials properties, mix properties, construction techniques, in-service performance, quality control, and testing technology. An emphasis was made to identify the common failure modes typical of such construction and to find out the opinion of the engineer in charge about the probable causes of such failures and the remedies that were or should have been taken. A copy of the questionnaire is given in the Appendix to this report.

The analysis and conclusions about field technology, given in the following pages, are based on 41% questionnaire returns (63% excluding Indiana).

Field Trips and Interviews

A number of visits were made by the project staff to interview county and state engineers dealing with cold mixes. Visits were also made to typical construction sites during the construction season. Information was gained about design, testing, and construction methods. Failure and distress problems were also discussed. Similar information was obtained by formal and informal consulting with the advisory committee of the project.

IDENTIFICATION OF FAILURE MODES

General Definitions

The definitions and criteria of failure in flexible pavements usually vary from one organization to another. The failure criteria can be both qualitative or quantitative. Hveem (5) considers "failure" as an indefinite term that has significant meaning only when all conditions are defined. In his opinion, it may mean crushing, rupture, or simply excessive plastic deformation in the pavement materials. The Asphalt Institute (131) relates pavement failures to four general terms: 1) cracking, 2) distortion, 3) disintegration, and 4) skid hazard. Failures are usually connected with the performance of the pavement; namely, the ability to serve. Yoder (132) defined "failed

pavements" as those which will not carry out their design function. From this point of view, he distinguishes between two different types of failures. The first, structural failure, leads to a collapse of the pavement structure or a breakdown of one or more of the pavement components of such magnitude to make the pavement incapable of sustaining the load imposed upon its surface. The second, functional failure, causes discomfort to passenger or high stresses in the plane or vehicle which passes over it due to its roughness. A functional failure is usually easy to correct and maintain. However, if not maintained in time, many types of functional failure may progress to a severe structural distress. The development of distress for both categories is gradual, and the severity of distress is largely a matter of opinion and judgement of the engineer or person observing the failure. However, the difference between the two types of failures is important, and the engineer must be able to distinguish between them.

A quantitative approach for the evaluation of the extent of pavement failure, and for the formation of failure criteria, was initiated during the AASHO Road Tests. Three terms were used to describe pavement conditions:

- 1) The general qualitative term "Present Pavement Serviceability" was defined by Carey and Irick (133) as the ability of the pavement to serve high-speed, high volume, mixed traffic in its present condition.
- 2) "Pavement Performance" has been defined by the same writers (133) as the rate of change of the serviceability with the cumulative number of axle load applications.
- 3) The "Terminal Serviceability" is defined as the lowest level of serviceability at which the pavement can still be considered able to serve the purpose for which it was intended.

The quantitative parameters of serviceability are two:

- The "Present Serviceability Rating" (PSR) is the mean of the individual ratings of the pavement made by the members of a specific panel selected for the purpose. (134)
- 2) The "Present Serviceability Index" (PSI) is a mathematical combination of values related to rutting, cracking, and patching obtained from certain physical measurements of a large number of pavements, so formulated as to predict, within prescribed limits the PSR of those pavements (134).

Generally, the present serviceability is 1) a measure of how well the pavement is meeting the requirements for which it was intended, 2) a criterion of the riding quality, and 3) an indication of how far the pavement is from a failure. The present serviceability was found to be influenced by the surface distortion of the longitudinal and transverse profiles and by the extent of cracking and patching. It cannot, however, characterize the present strength of the pavement (135), and its present skid resistance.

Classification of Failure Modes

Many failure modes were identified to characterize the deterioration of asphalt-treated cold mix bases and flexible pavements. Based on the nature and mechanism of distress, four major groups of failure modes were discernible:

- Cracking Approximately vertical random cleavage of the pavement due to natural causes or traffic action.
- Distortion A differential change of pavement surface from its original shape as a result of permanent plastic deformation.

- 3. Disintegration The breaking up of a pavement into small, loose fragments due to traffic or weathering.
- 4. Skid Hazard Any condition that might contribute to making a pavement slippery when wet.

A classification of the different failure modes within the major groups is given in Table 1. The modes are identified by the standard nomenclature and definitions recently adopted by the Highway Research Board (136).

ANALYSIS OF FAILURE MODES

It is assumed here that the mechanism of different failure modes within a given group are in most cases similar. Therefore, and in order to assure more simplicity and clarity, failure modes will be analyzed by group units.

This section will summarize literature and past research data. A comparison of these data with actual cold bases performance, as surveyed, will be presented in the succeeding sections.

Cracking

Cracking is mainly a functional failure which contributes to a gradual decrease in pavement serviceability due to an increase in pavement roughness and irregularity. If not corrected in time, the distress may accelerate gradually to form a severe structural failure, since cracks provide an easy path by which moisture can seep into the pavement to cause stripping, swelling, frost heaves, ravelling, pot holes, etc. (76).

TABLE 1 CLASSIFICATION OF FAILURE MODES IN FLEXIBLE PAVEMENTS

Major Group	Failure Mode	Description	Type	Applicable to cold mix bases
	Alligator Cracking	Interconnected cracks forming a series of small polygons that resemble an alligator skin or chicken-wire.	functional, progresses to structural	yes
	Block Cracking	Interconnected cracks forming a series of large polygons usually with sharp corners or angles.	functional, progresses to structural	yes
CRACKING	Longitudinal Cracking	A crack or break approximately parallel to the pavement center line, usually along the seam between two paving lanes.	usually functional	yes
CR,	Transverse Cracking	A crack approximately at right angles to the pavement centerline.	functional, progresses to structural	yes
	Slippage Cracking	Half-moon or cresent-shaped cracks in the direction of traffic.	usually functional	yes
	Rutting	Longitudinal channelized depressions that form under traffic in the wheel path and have a minimum length of about 20 ft.	structural	yes
8 .	Shoving	Plastic displacement resulting in local- ize bulging of the pavement surface in the direction of loading or pressure.	structural	yes
DISTORTION	Corrugation	Transverse plastic undulation at regular intervals in the surface of the pavement consisting of alternate valleys and crests less than 2 ft. apart.	structural	yes
Ω	Depression	Localized pavement area at an elevation lower than that of adjacent paved area or of the designed elevation.	usually functional	yes
	Upheaval	Localized upward plastic displacement of a pavement, usually accompanied by alligator cracking.	structural	yes
TON	Pot Holes	Localized disintegration resulted in bowl- shaped holes of various sizes in the pave- ment.	functional, progresses to structural	yes
TEGRATION	Ravellin g	Progressive separation of aggregate parti- cles in a pavement from the surface down- ward	functional, progresses to structural	
DISINT	Weathering	Gradual disintegration of the pavement sur- face, increasing the texture and exposing more and more aggregates.	functional	Yes in stage con-
GD GD	Bleeding	Upward movement of asphalt in a pavement resulting in the formation of a film of asphalt on the surface.	usually functional	yes
SKID	Polished Aggregate	Aggregate particles in the surface of a pavement that have been polished smooth under the action of traffic.	functional	Yes in stage con- struction

 $^{^{1}\}mathrm{For}$ definitions of Functional and Structural Failures, see Page 9.

There are four major causes of cracking: 1) shrinkage, 2) structural definciencies, 3) thermal stresses, and 4) fatigue.

Shrinkage Cracking

The cracking formed by shrinkage can be block cracks, longitudinal cracks, or transverse cracks. The shrinkage, particularly in mixes containing liquid asphalts, emulsions or cutbacks, may be caused by early compaction (improper drying and aeration). In this case, large amounts of water or volatiles are trapped and when they do evaporate, the pavement shrinks and cracks (58). Weathering effects may also cause pavements to swell and shrink back especially when sensitive, high PI soils are involved. Shrinkage cracking occurs more often when the asphalt is excessively hard (67). Another type of shrinkage cracking is that caused by thermal change and will be discussed later in this section.

Structural Cracking

Structural deficiencies fall into two categories: Inadequacies in the pavement thickness and inadequacies in the subgrade support capacity. The thinner a section is, the more liable it will be to fracture (45), particularly due to excess loading and thermal stresses. On the other hand, the thinner pavements tend to have a greater allowable deflection from a fatigue standpoint (12). Inadequate subgrade support capacity is of increased interest in secondary roads and usually results in differential soil settlement or plastic distortion. In any case, when structural deficiencies are present, cracking is only one part of an overall failure which can only be corrected by intensive structural remedies.

Thermal Cracking

Thermal cracking or low temperature cracking is a special form of shrinkage cracking in which the asphalt pavement cannot resist the stresses caused by contraction produced by temperature reduction (8). It is also affected by stripping and traffic action (76). Cracking resistance is reduced if the asphalt used is hard, brittle, and inflexible (8) either due to an age hardening-oxidation process, or because of an initial design error. At low temperatures the cracking strength of mixtures reaches a maximum at fairly high binder contents. Thus, asphalt paving mixtures containing the highest penetration asphalt and the highest percentage of asphalt consistent with the necessary stability requirements should prove most resistant to cracking at low temperatures (8). McLeod (137) correlated transverse thermal cracking with the temperature susceptibility of the asphalt as expressed by a Penetration-Viscosity (Pen-Vis) number.

The subgrade plays an important part in thermal cracking (76). One cause for stress buildup within the pavement is that as it contracts, it is restrained by the underlying layers. Cracking can also initiate in the subgrade when, with certain types of soils, the subgrade undergoes a significant amount of freezing shrinkage. Deep cracks can start within the subgrade and be reflected through the pavement to the surface.

There are two main design approaches for thermal crack resistance available to the engineer (76, 123). The first is to set viscosity and penetration specifications so that certain asphalts, particularly the harder grades, are eliminated. The second is to set a limiting stiffness or strain for the particular design application and compare the mix under consideration with these design limits. Haas, et al. (76) have proposed a procedure for calculating the probable fracture temperature based on the average coefficient of thermal expansion, the

expected temperature range and the stiffness modulus of the pavement.

McLeod (137) proposed a chart which allows one to select grades of asphalts that should eliminate transverse thermal cracking during the service life of the pavement.

Fatigue Cracking

Fatigue is the phenomenon of fracture under a repeated or fluctuating stress whose magnitude is generally less than the tensile strength of the material (124). The cracking mechanism associated with fatigue usually starts with cracking at the bottom of the asphaltic base or surface layer, then continues with propagation within the binder matrix to the surface. It can start at an isolated place in the wheel tracks of the travel lane and progress from these spots in opposite directions to a distance of as much as 200 ft. or more (67).

In reporting the results of the Zaca-Wigmore Test Road, Zube and Skog (67) indicated that longitudinal cracking preceded alligator cracking and that a very rapid ("almost explosive") increase in alligator cracking was observed after 10 percent of the lane area developed these cracks. Their conclusion was that it may be possible to predict the extent and time of future maintenance by determining when the first rapid increase in alligator cracking occurs. Alligator cracking seems to be the most common form of cracking resulting from fatigue failure as reported in the literature.

Fatigue life, as measured by the controlled-stress type of testing, (applicable to thick pavement structures) is affected by mixture variables in different ways than when tested in the controlled-strain type of testing (applicable to thin pavement overlays) (65).

An increase in mixture stiffness results in a longer fatigue life in the controlled-stress mode of loading. Factors such as dense graded mixtures,

harder asphalts, high compaction, relatively high asphalt contents (low water and volatiles in liquid) and rough textured aggregates increase the stiffness and therefore increase the fatigue lives (64, 65, 86, 90, 97). Accordingly, several suggestions and comments have been proposed. The amount of filler and asphalt in a mix should be such to produce maximum stiffness with minimum air voids, with sufficient asphalt to prevent stripping of asphalt from the coarse aggregate (86). The optimum asphalt content, based on fatigue behavior, is slightly less than I percent above the asphalt content selected on the basis of stability requirements and is dependent upon the type of gradation of the aggregate (125). Cutbacks and emulsions require aeration to reduce moisture and volatile contents in order to obtain maximum compaction and thus improve stiffness (86), however, maximum density alone does not necessarily result in maximum fatigue resistance (97).

For the controlled-stress mode of testing, asphalt viscosity may be the best physical property for predicting fatigue resistance (65). On the other hand, when the controlled-strain mode of loading is used, the effects are different. In this case, most of the factors mentioned above would result in greater stiffness and thus shorter fatigue lives (65).

Unusually close correlation between fatigue cracking and deflection has been established (12,56). The exact nature of this correlation has been presented in several ways. The most common quantitative methods of correlating deflection with fatigue cracking have been the magnitude of deflection method, the radius of curvature method, the 'Bending Index' method (in which the B.I. = the ratio of the deflection in inches to one half of the deflected length), and finally the slope of deflection method (56).

Two types of fracture must be considered in the cracking mechanism. Ductile fractures are those in which appreciable flow of material occurs before separation. Brittle fractures are those in which little or no flow occurs (45). The type of stress condition which may promote brittle fracture of a localized kind is brought about by impact. Binders of high viscosity and high elastic modulus have a greater liability to this type of fracture. At lower stress levels, the more slowly applied stresses may produce the ductile failure. Such stresses might be part of a creep failure or instability failure. When designing a flexible pavement to resist fatigue cracking, there are Provide a pavement or wearing surface solutions (12): 1) two main that is sufficiently flexible to accommodate repeated vertical deflections without serious cracking. This can be done mainly by using a thin bituminous surface layer, or materials that will provide a flexible mix, such as, softer asphalt, moderately high volatile content, rounded and smooth aggregates, etc. 2) Decrease the magnitude of vertical deflection to a tolerable limit by providing greater pavement stiffness by means of increasing the thickness and/or stiffness of the non-resiliant base or subbase.

Another solution that might be possible is to increase the tensile strength of the surface layer by adding filler to a binder which normally contains only a small amount of filler, by higher asphalt content, lower air voids, high quality aggregates, good asphalt-aggregate bonds, etc.

It can be seen that no one solution is the ultimate complete solution, and some of them are in contradiction. The conclusion is that an optimimum-combination of flexibility, stiffness, and tensile strength might provide the desirable mix and pavement design which will minimize fatigue cracking.

