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# Guide for Mechanistic-Empirical Design

## OF NEW AND REHABILITATED PAVEMENT STRUCTURES

FINAL REPORT

# APPENDIX B

NCHRP

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
National Research Council

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March 2004

## ACKNOWLEDGMENT OF SPONSORSHIP

This work was sponsored by the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Research Council.

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# APPENDIX B
# PAVEMENT STRATEGY SELECTION

## B.1 INTRODUCTION

The purpose of this appendix is to address the broad issues of pavement type and strategy selection. It includes updated versions of material that was part of previous AASHTO pavement design guides. The seasoned pavement designer enters the design process with a fairly good knowledge of what kind of pavement structure (or structures) will be appropriate for the project assigned. This knowledge is valuable in mechanistic-empirical design and will expedite the design process since the designer must provide the initial trial design. The designer must then review the predicted performance (key distresses and smoothness) of the trial design and make a decision on acceptability. If the trial design is not acceptable, the designer must then modify the design to provide acceptable performance.

The application of this Guide to the design process requires the designer to be involved in the development of the design. The procedure will not produce an acceptable design automatically. This mechanistic-empirical design process will make the design much better and more cost-effective and reliable. The designer will be able to take advantage of the many possibilities made available by the mechanistic-empirical design approach provided.

Some of the major issues are those involved with physical features of the roadway, described below as engineering and construction considerations, the existing pavement for rehabilitation design, functional highway class, aesthetic concerns, and pavement type selection for either rehabilitation or new design.

In practice, it is expected that the designer will try several trial designs for a given location. The designer may try more than one type of pavement (flexible, rigid, or semi-rigid) and various alternatives with each general type. The various trial designs will yield a variety of materials combinations and layer thicknesses. The designer is expected to examine the various engineering and construction considerations, the materials availability for the site in question, as well as future rehabilitation options before making a decision on which design to actually specify. Much of that final decision may depend on agency policy and/or on the life cycle cost analysis discussed briefly in section 4.3 and in detail in appendix C.

## B.2 ENGINEERING CONSIDERATIONS

Typically, engineering issues play a large part in determining the type, thickness, and other features of the pavement to be used. Some of the major issues here are roadway geometrics, roadway foundation, roadway peripheral features, overhead clearances, and on-grade structures.

### B.2.1 Roadway/Lane Geometrics

Lane widths may be fixed by design standards, yet there will be occasions, especially with rehabilitation design, where it is necessary to work with less than standard widths or more than standard widths. This consideration alone may determine shoulder width, the type of shoulder to be used, and whether certain drainage features are applicable. Lane widths will also play a major role in where wheel loads will be located. That feature alone can be important in determining the width and type of shoulder, as well as the type of pavement.

Longitudinal grades and the absence or presence of vertical curves can be important pavement design considerations, as they may influence drainage features and even the type and speed of traffic to use the facility. Slower traffic produces larger deformations, stresses, and strains in a pavement structure and requires special materials considerations.

### B.2.2 Roadway Foundation

Structural evaluation of the pavement foundation is discussed in PART 2, Chapter 2, Materials Characterization, and Chapter 5, Evaluation for Rehabilitation. However, from a construction point of view, there are issues other than structural that must be considered.

For new locations or reconstruction, the ability of the foundation to support construction equipment and processes may be an important concern. Sometimes it is necessary to stabilize subgrade soils with cementitious materials to provide a suitable working platform. Such stabilized subgrades often have not been considered as part of the pavement structure. With this Guide and the ability to model the pavement mechanistically, designers can be more confident of decisions in that regard.

The load-carrying capability of a native soil, which forms the subgrade for the pavement structure, is of paramount importance in pavement performance. Even in areas of limited extent the inherent qualities of such native soils are far from uniform, and they are further subjected to variations by the influence of weather.

The characteristics of native soils not only directly affect the pavement structural design but also may, in certain cases, dictate the type of pavement economically justified for a given location. As an example, problem soils that change volume with time require a pavement structure able to conform to seasonal variations in longitudinal and transverse profile. An approach sometimes used is to provide for stage construction to accommodate large expected deformations over time.

### B.2.3 Roadway Peripheral Features

Peripheral features such as guardrails, curbs and gutters, traffic control devices, overhead clearances, on-grade structures, and weigh-in-motion installations may play important roles in pavement design. Such features may have special bearing on rehabilitation work where the use of overlays may be prohibited or limited in thickness. In some cases, it is possible to raise guardrails, curbs and gutters, to reconstruct beneath overhead structures, or to increase overhead clearances. However, such adjustments may be prohibitively expensive such that economic considerations will drive the pavement design decision. In some cases, reconstruction is the economically desirable alternative as opposed to an overlay of any type.

## B.3 TRAFFIC CONSIDERATIONS

While the total volume of traffic affects the geometric requirements of the highway, the percentage of commercial traffic and frequency of heavy load applications have the major effect on the structural design of the pavement.

