Rehabilitation of Highway Pavements—an Engineering Challenge

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INTRODUCTION

There is no question that our country is currently confronted with the enormous task of identifying priorities for the allocation of funds and resources as required to solve national problems.

As members of the highway industry, we must accept responsibility for our portion of this task—we must examine the total needs of the national highway system and recommend plans of action that are most responsive to the economic, social, and environmental needs of our citizenry.

Data currently available fully supports the need for a major continuing program of highway improvements; it also shows that there is a need for a change in emphasis from the construction of new routes to the rehabilitation and upgrading of existing facilities.

The preparation of plans of action for these new rehabilitation programs and the development of technology required for implementation, represent a major engineering challenge.

The following comments speak briefly to the need for highway improvements and rehabilitation programs, and follow with a discussion of some of the technical problems associated with the rehabilitation of pavements.

HIGHWAY IMPROVEMENTS

Road and Street System

The federal publication “Highway Statistics,” indicates that there are approximately 3,790,000 miles of roads and streets in the United States. Of this total mileage, 21% (790,000) are under the administrative control of state government; 74% (2,790,000) are under county and municipal government; and, 5% (210,000) are under federal control.
The types of surfacing on this national system can be characterized in general terms as:

(a) No Surfacing—dirt and gravel roads
(b) Low-Type Surfacing—surface treatments, bituminous mixes, and penetrations with a total surface and base thickness of less than seven inches.
(c) High-Type Surfacing—bituminous concrete, Portland cement concrete with surface and base thicknesses of seven inches or greater.

For the national system, 54% (2,050,000) of the mileage has “no surface”; 24% (920,000) has “low-type surfacing”; and, 22% (820,000) has “high-type surfacing.”

In Indiana, administrative control of the 90,900 miles of roads and streets is divided as follows: state 11,500 (13%), and, county and municipal 79,400 (87%).

The mileage of each type of surfacing on the Indiana system is:

<table>
<thead>
<tr>
<th>Type of Surfacing</th>
<th>State</th>
<th>County and Municipal</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Surfacing</td>
<td>None</td>
<td>41,200</td>
</tr>
<tr>
<td>Low-Type Surfacing</td>
<td>400</td>
<td>33,600</td>
</tr>
<tr>
<td>High-Type Surfacing</td>
<td>11,100</td>
<td>4,600</td>
</tr>
<tr>
<td>Total</td>
<td>11,500</td>
<td>79,400</td>
</tr>
</tbody>
</table>

The statistics for the roads and streets in the nation and for Indiana clearly show that our transportation system is enormous in terms of total mileage, that all types of surfacing are involved and, that all levels of governments have major responsibilities.

New York State, "Master Plan for Transportation"

In giving consideration to future needs for highway improvements, we must remember that the total transportation system also includes railroads, airlines, buses, and transit. Our improvements are justified only to the extent that they contribute to an increased effectiveness of the total system.

In 1973, New York submitted to the governor and the legislature, a report entitled “Master Plan for Transportation.” This document presented the projected 20-year improvement needs for all types of transportation modes and facilities.

The total annual need was estimated at $1,366,000,000. Of this amount, 62% or $848 million was required for highways. Only 38% ($518 million) was for rail, air, bus, and transit.
In order of urgency of need, priorities for the $848 million annual highway improvement program were identified as:

Completion of the Interstate ............ $ 92 million (11%)
Resurfacing and Widening
Structure and Traffic Improvement .... $300 million (35%)
Reconstruction
New Construction ........................ $457 million (54%)

The annual needs for rural highways is $250 million. Of this amount, $148 million, or 60%, is for resurfacing and widening—the remainder for reconstruction and new construction.

New York's master plan shows a need for improvement programs for air, rail, bus, and transit; these needs, however, have not lessened the need for a major continuing program of highway improvements.

The plan emphasizes that priorities for improvements should focus on the rehabilitation and upgrading of services on existing facilities—resurfacing, widening, etc.

Implementation Procedures

To implement highway improvements, we normally designate our work procedure or project as: construction, reconstruction, rehabilitation, and maintenance. For the purpose of this discussion, these terms are briefly defined as follows:

(a) Construction—new alignment, full adherence to AASHTO design standards, major projects.

(b) Reconstruction—major adjustments of alignment, grades and geometrics for existing routes, adherence to AASHTO standards.

(c) Rehabilitation—upgrading services on existing routes, minor changes in alignment, no ROW takings, “expedient” standards, low cost.

(d) Maintenance—activities to decrease the rate of deterioration, repairs, and remedial work at spot locations.

The type of work accomplished under construction and maintenance projects is relatively easy to picture. The difference between reconstruction and rehabilitation can be illustrated by an example from a report by the state of Illinois.