University Record Recor

A systematic summary of the factors affecting general cracking failures in flexible pavement and cold mix bases, and the required properties associated with its prevention, is given in Figure 4.

Distortion

The distortion failure in flexible pavements is a gradual accumulation of permanent deformation or displacement in the pavement structure mainly due to repeated application of wheel loadings. This type of failure is considered as typically structural since, if not corrected early at some "critical" condition (103), it can deteriorate rapidly to a complete structural break up of the pavement system. Since this type of failure involves permanent displacements, it is usually referred to as "instability failure", "bearing capacity failure" (138), or "consolidation failure."

Distortion Mechanism

Two types of permanent displacements are involved in the distortion mechanism. The first, known as consolidation deformation, is due to in-service densification of the pavement materials (48, 79, 98, 110). The second, known as plastic deformation, is due to appreciable vertical and lateral shear failure movement of large masses underwheel loads (5,10). See Figure 5.

The consolidation deformation does not necessarily indicate instability (48). It is a local random rearrangement of particles into a denser interlock position which is usually more stable than the original one. Deep rutting and depressions may occur, but they do not progress. On the other hand, the plastic deformation is a result of extensive shear and bearing capacity failure accompanied by appreciable lateral movement in a definite failure surface resulting in upheavals. The movement distorts the stability equilibrium of the pavement into a structural break-up. This type of failure is the main concern when dealing with instability distortion.

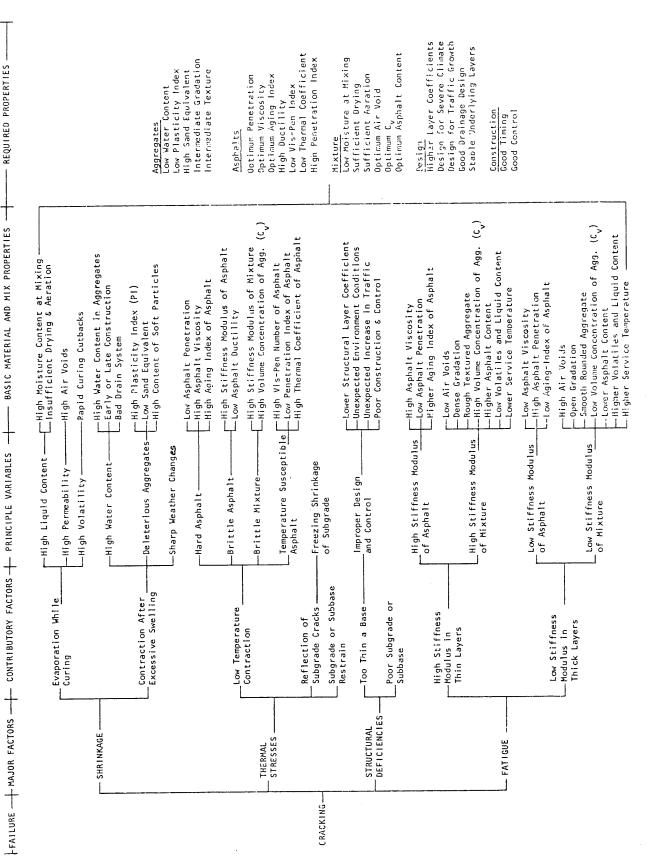
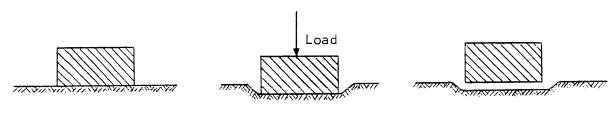


Figure 4 . Factors Affecting Crocking Fallure in Flexible Pavcments and Cold Mix Bases.



Densification (Consolidation Deformation)

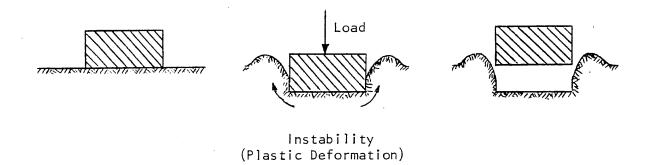


Figure 5. Diagram illustrating distortion caused by Densification and Instability (110).

The many factors affecting the stability resistance to distortion are as follows:

Granular Friction

A most important element in stability of asphalt-treated granular materials is the frictional resistance and particles interlocking provided by the aggregates. Thus, aggregates with higher geometric irregularities (rough textured and angular) will produce mixes with higher stability (139, 140, 141, 142, 143, 144, 145). Dense gradation and proper compaction will also contribute to the efficiency of aggregates interlocking and friction, by producing higher volumetric densities of the particles in the mix (41, 45, 110). It must be mentioned, however, that high initial unit weight or density are not always the best criteria for ultimate strength or stability (19, 113). The major emphasis must be given to the specific gradation and compaction method which will produce proper volumetric densities. Compaction temperature will have a large effect upon the ease with which this is accomplished.

Moisture, Liquid and Asphalt Content

The proper amount of moisture, liquid, and asphalt in the bituminous treated mixture is also a major factor related to stability. Mixes with too high an asphalt content are excessively plastic because the asphalt serves as a lubricant. The aggregates are pushed apart by the thick asphalt films so that they slide by each other and flow easily. This lubrication effect also results from a liquid content which is too high due to excess water or hydrocarbon volatiles. In general, stability increases as the amount of water and hydrocarbon volatiles decreases (19). This may be from the moisture content of the soil before mixing, from the mixing water added, if any, or from the gasoline or kerosene in the cutbacks or the water in emulsions.

It has been general practice in cold mix technology to allow a drying period, prior to compaction, to reduce the liquid content of the mixture in order to increase the initial stability. The liquid content which is optimum for compaction, is generally not equal to that which gives maximum stability. In general, maximum stability is achieved at a liquid content slightly below that for optimum compaction, and stability decreases rapidly at higher levels (20). If a drying back period is to be used, the mixture should be dried out just enough to provide the desired initial stability, then compacted. Too much drying will hurt the efficiency of compaction by increasing the air void content and the susceptibility to soaking up water (19).

Some researchers indicated adverse effects of drying on stability. Katti, et al. (38) pointed out some conditions under which compaction of a soil-cutbackwater system immediately following mixing produces a more stable product than a procedure in which a drying back period is included between mixing and compaction. the use of that mixing moisture content required for maximum density. Any amount of moisture greater than that required for maximum serves only to aid in obtaining a degree of distribution of cutback density asphalt approaching an intimate mix. The excess water must then be evaporated in order to obtain good densification by compaction. Evidently, enough mixing to give high degrees of asphalt distribution (i.e. an "intimate mix"), results in small soil aggregates in which some of the strength properties are destroyed. The smaller the aggregates, the higher the total surface area. Coverage of a high surface area with asphalt results in asphalt films that are too thin for optimum waterproofing and cohesion. It can be seen that in finer granular soils, the most thorough distribution of asphalt does not necessarily produce the most desirable stability properties and cannot insure highest stability. Highest stability is achieved at some degree of distribution less than that of an intimate mix.

Finer soil-aggregate mixtures are of interest since it is expected that the substandard natural aggregate may contain this type of material.

Michaels and Puzinauskas (20) also referred to similar trends. Conditions which favor very uniform distribution of asphalt through a fine-grained soil (such as dilute curbacks, high dispersing cutback solvents, low viscosity asphalts, low volatility, high temperatures, etc.) upon drying may interfere with the formation of soil-soil bonds, which can be much stronger than soil-asphalt bonds. Thus, dry strength is reduced. It can be concluded that fine-grained soils should be mixed until something less than an intimate mix has been achieved to obtain a "continuous asphalt-discontinuous matrix" condition (68). Coarse grained soils, however, should be mixed until an intimate mix is achieved (70).

Under conditions where water can evaporate from a cutback-treated soil during curing, more volatile cutback solvents give poorer stability than less volatile ones. Very low volatility solvents (such as kerosenes), however, which remain behind after cure, result in inferior stabilization (20). Any control of the stability by a density requirement should be accompanied by a limitation of water and hydrocarbon volatile content in the mix (19).

Instability can also be caused by too low an asphalt content. The asphalt binder serves to provide cohesion or liquid friction which is important for stability (110). This cohesion is dependent mainly upon the surface area of the sand and filler particles, upon the film thickness of asphalt at contact points and also upon the viscosity of the asphalt. The cohesive strength will increase as asphalt content increases up to an optimum after which further increases will cause lubrication by means of increasing the thickness of asphalt films.

Asphalt Consistency and Hardening

Asphalt consistency has a major effect on the stability of bituminous treated mixtures. A decrease in asphalt viscosity (stiffness) usually produces more stable mixtures with higher resistance to plastic deformations. On the other hand, harder

asphalt can produce mixtures which are more shear susceptible (119), and more cracking susceptable (see previous section).

Care should be given to choose liquid asphalts with a proper initial consistency of the residue. Great emphasis should also be given to the hardening of the asphalt residue during the service period. Many researchers consider this to be a most important factor that influences pavement durability, performance and serviceability. (115, 118, 119).

One of the major causes of hardening is overheating the asphalt at some time prior to or during construction. Since cutbacks and emulsions are combined with water and volatiles to lower their viscosity rather than heating to high temperatures, the danger of overheating is somewhat reduced. However, since in cold mixes the liquid asphalt may be heated, there are many times when the asphalt is subjected to high temperatures which may be above the critical value above which the asphalt properties are greatly impaired.

Several causes of asphalt hardening after construction has been completed are mentioned in the literature (8, 48, 68, 115, 116, 117, 146). The major causes are oxidation, polymerization, age hardening, absorption of oils by the aggregates, volatilization, and solar radiation.

Of all the hardening mechanisms, evaporation of volatiles and high temperature oxidation predominate during the mixing process and whenever the asphalt is hot. Oxidation at road service temperatures predominates under service conditions (117).

Water Susceptibility

Water susceptibility is another major cause of progressive instability in cold mix bases. Distortion failures due to water action are usually referred to as durability failures. Stripping, excessive pore water pressure, freeze &

thaw distress and frost heave are principle ways in which water is destructive.

Probably the most prominent form of water action is that of stripping in which the coating of bituminous binder around the aggregate is replaced by a water film causing loss of adhesion and shear strength. The standard form of stripping occurs when this bituminous coating is fully displaced by water, so that it can be visually observed. However, Nevitt (28) describes another form in which the asphalt film is not fully displaced. This may occur in two ways: one in which the asphalt film bridges over scattered areas where a water layer has formed, and another in which the moisture exposure is sufficient to form a limited thickness of water under the asphalt film, but not sufficient to completely eliminate its cohesive and shear strength.

One of the factors which most affects stripping is the type of aggregate used. It is well known that many aggregates used in road construction are hydrophilic and coat preferentially with water rather than asphalt. If an emulsion with the "wrong" charge is used, (for example an anionic emulsion on an electronegative aggregate) the aggregate's hydrophilic properties are enhanced (110). Surface texture, porosity, and angularity also affect the coatability (22).

A complete coating of the mix is a necessity. There are, however, many cases in which this is accomplished only with great difficulty. The aggregate may be damp, dirty, or dust coated to begin with (23); the design asphalt content may be too low (21, 89); the asphalt may be too hard to mix properly; or fine clays and porous aggregates may absorb excessive asphalt. Poor construction techniques such as insufficient mixing or overheating the mix, may also contribute to poor coating. All these tend to result in a discontinous asphalt film on the aggregate and increase the probability of stripping (23).

Asphaltic materials, particularly cutback asphalts, have very little stripping resistance just after mixing (48). They require a drying or a curing period

during which the volatile oils can evaporate enough so that the residual asphalt can obtain sufficient viscosity (39). If the curing period is not sufficiently long, stripping resistance may remain at a low level (18, 21). Once a sufficient part of the curing has taken place, the intrusion of water should be minimized by proper drainage, compaction, and sealing (89). A high void content, brought about by either poor gradation (21) or lack of proper compaction is also harmful. Stripping action is greatly reduced when asphalts which are too soft are avoided, since they are more readily replaced by the water (23, 25, 89). One must remember, however, that in many areas the use of harder asphalts has resulted in a high incidence of thermally indiced transverse cracking (8, 88). As a pavement ages, its stripping resistance is reduced due to the effects of age hardening.

Another form of water susceptibility is reduced shearing resistance due to pore water pressure. Although not found in high type bituminous mixes where good gradation is assured, the high moisture content in mixing, and the limited permeability of some stabilized high PI soils, presents the possibility of pore pressures building up enough to reduce the strength, or shearing resistance. A very high clay or silt content is necessary for this problem to become a significant one.

Two well known types of moisture-related failures are frost heave and freezethaw distress, otherwise known as spring breakup. Frost heave occurs when water in the subgrade or base course freezes forming ice lenses. These ice lenses grow as they are fed by capillary water (110). The water expands on freezing and tremendous pressures are built up resulting in heaving of the pavement. Frost heaves of more than a foot have been reported in Illinois(111). Spring breakup is a related failure in which, as the pavement thaws in the spring, a layer of unfrozed material forms on top of the layer of frozen material. The restricted drainage results in a reduced supporting capacity (79). These failure mechanisms are fairly well

understood and several solutions have been recommended. The most successful of these are replacing the frost susceptible soil with non-frost susceptible material (lowering the fines content to reduce capillary action), cutting off the capillary action by installing sand drains and restricting traffic through load limits during the spring months.

Recently, work done by The Asphalt Institute (112) indicates that the type of filler used plays an important role in influencing water susceptibility. Specifically, they found that specimens containing crushed gravels were considerably more water sensitive than mixes with natural uncrushed gravel particles and that when the filler prepared by crushed gravel was either replaced with limestone dust or treated with 1% of hydrated lime, the water sensitivity of the specimens was reduced considerably.

The desired properties, then, for maximum resistance to water action, would appear to be a dry, clean, non-hydrophilic aggregate of good shape and surface texture, a good gradation with a low void content, a minimum amount of fines in the filler, a high asphalt content using an asphalt of sufficient viscosity, sufficient aeration, good compaction and good drainage.

