Distresses and Related Material Properties for Premium Pavements

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In order for zero-maintenance pavements to be constructed, the materials from which they are built must withstand severe stresses without suffering extensive distress. In evaluating the conditions for which zero-maintenance pavements must be designed, it is necessary to clearly define and categorize these distresses, determine their causes, and rank the material properties that affect each distress in order of importance. The process used to prioritize these distresses and the material properties related to them is described, and a set of definitions on which this process is based is presented. The result of this effort is a minimum set of distresses and material properties that affect those distresses that must be considered in designing zero-maintenance pavements. Categories of distress noted in field surveys were ranked based on these definitions and processes. Only distresses that occur in premium pavements were included in the analysis, and each was evaluated to determine its impact on meeting the requirements for zero-maintenance pavements. The evaluations presented are subjective but were developed by using the experience of the project staff and sensitivity analyses based on models that predict distress. A detailed set of distresses and major material properties that affect those distresses are given for rigid, flexible, and composite premium pavements.

For several years, the Federal Highway Administration (FHWA) has pursued multiple research studies aimed at producing premium pavement structures for heavily traveled routes. The intent of these efforts has been to minimize maintenance, which not only disrupts traffic flow but also creates hazards and high user costs. The goal is the development of pavement structures that will be maintenance-free for 20 years and require only routine maintenance for 10-20 years thereafter.

Research is under way on the upgrading of conventional structures by use of improved conventional or new materials; this includes the development of new design materials. Field surveys have been conducted to study the nature of existing pavements that have performed essentially as zero-maintenance pavements. These diverse studies have produced valuable information for use on this and other zero-maintenance research projects.

An FHWA research project, Material Property Requirements for Zero-Maintenance Pavements, has as its goal the identification of material properties that will provide optimal performance in flexible, rigid, or composite premium or zero-maintenance pavements. The purpose of the portion of the study summarized in this paper was to identify various pavement distresses, to select those distresses that occur in premium pavements, and to identify the related material properties. This effort was subdivided into the following four tasks:

1. To develop a complete list of distresses for each pavement type, engineering properties related to the distress types, and factors that affect the engineering properties of the materials;
2. To assess the relative importance of distress types in terms of frequency of occurrence and to evaluate the effect on meeting the requirements of zero-maintenance pavements;
3. To assess the relative importance of material properties in each of the important distresses; and
4. To summarize the distresses and related material properties that have sufficient impact on pavement performance and maintenance requirements to warrant further consideration.

DEFINITIONS

The terms used to describe categories of distress, specific forms of distress, distress mechanisms, distress manifestations, response mechanisms, responses, material properties, and other descriptors must be clearly and concisely defined. Development of these definitions is necessary to ensure consistent use and to minimize the opportunity for personal interpretation. Most existing definitions were developed for the specific needs of other projects and were based on the level of understanding at that time (1-4). In view of recent advances in understanding of the physical pavement structure, the various loads, and the environment, some of these definitions needed updating; therefore, definitions were reviewed and evaluated for adequacy and consistency. Each of the definitions given by Hudson and others (3) was reviewed, and only those changes were made that appeared to be necessary to maintain the specificity of the definitions and to define needed terms.

1. A pavement structure is an organized combination of materials constructed in layers over a natural soil.
2. Material properties are those definitive descriptive measures of the quality of the material (5).
3. Distress is a condition of the pavement structure that reduces serviceability or leads to a reduction in serviceability.
4. Distress manifestations are the visible consequences of various distress mechanisms, which usually lead to a reduction in serviceability (3).
5. A distress mechanism is the physical or chemical process involved in or responsible for distress in pavements.
6. Structural failure is a fracture or distortion that may or may not cause an immediate reduction in serviceability but will lead to a future loss of serviceability.
7. Fracture is the state of a pavement material that is breaking.
8. Distortion is a permanent change in the shape of the pavement or pavement component.
9. Disintegration is the state of a pavement that is decomposing or abrading into its constitutive elements (3).
10. Reflection cracks are cracks that occur in the surface course of a pavement and that coincide with and are caused by the relative movement of cracks or joints in underlying layers.
11. Low-temperature cracks are generally transverse cracks that are caused when tensile stresses induced by frictional resistance of the underlying layer to thermal contraction of the surface layer exceed the tensile strength of the surface material.
12. Raveling is the progressive disintegration of an asphalt concrete layer from the surface downward by the dislodgment of aggregate particles. This can be caused by insufficient binder in the mix, hardening of the as-

phalt binder, wet or dirty aggregate, or aggregate with a smooth surface texture.

