10. Shell Pavement Design Manual--Asphalt Pavements and Overlays for Road Traffic. Shell International Petroleum Company, Limited, London, England, 1978.
11. H.C. Treybig, B.F. McCullough, P. Smith, H. Von Quintus, and P. Jordahl. Flexible and Rigid Pavement Overlay Design Procedure. Report FHWA-RD-77-133. Austin Research Engineers, Inc., Austin, Tex., 1977.
12. Asphalt Concrete Overlays of Flexible Pavements, Vol. 1. Development of New Design Criteria. Report FHWA-RD-75-75. Austin Research Engineers, Inc., Austin, Tex., 1975.
13. H.C. Treybig, B.F. McCullough, P. Smith, and H. Von Quintus. Overlay Design and Reflection Cracking Analysis for Rigid Pavements, Vol. 1--Development of New Design Criteria. Report FHWA-RD-77-66. Austin Research Engineers, Austin, Tex., 1977.
14. O. Schnitter et al. A Rigid Overlay Design Procedure for Texas SDHPT. Report FHWA-TX-79-177-13. Austin Research Engineers, Austin, Tex., 1978.
15. K. Majidzadeh and G. Ilves. Flexible Pavement Overlay Design Procedures, Vols. 1 and 2. Reports FHWA-RD-81-032 and FHWA-RD-81-033, 1981.
16. M.R. Thompson. Concepts for Developing a Nondestructive Based Asphalt Concrete Overlay Thickness Design Procedure. Department of Civil Engineering, University of Illinois, Urbana, 1982.
17. K. Majidzadeh and G. Ilves. Evaluation of Rigid Pavement Overlay Design Procedure, Development of the OAR Procedure. Report FHWA-RD-83-090. FHWA, Worthington, Ohio, 1983.
18. C. Bartell and K. Kampe. Development of the California Pavement Management System--Final Report. Report FHWA-CA-HM-7139-78-03. California Department of Transportation, Sacramento, 1978.
19. R.L. Lytton and G.L. Kohutek. Evaluation of AASHO Road Test Satellite and Environmental Studies. NCHRP Project 20-7-12, Phase II. Final Report Texas Transportation Institute, Texas A&M University, College Station, 1983.

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Project Evaluation for Overlay Selection and Design

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ABSTRACT

Overlays or resurfacings are used by agencies more often than any other rehabilitation technique. It has been suggested that they have been used in some instances when a different rehabilitation technique would have been better suited. This paper contains a description of an evaluation procedure to determine whether an overlay is required and whether other rehabilitation techniques might be substituted for the overlay. The description focuses on how to use an overlay design procedure in this evaluation. It is based on portions of the third volume of an FHWA report, Pavement Overlay Design Procedures and Assumptions (Report FHWA/RD-85/006-008), developed to provide a ready reference on overlay design for use by highway agency engineers. It was designed to provide assistance in determining what overlay design procedures are available for adoption, implementation, and use by an agency as well as to provide guidance on the use of an overlay design procedure. Pavements are rehabilitated to return damaged pavements to a condition that can continue to provide the desired level of service to the using motorists. Project evaluation is conducted to identify rehabilitation alternatives that meet this goal. In overlay design, the goal is directed more specifically to identifying the type of overlay that would be the most effective, the thickness of the needed overlay, and problems that would indicate that some other rehabilitation technique would be more suitable.

The basic objective of project evaluation is to identify and develop cost-effective rehabilitation techniques for the pavement while meeting imposed constraints such as available funds. In many cases, overlays are among several alternatives available to rehabilitate the pavement. Overlays only add layers of materials to the surface and may need to be combined with other techniques to develop an effective solution. In some cases, other techniques may be more cost effective than an overlay.

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FUNCTIONS OF AN OVERLAY

Overlays are used to either (a) strengthen existing pavements to support future traffic loadings or (b) improve surface characteristics of the pavement. Improvement of the surface characteristics can be directed at either the functional condition of the pavement (ridability) or safety problems such as skid resistance. The length of service provided is the primary measure of their success in providing the desired function.