It can be seen that the distortion mechanism which usually results from progressive instability, is quite complex. A systematic summary of the factors related to distortion distress is given in Figure 6.

Disintegration

The disintegration of a flexible pavement usually starts from the surface. It usually begins as a typical functional mode of failure but can progress rapidly into a structural distress. Two modes of failures are most common in this group: Ravelling and Pot holes:

Ravelling, or surface deterioration, is a progressive disintegration of a pavement from the surface downward by dislodgement of aggregate particles (108).

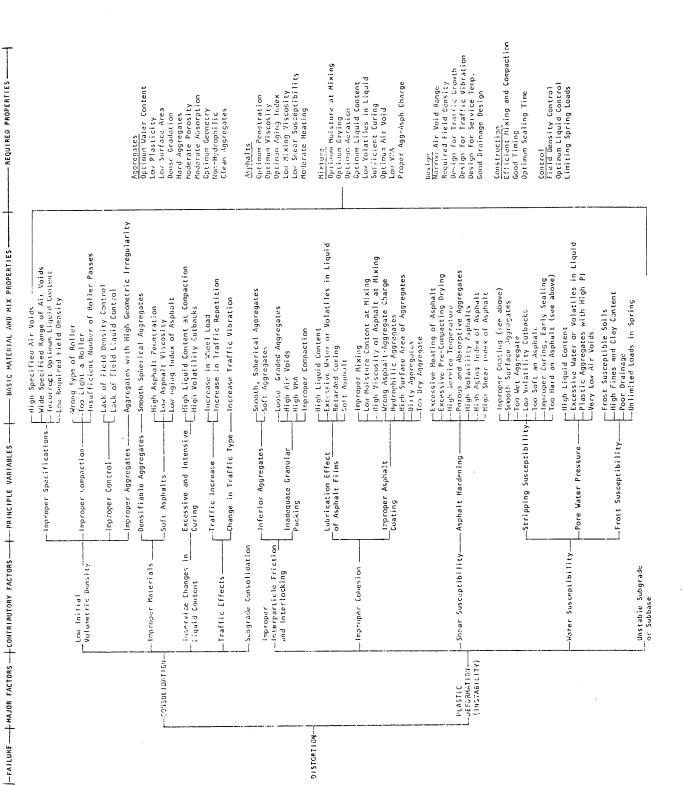


Figure 6. Factors Affecting Distortion Failure in Flexible Pavement and Cold Mix Bases

Usually, the fine aggregate comes off first leaving little "pock marks" on the pavement surface. As the erosion continues, larger and larger particles are broken free and the pavement soon has a rough and jagged appearance. Stevens (27) observed further that often with pavements laid late in the construction season, progressive disintegration occurred caused by fine dirt entering the honeycomb matrix which formed just below the surface as ravelling began. Ravelling disintegration can be evenly distributed over a large area of the pavement or base surface, or it can be localized in several spots.

Pot holes are another type of disintegration. They are localized, small, irregular depressions in the pavement. Pot holes are produced when traffic abrades small pieces of pavement out of localized weak spots in the surface. These spots disintegrate primarily because of a poor mixture containing excess fines, dirty aggregates, insufficient amounts of asphalt, or because the layer was poorly compacted or too thin. Softening of the base and subbase is also a major factor which contributes to the formation of pot holes. Pot holes can also result from progressive ravelling or from progressive cracking (usually block cracking) by which small blocks of mixture are disintegrated from the pavement surface, usually resulting in localized pot holes. This progressive cracking is sometimes called spalling (147).

Several general causes of disintegration have been proposed. Lack of compaction is, perhaps, the most important one. Whether it is due to poor construction weather, particularly cold weather, or poor construction techniques, it can result in a surface texture which is too open. If the pavement surface is not properly sealed before winter, water, silt and mud, grit and other foreign material enters the open pores and, especially under heavy traffic, works the aggregate loose. Other causes include poor mixing and underasphalting, causing a weak bond between the aggregate particles and the rest of the pavement; overheating of the asphalt mix, causing the asphalt to become more brittle; use of aggregate which is very abrasive;

and use of dirty aggregate. Generally, factors that contribute to improper coating and to durability stripping, are the major causes of pavement disintegration.

In the specific case of asphalt-treated cold mix bases, the drying and curing phases of the mix introduce additional sensitivity to disintegration. Early service upon an uncured base will promote disintegration. On the other hand, overdried and cured mixes will also be sensitive to progressive revelling.

Stevens (27) suggested that a rich, dense mix, well compacted and given a chance to seal under traffic during the summer season, is the most ravel-resistant structure that can be constructed. If these conditions cannot be met, the asphalt content of the mix should be slightly raised, heavy rubber-tired rollers making repeated passes should be used, and/or a coat should be used to seal the pores. Once revelling has begun, a seal coat is the best method of retarding further deterioration.

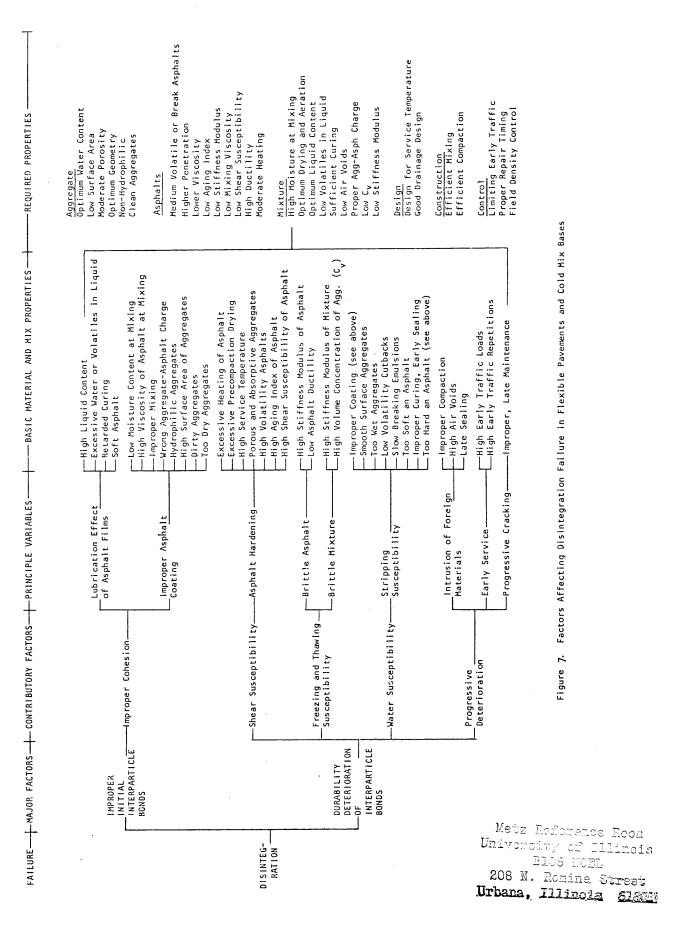
Another, but less severe form of disintegration is the weathering of the asphaltic surface. This is a gradual disintegration of the pavement surface, increasing the texture and exposing more and more aggregates due to drying out or loss of bitumen which is usually caused by severe climatic conditions.

For a systematic analysis of factors related to disintegration failure, see Figure 7.

Skid Hazard

Skid hazard is merely a functional failure and usually does not progress to any structural distress. It occurs in cold mix bases mainly during stage construction when the base functions as a wearing surface without surface treatment. Two different types of modes are classified in this group.

Bleeding, or flushing, is the upward movement of excessive asphalt and liquids in the formation of a slick film of asphalt on the surface. Sometimes



bleeding, which is initiated in the base, can penetrate overlaying layers.

Bleeding usually occurs during hot weather.

The most common cause of bleeding is overasphalting in one or more of the pavement layers. This can result from too rich a mix, too soft an asphalt, high moisture or liquid content, high volatile and water content in liquid, high percent voids filled with asphalt accompanied by decreasing of air voids (densification) under service. Overweight traffic and excessive vibration tend to promote bleeding.

Polishing of surface aggregates is another typical functional failure mode which contributes to the slipperiness of the pavement. Polishing is defined as a reduction of the microtexture of aggregate particles (148). Some aggregates, particularly some types of limestone, will become polished rather quickly (149, 150, 151). Others, such as some types of gravel, are naturally smooth and if they are used in a surface layer uncrushed, they have low skid resistance.

For a systematic analysis of the factors related to skid hazard, see Figure 8.

FAILURE MODES IN ACTUAL FIELD PERFORMANCE

The literature study presented above provides a refined analysis of the different failure modes and their causes which are likely to occur in cold mix bases. Since most of research works reviewed were based on controlled laboratory studies, it was possible to analyze the different modes of failure down to basic material and mix properties as presented in Figures 4, 6, 7, and 8.

Despite the refinement of the analysis, it merely provides a balanced treatment of the different failure modes and their causes. Therefore, it is still unknown what is the likelihood or frequency of occurence of each type of distress, or what weight should be given to every specified cause or required property.

-- BASIC MATERIAL AND MIX PROPERTIES ---

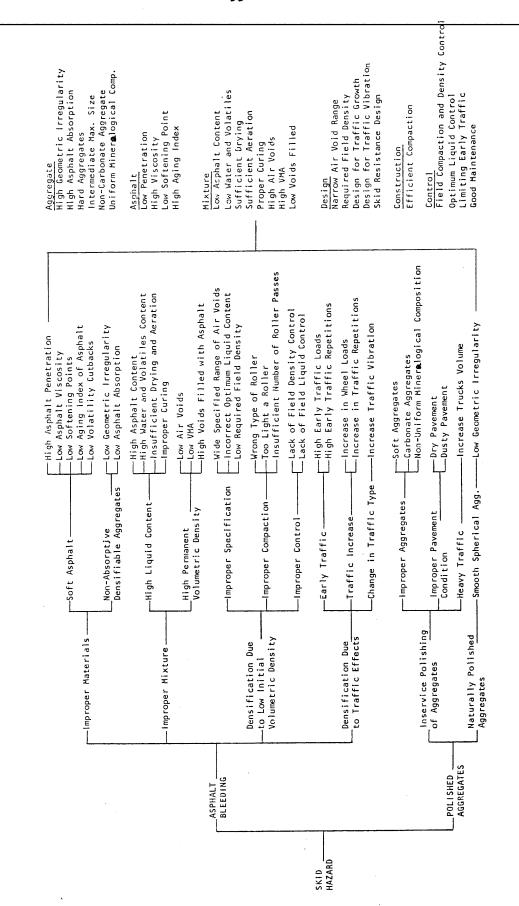


Figure 8. Factors Affecting Skid-Hazard Failure in Flexible Pavement and Cold Mix Bases

In order to complete the analysis and to gain the information which might link the laboratory studies to actual field performance, a survey of actual construction and service performance of cold mix bases was conducted at the county level in several midwestern states. The information gained in this survey made it possible to order failure modes and causes of distresses in priority levels, and thus, to give proper weights to different required properties.

Extent and Scope of the Survey

Table 2 summarizes the extent and scope of the survey of cold mix bases technology performed in counties of several midwestern states. The study was done by a mail survey. A detailed questionnaire was composed and sent to the prospective respondents.

Ten states were originally considered. Letters of inquiry were sent to DOT officials in each state with a request to furnish names of county engineers who had experienced and constructed cold mix bases. In cases where insufficient information was provided by the state DOT, additional inquiries were sent to other engineers who were familiar with construction activities in the states. Other names were provided by persons who answered the questionnaires.

Names of 104 county engineers in seven states, excluding Indiana, were collected to whom questionnaires were sent. Because of difficulties in singling out county engineers with particular cold mix experience, a general mailing to 91 county engineers in Indiana was made. As indicated in Table 2, 80 engineers (63.5% excluding Indiana) responded. A total of 72 questionnaires were finally selected for data analysis.

The counties selected represent a total of 5304 miles of cold mix base construction, which combines 3337 miles of road mix construction and 1967 miles of plant mix. They also represent a wide range of experience between 1 and 53 years (12.4 years as an average), and a range of 1 mile to 440 miles of construction in individual counties (a total average of 73.8 miles per county).

The distribution of mileage and experience is considerably different from state to state. For detailed information, see Table 2.

TABLE 2

SCOPE OF SURVEY OF COLD MIX BASES TECHNOLOGY IN COUNTIES OF MIDWESTERN STATES

-							-										
										Mileag	e of C	old Mix	Mileage of Cold Mix Bases Construction	nstructi	oo		
		63		ə				Road	Road Mix		-	Plan	Plant Mix		Total (Total Construction	lon
בחד החדי		tannoo	Кезроп	ldasilq	Years Expert				orm £y				ास्य इ. ४			Some⊊∑	
Number of Co Sampled ^l		19dmu%	Percent	Number of Ap Cealinuo	Капgе	her county	Number of Countles	Total Mileage	ਮੁਤਰ ਤੇ ਹਿਟ	Average per County	Number of Countles	Total Mileage	०० प्रभवतु <u>भवत</u> हिर	Average per County	Total Mileage	Sange per Co	тэq эдвтэvА Соипту
30		23	76.6	22	1-32	8.3	18	591	1-150	32.8	13	246	1-100	18.9	837	1-250	38.0
24		15	62.5	14	4-40	16,7	13	1217	8-240	93.6	10	386	6~200	38.6	1603	1-440	114.5
91	Ε	14	15.4	11	4-53	20,7	7	556	5-250 .	79.5	7	380	2-200	54.4	986	2-320	85.1
15		80	53.4	7	3~14	9.6		330	1-191	47.1	1	ı	ı	ŧ	330	1-191	47.1
13		1	53.9	9	3-20	8,2	9	66	6- 40	16.5	i	ι	ŧ	1	66	6- 40	16.5
10		9	60.0	5	3-25	15,2	'n	341	20-170	68,2	e.	217	7-170	72.3	558	7-340	111.6
5	_	2	100.0	-2	17-23	19.2	e	203	47~106	69,7	5	616	3-255	123,2	819	3-305	163.8
7		2	28.6	2	3-3	3,0	ι	ı	ľ	£ .	7	122	32- 90	61.0	122	32- 90	61.0
ON	None 4					,											
ž	None 4																
195	10	80	41.05	72	1-53	12.4	59	3337	1-250	56.6	04	1961	1-255	49.2	5304	044-1	73.8
		-		_										-			

 $^{1}_{\rm Countles}$ which indicated expertence with cold mix bases.