13. Ruts are longitudinal depressions that form in the wheel paths of flexible or composite pavements and result from compaction or lateral migration of one or more of the pavement-layer materials under the action of traffic and environment.

14. Shrinkage cracks are generally transverse cracks that are caused when tensile stresses induced by frictional resistance of the underlying layer to drying contraction of the surface layer exceed the tensile strength of the surface material. These cracks generally occur in portland cement concrete (PCC) and other cement-treated materials.

15. Spalling is cracking, breaking, or chipping of a rigid pavement along joints, edges, or cracks in which small portions of the slab are dislodged.

16. Faulting is a difference in the elevation of two adjacent rigid slabs at the joint or crack interface as a result of consolidation or swelling of underlying material, inadequate load transfer, or pumping.

17. D-cracking is a series of fine, crescent-shaped hairline cracks in a rigid slab surface, usually paralleling a joint or major crack.

18. Steel rupture is the occurrence of a tensile fracture failure in the reinforcing steel when excessive stress is transferred to the steel on fracture of adjacent concrete.

19. Punchouts are blocks of rigid pavement that are cracked around their periphery and displaced downward relative to the rest of the slab. Punchouts usually occur between closely spaced transverse cracks that are subsequently connected by longitudinal cracks.

20. Polished aggregates are surface aggregate particles that have smooth, rounded surfaces with fine microtexture, either in their original condition or after abrasive wear by traffic.

21. Fatigue cracks are cracks in a pavement layer caused by the combination of repetitive strains and apparent reduction of tensile strength caused by fatiguing of the layer material. The repetitive strains that cause fatigue are usually the result of passing wheel loads but may include thermally induced strains or other types of strains.

PAVEMENT DISTRESS

In this project, distress is defined as the condition of a pavement structure that reduces serviceability or leads to reduction of serviceability. Occurrence of distress may also require maintenance to restore serviceability. Distresses that do not directly result in significant losses of serviceability or lead to other distresses were of minor interest in this study.

The identification of distresses that affect the performance of the five types of pavement structures included in this project was the result of a combination of literature review and the experience of staff and consultants. The primary source of information was published field surveys, such as those by Darter and Barenberg (6), which identify the types of distress observed and, generally, the frequency of occurrence.

RELATED MATERIAL PROPERTIES

The identification of the material properties that have a significant effect on specific distresses was also the result of a combination of literature review and the experience of staff and consultants. Information is already available in the form of sensitivity analyses, such as that reported by Rauhut and others (7), and regression equations for various types of pavements. These studies are especially useful when the statistical significance of the various material properties is included.

RESEARCH APPROACH

The basic approach used to identify the various pavement distresses and the engineering material properties that affect these distresses involved an evolutionary process of review and refinement. The first cycle involved identifying and categorizing various distresses based on the experience of the research team. At the same time, the material properties that affect the specific distresses were identified. By using the resulting information as a base, a second cycle of review, expansion, and refinement was conducted. Previous identifications of distress from the literature and inputs from this research were introduced at this stage to ensure that all pertinent types of distress and related material properties had been considered (3, 6). The study was also expanded at this stage to identify the environmental, mix-design, construction, and traffic factors that influence the material properties.

During the second study cycle, each of the previously proposed distresses was carefully considered to determine whether it was a distress or a secondary effect. In addition, more definitive relations between distress and related material properties were developed, and a preliminary assessment of the relative importance of the various distresses and their related material properties was made. Finally, the results of this study were carefully reviewed to ensure that all pertinent distresses were considered and that the list of related material properties was complete.