As shown in Figure 1, an old existing roadway pavement is 18 to 20 feet wide with narrow shoulders and limited ROW. The major deficiency is the pavement surface. The question—“What improvements should be made?”
The designer presents two alternatives for consideration (Figure 2). The "expedient" design is a compromise of geometric standards; the pavement is widened and resurfaced for a full 24 feet. However, the shoulders remain narrow and are not stabilized. These less than
desired features eliminate the need for additional ROW and reduce requirements for changes in drainage facilities.

In the second alternative, the cross-section is developed to AASHTO standards—24-foot pavement and eight-foot stabilized shoulders. This design requires the taking of additional ROW, new drainage ditches and backslopes and the extension of pipes and culverts.

The first of these alternatives would be classified as rehabilitation—attaining the primary objective of restoring the pavement to a satisfactory level of service, upgrading the width to standards, but compromising on shoulder width to avoid new ROW and minimize costs.

The AASHTO design goes all the way to obtain desired standards. The type of work required and the costs are those necessary to realize this objective.

Relative to the comparative cost of the two designs in Illinois, the rehabilitation was $86,000 per mile and the reconstruction was $219,000.

REHABILITATION PROGRAMS

Rehabilitation programs may include several types of work. However, in most instances, the primary reason for including a specific project on such a program is to restore the pavement to a satisfactory condition. Widening will usually be included if the width is substandard. While the desirability of full-width shoulders is recognized by all designers, obtaining this objective for many existing roadways will require major adjustments in drainage ditches and backslopes, and the extension of culverts and pipes. These adjustments also frequently require the taking of additional ROW with all of the associated environmental problems.

When the designer has selected the most advantageous cross-section for the improvement, he will examine the roadside facilities. To the extent possible within the concept of an “expedient” design, he may eliminate, relocate or replace guard rail, sign posts, and fixed object hazards.

The three design controls that apply to most rehabilitation projects:

1. The boundaries of the improvement should be within the existing ROW.
2. While attempting to obtain geometric standards, recognize that compromises must be accepted.
3. Minimize cost.

New York's Experience

In 1969, New York initiated a formalized program for the rehabilitation of roadways. This work has been an outstanding success
and extremely well supported by the highway users. Due to the fact that all features of the improvements were not brought to "standards," federal funding could not be applied; financing was 100% state moneys.

Seventy-six contracts, involving 354 miles, were let in 1974 for a bid price of $73.5 million. The following tabulation provides some insight to the character of work done under this program.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridges and Structures</td>
<td>$14.7 million</td>
</tr>
<tr>
<td>Pavement Items</td>
<td>24.6 &quot;</td>
</tr>
<tr>
<td>Maintenance of Traffic</td>
<td>4.0 &quot;</td>
</tr>
<tr>
<td>Other Items</td>
<td>30.2 &quot;</td>
</tr>
<tr>
<td>Total</td>
<td>$73.5 million</td>
</tr>
</tbody>
</table>

Excluding bridges and structures, the program costs for all other types of work was $58.8 million or $166,000 per mile.

If we add the cost of pavement items and maintenance of traffic ($24.6 + 4.0) the cost of attaining the primary objective (upgrading the pavement surface) was $28.6 million or $81,000 per mile.

The types of work accomplished under "other items" ($30.2 million) included improvements in guard rail, signs, shoulders, ditches and backslopes, and drainage facilities.

While these projects were not brought to full AASHTO standards, a great improvement was made in service to the users at a relatively low cost. If funds are available, New York plans to continue its rehabilitation program at an annual rate of $100 million plus.

**PAVEMENT REHABILITATION**

As in the case of all engineering analyses, the first step is to perform surveys as required to provide facts concerning the problem. In regard to pavement rehabilitation work, survey data must support decisions on two problems: (1) which projects will be selected for improvement this year and which can be deferred?, and, (2) for a specific project, what remedial action should be taken? At the present time, many highway departments and many competent professionals fail to recognize that there is a difference in the type of survey information required to answer these two questions. Two field surveys, using different procedures, are required to obtain the necessary data.

**Surveys—Project Selection**

At all levels of government there is the necessity to "manage" a program of improvements for the total mileage of highways under your supervision. To perform this task effectively, data must be available on the "relative" condition of pavements within the system so
that priorities may be established on the basis of urgency of need. There is never sufficient funds to make all desired improvements immediately—there must be a selection process that determines project priorities.

I strongly suggest that the measurement procedure used to determine the condition of pavement surfaces, as required for management decisions on project selection, be a direct reflection of the highway users judgment as to whether or not the pavement is giving satisfactory service. The technology for this concept of “serviceability” is well developed and practical operational procedures are available for implementation.

The concept is very simple and direct. As shown on Figure 3, pavements serve the highway user. The user gives his judgment as to the level of service for each segment of the highway system—is it very good, good, fair, poor, or very poor? With these data on hand, we have a display of the relative condition of all pavements as determined by the people they serve.