Represents a general mailing to most Indiana county engineers.

No experience with cold mix bases, as indicated by the state DOT.

Spercent response, excluding Indiana's general mailing, was 63.5.

Structure of the Questionnaire Used in the Survey

The questionnaire used for this survey was made up of five major sections, in which questions were asked about Asphalts, Aggregates, Mixture, Construction, and Performance. Additional sections provided general information. As a whole, the data from each questionnaire reflect the cold mix bases technology in the county surveyed. In this report only performance data will be analyzed. Data from other sections will be used in later phases of the research, especially for selecting primary counties for a more quantitative study.

In the performance section, the respondents were asked to identify those failure modes which have occured in their road or plant mix constructions. To assure simplicity and accurate responses, only well known terminology was used. Therefore, no distinction was made between the different modes of cracking. On the other hand, five modes of distortion failure and two modes of disintegration failure were used. Based on the pretesting stage of the survey, additional types of failure, typical to cold mix construction, were added. These types of failure are "base softening" (or as used In field terminology "mushy areas"), and "slick planes".

For each failure mode checked, the engineer was asked to give his judgement and specify the cause, frequency of occurrence, and the remedy taken.

It was realized during the design of the survey and the pretesting stage, that county engineers might be hesitant in admitting failure. Therefore, in order to gain a more positive attitude, a remark was added to stress that the past work in asphalt treated cold mix bases has been experimental and failures have occurred in every phase of such construction; thus, the data obtained would not be used to evaluate their work, but merely to analyze the failures and find the proper causes.

See Appendix.

Occurrence Frequency of Failure Modes

Table 3 summarizes the frequency of occurrence of the different failure modes within six of the states surveyed. Data in the table indicate the portion of counties (in percent) within each state that has experienced the specified mode of failure. The different failure modes are combined in Table 4 according to major failure groups. The numbers indicate the portion of counties that have experienced at least one type of failure mode within each failure group. A distinction has been made between two types of distortion—instability and frost heave. Base softening failure was also added.

The above data indicate the following trends: As a total average, distortion failure is the most frequent failure among the counties surveyed (76.5%). Less frequent is disintegration distress (69%) and third in the order is cracking failure (57.4%). Other failure groups show relatively low frequencies of occurrence (29.4% - 33.8%)

These general trends can sometimes be different among the states. Nebraska and lowa, for example, show higher frequencies of cracking and disintegration failures and a lower number of distortion failures.

Some of the failure groups are often closely related. A high frequency of cracking is accompanied by intensive disintegration and frost heave (hard asphalt, low temperature, low asphalt, water action) as shown for Kansas, Nebraska, Minnesota, and Iowa. Also a high frequency of distortion distress is related to a higher frequency of bleeding and base softening (high liquid and asphalt content) as shown for Illinois, Kansas, Michigan, and Minnesota. On the other hand, no consistant relationship exists which relates the frequency of occurrence of distortion, bleeding, and base softening to the occurrence of cracking, disintegration and frost heave.

TABLE 3

OCCURRANCE OF FAILURE MODES IN COLD MIX BASES WITHIN THE MIDWESTERN STATES SURVEYED

	би		Dist	ortion			Disintegr	ation	Skid Hazard	Base Soften- ing
STATE	Cracking	Rutting	Shoving	Corrugation	Depression	Frost heave	Ravelling	Pot-holes	Bleeding	Mushy Areas
Illinois	27	41	45	55	23	18	32	27	27	27
Kansas	86	64	64	57	57	36	71	64	36	50
Nebraska	83	- 33	33	17	17	67	67	17	17	0
Michigan	50	50	33	33	17	0	50	67	33	17
Minnesota	75	75	75	25	25	100	75	75	75	50
Iowa	100	40	0	0	60	60	60	20	20	0
Indiana	45	45	45	27	18	9	45	45	45	36
Average	57.4	48.5	45.6	39.7	30.9	30.9	51.5	44.1	33.8	29.4

Numbers indicate the portion of counties (in percent) within each state that has experienced a given failure mode, e.g. 30% of the counties surveyed in Illinois had cracking failure in cold mix bases.

TABLE 4

OCCURRANCE OF MAJOR FAILURE GROUPS
IN COLD MIX BASES WITHIN THE
MIDWESTERN STATES SURVEYED

STATE	Cracking	Distortion (Instability)	Distortion (frost heave)	Disintegration	Skid Hazard	Base Softening
Illinois	27	82	18	45	27	27
Kansas	86	93	36	86	36	50
Nebraska	83	50	67	83	17	0
Michigan	50	83	0	67 .	33	17
Minnesota	75	75	100	100	75	50
lowa	100	60	60	80	20	0
Indiana	45	64	9	73	45	36
Average	57.4	76.5	30.9	69.1	33.8	29.4

Numbers indicate the portion of counties (in percent) within each state that has experienced at least one type of failure modes within each failure group.

Illinois, Michigan and Indiana show the lowest amount of cracking and frost heave compared to the other states. This may indicate a tendency toward a design of more flexible mixtures as influenced by the state DOT. The opposite may be applicable to Kansas, Nebraska, Minnesota, and lowa; where the high frequency of cracking and disintegration might indicate a tendency toward a design of stiffer mixtures.

It might be of interest to notice that county engineers from states which represent more average years of experience generally admit more failure cases than engineers of the other states (see also Table 2).

Causes of Major Failure Groups

More than four hundred cases of failure were admitted in the survey. About 260 were explained, and causes were given. As expected, the causes were given in general terms and terminology; therefore, a less refined analysis was possible. This analysis is given in terms of the major factors and principle variables affecting failure in cold mix bases². No attempt was made to go down to basic material and mix properties. Figures 9 through 12 represent analytical charts which classify and order causes of base distress, as pointed out by the engineer, in the four major groups of failure (cracking, distortion, disintegration, and skid hazard)³. All principle variables which were indicated as causes of failures were grouped into about ten major contributory factors. Number of repetitions in admitting each factor were counted, and are given in percentages on the Figures. A summary of opinions for all groups is given in Table 5.

In every state surveyed, more than 65% of the counties surveyed use state specification for choosing asphalts and aggregates.

²As guoted from the questionnaire.

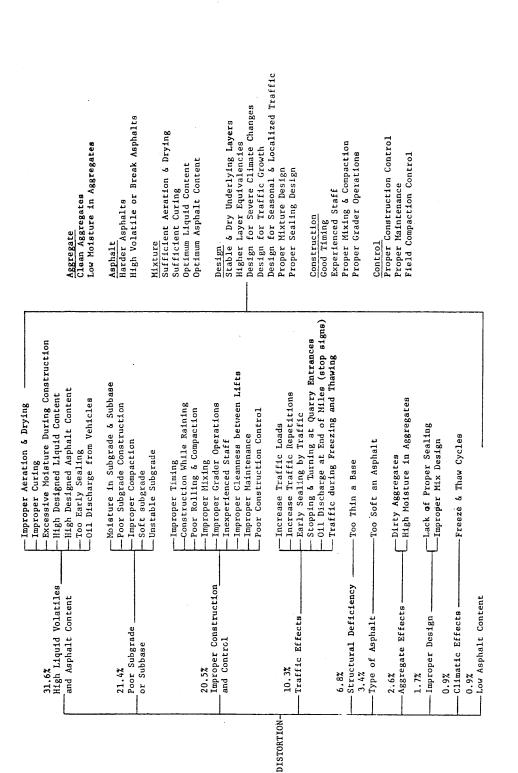
 $³_{\text{Excluding frost heave and base softening.}}$

PRINCIPLE VARIABLES

- FAILURE - HAJOR & CONTRIBUTORY FACTORS -

Causes of Cracking Failure in Cold Mix Bases as Indicated by County Highway Engineers Figure 9.

Total 41 cases



PRINCIPLE VARIABLES

FAILURE --- MAJOR & CONTRIBUTORY FACTORS

Total 117 cases

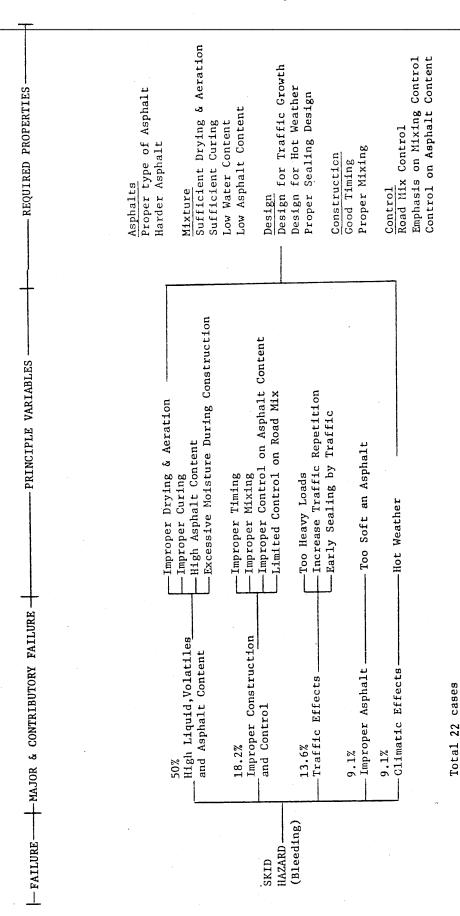
Pigure 10. Causes of Distortion Failure in Cold Mix Bases as Indicated by County Highway Engineers

PRINCIPLE VARIABLES

--- FAILURE - MAJOR & CONTRIBUTORY FACTORS -

Figure 11. Causes of Disintegration Failure in Cold Mix Bases as Indicated by County Highway Engineers.

Total 65 cases



Causes of Skid Hazard (Bleeding) Failure in Cold Mix Bases as Indicated by County Highway Engineers Figure 12,

TABLE 5

MAJOR CAUSES OF FAILURE IN COLD MIX
BASES AS INDICATED BY COUNTY HIGHWAY ENGINEERS
(A SUMMARY FOR ALL FAILURE MODES AND ALL COUNTIES SURVEYED)

Cause of Failure in Cold Mix Bases	Number of cases	Percent
High liquid, volatiles or asphalt content	74	26.0
Improper design, construction and control	59	20.7
Unstable underlying layers	56	19.7
Increase in traffic loads and repetitions	26	9.1
Structural inadequacy (too thin a base)	19	6.7
Wrong type of asphalt	13	4.6
Low liquid and asphalt content	12	4.2
Effects of severe climate	11	3.9
Wrong type of aggregates	9	3.2
Lack of proper sealing	6	2.1

 $^{^{1}{\}rm Includes}$ base softening and mushy areas failures.

TABLE 6

CAUSES OF FLEXIBLE PAVEMENT FAILURE
AS POINTED BY FIELD ENGINEERS IN JAPAN (152)

Causes of pave -ment failure	Number of cases	%		of cases	%
Increase in tra -ffic volume	63.	19.1	Insufficient compoc -tion of subgrade	20	6.1
Weak subbase	46	14.0	Poor drainage	i 9	5.8
Settlement of fill	27	8.2	Hardening of asphalt binder	18	5.5
Insufficient pave - ment thickness	27.	8.2	Weak subgrade	14	4.2
Frost heave	25	7.6	Others	7	21.3

Note) Other causes are

- · Low binder content
- Cracking of cement stabilized layer
- Seasonal period of construction
- Poor asphalt mixtures
- Tire chain
- Aggregate of low grade .

Generally, the causes of failure, and the required properties assessed, are in agreement with the refined analysis presented by Figures 4, 6, 7, and 8. Therefore, additional refinement is added here by the different weights given to each major cause. Since this survey represents considerable experience in cold mix base construction, it is believed here that the analysis is also realistic and practical.

The most critical and frequent cause of failure which is typical to any mode of distress in cold mix construction is the improper amounts of liquid in the mixture (26.0 percent of all cases). Excessive amounts will induce bleeding, distortion, and cracking, while a deficiency in liquid and asphalt content will dominate disintegration and also affect cracking.

Other major causes are related to improper construction and control (20.7%). This factor is also critical in cold mix construction since the proper amount of liquid in the mixture is very sensitive to construction timing, curing, aeration methods, mixing, compaction, and sealing.

Pavement design factors were also considered as major causes for base distress. Unexpected traffic, climatic effects, and structural deficiencies were indicated as frequent contributory factors for all failure groups.

It is quite surprising to notice that asphalt and aggregate factors were indicated as relatively minor causes for cold base failures.

Unstable underlying layers were indicated as the third major factor affecting base distress (19.7%). Stable subgrade and subbase are, of course, the first requirements for every type of pavement, thus it does not relate specifically to cold mix technology.

It might be interesting to compare Table 5 with Table 6, which summarizes failure causes of flexible, hot mix pavements, as pointed out by field engineers

Metz Reference Room University of Illinois BIOS NCEL 208 N. Romine Street Urbana, Illinois 61831 in Japan (152). The data in Table 6 indicates that unstable underlying layers and increases in traffic volume are the major failure causes of conventional hot mix pavements (32.1% and 19.1%, respectively). Other factors, as poor asphalt mixtures and improper construction (which are the major causes of failures in cold mix bases — as indicated by Table 5), are only minor causes here. This reflects the complex behavior of cold mixes, and their special sensitivity to proper mix design, construction and control, as compared to conventional hot bituminous mixes.

For a more refined study of each cause of failure, see the analysis of failure modes discussed in the previous sections.