Traffic forecasts for design purposes have generally projected normal growth in the immediate corridor with an appropriate allowance for changes in land use and potential commercial and industrial development. However, experience over the past several decades has shown that the construction of new major highway facilities diverts large amounts of heavy traffic from other routes in a broad traffic corridor. This, coupled with a decline in the quantity of railroad services, has resulted in a considerable underestimation of traffic growth, particularly commercial traffic. Also, historically there have been increases in legal loads to which pavement structures are subjected during their design life. The result of all factors is that cumulative traffic has been badly underestimated on many pavements.

For these reasons, on pavement designs for major facilities agencies may wish to incorporate an appropriate standard deviation in the various components that make up the traffic estimation (e.g., growth rate of trucks). Agencies may choose to establish minimum structural requirements for all alternate pavement types to ensure adequate performance and service life for minor facilities where traffic is unknown. Alternate strategies comprised of various combinations of initial design, maintenance, and rehabilitation can be developed to provide equivalent service over a given period of time although the initial designs are not equivalent. Life cycle costs play a major role in evaluating the efficacy of such alternate strategies. For heavily trafficked facilities in congested locations, the need to minimize the disruptions and hazards to traffic (i.e., to minimize user costs) may dictate the selection of those strategies having long initial service life with little maintenance or rehabilitation designed at a high level of reliability. For these very heavily trafficked pavements, all possible modes of failure and risks should be considered and minimized to ensure a long-lasting and reliable pavement structure.

## B.4 ENVIRONMENTAL CONSIDERATIONS

Weather affects the subgrade as well as the pavement-wearing course. The amount of rainfall, snow and ice, and frost penetration will seasonally influence the bearing capacity of subgrade materials. Moisture, freezing and thawing, and winter clearing operations will affect the performance and maintenance costs of pavement-wearing surfaces. These surfaces, in turn, will have some effect on the ease of winter clearing operations due to differences in thermal absorption or to the ability of the pavement to resist damage from snow and ice control equipment or materials. Each of these factors engenders "tradeoffs" the designer must consider.

Some designers, in the selection of a pavement strategy, will look to the performance of various pavements as experienced by other agencies. In drawing upon the performance of pavements elsewhere, it is most important to take into consideration the conditions pertaining to the particular environment. The climate model incorporated in this Guide will develop useful comparative information.

## B.5 CONSTRUCTION CONSIDERATIONS

Stage construction can be mandated politically or because of special traffic handling considerations. For these reasons, stage construction may dictate the pavement strategy selected. Often, stage construction does not work well because the first stage of construction is allowed to deteriorate too much before the next stage is placed. This will result in early failure of the second stage.

Other considerations—such as speed of construction, accommodating traffic during construction, safety to traffic during construction, ease of replacement, anticipated future widening, seasons of the year when construction must be accomplished, and perhaps others—might have a strong influence on the strategy selections in specific cases.

Construction considerations can be especially important when the design of rehabilitation projects is underway. For example, limited overhead clearances may preclude an overlay or limit its thickness such that a type selection issue evolves. Other geometric factors, such as roadway width, guardrail heights and cut-fill slopes often impact the design decision.

### B.5.1 Availability of Local Materials or Contractor Capabilities

The availability and adaptability of local material may influence the selection of pavement strategy. Also, the availability of commercially produced mixes and the equipment capabilities of area contractors may influence the selection, particularly on small projects.

### B.5.2 Recycling

The opportunity to recycle material from an existing pavement structure or other sources may dictate the use of a particular strategy. Future recycling opportunities may also be considered. Because of advances in recycling technologies it may be possible to recycle one pavement type into another such that type selection becomes driven by economic or construction expediency considerations.

### B.5.3 Conservation of Materials and Energy

Selection of a pavement strategy may be influenced by the criticality of materials supply as well as by the energy requirements of materials production. The construction energy requirements associated with various pavement types may be an additional consideration.

## B.6 OTHER CONSIDERATIONS

### B.6.1 Performance of Similar Pavements in the Area

To a large degree, the experience and judgment of the highway engineer is based on the performance of pavements in the immediate area of their jurisdiction. Past performance is a valuable guide, provided there is good correlation between conditions and service requirements of the reference pavements and the designs under study. As is always the case with projections, the designer is cautioned not to rely too heavily on short-term performance records, and on those long-term records of pavements that may have been subjected to relatively light loadings for large portions of their history. The need for periodic reanalysis of performance is apparent. Full use should be made of historical performance records in the agencies pavement management system for this purpose.

### B.6.2 Adjacent Existing Pavements

Provided there is no radical change in conditions, the choice of a pavement strategy may be influenced by the performance of adjacent existing sections. Those providing cost effective performance may serve as the model for future pavements. Conversely, unacceptable performance of existing pavements may suggest that the designer consider a variation in design, or another type of pavement for future work. The designer should also be mindful that continuity of pavement type would provide for continuity of maintenance operations and experience, which may or not be desirable depending on how well the adjacent pavements have performed.

### B.6.3 Traffic Safety

The particular characteristics of a wearing course surface, the need for delineation through pavement and shoulder contrast, reflectivity under highway lighting, and the maintenance of a nonskid surface as affected by the available materials may each influence the pavement strategy selected in specific locations.