![Diagram of Pavement Serviceability](image)

**Figure 3**

The concept of “serviceability” can also be used to determine the change in level of service with time for a particular segment of pavement.

As represented on Figure 4, the initial as-constructed serviceability for this pavement was “very good.” Subsequent periodic determinations indicate that as the pavement gets older, its rating decreases to “good” and then to “fair,” “poor,” and “very poor.”
It is probable that the highway manager will establish a rating of "fair" as the minimum desired level of service. When pavements reach this level, they become candidates for remedial action.

It is not practical to obtain the highway users judgment rating for each segment of the highway system. Consequently, it is necessary to employ mechanical measurement equipment, the output from which has been correlated with the judgments made by the users as to the level of service.

New York has accepted the concept of "serviceability" for pavement condition surveys and had adopted a modification of the Portland Cement Association's "Road Meter" as its measurement device. This equipment measures the relative movement of the rear axle of a passenger car with respect to the frame of the car. In effect, it measures the smoothness of the ride, or conversely, the roughness of the pavement. Prof. E. J. Yoder was chairman of a three-day workshop at Purdue in 1972 for the evaluation of this device—details are given in HRB Special Report 133.

This coming summer, the New York program for serviceability measurements will be fully operational. It has the capacity to make readings on the entire system annually. Computer storage of data can be easily retrieved to answer questions presented by all levels
of management—county engineers or department executives. Personally, I believe that this procedure of determining pavement condition represents a major technical breakthrough.

**Surveys—Design**

Unlike the generalized pavement condition data required to make decisions on project priorities and selection, the designer needs detailed information to determine the most effective type of remedial treatment.

As a minimum, this information must be sufficient for him to construct a log of the life history of the pavement and assign causes for the pattern of performance. From the records, there must be the as-constructed data on cross-section and materials used, the type and volume of traffic imposed over the years, and, the maintenance effort in terms of patching and other remedial work. From field observations, the present condition of the pavement must be logged—extent of cracking, potholes, rutting, and other defects. By explorations (digging holes), the thickness and characteristics of each layer of the pavement and its subgrade must be determined. With these data on hand, the designer, by application of available technology and experience, can evaluate the performance of the pavement and determine the type and extent of improvements required to provide the desired level of service in the future.

In my opinion, we have not assigned enough significance to the importance of detailed surveys for pavement rehabilitation projects. Good designs require good survey information. We should assign the best available engineering talent to this task.

**Overlay Design**

There are numerous formalized procedures currently used for the design of pavement overlays—descriptions can be obtained from the literature. In all cases, however, the procedures used are only guidelines and must be modified on the basis of local conditions and experiences.

For all projects, the designer should think in terms of alternatives and relate each proposal to the anticipated service life. Figure 5 shows two graphs. On each, the vertical scale is “serviceability” in terms of very good, good, and fair. The original pavement represented on the left side of each graph has deteriorated over a period of years from very good to fair. The design question is: “What type of overlay do I use to return the serviceability to very good and what will be the service life of this treatment?”

In the upper graph, a “heavy overlay” (say 2½ inches or greater) will return the serviceability to the very good class—the estimated deterioration of this treatment with time is as shown.
In the lower graph, we examine the probable service history of a "light overlay" (say one inch), followed in a period of years by a second "light overlay." As shown, the first "light" treatment did not provide the years of service obtained from the "heavy" treatment. However, the two "light" treatments are estimated to give a greater service life than the single "heavy" treatment.

The choice between alternatives may depend upon first costs, cost per year of life, or other factors. Relative to first costs, there can be substantial differences. As shown in Figure 6, the costs of the 1974 resurfacing program by maintenance forces in New York were $5,800 per mile for surface treatments, $14,600 for 1-in. bituminous concrete overlays, and $31,000 for 2 1/2-in. overlays. On the basis of cost-ratios, it might be expected that the service life of the 1-in. treatment would be 2.5 that of the surface treatment; the 2 1/2-in. treatment, 5.4 times. These types of comparisons are essential in selecting the proper design for a particular project.

Over-Restrictive Specifications

Our specification books include descriptions of allowable procedures for the operation of plants and equipment. In some instances, these limitations set are over-restrictive and result in a reduction in the
volume of production that can be obtained from modern equipment. This, in turn, means higher costs.

As an example, from experiences in New York, producers of bituminous concrete indicated that our specifications controlling the mixing time were not in keeping with the production capacity of their new modern plants. In cooperation with industry, we undertook a study to relate mixing time with practical and economical plant operations, and the requirement for satisfactory coating of the aggregates. This study showed that the producers were correct; our requirements were over-restrictive.