REQUIRED PROPERTIES

The basic materials properties, and the principle variables which are related to the failure mechanism of cold mix bases have been discussed in the previous sections, and were summarized for each failure group in Figures 4 and 6 through 12. Based on these properties and variables (failure causes), required properties were assessed to each failure group. They were grouped to characterize the desired factors of aggregates, asphalts, mixture, design, construction, and control, and were also summarized in Figures 4 and 6 through 12.

All required properties from the different failure groups were combined together to characterize general satisfactory performance requirements in cold mix bases. They are summarized in Table 7.

Basically, two types of required properties were identified:

- 1) Definite trend properties.
- 2) Non-definite optimizable properties.

7	
TABLE	

REQUIRED PROPERTIES IN COLD MIX BASES (A Summary For All Failure Modes)

뒴	on Control Control Control Control of Optimum ontent d Mix is Traffic g Traffic
CONTROL	Definite Trend Properties Field Compaction Control Field Density Control Mixing Control Field Control Field Control Control of Optimum Liquid Content Control on Road Mix Operations Limiting Early Traffic Limiting Spring Traffic Proper Repair Timing and Maintenance
CONSTRUCTION	Definite Trend Properties Good Construction Timing Experienced Staff Efficient Mixing & Compaction Proper Grader Operations Proper Construction Control Non-Definite Optimizable Properties Optimum Sealing Timing Optimum Stockpiling of plant Mixes
DESIGN	Definite Trend Properties Higher Layer Equivalencies Design for Traffic Growth Design for Traffic Vibration Design for Seasonal and Localized Traffic Design for severe Climate Stable Underlying Layers Design Good Drainage Design Required Field Density Narrow Air Void Range Proper Mixture Design Proper Sealing Design Skid Resistance Design
MIXTURE	Definite Trend Properties Proper Asphalt-Aggregate Charge in Emulsions Non-Definite Optimizable Properties Optimum (Noderate to high) Drying and Aeration Optimum (Noderate to Low) Volatiles in Liquid Optimum (Moderate to Low) Volatiles in Liquid Optimum Asphalt Residue Optimum Asphalt Residue Optimum Ar Void Optimum Widerate to Low) Voids Filled Optimum Stiffness Modulus
ASPHALTS	High Ductility Low Visc-Pen Index Low Usc-Pen Index Low Thermal Coeff. High Pen. Index Low Mixing Viscosity Low Shear Susceptability Non-Definite Optimizable Properties Optimum Penetration Optimum Viscosity Medium to Rapid Curing Cutback (NC, RC) Medium to Rapid Set Emulsions (MS, RS) Optimum (Low to Moderate) Volatiles Content
AGGREGATES	Definite Trend Properties Clean Aggregates Low Deleterious Content Low Plasticity High Sand Equivalent Hard Aggregates Non-Garbonite Aggregates Non-Carbonite Aggregates Composition Low Surface Area Non-Definite Optimizable Properties Optimum Moisture (water) Content Content Optimum Absorption characteristics Optimum (High to Moderate) Geometric Irregularity Optimum (Conse to Intermediate) Ceometric Irregularity

Optimum Filler Content Intermediate Naximum Aggregate Size

The first group represents the predictable part in the behavior of cold mixes. Here properties possess definite trends in their contribution to failure or satisfactory conditions. These trends are usually consistent for all applicable failure models. Therefore, for example, softer aggregates, shear susceptible asphalts or improper aggregate-emulsion electrostatic charges will always contribute to the probability of failure occurrance. The definite nature of these required properties and the fact that they usually dominate the basic requirements for the individual ingredients (aggregates or asphalts), simplifies the assignment of controls and constraints for aggregate and asphalt properties. In general, the design or control criteria will require either lower or upper levels only.

The complexity of cold mix behavior is introduced by the second group, the non-definite optimizable properties. As can be seen in Table 7, these properties dominate the behavior of the combined mixture. In this case, no definite trends can be obtained between a specific property and its relationship to failure or satisfactory performance. In most instances, the same failure mode is likely to occur both at lower or upper levels of a property, thus, an optimum level exists in which the likelihood of failure is minimum. The complexity of this behavior is further strengthened by the fact that the optimum level and the basic trends of a specific property usually vary with different types of failure groups.

Figures 13 through 16 represent the complex behavior of selected properties of aggregate, asphalt, and mixture.

Figure 15, for example, represents relationships between liquid (or volatiles) content and the relative failure probability in cold mixes. It can be seen that minimum chances for distortion failure are likely to be between low and intermediate liquid contents. Higher liquid contents

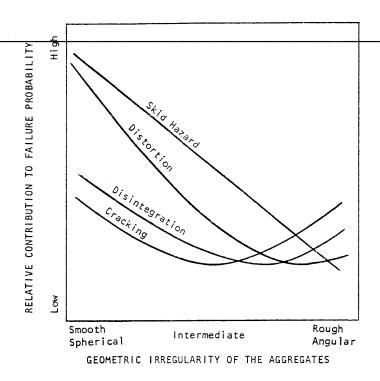


Figure 13. Hypothetical relationship between the geometric irregularity of aggregates and failure groups in cold mix bases.

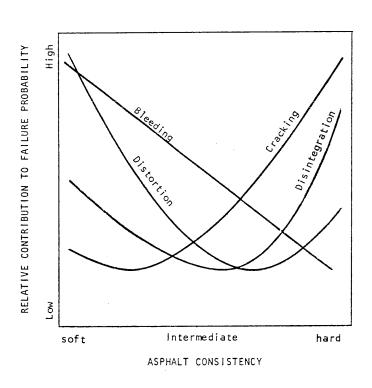


Figure !4. Hypothetical relationship between asphalt consistency and different failure groups in cold mixes.

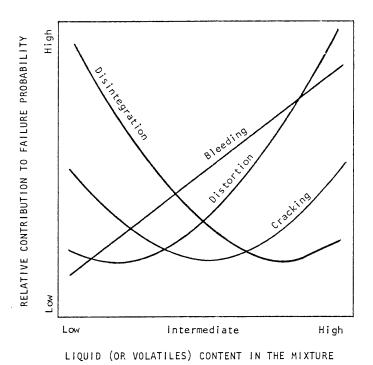


Figure 15. Hypothetical relationship between liquid content and different failure groups in cold mixes.

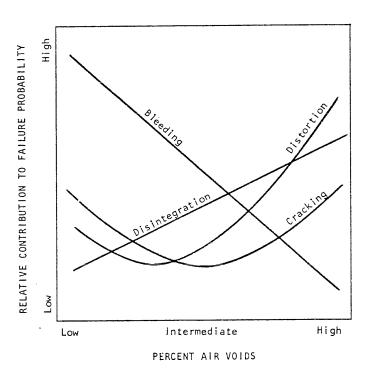


Figure 16. Hypothetical relationship between percent air voids and different failure groups in cold mixes.

will sharply promote distortion while lower contents will also tend to promote rutting or shoving, but to a very moderate extent. Opposite trends characterize disintegration failures. Here minimum failure chances are likely to occur between intermediate and high liquid contents. Lower contents will sharply promote base disintegration while higher contents will promote ravelling to a moderate extent. Cracking failure represents more balanced trends. Optimum conditions usually occur at intermediate liquid contents. At lower or higher contents, cracking failure is assumed to have a similar probability of occurrence. The influence of liquid content on skid hazard (bleeding) is completely different since it represents a definite trend behavior. The probability of bleeding will always increase with higher liquid contents.

Similar presentation of three additional selected properties for aggregates, asphalt, and the mix are given in Figures 13, 14, and 16.

It must be emphasized here that the above figures introduce only hypothetical, qualitative, and relative trends which are meant to characterize the influence of a given property on failure probability. Therefore, the shape of the curves and their absolute position are merely approximations. On the other hand, the relative trends of each curve and their mutual relationship were qualitatively based on the analytical study and the field survey performed in this research.

The trends in these figures indicate that the same property can have an opposite influence on different types of failures in cold mix bases (e.g. increase of air voids in the mixture to high levels can increase the probability of distortion, disintegration and cracking failures while at the same time decreasing the probability of bleeding failure, as can be seen in Figure 16.). Therefore, if the overall satisfactory performance is desired, all the different curves must be averaged to provide a combined performance

characteristic for the given property. However, in some instances, different weights must be given to different failure modes and also to different required properties. This will vary basically from one location to another. Consider, for example, designing county roads in Iowa. Based on Table 4, it can be seen that most of the emphasis should be given to cracking and disintegration while less emphasis must be given to distortion and skid hazard. Therefore, if one considers a combined performance characteristic of a given required property, different weights should be given to different failure groups when averaging the various trends (curves).

Figures 13 through 16 represent only a few selected properties extracted from Table 7. For a future quantitative evaluation, similar curves must be drawn for all definite-trend and optimizable properties in order to assure reliable evaluation of the basic controls, limits, and constraints. When considering all the required properties, a distinction should also be made between major and minor properties. Table 5 can give some preliminary indication of relative importance of some required properties. For example, major consideration should be given to controlling the liquid content in the mixture, or to finding proper constraints for design and construction factors. These factors may be even more crucial when substandard aggregates are involved.

It can be seen that the evaluation of the different trends in the required properties, together with the proper judgement to distinguish between major and minor failure modes or between important and less important properties, may provide a systematic and meaningful way to find control levels or constraints on basic required properties for materials, mixture design, and construction of cold mix bases.

At this stage, the various trends, as expressed in Table 7 and in Figures 13 through 16, are merely relative and qualitative. Therefore, one of the major

goals in future phases of this research will be a quantitative formation of the relationship between basic required properties and the probability of occurrence of different failure modes as expressed in the above figures.

SUMMARY

Three major efforts were combined in this analytical study which was based on a literature review and an actual field survey:

- (1) Identification of the various types of failure which frequently occur in actual cold mix bases.
- (2) Analysis of the failure modes to identify the major factors that cause the various types of distress.
- (3) Relation of the failure causes to the required properties needed for a satisfactory performance.

As end results, required properties were identified for aggregates, asphalts, mixture, design, construction, and control. Each given property can be qualitatively related to an applicable failure group. For each such combination, the following information is (or can be) available:

- The relative significance of the given property as related to the performance of actual cold mix bases.
- b) The local frequency of occurrence of the given failure group in actual service performance of cold mix bases.
- c) The relationship between different levels of the required property and the probability of occurrence of the given failure group.

This information will permit the determination of constraints or control limits for each required property, and also of priority levels for each failure mode as related to a given property.

At this stage, the mutual relationship between a property and a failure mode is mainly qualitative. The priority levels are also limited since they

are based on a localized survey. Therefore, the next step is to study the different testing techniques used in bituminous materials and to assign an appropriate testing procedure for measuring each significant required property. The testing procedures selected will be used to formulate quantitative relationships between the property measured and the probability of different failure modes. Testing of field sections, or the results from a comprehensive field survey, may be needed in order to assign priority levels to properties and failure modes. Finally reliable constraints and control limits can be assigned for a satisfactory structural behavior of actual cold mix bases.

It is anticipated that a systematic optimization technique will be needed to find the minimum likelihood of occurance of a given combination of failure modes under a specified property. This approach will also be used to optimize the proper range of control limits or constraints for each property.

Additional work on this study will be concentrated primarily on the failure modes of cracking, distortion, and disintegration. The functional failure mode of skid hazard, though not a primary consideration of this study, was included in this report to provide information on all aspects of potential problems which may be encountered with materials used in base course construction. In regard to base courses, skid hazard is of concern only when stage construction is employed, in which case the base course may temporarily serve as a surface layer for a significant period of time. Skid hazard is not considered to be a determining criteria for rejecting material to be used in base course construction; however, when the base course serves as a surface layer during stage construction, skid hazard needs to be considered in the total design to determine if a skid-resistant treatment is required during the first stage of construction.

REFERENCES

- 1. McKesson, C. L., "Bituminous Emulsion Stabilized Roads," <u>Proceedings</u>, Highway Research Board, Vol. 18, Part II (1938), pp. 283-288.
- 2. Roediger, J. C. and E. W. Klinger, "Soil Stabilization Using Asphalt Cutbacks as Binders," <u>Proceedings</u>, Highway Research Board, Vol. 18, Part II (1938), pp. 299-305.
- 3. McKesson, C. L., "Recent Developments in the Design and Construction of Soil-Emulsion Road Mixtures," <u>Proceedings</u>, Highway Research Board, Vol. 20 (1940), pp. 856-764.
- 4. Zapata, J., "A Method for Evaluating Performance in Service of Slow-Curing Asphalts," <u>Bulletin No. 124</u>, American Society for Testing Materials, October, 1943, pp. 31-39.
- 5. Hveem, F. N. and R. M. Carmany, "The Factors Underlying the Rational Design of Pavements," Proceedings, Highway Research Board, Vol. 28 (1948), pp. 101-136.
- 6. Pauls, J. T. and J. F. Goode, "Further Developments and Application of the Immersion-Compression Test," Public Roads, Vol. 25, No. 6 (December, 1948).
- 7. Pauls, J. T. and H. M. Rex, "Design Problems Encountered in the Use of Local Aggregates," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol, 18, (1949).
- 8. Rader, L. R., "Design of Bituminous Pavements with Respect to Stability and Resistance to Cracking," paper presented at the Bituminous Roads Institute, University of Wisconsin, Madison, Wisconsin, March, 1951.
- 9. Brown, M. and F. J. Benson, "Significance of Tests for Asphaltic Materials," Bulletin No. 119, Texas Engineering Experiment STation, Texas A & M University, 1951, pp. 59-66.
- 10. Hodges, R. L., "Ideas in the Use of Emulsified Asphalt," Roads and Streets, Vol, 95, No. 7 (1952), pp. 83-85.
- 11. Louisiana Department of Highways, "Control of Soil-Asphalt Stabilization During Construction," June, 1955.
- 12. Hveem, F. N., "Pavement Deflections and Fatigue Failures," <u>Bulletin No. 114</u>, Highway Research Board, 1955, pp. 43-87.
- 13. Waller, H. F., Jr., "The Unconfined Compression Test Bituminous Mixtures," Bulletin No. 212, American Society for Testing Materials, February, 1956, pp. 56-57.
- 14. Griffin, R. L., T. K. Miles, C. J. Penther, and W. C. Simpson, "Sliding Plate Microviscometer for Rapid Measurement of Asphalt Viscosity in Absolute Units," Special Technical Publication No. 212, American Society for Testing Materials, 1956, pp. 36-50.