RESULTS

The first two study cycles produced a complete set of distresses for each pavement type, a complete set of material properties that affect the specific distresses, and a reasonably complete set of independent mixture and construction factors—i.e., type of aggregate, cement factor, and mixing temperature—that affect these material properties. The final cycle involved establishing the relative importance of the distresses and their related material properties. These decisions were based on (a) the results of field surveys and the combined experience of the project staff and consultants, which were used to establish the distresses that warranted consideration [the work of Darter and Barenberg (6) and McCullough and others (8) provided the primary sources of field survey information] and (b) the results of the field surveys, sensitivity analyses on both regression and theoretical models, and the combined experience of the project staff and consultants, which were used to rank the material properties in order of their importance to specific distresses.

In developing these rankings, considerable use was made of the results reported by Darter and Barenberg (6) and McCullough and others (8). In both of these studies, significant efforts were expended to collect condition data for U.S. pavements. As a part of these condition surveys, summaries of the severity and frequency of occurrence of distress were prepared. Results from discussions with 13 state highway agencies in the United States were used in developing the rankings used by Darter and Barenberg (6). These discussions provided a basis for transforming the information from the condition survey into the severity categories used.

An example of the type of summary information prepared by Darter and Barenberg for flexible pavements is given in Table 1 (6). Similar data are reported here for composite pavement, jointed concrete pavement (JCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP). The information in each table represents the type of moderate to severe distress observed in pavements that exhibited lives consistent with that desired for zero-maintenance pavements.

It should be noted that these distress rankings are for pavements that survived for 20 years and may not be applicable to pavements in general. The survival of a particular pavement may have resulted from favorable environmental, traffic, and construction factors rather than optimal material properties.

In this paper, some of the identifications for and rankings of distresses differ from those reported by Darter and Barenberg. The reasons for these differences are the following:

1. The distresses noted by Darter and Barenberg (6) were not identified within constraints such as those imposed by the definitions presented earlier, so Darter and Barenberg included as distresses two items that do not qualify within these constraints: weathering asphalt and polished aggregate.
2. Other distresses noted by Darter and Barenberg fit the definition of distresses but are not subject to material optimization within the context of this research effort. These distresses include joint filler extrusion or stripping, shoulder distress, interconnecting cracking, paved shoulder distress, and joint filler stripping.
3. Some distresses were identified more by their distress manifestations than by the cause of distress. For instance, distress in composite pavement included transverse, longitudinal, edge, and random cracking, whereas the terminology in this paper would include all surface cracking in composite pavements under reflection cracking and fatigue cracking. Similarly, corner cracking, longitudinal cracking, and diagonal cracking for JRCP are combined in this report as fatigue cracking.

Table 1. Summary of types of distress found in flexible pavements and rated moderate to severe.

Type of Distress	Number of Distresses	
	Found	Maintained[a]
Longitudinal cracking (lane joint in nearly all cases)	11	5
Transverse cracking (including reflective)	10	7
Alligator (fatigue) cracking	9	5
Polished aggregate	8	0
Rutting	6	1
Weathering asphalt	4	0
Depressions	3	0
Alligator or transverse cracking[b]	14	9
Alligator, transverse, or longitudinal cracking or rutting[b]	17	10

[a]Maintenance performed only for distress indicated.
[b]Whichever type was rated highest for each pavement.

Thus, the identifications of distresses and their importance rankings were developed by using those prepared by Darter and Barenberg (6) as a beginning point and then modifying them to represent the combined experience and opinion of the research team.

Moderate to severe distresses that occurred frequently were retained for additional study. Other minor distresses—i.e., distresses that do not occur if design is adequate or do not require significant maintenance—were eliminated, although some are briefly discussed. Fatigue cracking is typical of the distresses considered to be significant, whereas shoving and raveling of a flexible surface were omitted from further study because they can be and have been controlled by adequate mixture design.