EVALUATION STEPS

Project evaluation is conducted in a series of steps to determine which techniques (including several types of overlays) are the most cost effective. To achieve this goal, the cause and extent of deterioration must be determined. Only then can a solution be developed that addresses the problem rather than just a symptom. Once an overlay has been selected as an appropriate alternative, the project evaluation defines the type of overlay and the thickness of overlays to consider. A rational overlay design procedure becomes an integral part of project evaluation.

Pavement evaluation is a complex engineering problem. It requires a systematic approach to adequately quantify and analyze the many variables that influence identification and selection of appropriate rehabilitation techniques. More preliminary engineering effort is required for pavement rehabilitation than for new construction because of the additional element of evaluating the factors surrounding the existing pavement. However, the expenditure of relatively moderate funds in pavement evaluation can reduce life-cycle costs by ensuring that the selected rehabilitation technique will more closely meet the design life.

In new design, many of the design parameters must be assumed or developed from laboratory tests. In rehabilitation design, the existing materials in the existing pavement are in place. The existing material properties can be accurately determined for use in the design; they do not need to be assumed. In addition, the condition and past or current traffic can be determined. This gives more complete data for analysis with less reliance on assumed values. One could consider the existing pavement an experiment or test of how the pavement has performed under the traffic and environment to which it has been subjected. A careful examination provides much useful information on what has caused the pavement to deteriorate and provides insight into how it is likely to perform in the future if an overlay, or other rehabilitation technique, is applied.

The size of the project and importance of the highway to the system influence the amount of time and funds that will be expended in evaluation. Pavements on high-volume major highways should be subjected to more testing and evaluation than those on low-volume secondary highways. The concepts and evaluation procedure described herein are valid for a highway with any volume of traffic; only the amount of testing and time expended in reaching the conclusions should vary.

EVALUATION FACTORS

A thorough pavement evaluation requires analysis of a large number of factors. The process could be used as a tool in finding answers to the following questions:

1. Is the pavement functionally adequate?
2. Is the pavement structurally adequate for future traffic?
3. Is the rate of deterioration abnormal?
4. Are the pavement materials durable?
5. Is the drainage adequate?
6. Does the condition vary substantially along the length of the project or between lanes?
7. Does the climate require special consideration?
8. Has previous maintenance been abnormal?
9. What traffic control options are available?
10. What geometric factors will impact on the design?
11. What is the condition of the shoulders?

If the designer can answer all of these questions, he can develop rehabilitation alternatives that should provide cost-effective performance.

DATA COLLECTION

To be able to answer all of these questions, substantial amounts of information may need to be collected. The data are often classified as follows:

- Pavement functional condition,
- Pavement structural condition,
- Pavement design,
- Shoulder condition,
- Layer material properties,
- Subgrade soil properties,
- Traffic loadings,
- Climatic factors,
- Drainage,
- Influencing geometric factors,
- Safety aspects,
- Utilities, and
- Other miscellaneous factors.

If the data collection and analysis effort is not managed properly, undue costs with little benefit can result.

The data collection and analysis process should follow a systematic building block sequence. The first step should encompass the collection of data available to the designer from files, reports, and data banks. Generally, this includes information on original construction, design reports, soil reports, quality control reports, climatic information, past traffic, projected traffic, previous rehabilitation techniques used, past maintenance levels, and results of performance surveys (usually roughness and skid). These data should be assembled and used to answer as many of the preceding questions as possible. The results of this step are used to determine any need for additional information.

The second step is a field survey that normally includes a thorough distress survey, surface drainage observations, identification of possible traffic control options, identification of geometric constraints, and determination of shoulder condition. This information should then be combined with the other available information to determine whether specialized testing and studies are required.

Generally, strip maps of load-related distress types, moisture-related distress types, and soil types are helpful in determining the need for deflection testing, soil testing, material testing, and the location of tests. The strip maps help to (a) determine whether the deterioration is uniform throughout the project and (b) establish relationships between soil types and deterioration or between drainage and deterioration, if they exist. These processes help determine whether the pavement deterioration is primarily the result of load or environmental causes. If past distress surveys are available, the rate of deterioration can also be determined. The type, severity, and amount of distress also help determine the amount and type of preoverlay repair required.

