National Research Council

# STRATEGIC HIGHWAY RESEARCH PROGRAM

# SPECIFIC PAVEMENT STUDIES
# EXPERIMENTAL DESIGN AND RESEARCH PLAN
# FOR EXPERIMENT SPS-7
# BONDED PORTLAND CEMENT CONCRETE OVERLAYS

STRATEGIC HIGHWAY RESEARCH PROGRAM
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SPECIFIC PAVEMENT STUDIES

EXPERIMENTAL DESIGN AND RESEARCH PLAN FOR EXPERIMENT SPS-7,

BONDED PORTLAND CEMENT CONCRETE OVERLAYS

## INTRODUCTION

The study of existing bonded portland cement concrete (PCC) overlays was originally planned as experiment GPS-8 of the General Pavement Studies (GPS). However, due to the unavailability of a sufficient number of candidate projects, this study was dropped from the General Pavement Studies and included in the Specific Pavement Studies portion of the Long-Term Pavement Performance program. Successful completion in this study will result in improved design and construction procedures for bonded concrete overlays.

The experimental designs and research plans presented here for the Specific Pavement Studies experiment SPS-7, "Bonded Portland Cement Concrete Overlays" were adapted from the General Pavement Studies experiment on bonded concrete overlays originally described in the May 1986 Strategic Highway Research Program Research Plans issued by the Transportation Research Board. Study parameters have been added to the original experimental design factors to ensure adequate evaluation and analysis of those factors that influence pavement performance. These plans have been prepared by SHRP with input from several highway agencies and other interested parties. This research plan will be used by highway agencies and SHRP as a guide for selecting candidate projects to be constructed for inclusion in the SPS-7 experiment and for the design and construction of test sections.

## PROBLEM STATEMENT

Bonded concrete overlays are used to improve the serviceability and extend the service life of concrete pavements that are in need of structural and/or rideability improvements. As the name implies, bonded concrete overlays are designed to achieve a total permanent bond of the new overlay to the existing concrete and to result in a monolithic pavement section that has improved load carrying capacity. Although bonded concrete overlays have been used since 1910, their use has not been widespread in the past due to the high cost of preparation of the existing concrete pavement surface. With the advances in concrete removal techniques and overall improvements in concrete placement methods, bonded concrete overlays can be an effective rehabilitation alternative for pavements that are in need of structural improvements.

Bonded concrete overlays used for highway pavements have ranged in thickness from 2 to 5 inches, with 3 and 4 inch thick overlays being the more prevalent. When a bonded concrete overlay is used, steps are taken to ensure complete bond with the existing pavement so that the overlay becomes an integral part of the base (existing) slab.

Bonded PCC overlays have been used to extend the life of jointed plain, jointed reinforced, and continuously reinforced concrete pavements. For jointed pavements, joints are provided in the overlay to match the existing pavement joints, including those formed by pre-overlay full-depth repairs.

It is recognized that properly constructed bonded concrete overlays can extend the service life of existing concrete pavements. However, questions need to be answered regarding the degree of life extension and the provisions needed to promote good bonding of the overlay and minimize distress over the life of the overlaid pavement.

A common failure mode for bonded overlays is the delamination between the overlay and the existing pavement. While some delamination can be tolerated, excessive delamination will lead to rapid failure of the overlay. Delamination generally initiates during the first few days of overlay construction and has been attributed to drying of the bonding grout before overlay placement and/or adverse conditions that occur prior to development of adequate interface bond strength. These conditions include differential curling in the overlay and existing pavement, excessive drying shrinkage in the overlay, large temperature differentials between the overlay and existing pavement, and secondary joint cracking.

Weak bonding at the interface of the overlay and existing pavement may also result from inadequate preparation of existing surface. It is essential that the existing pavement surface be thoroughly cleaned so that all foreign matter and surface contaminants are removed. The most common methods used to prepare the existing pavement surface are cold milling and shot blasting. Sandblasting, waterblasting, and/or airblasting may then be used as a secondary cleaning operation to supplement these procedures. A nominal of a 1/4 inch depth of surface material is generally removed in the surface preparation process.

Bonding grouts commonly used are neat-cement and sand-cement grouts. Epoxy grouts, although have been used in some projects, are not considered practical for large projects because of pot life considerations. Although few bonded concrete overlays have been constructed without use of a bonding grout, no clear consensus exists regarding the need for use of a bonding grout or the type of grout. In some cases, construction related problems with the grout layer have been identified as a primary cause for early failure of bonded overlays.

