Abridgment

Defining Pavement Maintenance and Distress Precursors for Pavement Maintenance Measurements

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An instrument for monitoring conditions indicating pavement deterioration that can be repaired with maintenance treatments has been designed and is being developed at the University of Texas at El Paso as part of a Strategic Highway Research Program (SHRP) project. The measurements made by the device are described. The focus of the SHRP research is to assist with identifying the need for and the effectiveness of maintenance activities, especially preventive maintenance. Considerable effort was directed at distinguishing preventive maintenance from rehabilitation. During this process, the types of damage that lead to the types of distress that are generally addressed with preventive maintenance were postulated. Furthermore, the mechanisms involved in developing different types of distress suitable for maintenance treatments were developed in a conceptual manner. To determine when these mechanisms should be measured, the precursors of the various distress types were hypothesized, and levels that should be considered significant were proposed.

The goal of the Strategic Highway Research Program (SHRP) Project H-104b is to develop equipment that measures the times at which maintenance treatments should be applied and the effectiveness of the treatments, especially preventive maintenance treatments. Part of the first year's work was spent defining the types of damage that could be measured with the equipment and that would be addressed with preventive maintenance. In addition, the level of accuracy required in the proposed measurements had to be determined. These measurements were to identify changes in the pavement layers at early stages of damage to allow preventive maintenance to be applied to prevent—or at least reduce the development rate of—further damage. An instrument has been designed and a prototype built at the University of Texas at El Paso. It is believed that it can make measurements that determine the following conditions: moisture in asphalt concrete pavement (ACP) layers, voids or loss of support in portland cement concrete pavements (PCCPs), fine cracking in ACP, delamination of overlays, and aging of asphalt (*1*).

This paper concentrates on the process used in the SHRP H-104b project to define preventive maintenance, to identify distress types typically addressed with preventive maintenance, to identify damage mechanisms leading to the development of these distress types, and to define accuracy levels needed for measurement. The effort is preliminary in nature; however, it is presented as a first step in defining distress mechanisms and precursors. It is hoped that this will lead to further efforts to define the underlying causes of distress that can be addressed with maintenance in a effort to ensure that the maintenance applied addresses the causes rather than the symptoms of pavement damage. The reader is referred to Nazarian et al. (*1*) for details of the procedures used.

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DEFINING MAINTENANCE

The first step was to define maintenance types and classifications, because current definitions vary among agencies and over time. The following is presented to develop a coherent set of maintenance terminology.

- Routine Maintenance: This is localized maintenance activity such as pothole patching, spot sealing, and other repairs that are not funded for specific planned treatments for identified pavement segments.
- Programmed Maintenance:
  —Preventive: Treatments are applied to preserve the existing pavement surface integrity and reduce the rate of deterioration. Examples include programmed joint and crack sealing, chip seals, slurry seals, fog seals, and rejuvenator applications (including minor surface preparation).
  —Corrective: Treatments are applied to an existing pavement to maintain surface characteristics (surface friction restoration and moisture penetration resistance) and the structural integrity for continued serviceability. Examples include programmed joint sealing with partial depth patching to repair joints, slurry seals, chip seals, friction courses, thin asphalt overlays (1.25 in. and less) (including minor patching and shape correction) applied to correct surface friction problems or repair surface cracking.
- Rehabilitation:
  —Restoration: New surface layers and repairs are intended to restore the pavement structure to a level approximately equivalent to that which was orignially present. Examples include joint replacement, full-depth slab replacement, full-length overlays with minor repairs to the

existing pavement, and surface treatment with major shape corrections and selective deep patching.

—Major Rehabilitation: Lane-width, full-length layers are added to the existing surface to increase the structural strength to handle increased future traffic loads. Examples include overlays with selective deep patching and recycling one or more pavement layers.

- Reconstruction: This is lane-width, full-length removal and replacement of pavement, mostly on existing alignment, including rehabilitation of associated structures generally to improved standards.

The definition of preventive maintenance in this list was used for the H-104b project.

DAMAGE REPAIRED WITH MAINTENANCE

The next step in the SHRP H-104b study was to determine the types of distress that are generally treated with preventive maintenance and the ways these treatments are programmed. The ultimate goal is to determine the precursors of such distress, but the more advanced stages are discussed before the precursors are postulated. The types considered included

1. Increased moisture in pavement base, subbase, and subgrade layers (ACP) leads to fatigue-type failures that occur because of the decreased strength of these pavement layers (*2*);
2. Moisture under joints (PCCP) leads to a decrease in the strength of base or subgrade materials, increases stresses in the slab, and leads to void development (*2*);
3. Voids or loss of support (PCCP) increase stresses in the slab, increase fatigue-related cracking of the pavement, and lead to faulting (*3*);
4. Overlay delamination allows excessive movement at the bottom of the overlay relative to the top where the wheel load is in contact with the pavement, increasing strains and reducing pavement life;
5. Fine cracking (ACP) is discontinuities in the asphalt concrete structure that reduce the surface modulus and eventually widen to allow moisture infiltration; and
6. Asphalt pavement aging is mostly attributed to progressive oxidation of the in-place asphalt concrete (*4*).

The ability to measure or infer changes in material properties and pavement responses to the test equipment is described in detail by Nazarian et al. (*1*). The different pavement layer properties and changes that can be measured are developed, and their relationships to the distress types are presented.