The final step includes deflection testing, coring, borings, and materials sample retrieval as needed. This collection effort should be coordinated to make maximum use of data as collected to determine testing locations and needs. Deflection testing can be quickly conducted from the surface showing areas of nonuniformity that should be sampled with cores and borings. These final data should be returned for any laboratory tests needed as well as for final analysis.

An example follows of steps that an agency might use to collect data for a pavement evaluation (2):

1. Office data collection--this would include such items as location, year constructed, design, available materials and soil properties from published soil reports and previous surveys, traffic, climate, and construction data. Any previous performance data from pavement management studies should be obtained.
2. First field survey--this would include such items as distress, drainage observations, general roughness to user, possible traffic control options, obstructions, and safety aspects.
3. Evaluation of data collected thus far with a determination of the need for additional data collection--a list of possible rehabilitation alternatives might be developed at this stage to help in assessing further data needs.
4. Second field survey--this would include such items as coring, sampling, deflection testing, roughness, skid resistance, drainage testing, and vertical clearances.
5. Laboratory testing of samples--including material strength, permeability, composition, density, and gradations.
6. Another evaluation of data collected thus far with a determination of the need for additional data.
7. Final field and office data collection.

Figure 1 is an example of an overall pavement evaluation summary and checklist that follows this type of approach.

EVALUATION FACTORS IN OVERLAY DESIGN

Functional Adequacy

Functional adequacy is usually used to describe the adequacy of the pavement to meet its basic purpose of providing a smooth and safe riding surface. Func-

STRUCTURAL EVALUATION
Existing distress:
Little or no load-associated distress
Moderate load-associated distress
Major load-associated distress
Structural Load-Carrying Capacity Deficiency:
Yes, No

FUNCTIONAL EVALUATION
Roughness:
Very Good, Good, Fair, Poor, Very Poor
Measurement:__________
Present Serviceability Index/Rating:______
Skid Resistance:
Satisfactory, Questionable, Unsatisfactory
Rutting Severity:
Low, Medium, High

VARIATION OF CONDITION EVALUATION
Systematic variation along project:
Yes, No
Systematic variation between lanes:
Yes, No
Localized variation (very bad areas) along project:
Yes, No

CLIMATIC EFFECTS EVALUATION
Climatic Zone (see Module II B):
Moisture Region: I Moisture throughout year
II Seasonal moisture
III Very little moisture
Temperature Region: A Severe frost penetration
B Freeze-thaw cycles
C No frost problems
Severity of moisture-accelerated damage:
Low, Medium, High
Describe (asphalt stripping, pumping,_________)
Subsurface drainage capability-BASE:
Satisfactory, Marginal, Unacceptable
Subsurface drainage capability-SUBGRADE:
Satisfactory, Marginal, Unacceptable
Surface drainage capability:
Acceptable, Needs Improvement
Describe:__________

PAVEMENT MATERIALS EVALUATION
Surface- Sound condition, Deteriorated
Describe:__________
Base- Sound condition, Deteriorated
Describe:__________
Subbase- Sound condition, Deteriorated
Describe:__________

SUBGRADE EVALUATION
Structural support:
Low, Medium, High
Moisture softening potential:
Low, Medium, High
Temperature problems:
None, Frost Heaving, Freeze-Thaw Softening
Swelling Potential:
Yes, No

PREVIOUS MAINTENANCE PERFORMED EVALUATION
Minor, Normal, Major
Has lack of maintenance contributed to deterioration?
Yes, No
Describe:__________

RATE OF DETERIORATION EVALUATION
Long Term:
Low, Normal, High
Short Term:
Low, Normal, High

TRAFFIC CONTROL DURING CONSTRUCTION
Are detours available so that facility can be closed:
Yes, No
Must construction be accomplished under traffic?
Yes, No
Could construction be done at off-peak hours?
Describe:__________

GEOMETRIC AND SAFETY FACTORS
Current Capacity:
Adequate, Inadequate
Future Capacity:
Adequate, Inadequate
Widening Required Now:
Yes, No
List high-accident locations:__________
Bridge clearances problems:__________
Lateral obstruction problems:__________
Utilities problems:__________
Bridge Pushing problems:__________