Current New York specifications carefully define each of the events that occur during the entire mixing procedure. As shown in Figure 7, these events are: charge aggregates, dry mixing, introduce asphalt, finish mixing, and discharge. The specifications refer to a minimum of 15 seconds for dry mixing time (events 1 and 2), and 45 seconds for wet mixing time (events 3 and 4). In addition, there is provision for a reduction in each of these times, based on plant tests to demonstrate that satisfactory coating is obtained.

For New York, the clarification of definitions and the option to reduce cycle time on the basis of coating tests, permitted an increase in the rate of production of as much as 25 percent without any lowering of quality.

Since the costs of rehabilitation work is largely dependent upon the cost of materials, I recommend that we continue to examine our specifications to see whether or not they are over-restrictive.
Temperature Requirements for Bituminous Concrete

As illustrated in Figure 8, the subject of temperature requirements for bituminous concrete requires the consideration of a sequence of interdependent events—mixing, laydown, and compaction.
During mixing, the temperature required is that necessary to obtain satisfactory coating of the aggregate. While this value is dependent upon the viscosity characteristics of the asphalt cement, it has been suggested that, as an average, satisfactory coating can be obtained in the range of 275°—substantially lower than the 325° average currently used.

During laydown, temperature contributes to workability. In general, there are no temperature-related problems during this operation—the mix arriving from the plant has sufficient workability for placement.

During compaction or rolling, we are attempting to obtain a satisfactory density. Temperature of the mix at this point is critical. Most of the densification desired must be obtained during the breakdown (or initial) rolling. Experience indicates that at the completion of this operation, the mix should not be cooler than about 175°. From thermal equations, it is possible to compute the elapsed time for a bituminous mat to cool from the laydown temperature to 175°. This, in effect, is the time available to complete the breakdown rolling. The major variables are the thickness of the mat and the temperature of the base surface on which it is laid.

The relationship between laydown temperature and cooling time to 175° for a 2-in. mat on a 50° base is shown in Figure 9. If laydown is 280°, it takes 15 min. to cool to 175°; for 260°, it takes 12 min. As
previously mentioned, these are the times available for the completion of breakdown rolling.

In Figure 10, the effects of mat thickness are shown. For laydown of 260°, the 1½-in. mat cools to 175° in 8 min.; the 2-in. mat in 12 min. The thinner the mat, the less time available for breakdown rolling.

Observation of construction projects has demonstrated that it is practical to coordinate laydown and rolling to the degree that breakdown can be accomplished in 8 min. Using this period of time as a control, Figure 11 shows the relationship between base temperature and minimum laydown temperature. For a base of 40°, as may occur early or late in the paving season, the minimum laydown temperature of the 1½-in. mat is 265°; for a 2-in. mat, 235°. Similar values are available for a base temperature of 80°: for the 2-in. mat, 220° and for the 1½-in. mat, 240°. If the temperature is less than these values, satisfactory density cannot be obtained during the available 8-min. breakdown time.

If we accept the practicality of an 8-min. breakdown rolling time, this figure indicates that for the major portion of the paving season when base temperatures are high, a laydown temperature in the range of 240°—250° may be adequate for mat thicknesses as little as 1½ in. Since there is little loss in temperature during the summer from plant

**BIT. CONC, x COOLING DURING BREAKDOWN ROLLING**

![Figure 10](image_url)
to laydown, it appears that a mixing temperature in the range of 250°—260° would satisfy all requirements of laydown and compaction. We should investigate to determine whether or not this range will provide adequate coating of the aggregates. If the answer is affirmative, mixing temperature should not exceed these values.

Technology fully documents the fact that higher mixing temperatures are detrimental to the quality of the asphalt. From the plant operations point of view, higher temperatures mean an increase in the amount of fuel oil required for processing—an increase in costs. I suggest that these factors are of such importance that we must reevaluate the temperature requirements for bituminous concrete from mixing through breakdown rolling. It is probable that an improved product can be obtained at lower costs.

CLOSING REMARKS

Even the most conservative estimates show that there is a need for the continuation of a major highway improvements program. This program, however, will emphasize the rehabilitation and upgrading of existing facilities rather than the construction of new routes.

To provide management with a means of determining project priorities for improvements, we must have more definitive information in
regard to the condition of pavements on our system. I suggest that the concept of "serviceability," using currently available measurement equipment, is the best procedure for obtaining these data.

To provide the surveys and designs required for rehabilitation work, we must first acknowledge to ourselves that the type of problems involved are complex and technically demanding. Secondly, we must find a way to coordinate more effectively the engineering talent available in our various operating units. Each of these units—soils, materials, design, construction, and maintenance—has knowledge and experience that is unique, it must be brought together and used.

It is my opinion that the engineering challenges presented by a continuing program for the rehabilitation and upgrading of existing facilities equals or perhaps surpasses those that we faced in the construction of the interstate and expressway programs. I'm sure that, as in the past, we will meet these challenges and fulfill our national responsibilities.