### B.6.4 Incorporation of Experimental Features

In some instances, it is necessary to determine the performance of new materials or design concepts by field testing under actual construction, environmental, or traffic conditions. The incorporation of such experimental features may dictate the strategy selected.

### B.6.5 Stimulation of Competition

Most agencies consider it desirable to encourage improvements in products and methods through continued and healthy competition among the paving industries and materials suppliers.

Where alternate pavement designs have comparable initial costs, including the attendant costs of earthwork, drainage facilities, and other appurtenances, and provide comparable service life or life-cycle cost, the highway agency may elect to take alternate bids to stimulate competition and obtain lower prices. If this procedure is used, it is essential that good engineering practices and product improvement not be abandoned for the purpose of making cost more competitive.

Where several alternate materials are considered structurally equivalent or can be used in such a way as to provide for structural equivalency, agencies are encouraged to permit contractors the option of using any of the approved materials.

### B.6.6 Municipal Preference, Participating Local Government Preference, and Recognition of Local industry

The issues raised by consideration of municipal or local government preferences and local industries may be outside the purview of most highway engineers. However, the highway administrator cannot always ignore them, especially if other factors do not yield a clear pavement type preference.

### B.6.7 Consideration of Future Maintenance and Rehabilitation Alternatives

Through the later half of the initial design period the pavement will likely show more and more deterioration that will require significant maintenance to keep it in service. The designer should consider the type an cost of such maintenance and make sure that the agency will have not only the resources to accomplish this work, but also the ability to close the traffic lanes as required. This is a critical aspect that is often forgotten. In addition, at the end of the design period, a major rehabilitation will be required. The designer should consider the options and make sure that this will be acceptable to the highway agency involved.

## B.7 ECONOMIC CONSIDERATIONS (LIFE CYCLE COST ANALYSIS)

Life cycle cost analysis is a process for evaluating the total economic worth of a project by analyzing initial costs and discounted future costs, such as maintenance, rehabilitation, reconstruction, and user costs over the life of the project. Such an economic analysis may be an important part of the pavement type selection process depending upon agency policy.

It is essential that all costs occurring during the life of the project be included in the analysis. These include both the agency construction and maintenance costs and those costs incurred by users of the facility.

A brief description of LCCA follows; details are provided in appendix C.

### B.7.1 Future Costs

Estimates of future costs will be made using *constant* or *real* dollars. Constant dollars reflect dollars with the same or constant purchasing power over time. In this case the cost of performing an activity does not change as a function of the future year in which it is accomplished.

### B.7.2 Discount Rate

*Real* discount rates should be used when using constant dollars and are used in this procedure. Real discount rates reflect the true time value of money with no inflation premium and should be used in conjunction with non-inflated dollar cost estimates of future investments. Discount rates can significantly influence the analysis result. LCCA should use a reasonable discount rate that reflects historical trends over periods of time. Annual updates to OMB Circular A-94 provide a reasonable estimate of appropriate real discount rates to apply to public projects.

### B.7.3 Analysis Period

The analysis period is the number of years chosen for the consideration of costs in a life cycle cost analysis. The analysis period should be sufficiently long to reflect the long-term cost differences associated with the design alternatives. The analysis period should be long enough to include at least one rehabilitation activity for each alternative. The analysis period used should be the same for all alternatives analyzed and may be dictated by agency policy.

### B.7.4 Agency Costs

Agency costs include all costs incurred directly by the agency over the life of the project. They typically include design costs (preliminary engineering, contract administration, construction supervision associated with new construction and rehabilitation), initial construction costs, and future maintenance and rehabilitation costs. Routine reactive-type maintenance (maintenance in reaction to undesirable pavement conditions) cost data normally is not available except on a very general, area wide cost per lane mile. Fortunately routine reactive-type maintenance costs are low relative to the other agency costs and do not vary significantly by pavement type. When discounted to the present, reactive-type maintenance cost differences generally have a negligible effect on NPV and can be ignored.

*Salvage value* represents the value of an investment alternative at the end of the analysis period. It is used by some agencies for economic evaluation.

*Residual value* refers to the net value for recycling the pavement. It can be significant due to the increasingly importance and use of recycled materials in construction of new pavements. Residual value of a paving material depends on factors, including, volume and location of the material, contamination, age, durability, and anticipated use at the end of the pavement design life.

### B.7.5 User Costs

User costs are the delay, vehicle operating, accident, and discomfort costs incurred by the users of a facility. In LCCA, user costs of concern are the differential costs incurred by the user between competing pavement alternatives, including costs of their associated maintenance and rehabilitation strategies, over the analysis period.

In the LCCA of pavement design alternatives, there are user costs associated with both normal operations and work zone operations. During normal operations, user costs are a function of the differential pavement performance (smoothness) of the alternatives. The work zone operations category reflects user costs associated with using the facility during periods of construction, maintenance, and rehabilitation activities that restrict the capacity of the facility and disrupt normal traffic flow.