TRAFFIC LOADINGS
ADT (two-way):__________
AADT (two-way):__________
Accumulated 18-kip ESAL:__________
Current 18-kip ESAL/year:__________

SHOULDERS
Pavement Condition:
Good, Fair, Poor
Localized Deteriorated Areas:
Yes, No

FIGURE 1 Overall pavement evaluation summary and checklist (2).

tional adequacy is often measured in terms of roughness and surface friction. An overlay can be used to correct either of these problems, and no real thickness design procedure is used. The minimum constructible thickness of overlay that will correct the problem is normally selected. This is often about 1 1/2 in. (38 mm) of flexible overlay. Diamond grinding can be used to correct some surface problems in rigid pavement and cold milling can be used to correct some surface problems in flexible pavements. These should be considered in conjunction with an overlay or as alternatives to an overlay where only functional adequacy is a problem. Functional adequacy is normally used as a criterion in determining whether rehabilitation is needed. It is seldom a direct input for the overlay design.

Structural Adequacy

Structural adequacy indicates the ability of a pavement to withstand the expected traffic loadings. All rational overlay design procedures use some method to determine the amount of additional thickness needed for future traffic loadings. If no overlay is needed, it is generally assumed that the pavement is structurally adequate based on the system used in the analysis. Any of the overlay types can be used to upgrade the structural capacity of existing pavements. The type of distress can be used to determine how the pavement has performed structurally to the present; however, it is difficult to use distress to predict future structural performance. Deflection testing or component analysis based on cores and borings are normally used in conjunction with traffic projections to predict future structural performance and indicate that the pavement is structurally adequate or that additional strength is required. This structural evaluation is the primary input to all rational overlay systems in determining overlay thickness required for any of the overlay types.

Rate of Deterioration

The rate of deterioration is an important factor in determining the cause of deterioration and the time at which an overlay should be applied. If the pavement life has exceeded the original design life and has recently reached a level at which rehabilitation is being considered, the pavement may be capable of being rehabilitated with a minimum thickness overlay if traffic is expected to be the same. However, if the pavement requires rehabilitation in a period much shorter than its design life, or if the traffic is expected to increase dramatically, a very thorough analysis of the cause of early deterioration should be completed to prevent the recurrence of early deterioration in the rehabilitated pavement. This could lead to the determination that reconstruction or some other more complete rehabilitation technique should be used rather than an overlay. It may indicate the need for more expensive overlay types such as unbonded portland cement concrete (PCC) overlays rather than thin flexible overlays to reach the desired design life. The rate of deterioration is usually measured in terms of a functional index (PSI), distress index (PCI) or increased in amount of a given distress type. The rate of deterioration is not normally considered directly in overlay design.

Material Durability

Both the existing materials and the materials in the overlay affect the life of the rehabilitated pavement. Most overlay design procedures do not address specific material requirements. They assume that both the existing and overlay materials are constructed of durable materials and expect the proper specifications to be used to ensure that this is achieved. The existing materials should first be investigated to determine that they have not deteriorated by coring and NDT. An overlay with a 20-year design life based on the fatigue of the overlay and existing pavement (constructed on an existing pavement composed of materials that will fail in 7 years from durability problems) will not reach its design life no matter how well it is designed. Another option (other than overlay) should be selected in such a situation. On the other hand, a pavement that is raveling may benefit from an overlay that will cover the deteriorating surface and prevent further deterioration. The mix used in the overlay should be a stable and durable mix.

Drainage

Drainage is not normally a direct input to overlay design; however, all overlay design procedures assume that proper drainage is provided. Much has been written about subsurface drainage in the last few years, and all investigations should begin with surface drainage (2). Failure to provide adequate drainage can lead to premature failure of an overlay or other rehabilitation technique. Moisture-related distress types, presence of moisture in the pavement structure, surface drainage problems, and highly variable deflections may indicate moisture-induced damage that can be addressed with improved drainage. Carpenter et al. describe a procedure to determine the influence of drainage and other moisture-related problems on the performance of pavements (2). This, or some similar technique, should be used to determine if moisture-related problems are present.