- 15. Gilley, D. R., "The Use of Emulsified Asphalt in Surface Course Mixes and Base Stabilization," Proceedings, Canadian Technical Asphalt Association, Vol. 2 (1957), pp. 34-48.
- 16. Winterkorn, H. F., "Granulometric and Volumetric Factors in Bituminous Soil Stabilization," Proceedings, Highway Research Board, Vol. 36 (1957).
- 17. Mack, C., "Physical Aspects of Hardening of Paving Asphalts," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 27 (1958), pp. 183-185.
- 18. Craig, W. G., "Variables of the Static Asphalt Stripping Test," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol, 27 (1958), pp. 519-549.
- 19. Herrin, M., "Drying Phase of Soil-Asphalt Construction," <u>Bulletin No. 204</u>, Highway Research Board, 1958, pp. 1-13.
- 20. Michaels, A. S. and V. Puzinauskas, "Improvement of Asphalt-Stabilized Fine-Grained Soils with Chemical Additives," <u>Bulletin No. 204</u>, Highway Research Board, 1958, pp. 14-45.
- 21. Parr, W. K., "Field Observations of the Behavior of Bituminous Pavements As Influenced by Moisture," <u>Special Technical Publication No. 240</u>, American Society for Testing Materials, 1958, pp. 3-15.
- 22. Rice, J. M., "Relationship of Aggregate Characteristics to the Effect of Water on Bituminous Paving Mixtures," <u>Special Technical Publication No. 240</u>, American Society for Testing Materials, 1958, pp. 17-34.
- 23. Klinger, E. W. and J. C. Roediger, "Laboratory and Field Studies of Asphalt Paving Mixtures," <u>Special Technical Publication No. 240</u>, American Society for Testing Materials, 1958, pp. 35-47.
- 24. Critz, P. F., "Laboratory Study of Anti-Stripping Additives for Bituminous Materials," <u>Special Technical Publication No. 240</u>, American Society for Testing Materials, 1958, pp. 48-58.
- 25. Brown, A. B., J. W. Sparks and G. E. Marsh, "Objective Apprasial of Stripping of Asphalt from Aggregate," <u>Special Technical Publication No. 240</u>, American Society for Testing Materials, 1958, pp. 59-83.
- 26. Goetz, W. H., ''Methods of Testing for Water Resistance of Bituminous Paving Mixtures,'' <u>Special Technical Publication No. 240</u>, American Society for Testing Materials, 1958, 84-96.
- 27. Stevens, P. E., "Ravelling," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 28 (1959), pp. 1-15.
- 28. Nevitt, H. G., "Wanted: More Information on Stripping," Roads and Streets, Vol. 102, No. 5 (May, 1959), p. 213.
- 29. McRae, J. L. and C. R. Foster, "Theory and Application of a Gyratory Testing Machine for Hot-Mix Bituminous Pavement," <u>Special Technical Publication No. 252</u>, American Society for Testing Materials, 1959, pp. 9-21.

- 30. Goode, J. F., "Use of the Immersion-Compression Test in Evaluating and Designing Bituminous Paving Mixtures," <u>Special Technical Publication No.</u> 252, American Society for Testing Materials, 1959, pp. 113-129.
- 31. Merteus, E. W. and J. R. Wright, "Cationic Asphalt Emulsions: How they Differ from Conventional Emulsions in Theory and Practice," <u>Proceedings</u>, Highway Research Board, Vol. 38 (1959), pp. 386-397.
- 32. Bower, H. C., "Cationic Asphalt Emulsions," <u>Proceedings</u>, Canadian Technical Asphalt Association, Vol. 4 (1959), pp. 67-80.
- 33. Bird, G., "Stabilization Using Emulsified Asphalt," <u>Proceedings</u>, Canadian Good Roads Association (now Roads and Transportation Association of Canada), 1959, pp. 105-116.
- 34. Hignell, E. T., "Soil Stabilization with Asphalt," <u>Proceedings</u>, Canadian Good Roads Association (now Roads and Transportation Association of Canada), 1959, pp. 117-121.
- 35. Kerr, J. W. G., "Experience with Surface Treatments in British Columbia," <u>Proceedings</u>, Canadian Good Roads Association (now Roads and Transportation Association of Canada), 1959, pp. 155-173.
- 36. McConnaughay, K. E., "Emulsified Asphalt Tests and Specifications," Special Technical Publication No. 294, American Society for Testing Materials, 1960, pp. 51-67.
- 37. Mertens, E. W., L. D. Coyne and E. D. Rogers, "Cationic Asphalt Emulsions Recommended Tests and Specifications," <u>Special Technical Publication No. 294</u>, American Society for Testing Materials, 1960, pp. 68-84.
- 38. Katti, R. K., D. T. Davidson and J. B. Sheeler, "Water in Cutback Asphalt Stabilization of Soil," <u>Bulletin No. 241</u>, Highway Research Board, 1960, pp. 14-48.
- 39. Abbott, F. P. and W. G. Craig, "Determination of Age Hardening Tendencies and Water Susceptibility of Paving Asphalt by the Sonic Method," <u>Bulletin No. 270</u>, Highway Research Board, 1960, pp. 20-37.
- 40. Goodwin, W. A., "Correlation Between Saybolt-Furol Viscosimeter and the Brookfield Syncro-Lectric Viscometer for Measuring Viscosity of Cutback Asphalts," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 30 (1961).
- 41. Kimble, F. W. and W. B. Gibboney, "Control of Field Density of Bituminous Concrete with a Gyratory Compactor," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 30 (1961).
- 42. Schweyer, H. E. and T. L. Bransford, "Viscosity Measurements with the Sliding Plate Microviscometer," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 30 (1961).
- 43. Oglio, E. R., J. A. Zenewitz and W. J. Halstead, "Comparison of Zeitfuchs Cross-Arm and Saybolt Furol Viscometers for Measuring Viscosity of Cutback Asphalts," Public Roads, Vol. 31, No. 12 (February, 1962), pp. 248-251.

- 44. Puzinauskas, V. P. and B. F. Kallas, "Stabilization of Fine-Grained Soils with Cutback Asphalt and Secondary Additives," <u>Bulletin No. 309</u>, Highway Research Board, 1962, pp. 9-36.
- 45. Road Research Laboratory (now Transport and Road Research Laboratory)

 Bituminous Materials in Road Construction, London: Her Majesty's Stationery

 Office, 1962.
- 46. Skog, J. and E. Zube, "New Test Methods for Studying the Effect of Water Action on Bituminous Mixtures," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 32 (1963), pp. 380-411.
- 47. Campen, W. H., J. R. Smith, L. G. Erickson and L. R. Mertz, "Factors that Control Asphalt Requirement of Bituminous Paving Mixtures and a Method for Determining the Proper Asphalt Content," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 32 (1963), pp. 530-552.
- 48. Holmes, C. D. and W. D. Steward, "An Annotated Bibliography of the Design of Asphalt-Aggregate Cold Mixtures," Ontario Joint Highway Research Programme Report No. 29, Civil Engineering Report No. 37, Queen's University, Kingston, Ontario, June, 1964.
- 49. Dunning, R. L. and F. E. Turner, "Asphalt Emulsion Stabilized Soils as a Base Material in Roads," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 34 (1965), pp. 356-396.
- 50. Ruth, B. E. and J. H Schaub, "Gyratory Testing Machine Simulation of Field Compaction of Asphaltic Concrete," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 35 (1966), pp. 451-484.
- 51. Riley, J. C. and G. C. Blomquist, "Asphalt Stabilization of Selected Sand and Gravel Base Courses," <u>Circular No. 46</u>, Highway Research Board, September, 1966.
- 52. Lefebvre, J. A., "A Suggested Marshall Method for Cutback Asphalt-Aggregate Paving Mixtures," <u>Proceedings</u>, Canadian Technical Asphalt Association, November, 1966.
- 53. Field, F. and W. A. Phang, "Stripping in Asphaltic Concrete Mixes: Observation and Test Procedures," <u>Proceedings</u>, Canadian Technical Asphalt Association, Vol. 12 (1967), pp. 61-73.
- 54. Gregg, J. S., G. L. Dehlen and P. S. Rigdent, "On the Properties, Behavior and Design of Bituminous Stabilized Sand Bases," <u>Proceedings</u>, Second International Conference on the Structural Design of Asphalt Pavements, Ann Arbor, Michigan, 1967, pp. 863-882.
- 55. Monismith, C. C., R. L. Terrel and C. K. Chan, "Load Transmission Characteristics of Asphalt-Treated Base Courses," <u>Proceedings</u>, Second International Conference on the Structural Design of Asphalt Pavements, Ann Arbor, Michigan, 1967, pp. 883-907.
- 56. Kung, K. Y., "A New Method in Correlation Study of Pavement Deflection and Cracking," <u>Proceedings</u>, Second International Conference on the Structural Design of Asphalt Pavement, Ann Arbor, Michigan, 1967, pp. 1037-1046.

- 57. Chevron Asphalt Company, Bituminous Base Treatment Manual, 1967.
- 58. Foster, C. R., "Thickness Equivalencies," National Asphalt Paving Association, Riverdale, Maryland, September, 1967.
- 59. Terrel, R. L. and C. L. Monismith, "Evaluation of Asphalt-Treated Base Course Materials," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 37 (1968), pp. 159-199.
- 60. Brahma, S. P., "Influence of Curing of Cut-Back Asphalt on the Strength and Durability of Asphalt Concrete," Highway Research Board, 1968.
- 61. Finn, F. N., R. G. Hicks, W. J. Kari and L. D. Coyne, "Design of Emulsified Asphalt Treated Bases," <u>Highway Research Record No. 239</u>, Highway Research Board, 1968.
- 62. Robnett, Q. L., T. H. Stremlau and M. R. Thompson, "Interim Report Materials Development and Utilization," Project IHR-94, Illinois Cooperative Highway Research Program, University of Illinois at Urbana-Champaign, March, 1968 (not for publication), pp. 1-5, 23-24.
- 63. Brahma, S. P., "Final Report of the Study Determination of Strength Equivalencies of Bituminous Mixes," <u>Engineering Experiment Station Series No. 14</u>, North Dakota State University, Fargo, North Dakota, August, 1968.
- 64. Pell, P. S. and I. F. Taylor, "Asphaltic Road Materials in Fatigue," Proceedings, Association of Asphalt Paving Technologists, Vol. 38 (1969).
- 65. Santucci, L. E. and R. J. Schmidt, "The Effect of Asphalt Properties on the Fatigue Resistance of Asphalt Paving Mixtures," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 38 (1969).
- 66. Schmidt, R. J. and L. E. Santucci, "The Effect of Asphalt Properties on the Fatigue Cracking of Asphalt Concrete on the Zaca-Wigmore Test Project," Proceedings, Association of Asphalt Paving Technologists, Vol. 38 (1969).
- 67. Zube, E. and J. Skog, "Final Report on the Zaca-Wigmore Asphalt Test Road," Proceedings, Association of Asphalt Paving Technologists, Vol. 38 (1969).
- 68. Robnett, Q. L. and M. R. Thompson, "Soil Stabilization Literature Reviews," Highway Engineering Series No. 34, Illinois Cooperative Highway Research Program Series No. 105, University of Illinois at Urbana-Champaign, Illinois, July, 1969, Part C.
- 69. Robnett, Q. L. and M. R. Thompson, "Soil Stabilization Literature Reviews," Highway Engineering Series No. 34, Illinois Cooperative Highway Research Program Series No. 105, University of Illinois at Urbana-Champaign, Illinois, July, 1969, Part D.
- 70. Robnett, Q. L. and M. R. Thompson, "Stabilization of Illinois Materials -Development of Guidelines and Criteria," Highway Engineering Series No. 35, Illinois Cooperative Highway Research Program Series No. 107, University of Illinois at Urbana-Champaign, Illinois, September, 1969, pp. 59-67.

- 71. Holmes, A. and E. W. Klinger, "Suggested Methods of Field Procedure for the Design of Cutback Asphalt-Soil Mixtures," <u>Special Procedures for Testing Soil and Rock for Engineering Purposes</u> (STP No. 479), Fifth Edition, American Society for Testing Materials, Philadelphia, June, 1970, pp. 404-409.
- 72. Hovis, O. W., "Suggested Method for Determining Suitable Proportions of Soil-Asphalt or Soil-Aggregate-Asphalt," Special Procedures for Testing Soil and Rock for Engineering Purposes (STP No. 479), Fifth Edition, American Society for Testing Materials, Philadelphia, June, 1970, pp. 410-411.
- 73. Thurston, R. R., "Suggested Method of Test for Stability of Mixtures of Soils and Liquid Asphaltic Products," <u>Special Procedures for Testing Soil and Rocks for Engineering Purposes</u> (STP No. 479), Fifth Edition, American Society for Testing Materials, Philadelphia, June, 1970, pp. 412-417.
- 74. Heriot, L. W., "Suggested Method of Test for Quantity of Cutback Asphalt for Stabilizing Sandy Soils," Special Procedures for Testing Soil and Rock for Engineering Purposes (STP No. 479), Fifth Edition, American Society for Testing Materials, Philadelphia, June, 1970, pp. 418-419.
- 75. McKesson, C. L., "Suggested Method of Test for Bearing Value of Sand-Asphaltic Mixtures," Special Procedures for Testing Soil and Rocks for Engineering Purposes, (STP No. 479), Fifth Edition, American Society for Testing Materials, Philadelphia, June, 1970, pp. 420-422.
- 76. Canadian Good Roads Association (now Roads and Transportation Association of Canada), "Low Temperature Cracking in Canada The Problem and its Treatment," Proceedings, 1970, pp. 69-96.
- 77. Shields, B. P., K. O. Anderson and J. M. Dacyszyn, "An Investigation of Low Temperature Transverse Cracking of Flexible Pavements," <u>Proceedings</u>, Canadian Good Roads Association (now Roads and Transportation Association of Canada), 1969, pp. 273-308.
- 78. "Basis for the Development of a Soil Stabilization Index System," Research Foundation, Texas A & M University, College Station, Texas.
- 79. McConnaughay, K. E., Inc., "Design of Flexible Pavements," Lafayette, Ind.
- 80. McConnaughay, K. E., "Improving Asphalts by Means of the Emulsification Process," Lafayette, Ind.
- 81. Peterson, D. E., W. R. Delis and D. L. Mangrum, "A System for Planning Roadway Improvements," Utah State Department of Highways.
- 82. Krukar, M. and J. C. Cook, "Comparison of Washington State University Test Track Experimental Pavement Ring No. 2 and 3," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 40 (1971).
- 83. Terrel, R. L. and C. K. Wang, "Early Curing Behavior of Cement Modified Asphalt Emulsion Mixtures," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 40 (1971).
- 84. Jiminez, R. Z., "Setting and Durability of Asphalt Emulsions," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 40 (1971), pp. 463-486.