Distresses

Distress is the condition of a pavement structure that reduces serviceability or leads to a reduction in serviceability. The three basic categories of distress, defined in the list above, are fracture, distortion, and disintegration. Several manifestations of distress within each of these categories have been observed in the field. Table 2 gives the major distresses in each category. On the basis of the definition of distress, a number of effects that have often been labeled distresses were eliminated. It is recognized that, although these affect the development of distress, they are not themselves distresses. Examples of such effects are curling and pumping.

The number of distresses was also reduced by combining into one distress those subgroups that have been used to account for small variations in the observed distress manifestations—e.g., types of cracking such as corner, diagonal, longitudinal, second-stage, third-stage, progressive, and random, all of which have been used in the past to account for slight variations in the observed crack pattern.

Another group of distresses eliminated from further consideration is those distresses that basically occur in secondary highways and would not be expected to occur in premium pavements, such as shoving, slippage, and corrugations. These distresses must be kept in mind, however, to ensure that distresses that can be avoided

Table 2. Pavement distress by distress category and pavement type.

Type of Pavement	Fracture	Distortion	Disintegration
Flexible	Fatigue cracking Thermal cracking Slippage cracking[a]	Differential frost heave Differential compaction-swelling Shoving[a] Rutting Corrugations[a]	Stripping Raveling Reduced skid resistance
Rigid	Fatigue cracking Shrinkage cracking Thermal cracking Blowups Spalling	Faulting Differential frost heave Differential compaction-swelling	D-cracking Scaling Reduced skid resistance
Composite	Fatigue cracking Thermal cracking Slippage cracking[a] Reflection cracking	Differential frost heave Differential compaction-swelling Shoving[a] Rutting Corrugations[a]	Stripping Raveling Reduced skid resistance

[a]Not important in premium pavements that use current design and construction techniques but should be considered to ensure that the condition does not develop.

by proper design and construction do not result when changes in material, mixture, and structural design are made to eliminate other distresses.

There is considerable recent evidence that stripping is an important distress in flexible pavements. However, the process of stripping is a very complicated physical-chemical interaction between the asphalt and the aggregate, and the effects of material properties on stripping are not well defined. Since the objective of this project is to optimize material properties and since stripping was not a major distress in nationwide surveys of flexible pavements (6), stripping was not considered further.

Table 3. Material properties considered to affect distresses in premium pavements.

Material Property	Type of Pavement Affected		
	Rigid	Flexible	Composite
Constants of the fatigue equation	X	X	X
Tensile strength	X	X	X
Shrinkage characteristics	X		X
Coefficient of thermal expansion	X	X	X
Aggregate characteristics	X	X	X
Compaction-volume change characteristics	X	X	X
Erodibility of subbase and subgrade materials	X		
Frost susceptibility of subgrade soil	X	X	X
Mixture stiffness[a]	X	X	X
Permanent deformation characteristics		X	X
Bond (adhesion)	X	X	X

[a] Includes stability, creep compliance, and elastic properties.

Material Properties

Engineering material properties are defined as those properties that can be used with a constitutive equation to predict the physical behavior of a material in a particular environment. For example, Hooke's Law can be used to describe the state of stress or strain of a linear, elastic material. By using Hooke's Law, other physical laws, and decision or design criteria, one can assess the suitability of a material with a certain modulus of elasticity (from Hooke's Law) for a particular application. Since modulus of elasticity is useful in evaluating the application of the material, it is categorized as an engineering property but is also a property of the material. Material properties, then, are those engineering properties that are used to represent the materials in mathematical models and equations or in decision criteria. These, in turn, are used to evaluate the behavior and the suitability of materials for particular application.

The material properties initially identified as having important effects on distresses in premium pavements are given in Table 3. Each of the distresses included was considered by the project team to affect the occurrence and magnitude of a distress. For clarity and ease of presentation, the distresses are also given separately in Tables 4, 5, and 6 for each pavement type even though several of the distresses occur in more than one pavement type.

In Tables 4-6, the independent material properties that affect a particular distress are coded by letter to indicate the type of material and the layer to which each property applies. For example, in Table 4, low-

Table 4. Relation between material properties and distresses by type of material and layer affected: premium flexible pavements.