Condition Variability

Highway pavements are normally constructed in long multi-mile segments. These segments are often used as "uniform segments" when managing the pavement network. However, many pavements will not perform uniformly even though they have the same structural section and are subjected to similar traffic. As a result, it may be more economical to apply different rehabilitation techniques, or overlay thicknesses, to sections that are performing differently. Deflection and distress can be used to select design sections. It is generally helpful to plot strip maps of deflection results and distress levels along the project to determine whether significant differences exist along the section. Some overlay procedures make a statistical analysis of deflections to evaluate this. On multilane facilities, the lane subjected to the heaviest traffic may deteriorate more quickly. In this situation, different treatments may be considered for different lanes. A comparison of strip maps along each lane can be helpful in making this analysis. Where significant differences are found, overlays of different thicknesses can be designed.

Climatic Considerations

Climate is normally only considered indirectly in overlay design. Daily temperature changes are considered in normalizing deflection measurements and some procedures use a seasonal adjustment factor on deflection measurements. However, an overlay that performs satisfactorily in a warm, dry climate may not perform as well in a cold, wet climate. This is particularly true when reflective cracks are a significant problem. Climates that have extreme heat, extreme cold, continuous moisture, and many freeze-thaw cycles are just a few that require special consideration. Many state highway agencies have several different climatic zones that should be considered. Although a few overlay design procedures use a regional factor to account for climatic differences, most do not address climate.

Some materials are more durable in one climate than another. Material properties are often balanced to achieve desired performance. For instance, the stiffness of asphalt concrete is increased to increase stability and prevent rutting; however, the stiffness is decreased to retard thermal cracking. As a result, the stiffness must be balanced to achieve desired performance in an area where both are a problem. The material properties and overlay type must be selected that will perform adequately in the given climate. Most overlay design procedures do not address this problem; it is expected to be considered in the material selection.

Prior Maintenance

The serviceability of a pavement may be maintained at an acceptable level by applying patching and other maintenance techniques. However, after a period of time, the needed maintenance may become too excessive and expensive to continue that approach. When that occurs, more drastic rehabilitation techniques are required even though the functional condition is acceptable. Overlays are one of the possible rehabilitation techniques. On the other hand, the lack of timely maintenance may have contributed to the present state of deterioration. Most overlay design procedures do not address this directly. A good maintenance management system may indicate excessive maintenance. Where that data is not available from records, excessive patching and interviews with maintenance personnel can indicate the existence of a problem.

Traffic Control Options

The traffic control options may have a major impact on the type of overlay or rehabilitation technique applied. Some major urban freeways in the United States are so heavily traveled that closing even a single lane during peak traffic periods creates massive traffic jams. Some rural roads are so remote that a detour would cause many miles of additional travel for the user. Both indicate the need to carefully determine the traffic control options and select a rehabilitation technique that will provide the desired service to the pavement user while minimizing delay as much as possible. Typical solutions include (a) construction of the overlay in off-peak hours, (b) construction of one lane of overlay at a time while maintaining traffic on the other lanes, and (c) rerouting the traffic to adjacent highways during the construction. On the other hand, it may be possible to decrease the construction cost and increase construction quality by routing traffic off the road during construction. Alternate routes should be identified and investigated for feasible use.

Geometric and Safety Factors

Vertical clearances, utilities, and guardrails are geometric factors that often have an impact on selection of overlays as a rehabilitation alternative; however, sideslope and other factors can also have an impact. If vertical clearances are at, or near, the legal limit, overlays that decrease overhead clearance may be unacceptable without using partial removal, full removal, and replacement under the overhead obstructions or raising the overhead structure. When only limited clearance is available, an overlay such as a fully bonded PCC overlay, which adds the minimum thickness possible, may be more attractive to the designer. When thick overlays are applied, the guard railing adjacent to the pavement must often be raised to match the increase in pavement height. Sideslopes may also be affected by this. In urban areas, curbs and utility covers will also need to be adjusted if an overlay is selected. Although these are direct inputs to overlay design, they influence the overall cost of the alternative and must be considered in the final cost analysis.