- 85. Cechetini, J. A., ''Modified CKE Test,'' <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 40 (1971), pp. 509-526.
- 86. Kallas, B. F., "Mix Design Considerations," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 41 (1972).
- 87. Readshaw, E. E., "Asphalt Specifications in British Columbia for Low Temperature Performance," British Columbia Department of Highways, February, 1972.
- 88. Robertson, W. D., "Discussion of paper 'The Effect of Water on the Resilient Modulus of Asphalt-Treated Mixes' by R. J. Schmidt and P. E. Graf," Imperial Oil Enterprises, Ltd., Sarnie, Ontario, February, 1972.
- 89. Schmidt, R. J. and P. E. Graf, "The Effect of Water on the Resilient Modulus of Asphalt Treated Mixes," Chevron Research Company, Richmond, California, February, 1972.
- 90. Raithby, K. D. and A. B. Sterling, "Some Effects of Loading History on the Fatigue Performance of Rolled Asphalt," <u>Transport and Road Research Laboratory Report No. LR 496</u>, Crowthorne, Berkshire, England, 1972.
- 91. Epps, J. A., D. D. Currin, B. M. Galloway and W. A. Dunlap, "Critical Review Methods of Evaluating Bituminous Stabilized Soils," Unpublished paper presented at the Highway Research Board Annual Meeting, January, 1972.
- 92. Gannon, C. R. and K. Majidzadeh, "A Laboratory and Field Study on the Use of Elastomers in Hot Mix Emulsified Asphalts," Highway Research Record No. 404, Highway Research Board, 1972, pp. 33-41.
- 93. Bergeson, K. L. and J. M. Hoover, "Coeficients of Relative Strength for Iowa Granular Base Materials," <u>Highway Research Record No. 405</u>, Highway Research Board, 1972, pp. 1-16.
- 94. Moore, W. M., S. C. Britton and F. H. Scrivner, "Relation of Stress to Strain for a Crushed Limestone Base Material," <u>Highway Research Record No. 405</u>, Highway Research Board, 1972, pp. 17-18.
- 95. Jones, T. R., E. L. Otten, C. A. Machemehl, Jr. and T. A. Carlton, "Effect of Changes in Gradation on Strength and Unit Weight of Crushed Stone Base," Highway Research Record No. 405, Highway Research Board, 1972, pp. 19-23.
- 96. McDowell, C., "Progress Report on Soil-Bituminous Stabilization," <u>Highway</u> Research Record No. 405, Highway Research Board, 1972, pp. 132-136.
- 97. Howeedy, M. F. and M. Herrin, "Behavior of Cold Mixes Under Repeated Compressive Loads," <u>Highway Research Record No. 404</u>, Highway Research Board, 1972, pp. 57-70.
- 98. Witczak, M. W., "Design Analysis Asphalt Concrete Overlay Requirements for Runway 18-36, Washington National Airport," Research Report 72-4, The Asphalt Institute, College Park, Maryland, September, 1972.

Metz Reference Room University of Illinois Blo6 Tohn 208 N. Romine Street Urbana, Illinois 61801

- 99. The Asphalt Institute, "A Method of Mix Design for Emulsified Asphalt Base Course Mixtures Using California Test Procedures," draft of a supplement to "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types," MS-2, 1972.
- 100. The Asphalt Institute, "A Method of Mix Design for Cutback Asphalt Mixtures Using the Marshall Test Procedures," draft of a supplement to "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types," MS-2, 1972.
- 101. The Asphalt Institute, "A Method of Mix Design for Cutback Asphalt Mixtures Using California Test Procedures," draft of a supplement to "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types," MS-2, 1972.
- 102. Road and Transportation Association of Canada, "Low Temperature Pavement Cracking Studies in Canada," <u>Proceedings</u>, Third International Conference on the Structural Design of Asphalt Pavements, London, 1972, pp. 581-589.
- 103. Cronez, D., "Failure Criteria for Flexible Pavements," <u>Proceedings</u>, Third International Conference on the Structural Design of Asphalt Pavements, London, 1972, pp. 608-612.
- 104. Hoystra, A. and A. J. G. Klomp, "Permanent Deformation of Flexible Pavements Under Simulated Road Traffic Conditions," <u>Proceedings</u>, Third International Conference on the Structural Design of Asphalt Pavements, London, 1972, pp. 613-621.
- 105. Nagumo, S., M. Tsukinari and S. Tanimoto, "Deflection Criteria for Asphalt Pavements," <u>Proceedings</u>, Third International Conference on the Structural Design of Asphalt Pavements, London, 1972, pp. 670-691.
- 106. Kaukar, M. and J. C. Cook, "Practical Design Applications Based on Washington State University Test Track Results," <u>Proceedings</u>, Third International Conference on the Structural Design of Asphalt Pavements, London, 1972, pp. 866-878.
- 107. Livneh, M. and E. Shklarsky, "The Splitting Test for Determination of Bituminous Concrete Strength," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 31 (1962).
- 108. "Standard Nomenclature and Definitions for Pavement Components and Deficiencies," Special Report No. 113, Highway Research Board, 1970.
- 109. Ishai, I. and E. Tons, "Factors in Bituminous Concrete Design," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 42 (1973).
- 110. Oglesby, C. H. and L. I. Hewes, <u>Highway Engineering</u>, Second Edition, New York: John Wiley and Sons, Inc., 1963.
- 111. Danner, E., "Systems Approach to Pavement Design," Class Notes, University of Illinois at Urbana-Champaign, Fall, 1972.
- 112. The Asphalt Institute, "Tests on Water Sensitivity of Paving Mixtures," R & D Progress, Vol. 1, No. 4 (December, 1972).

- 113. Carpenter, J., "Stress Deformation Characteristics of Sand-Bituminous Mixtures," Special Technical Publication No. 294, American Society for Testing Materials, 1960, pp. 3-18.
- 114. The Asphalt Institute, "Mix Design Methods for Asphalt Concrete," Manual Series No. 2 (MS-2), Third Edition, October, 1969.
- 115. Traxler, R. N., "Durability of Asphalt Cements," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol.32 (1963), pp. 44-63.
- 116. Gotolski, W. G., S. K. Ciesielski, R. W. Smith and J. A. Kofalt, "Study of Physical Factors Affecting the Durability of Asphaltic Pavements," Highway Research Record No. 231, Highway Research Board, 1968, pp. 1-23.
- 117. Lee, D., "Development of a Laboratory Durability Test for Asphalts," <u>Highway</u> Research Record No. 231, Highway Research Board, 1968, pp. 34-49.
- 118. Traxler, R. N., "Changes in Asphalt Cements During Preparation, Laying and Service of Bituminous Pavements," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 36 (1967).
- 119. Kavdhal, P. S., L. D. Sandvig and M. E. Wenger, "Shear Susceptibility of Asphalts in Relation to Pavement Performance," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 42 (1973).
- 120. The Asphalt Institute, "The Asphalt Handbook," Manual Series No. 4 (MS-4), 1965.
- 121. Shattuck, C. L., "Measurements of the Resistance of Oil Asphalts (50-60 pen.) to Changes in Penetration and Ductility at Plant Mixing Temperatures," Proceedings, Association of Asphalt Paving Technologists, Vol. 11 (1940).
- 122. Hveem, F. N., "Quality Tests for Asphalts A Progress Report," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 15 (1943).
- 123. Haas, R. C. G., "A Method for Designing Asphalt Pavements to Minimize Low Temperature Shrinkage Cracking," <u>Research Report 73-1</u>, The Asphalt Institute, January, 1973.
- 124. American Society for Testing Materials, "Revision of Section II, Manual on Fatigue Testing, Special Technical Publication No. 91, 1959.
- 125. Epps, J. A. and C. L. Monismith, "Influence of Mixture Variables on the Flexural Fatigue Properties of Asphalt Concrete," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 38 (1969).
- 126. Kallas, B. F. and V. P. Puzinauskas, "Flexural Fatigue Tests on Asphalt Paving Mixtures," Research Report 72-5, The Asphalt Institute, August, 1972.
- 127. Barenberg, E. J., C. L. Bartholomew and M. Herrin, "Pavement Distress Identification and Repair," <u>Technical Report P-6</u>, Construction Engineering Research Laboratory, Champaign, Illinois, March, 1973.

- 128. van der Poel, C., "A General System Describing the Viscoelastic Properties of Bituminous Materials and its Relation to Routine Test Data," <u>Journal of Applied Chemistry</u>, Vol. 4, May, 1954.
- 129. Pell, P. S. and J. M. Hanson, "Behavior of Bituminous Roadbase Materials Under Repeated Loading," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 42 (1973).
- 130. Awad, I. S., F. R. Rutz and R. L. Terrel, "Characterization of the Stress-Strain Relationship for Asphalt Treated Base Materials," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 42 (1973).
- 131. The Asphalt Institute, "Asphalt in Pavement Maintenance," Manual Series No. 16 (MS-16), 1967.
- 132. Yoder, E. J., <u>Principles of Pavement Design</u>, New York: John Wiley & Sons, Inc., 1964.
- 133. Carey, W. N., Jr. and P. E. Irick, "The Pavement Serviceability-Performance Concept," <u>Bulletin No. 250</u>, Highway Research Board, 1960.
- 134. The Asphalt Institute, "Asphalt Overlays and Pavement Rehabilitation," Manual Series No. 17 (MS-17), 1969.
- 135. Cartayne, P. C. and R. N. Walker, "A Fresh Look at the Interpretation of Pavement Serviceability and an Experiment to Measure the Riding Quality of Roads in South Africa," <u>Proceedings</u>, Third International Conference on the Structural Design of Asphalt Pavements, London, 1972, pp. 776-785.
- 136. "Standard Nomenclature and Definitions for Pavement Components and Deficiencies," Special Report No. 113, Highway Research Board, 1970.
- 137. McLeod, N. W., "A 4-Year Survey of Low Temperature Transverse Pavement Cracking on Three Ontario Test Roads," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 41 (1972), pp. 424-493.
- 138. Barksdale, R. D., "Repeated Load Test Evaluation of Base Course Materials," Final Report on Contract Research, Project No. 7002, Georgia Highway Department Research, 1972.
- 139. Herrin, M. and W. H. Goetz, "Effects of Aggregate Shape on Stability of Bituminous Mixtures," <u>Proceedings</u>, Highway Research Board, Vol. 36 (1957), pp. 382-387.
- 140. Griffith, J. M. and B. F. Kallas, "Aggregate Voids Characteristics in Bituminous Paving Mixtures," <u>Proceedings</u>, Highway Research Board, Vol. 36 (1957), pp. 293-307.
- 141. Shklarsky, E. and M. Livneh, "The Use of Gravel for Bituminous Paving Mixtures," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 33 (1964), pp. 584-610.
- 142. Field, F., "The Importance of Percent Crushed in Course Aggregates as Applied to Bituminous Pavements," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 27 (1958), pp. 294-320.

- 143. Wedding, P. A. and R. D. Gaynor, "The Effect of Using Gravel as the Coarse and Fine Aggregate in Dense Graded Bituminous Mixtures," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 33 (1964), pp. 584-610.
- 144. Monismith, C. L., "Influence of Shape, Size and Surface Texture on the Stiffness and Fatigue Response of Asphalt Mixtures," <u>Special Report No. 109</u>, Highway Research Board, 1970, pp. 4-11.
- 145. Maupin, G. W., "Effect of Particle Shape and Surface Texture on the Fatigue Behavior of Asphalt Concrete," <u>Highway Research Record No. 313</u>, Highway Research Board, 1970, pp. 55-62.
- 146. Traxler, R. N. and M. D. Shelby, "Reduction of Asphalt Hardening in Surface Course of Bituminous Pavement," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 42 (1973).
- 147. Olsen, R. E., J. Y. Welborn and B. A. Vallerger, "Pavement Evaluation to Evaluate the Effect of Asphalt Aging on Pavement Condition," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 38 (1969).
- 148. "Skid Resistance," NCHRP Synthesis of Highway Practice No. 14, Highway Research Board, 1972.
- 149. Gramling, W. L., "Effect of Aggregate Mineralogy on Polishing Rate and Skid Resistance in Pennsylvania," <u>Highway Research Record No. 341</u>, Highway Research Board, 1970.
- 150. Serafin, P. J., "Michigan Experience with Different Materials and Designs for Skid Resistance of Bituminous Pavements," <u>Highway Research Record No. 341</u>, Highway Research Board, 1970.
- 151. Sherwood, W. C. and D. C. Mahone, "Predetermining the Polish Resistance of Limestone Aggregates," <u>Highway Research Record No. 341</u>, Highway Research Board, 1970.
- 152. Nagumo, S., M. Tsukinari and S. Tanimoto, "Deflection Criteria for Asphalt Pavements," <u>Proceedings</u>, Third International Conference on the Structural Design of Asphalt Pavements, London, 1972, pp. 670-691.
- 153. Schmidt, R. J., "A Practical Method for Measuring the Resilient Modulus of Asphalt-Treated Mixes," <u>Technical Paper No. 161</u>, Chevron Asphalt Company, 1970.
- 154. Shook, J. F. and B. F. Kallas, "Factors Influencing Dynamic Modulus of Asphaltic Concrete," <u>Proceedings</u>, Association of Asphalt Paving Technologists, Vol. 38 (1969), pp. 140-178.