Material Property	Cracking						
	Fatigue	Low-Temperature	Rutting	Compaction-Swelling[a]	Raveling	Stripping	Reduced Skid Resistance
Stiffness[b]	a, b, c, d, e	a, b	a, b, c, d, e		a	a, b	
Coefficient of thermal expansion		a, b					
Tensile strength		a, b					
Permanent deformation characteristics			a, b				
Aggregate characteristics						a, b	a
Compaction-volume change characteristics				e			
Frost susceptibility				e			
Bond (adhesion)						a	a, b
Fatigue constants	a, b						

Note: a = asphalt concrete surface, b = asphalt-treated material, c = lime-treated material, d = untreated granular material, and e = subgrade soil.
[a] Large, relative vertical differential displacements. [b] Includes stability, creep compliance, and elastic properties (E, ν).

Table 5. Relation between material properties and distresses by type of material and layer affected: rigid pavements.

Material Property	Cracking								
	Fatigue	Drying Shrinkage	Low-Temperature	Blowups	D-Cracking	Polishing	Spalling	Faulting	Compaction-Swelling
Mixture stiffness[a]	a, b, c, d, e, f		a, b	a					
Fatigue constants	a								
Tensile strength	a	a	a						
Coefficient of thermal expansion			a	a			a		
Tensile strength of paste					a	a			
Permeability of paste					a	a			
Pore and air-void characteristic of paste					a				
Aggregate characteristics					a	a			
Compaction-volume change characteristics									f
Erodibility								b, c, d, e, f	
Bond (adhesion)								b, c, d, f	
Frost susceptibility									f
Shrinkage characteristics		a							

Note: a = PCC surface, b = asphalt-treated materials, c = cement-treated materials, d = lime-treated materials, e = untreated granular material, and f = subgrade soil.
[a] Includes stability, creep compliance, and elastic properties (E, ν).

Table 6. Relation between material properties and distresses by type of material and layer affected: premium composite pavements.

Material Property	Cracking: Fatigue	Cracking: Low-Temperature	Cracking: Reflection[a]	Rutting	Compaction-Swelling[b]	Raveling	Stripping	Reduced Skid Resistance
Mixture stiffness[c]	b, c, d, e, f, g		a, c, d, e, f, g	a, c, d, e, f, g		b	b, c	
Fatigue constants	b, c, d		a			b	b, c	
Tensile strength		b, c	a					
Shrinkage characteristics			a					
Coefficient of thermal expansion		b, c, d	a					
Aggregate characteristics			a					b
Compaction-volume change characteristics					f, g			
Permanent deformation characteristics[c]				b, c				
Frost susceptibility					g	g	g	
Bond (adhesion)						b	b, c	

Note: a = asphalt concrete surface, b = PCC, c = asphalt-treated material, d = cement-treated material, e = lime-treated material, f = untreated granular material, and g = subgrade soil.
[a]Reflection cracking can be caused by any cracking of the PCC layer. See the PCC pavement distress summary for a breakdown of the various forms of cracking.
[b]Compaction-swelling refers to any large, relative vertical differential displacements.
[c]Includes stability, creep compliance, and elastic properties (E, ν).

Table 7. Priority ranking of significant distresses selected for future study.

Priority Ranking	Flexible Pavements	Rigid Pavements: JCP	Rigid Pavements: JRCP	Rigid Pavements: CRCP	Composite Pavements
1	Fatigue cracking	Fatigue cracking	Low-temperature and shrinkage cracking	Crack spalling	Reflection cracking
2	Rutting	Joint faulting	Fatigue cracking	Fatigue cracking	Fatigue cracking
3	Low-temperature cracking	D-cracking	Crack faulting	Low-temperature cracking	Rutting
4	Reduced skid resistance	Joint spalling	Joint spalling	Shrinkage cracking	Reduced skid resistance
5			D-cracking	Punchouts	
6				Steel rupture	

temperature cracking is affected by (a) the mixture stiffnesses of the surface and asphalt-treated base, (b) the coefficient of thermal expansion of the surface and asphalt-treated base, and (c) the tensile strength of the asphalt concrete surface and asphalt-treated base.