Shoulder Condition

Shoulder considerations are not direct overlay design inputs; however, they also can influence the total alternative costs. If the shoulders are in good condition, an alternative that does not require resurfacing of the shoulders may be more attractive because the shoulders will normally need to be raised to match the traveled surface height. However, if the shoulders need repair and analysis indicates that an overlay will provide the shoulder serviceability desired, then the overlay will be a more attractive alternative.

Traffic Loadings

A knowledge of the accumulated 18-kip single-axle loads in the heaviest traveled lane and other lanes is necessary to assess the remaining life of the pavement. Estimated future traffic is required to determine overlay thicknesses in all rational overlay design procedures. Traffic information is normally a direct input for determining the overlay thickness to withstand future loadings. This information is collected from the traffic bureau, W-4 tables, and traffic maps published by the highway agency. Future traffic is normally estimated by the highway agency traffic bureau.

SUMMARY

Project evaluation is absolutely essential in (a) identifying the cause of pavement deterioration, (b) preventing early deterioration of the rehabilitated pavement, and (c) avoiding "overdesign." This evaluation can be costly, sometimes more than new pavement design evaluation. However, it should generally provide a good return in better performance and more economical design. A sequenced procedure will help build data collection on the available or previously collected data to ensure that data collection costs are limited to that needed. An evaluation summary checklist can help lead the designer through the often complex evaluation process.

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REFERENCES

1. M.I. Darter et al. Techniques for Pavement Rehabilitation, Participants Manual. National Highway Institute, Federal Highway Administration, U.S. Department of Transportation, 1984.
2. S.H. Carpenter, M.I. Darter, B.J. Dempsey, and S. Herrin. A Pavement Moisture Accelerated Distress (MAD) Identification System--Volume 1. Report FHWA/RD-81/079. University of Illinois, Urbana, 1981.

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Experimental and Field Investigation of the Influence of Relative Rigidity on the Problem of Reflection Cracking

ABD EL HALIM OMAR ABD EL HALIM

ABSTRACT

Because of the state of the economy, it is no longer viable to reconstruct a roadway that has been left to deteriorate with time. One of the most commonly used methods to keep pavements in service is to construct a new asphalt layer over the existing structure. However, it has been found that this new asphalt overlay does not serve its intended purpose as, in most cases, cracks soon appear. It is believed that these cracks are caused by a combination of different factors. However, a serious deficiency in present analytical approaches dealing with the observed cracks is the assumption that the new asphalt overlay is structurally sound. A new approach in investigating the important parameters that govern the structural behavior of the asphalt overlay at the time of construction has indicated that surface cracks can be induced, which results in the destruction of the structural integrity of the newly constructed overlay. Based on the results of this analysis, two experimental models were developed. The first model is a simple composite beam designed to verify the assumptions of the new approach. The second model is directed to the phenomenon of surface cracks. The new theoretical approach is presented in this paper and the developed experimental models are described. Finally, it provides a model of a new compactor that has been developed to prevent construction cracks so that new pavement can be described as "sound."

The problem of asphalt overlay cracking has been known for many years. Asphalt overlays are often used to correct a cracked, old surface and, consequently, to restore the riding quality of the road surface. However, field observations and research work have indicated that cracks will develop on the new pavement surface in a relatively short time (1-3). Thus, the desired riding quality has not been achieved and the considerable investment is wasted. Therefore, if a reliable method and an economic technique could be devised to minimize or delay the occurrence of the observed cracks, it would certainly be a valuable approach to pavement designers and engineers.

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A comprehensive research program was started in 1983 at Carleton University and its main objective was to examine overlay pavement structures at the time of construction. It was felt that the conditions and method of compaction of asphalt overlays were responsible for a large portion of the cracks observed later on the surface of the pavement.

Results of the analytical phase of the research have indicated that present compaction equipment will induce cracks on the surface of the new added layer. To verify the analytical findings, field data were gathered and analyzed. It was concluded from the collected observations that the analytical approach is, in fact, a reliable theoretical tool. Subsequently, a laboratory investigation was carried out to verify the general assumptions and findings of the analytical approach and to simulate observed