POSTULATING REQUIRED ACCURACY FOR MEASUREMENTS

The remaining life of a pavement is controlled by the complex interaction of factors such as traffic loadings, pavement structure, drainage, road geometry, climate, material durability, and maintenance actions. Below a certain measurement level, changes in the distress precursors are not significant enough to predict accurately changes in the pavement. If the distress precursors are identified too late, preventive maintenance treatments will not be enough and rehabilitation or reconstruction will be required.

The Texas Flexible Pavement System (TFPS) (*5*) was used to determine how early small changes in the pavement layer properties affect the ultimate pavement life, as defined by fatigue cracking, rutting, and serviceability. This was then used to define the levels of accuracy and precision required for maintenance measuring equipment.

The TFPS model predicts fatigue cracking, rutting, and serviceability as a function of traffic loadings. The impact of changes in base modulus values was used as the primary analysis tool to determine the accuracy needed for changes in base moisture levels. Fatigue cracking was used as the ultimate damage avoided by applying preventive maintenance. Depending on the quantity of cracks, four levels of maintenance or rehabilitation activities were envisioned. Within Level 1, the pavement is in satisfactory condition and no treatment—other than occasional localized maintenance—is needed. In Level 2, maintenance is appropriate for the pavement section. In the more severe cases of Levels 3 and 4, overall rehabilitation or reconstruction is necessary.

To predict the need for preventive maintenance, all measurements were made when the pavement was in Level 1 to predict when the pavement would reach a level at which preventive maintenance was needed or beyond which preventive maintenance would not be appropriate.

TFPS considers the long-term effect of seasonal variation of modulus due to changes in moisture content on the development of fatigue cracks. However, it does not model significant changes that develop partly through the life of the pavement. If the pavement starts with a given set of material parameters and early in its life the material is subjected to an increase in moisture that reduces its stiffness, future deterioration will be influenced by this early change, because it would reduce material stiffness more than would changes due only to seasonal variations in the model.

A conceptual model developed using TFPS allowed the determination of the impact of changes in pavement layers early in the pavement life on the number of load applications, or time, until the pavement reaches established cracking levels. This procedure is considered adequate only for low levels of damage and small quantities of distress (such as those used in this study). By using this approach, early changes in pavement parameters can be used to predict their impact on ultimate life and rate of pavement deterioration to provide the information needed to determine if the preventive maintenance extends the ultimate pavement life or reduces the rate of deterioration.

Accuracy of Measurements Required

The modulus of the base or subgrade and changes in the moduli can be measured within a finite accuracy. Therefore, there is a level of change below which measurements are not accurate enough to detect, and if this change is considered the distress precursor, there is a level below which the distress precursor cannot be detected. Upper limits, or trigger values, for no maintenance, preventive maintenance, and overall maintenance were set at 2 percent, 5 percent, and 20 percent cracked area based on engineering judgments. Future studies should set these on the economic impact of delaying the maintenance.

Variation in fatigue cracking as a function of number of equivalent single axle loads was calculated for the cases in which the modulus of base was 10 to 50 percent less than a control section. Using the conceptual procedure developed earlier, a damage curve for the situation in which the modulus of base was reduced by 10 to 50 percent because of changes in the equilibrium moisture at a given time. It is conservatively assumed that the change in equilibrium moisture (and as a result the modulus) occurs as soon as the percentage cracking of the control pavement section deviates from zero.

In the next step, the degree of accuracy is determined at which the change in modulus must be measured. It is assumed that the maintenance engineer would like to know within the following 3 years whether maintenance is necessary and, if so, whether it should be localized or overall.

Table 1 shows the degree of accuracy with which the modulus of the base must be measured for different levels of cracking and numbers of years from the date of change in modulus to scheduled treatment. These values are obtained from figures presented by Nazarian et al. (*1*). It can be seen that for a typical pavement, an accuracy of 25 to 30 percent is sufficient. This procedure was repeated for more than one climatic zone, and it was determined that climatic zone had little effect on the accuracy needed.

The advantage of this process is that for each climatic region, each acceptable level of maintenance, and each economically feasible level of deferred maintenance, the required level of measurement accuracy can be determined. Although it is not described in this paper, the same process can be applied to the loss of strength in the subgrade or the subgrade and base combined.

Other Measures

A similar approach was used to determine the accuracy of measurements needed for voids or loss of support in PCCPs, moisture under joints of PCCPs, delamination of overlays, and fine cracking. Aging of asphalt layers was not addressed because adequate precursors had not been defined.

TABLE 1 DEGREE OF ACCURACY NECESSARY FOR DETECTING MOISTURE IN BASE (*1*)

Acceptable Fatigue Cracking (Percent)	Required Accuracy in Measuring Base Modulus (Percent)		
	Year 1	Year 2	Year 3
5	>50	25	10
10	>50	45	30
15	>50	>50	42
20	>50	>50	>50

FUTURE WORK

The equipment under development is programmed to be field tested as this paper is being made final. Considerable field testing of known conditions are planned to define the accuracy level available from the equipment.

SUMMARY

A device is being developed to measure early development of damage in pavements. These measurements are designed to allow the maintenance engineer to determine when maintenance—particularly preventive maintenance—should be applied to the pavement and whether the treatment has been effective. To accomplish this, the project team defined preventive maintenance, the types of damage that can be measured with the equipment that lead to maintenance treatments, and the accuracy needed in the measurements.

This was a first attempt to establish distress precursors and levels of accuracy needed in measurements. More work is needed to define precursors of all types of distress that maintenance activities address. The process needs considerable calibration, but it is hoped that it will be the first step in developing reasonable estimates of the effects of early changes in pavement properties on the pavement's long-term performance.

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