Dependent material properties have generally not been included in the lists of properties prepared in this study. Although dependent material properties can affect the magnitude of the independent property, all too often the relation is a statistical correlation rather than one of cause and effect. Since the dependent material properties are related to the independent properties and often are more easily or conveniently measured, they can be used in place of the independent material property in engineering analyses. For example, density, aggregate gradation and type, temperature susceptibility of the asphalt cement, air-void characteristics, and several other factors are related to the fatigue characteristics of an asphalt concrete mixture. In this study, fatigue characteristics are included in the optimization studies and not the other (dependent) properties. Since the independent properties are to be optimized, it is necessary to optimize the property that produces the effect rather than a second property with which the first may be correlated.

The importance of this approach is illustrated by the number of engineers who believe that increased density is always desirable. An attempt to maximize density does not mean necessarily that distress will be minimized or that other material properties will be maximized. In fact, in many cases material properties will not be maximized nor distress minimized. For example, fatigue life is not maximized at maximum density. In addition to not maximizing fatigue life, increasing density past optimum can lead to other distresses such as bleeding.

Both stiffness and air voids were considered to influence the fatigue properties of asphalt mixtures even though both are dependent on the same factors as are the fatigue properties. In addition, stiffness can account for the effect of a number of independent factors and has been used extensively, and air voids produce flaws that affect crack propagation.

Factors That Affect Material Properties

Factors that are believed to affect the magnitude of the various material properties were also identified and are given elsewhere (9, Appendix A). This information provided valuable insight in the evaluation of the relative significance of material properties for this project. All factors that have an effect on the various material properties were listed for each property and categorized to indicate whether the factor related to environment, mixture design and materials, construction, traffic, or time.

Distress Ranking

From the previous tables of various distresses, it was necessary to select those distresses that are of primary concern in producing premium pavements and that must be considered in the analysis or design of the pavement structures to minimize their occurrence and associated effects. Distresses not included in this list have been eliminated through improvements in existing design procedures, proper selection of materials, or proper construction practices, including quality control.

The results from condition surveys reported by Darter and Barenberg (6) and McCullough and others (8) were extensively used along with the experience of project engineers and consultants to rank order the pavement

Table 8. Priority ranking for material properties that affect major distresses found in premium flexible pavements.

Material Property	Layer	Fatigue Cracking	Rutting	Low-Temperature Cracking	Reduced Skid Resistance
Fatigue constants	Surface	1			
	Base	6			
Tensile strength	Surface			3	
Coefficient of thermal expansion	Surface			1	
Aggregate characteristics	Surface	-[a]	-[a]		1
	Base	-[a]	-[a]		
	Subbase	-[a]	-[a]		
Mixture stiffness[b]	Surface	2	1		
	Base	3	5		
	Subbase	4	7		
	Subgrade	5	3		
Permanent deformation characteristics	Surface		2		
	Base		6		
	Subbase		8		
	Subgrade		4		

Note: Rankings are based on the effect of a property on distress and not the ability to control that property in design.
[a]The effect of the variable is included with other properties.
[b]Includes stability, creep compliance, and elastic properties of any pavement layer.

Table 9. Priority ranking for material properties that affect major distresses found in premium composite pavements.

Material Property	Layer	Reflection Cracking	Fatigue Cracking	Rutting	Reduced Skid Resistance
Mixture stiffness[a]	Surface	1	4	2	
	Base[b]	3	1	3	
Fatigue constants	Surface		3		
	Base[b]		2		
Tensile strength	Surface	4			
	Base[b]				
Coefficient of thermal expansion	Surface	5			
	Base[b]	2			
Aggregate characteristics	Surface				1
Permanent deformation characteristics	Surface			1	

Note: Rankings are based on the effect of a property condition and not the ability to control that property in design.
[a]Includes stability, creep compliance, and elastic properties of any pavement layer.
[b]Existing PCC pavement in some situations.