APPENDIX

A COPY OF THE QUESTIONNAIRE AND COVER LETTER USED IN THE SURVEY STUDY OF LOCAL COUNTY ROADS

Plant Mix

17. Do you use a consultant to design your cold mixes?

Other

III Taloot Laboratory

1HR-505

STRUCTURAL EVALUATION OF ASPHALT-AGGREGATE COLD MIX BASES

QUESTIONNAIRE No. 1

(If additional space is needed, please use the enclosed blank page. Numbers in

A. 6	ENERAL				[/
ì	. Name of perso	on answering			
2	. Title				
3	. Affiliation				(5
4	. Business Mai	ling Address			
c	. Phone Number				(
,	. Phone Number				
6	 Type and amore your agency. 		treated cold mix	* bases consti	ructed by
			Estimated Milea		
	Road mix (Mix	xed in place)		(io-12	2)
	Plant Cold Mi	i×		(13-19	5)
•	Other (Specif	fv)		(16-18	٤)
7		•	alt treated cold	mix base job	
	(years)?				(19,20
					3
		Road Mix	Plant Mix	Other	3
	Soft particles		(65)	0ther /(66	
	Soft particles Soundness	(64)	(65)	/(66)
	Soundness	(64) (67)	(65)	/(66 /(69)
	Soundness Moisture Conten Los Angeles	(64) (67) t(70)	(65) (68) (71)	/(66 /(69 /(72)) }
	Soundness Moisture Conten Los Angeles abrasion	(64) (67) (c) (70) (73)	(65) (68) (71) (74)	/(66 /(69 /(72 /(75)))
	Soundness Moisture Conten Los Angeles	(64) (67) t(70)	(65) (68) (71)	/(66 /(69 /(72)))
	Soundness Moisture Conten Los Angeles abrasion Visual	(64) (67) (c) (70) (73)	(65) (68) (71) (74)	/(66 /(69 /(72 /(75)))
	Soundness Moisture Conten Los Angeles abrasion Visual Inspection	(64) (67) (c) (70) (73)	(65) (68) (71) (77) (77)	/(66 /(69 /(72 /(75))))
	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other:	(64) (67) (57) (70) (73) (76)	(65) (68) (71) (74) (77)	/(66 /(69 /(72 /(75 /(78))))
	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other:	(64) (67) (70) (73) (76) (79) (2)	(65) (68) (71) (77) (77)	(66 /))))
13.	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other:	(64) (67) (70) (73) (76) (79) (2) (ny written spec	(65) (68) (71) (77) (77) (80) (3)	(66 (72 (72 (73 (78 (10) (14) (14)))))
13.	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other: Do you follow as controlling the	(64) (67) (70) (73) (76) (79) (2) (ny written spec	(65) (68) (71) (77) (77) (80) (3)	(66 /))))
13.	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other: Do you follow a controlling the If yes, are tho	(64) (70) (73) (76) (79) (2) (79) (2) (2) (3) (4) (79) (5) (79) (5) (79) (79) (79) (79) (79) (79) (79) (79	(65) (68) (71) (74) (77) (80) (3) diffication for see	(66 (72 (72 (75 (77) (78 (1) (4) (1) (2) (1) (2) (3) (4) (4) (4) (5) (6) (7) (7) (7) (7) (7) (7) (7) (7)))))
13.	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other: Do you follow a controlling the If yes, are tho	(64) (70) (73) (76) (79) (2) (79) (2) (2) (3) (4) (79) (5) (79) (5) (79) (79) (79) (79) (79) (79) (79) (79	(65) (68) (71) (74) (77) (80) (3) diffication for set of s	(66 (72 (72 (75 (77) (78 (1) (4) (1) (2) (1) (2) (3) (4) (4) (4) (5) (6) (7) (7) (7) (7) (7) (7) (7) (7)))))
13. 14.	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other: Do you follow a controlling the If yes, are tho County / (8)/	(64) (70) (77) (77) (77) (79) (2) (2) (2) (3) (4) (79) (79) (2) (79) (2) (4) (79) (79) (79) (79) (79) (79) (79) (79	(65) (68) (71) (74) (77) (80) (3) diffication for set of s	(66 (72 (73 (75 (77) (78 (10)	(3)/.
13. 14. MIX	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other: Do you follow a controlling the If yes, are tho County / (8)/	(64) (67) (170) (73) (76) (79) (2) (2) (2) (2) (3) (4) (79) (79) (79) (79) (79) (79) (79) (79	(65) (68) (71) (77) (80) (30) (iffication for set of or sphalts? (he state / (6)) (iftant / (9)7), (iftedure in design	(66 (72 (73 (75 (77) (78 (10)	(3)/.
13. 14. MIX	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other: Do you follow a controlling the If yes, are tho County (8)7 Do you follow as treated base min	(64) (67) (70) (73) (76) (79) (2) (1) (1) (2) (2) (3) (4) (79) (79) (79) (79) (79) (79) (79) (79	(65) (68) (71) (77) (77) (80) (3) diffication for see al/or asphalts? the state / (6) ditant / (9)7, discourse in design	(66 (72 (73 (75 (77) (78 (10))))) (() () () () () () ()
13. 14. MIX 15.	Soundness Moisture Conten Los Angeles abrasion Visual Inspection Other: Do you follow a controlling the If yes, are tho County / (8)/	(64) (67) (70) (73) (76) (79) (2) (1) (1) (2) (2) (3) (4) (79) (79) (79) (79) (79) (79) (79) (79	(65) (68) (71) (77) (77) (80) (3) diffication for see al/or asphalts? the state / (6) ditant / (9)7, discourse in design	(66 (72 (73 (75 (77) (78 (10))))) (2) (7) (3) (3) (3)

(13)

yes /__/ no /__/(15)

In connection with our current IRR-505 research project entitled "Structural Evaluation of Asphalt-Aggregate Cold Mix Pases," information is needed in order to evaluate actual base courses constructed with granular materials stabilized with enulsions or cutbacks. This evaluation will help us to relate field performance and failure nodes to the required properties of the stabilized materials and to the proper tests to measure then.

Since the main objective of the research is to improve paving Since the bain objective of the research is to improve paying technology in low-traffic roads, it is realized that such information can be obtained mainly from county and township road experience. You have been recommended to us as one who has had experience with cold mixes and who is introvested in doing a better job with the material he has. Could you please take some time to provide us with some information about this material.

Enclosed is a questionnaire which (when filled) may provide us with preliminary information to classify the past and current stabilized base construction in your locality. In order to help improve and modernize our nijiway technology, we hope that you will express your interest by filling in this questionnaire and mailing it in the enclosed stamped envelope.

Let us stress that the information requested is purely technical and will be used only for research purposes. We realize that in the pist, work in asphalt-treated cold mix bises has many times been experimental work, and failure cases have been unpreventable. We would like to know about them, and we need your help for that.

If you desire additional information about the project, please see the attached "General Purposes and Scope." We will inform you directly about the results of this work.

Thank you for your cooperation.

Sincerely.

Dr. Ilan Ishai Research Associate in Civil Engineering Project Investigator, IHR-505

ASPHALTS

8.	Specify	the	type	of	asphalt	used	(e.g.	MC-800,	HFE-300,	etc.)
			Roa	d M	ix	Plar	nt Mix	0	ther (spe	clfy)

Cutbacks	(21)	(22)	(23)
Emulsions	(24)	(25)	(26)
Tars	(27)	(28)	(29)

9. Which of the above do you prefer?

(30)	(31)	(32)
------	------	------

10.. Do you test your asphalts (or send samples for testing) for yes /___/ quality criteria? no /__/ (33)

C. AGGREGATES

11. Check the type of aggregates used:

	33 3		
	Road Mix	Plant Mix	Other
tocal pit-run gravel	(34)	(35)	(36)
Crushed stone	(37)	(38)	(39)
Natural sand	(40)	(41)	(42)
Stone sand screenings	(43)	(44)	(45)
Slag	(46)	(h7)	(48)
Other:			
	(49)	(50)	(51)
	(52)	(53)	(54)
Quality criteri	a used to contro	I the aggregates	(check)

(56) 7 (55) 7 (57) Gradation % Filler (-#200)______(58) (59) (62) (61) Clay content or plasticity

Plant Mix

Road Mix

(Question 12 continued on next page)

Oti.er

THE TE WAS AND DESCRIPTION WITH HAME AND BUSINESS?	23. How do you control construction (check)
18. If yes, can you provide us with make and address?	Road Mix Plant Mix Other:
	Plant Inspection /(45) /(46)
	Field does:ty or
Phone No(16)	Poisture control / (50) / (51) / (52)
19. Do you use any laboratory tests for quality central of your cold	Thickness required /
mixes? yes /	Smoothness required ((56)(57)(58)
20. If yes, please check:	Visual Inspection /(53) /(60) /(61)
Road Hix Plant Hix Other	Other:
Extraction (18) (19) (20) (asphalt content)	(64)
Extraction (21) (22) (23)	(65)(66)(67)
(gradation) Tests on asphalt/(24) /(25) /(26)	24. If visual inspection is used, can you specify some of the criteria
residue Stability tests /	
(specify)	(68)
Density and(30)(31)(32) vcids	25. If using plant mixing, do you stockpile the cold nixes prior to
Other:	road construction? yes / no / (69)
(33) (34) (35)	26. If yes, for how long (average no. of days)?(70,71)
(36) /(37) /(38)	27. Do you apply wearing surfaces on top of the cold mix bases?
	surface treatment $\sqrt{(72)}$ hot mix $\sqrt{(73)}$ nothing $\sqrt{(74)}$
E. CONSTRUCTION	
21. Do you follow any written standard specification for construction	F. PERFORMANCE
of the asphalt-treated cold mix bases (mixing, laying, compaction,	Let us stress again that in the past we know much of the work in asphal
etc.)// yes //	treated cold mix bases has been experimental. Fallures have occurred i
22. If yes, are those written by the state / (40)/, district / (41)/,	every phase of such construction. We would like to analyze these dis-
county $/$ $(42)/$, private consultant $/$ $(43)/$, your agency $/$ $(44)/$.	tresses and we need your help for that.
6	7
ave any types of failure or distress occurred in your past Jobs	A marting department of the contract of the co
cracking, rutting, corrugation, shoving, raveling, etc.)?	
res /	
an you identify the failure cases that occurred in your past jobs.	
check)?	
Road Mix Plant Mix Other	
cracking /	
Nutting /(5) /(6) /(7)	(41,42)
shoving (8) (9) (10)	31. Do you plan more work with asphalt-treated cold mix bases in the
Raveling (11) (12) (13)	near future? yes / no / (43)
Corrugation / (14) / (15) / (16)	32. If not, why?
Depressions (17) (18) (19)	
Bleeding (20) (21) (22)	
Pot holes (23) (24) (25)	
Slick planes (26) (27) (28)	33. Hay we contact you again for further information?
Frost boils (29) (30) (31)	yes no (44)
Mushy areas (32) (33) (34)	34. Do you know anybody else doing work with asphalt treated cold mix
Other:	bases?
/(35) / (36) / (37)	
Based on your experience and judgment, can you specify the cause	
and frequency of occurrence of the failures checked, and the remedy	(45)
taken. (e.g., Corrugationappeared during the following summer	35. Please estimate the approximate length of time it took you to fill
after construction. Base was rescarified, dried, and recompacted.	out this questionnaire (hours)
Performed satisfactorily ever since.)	For less $\sqrt{\frac{(46)}{1}}$ 2 $\sqrt{\frac{(47)}{1}}$ 3 $\sqrt{\frac{(48)}{1}}$
	2 (-110)

30.

(Blank lines continued on next page)

Ω

We will appreciate any comments or suggestions. Please feel free to ress your opinion. Use this sneet. It will be most helpful if you could ach copies of specifications and/or standards and procedures used by your ncy for construction of asphalt treated bases.

IHR-505

STRUCTURAL EVALUATION OF ASPHALT-AGGREGATE COLD MIX BASES

General Purpose and Scope

The purpose of IHR-505 research project is to establish tentative methods of testing, quality criteria, and mix design projection for evaluating pertinent properties of basis constructed with granular materials stabilized with emulsions or cutbucks, also to establish a method which can be used to relate the test results to the structural response of the stabilized material for the design of flexible payerents utilizing these materials.

This research can result in economical benefits when substandard (currently out of specification) aggregates can be stoillied successfully with emulsified or outback asphalts for construction of quality saces for economical use on low-traffic roads. A second benefit that may become quite important in the future is the conservation of the rapidly disappearing quality aggregate sources which are needed in construction of ligher type roads. If successful, this research can also led to a more technical and engineering type construction and control of apphalt-treated cold mix bases, and thus may prevent many of the early unexplained further cases which are likely to occur in the present tachnology.

Currently, information is not available that (1) permits a critical evaluation of the actual field behavior and failure modes of liquid asphalt stabilized mixtures, (2) establishes all mixture properties necessary for a proper performance in the field, and (3) allows the cetarmination of testing procedures and criteria that can be used to evalvate all the required properties.

In order to overcome this and to insure the practical success of the project, the first stage of the investigation has been designed to collect and analyze duta and feedbacks from past and present purcents, and field construction experience. An emphasis will be rade here to analyze and evaluate frequent failure modes and to relate them to the required properties of the stabilized material and to the proper tests to the assure them. This will be implemented in the future to establish quality criteria, mix design procedure and structured coefficients for pavement design.