Table 10. Priority ranking for material properties that affect major distresses found in premium rigid pavements.

Material Property	Layer	Joint and Crack		Cracking			Punchouts	Steel Rupture
		Faulting	Spalling	Fatigue	D	Low-Temperature and Shrinkage		
Stiffness[a]	Surface		3	2			2	2
	Subbase			3				
Fatigue constants	Surface			1				
Coefficient of thermal expansion	Surface		1			2	1	1
Permeability of paste	Surface				2			
Pore and air-void characteristics of paste	Surface				2			
Aggregate characteristics	Surface				1			
Erodibility	Surface							
	Subbase	1						
	Subgrade	2						
Tensile strength								
Concrete	Surface	3	2	4	4	1	3	3
Steel	Surface							4
Shrinkage coefficient	Surface					3		

Note: Rankings are based on the effect of a property on distress and not the ability to control that property in design.
[a]Includes stability, creep compliance, and elastic properties of any pavement layer.

distresses given in Table 2. The resulting priority ranking of pavement distresses is given in Table 7. The results of the priority ranking of distress will be used in further research to more clearly define the material properties that most affect the occurrence and extent of distress. The models used to predict the occurrence of these distresses have typically included variables such as material properties, traffic, and environmental effects. A second priority ranking was performed to allow for the inclusion of the most significant material properties in the evaluation of the available models. These priority rankings (by layer) of material properties that affect distress in premium pavements are given in Tables 8, 9, and 10. In developing the priority rankings for material properties within a particular distress, the rankings were based on total effect and no consideration was given to whether the material property could be controlled or manipulated during design.

SUMMARY

The pavement distresses that occur most frequently and have the greatest effect have been noted and ranked in order of their effect on realizing the objective of zero-maintenance pavements for each type of pavement. The material properties that affect each of the distresses have also been noted and ranked. To determine optimal values of each of these material properties, the effect of change in these properties on structural response must be evaluated and compared with the requirements for zero-maintenance pavements. It should be noted, however, that some important distresses cannot be evaluated by using available analytical models and must be investigated in special studies. Papers by Rauhut and others (9 and a paper elsewhere in this Record) include detailed discussions of analytical models that predict distress as a function of material properties, load, and environmental factors.

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Evaluation of Permanent Deformation in Asphalt Concrete Pavements

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Results of an evaluation of permanent deformation, or rutting, in asphalt concrete pavements subject to traffic load and environmental conditions are presented. Because previous studies have shown rutting to be a major mode of distress in various pavement systems, rutting criteria should be considered in any rational method of pavement design. For practical applications, it is often necessary to estimate the rutting expected in a pavement for a certain period or set of conditions. To accomplish this, a model of rutting estimation is necessary. An approach to rutting estimation applied successfully to subgrade soils in research at Ohio State University was used to study the variation of rutting parameters with asphalt content, temperature, and loading conditions for two mixtures that met Ohio specifications for surface-course mixtures. The data and results were obtained from uniaxial dynamic tests performed on laboratory-prepared samples and from previous research conducted at Ohio State University. The findings of the study, and comparisons with results of previous similar studies, indicate that a direct general relation exists between rutting parameters, dynamic moduli, and applied stress. The rutting parameter m was found to be almost constant within the range of study, which confirms previous results on subgrade soils that showed m to be an almost universal constant independent of soil type, stress, dynamic modulus, or saturated environmental conditions. A method for estimating permanent deformation in asphaltic concrete layers is proposed on the basis of the relation found in this study, in which the dynamic modulus was found to characterize such mix properties as density, asphalt content, gradation, air voids, and temperature with respect to rutting criteria. A general relation was also found between the rutting parameter A and the dimensionless ratio of dynamic modulus to applied stress. This relation satisfactorily describes the test results regardless of other influential factors such as type of material.

A recent survey among various state highway departments by the American Association of State Highway and Transportation Officials (AASHTO) has shown the importance of excessive permanent deformation, or rutting, as a common cause of failure in flexible pavements. Table 1 gives a summary of the most prevalent types of pavement distress reported by state highway