Another critical element in evaluating performance of bonded concrete overlays is the overlay thickness. Traditionally, bonded concrete overlays are used for pavements that are not exhibiting severe distresses. The overlay thickness is considered to be directly additive to the remaining thickness of the existing pavement. Additional performance life is based on the total thickness of the resulting concrete slab. It is generally accepted that thicker overlays have less potential for delamination and result in lower critical stresses and deflections in the slab system than thinner overlays. Therefore, thicker overlays are expected to provide a longer life extension of the pavement than thinner overlays. However, no information is available on the cost effectiveness or life extension provided by an additional overlay thickness.

To date, use of bonded concrete overlays has been more prevalent in the wet-freeze and wet-no freeze regions. Therefore, controlled field experiments are necessary to determine the influence of other climates on the performance of bonded concrete overlays. This will help establish where and under what conditions bonded concrete overlays are a viable rehabilitation alternative.

## OBJECTIVE

The objective of this experiment is to measure the additional pavement life that results from the use of bonded concrete overlays, evaluate the effectiveness of surface preparation techniques, and investigate the influence of climate on the performance of bonded concrete overlays. The proposed experiment encompasses overlays on jointed plain, jointed reinforced and continuously reinforced concrete pavements. The factors to be addressed in this experiment include surface preparation, use of bonding grout, and overlay thickness. The analysis of the information provided through implementation of this experiment will provide substantially improved tools for evaluating the effectiveness of bonded concrete overlays as a rehabilitation technique for existing concrete pavements.

## PRODUCTS

Some products of this experiment will help accomplish the objectives of the SHRP Long-Term Pavement Performance program as stated in the May 1986 Final Report on the Strategic Highway Research Program Plans. The key products from the proposed study will include:

1. Evaluation of existing design methods.
2. Determination of the effects of specific design features on pavement performance.
3. Development of a comprehensive data base for use by state and provincial engineers and other researchers.

Development of the national data base is the tool to expedite the analyses needed to produce other products. This data base will permit centralized and efficient distribution of massive quantities of data to participating highway authorities, researchers, and other interested parties.

The proposed experimental design is aimed directly at determining the effects of the following specific pavement design and construction features:

1. Overlay thickness.
2. Bonding material.
3. Surface preparation.
4. Type of existing concrete pavement.

The interaction of these factors will be determined in combination with the effect of environmental region. The effects of these factors will be studied under realistic field conditions with significant materials and construction control. This experiment will add significantly to the understanding of long-term performance of bonded portland cement concrete overlays.

## BENEFITS TO PARTICIPATING AGENCIES

This experiment will provide participating agencies with actual data on the cost and performance of bonded concrete overlays under traffic and environmental conditions encountered in their locality. This data is necessary for the accurate assessment of the bonded concrete overlay options in concrete pavement rehabilitation programs and pavement management systems.

While all highway agencies will benefit from the information, knowledge and products that result from this research, participating agencies will accrue additional direct benefits. Since a portion of this research will be conducted in an agency's jurisdiction on test sections constructed using materials and techniques employed by that agency and exposed to local climate and truck loadings, participating agencies will be able to make direct use of the results. Test sections within an agency's jurisdiction will also allow that agency an opportunity to directly relate their pavement monitoring and performance evaluation methods to those employed by SHRP.

Sponsoring agencies have the opportunity to expand the experiment to address some of the local or regional interests and concerns and incorporate innovative technology. For example, agencies interested in evaluating other bonding materials or concrete types could construct additional test sections near the SHRP test sections and directly compare their performance to that of the basic experimental test sections. This approach provides participating agencies the opportunity to conduct intensive pavement field research relatively economically by taking advantage of the research infrastructure established for the SHRP study.

SHRP encourages the construction of supplemental test sections and is prepared to assist interested agencies in the experimental design, data collection, and performance evaluation of such supplemental experiments. Further, if a group of participating agencies desire to join together in such activity, SHRP is also prepared to work with these states and/or provinces to coordinate a multi-state/provincial supplemental experiment. The section of this report, "Ideas for Extension of Experiment by Participating Highway Agencies," identifies potential areas for further study in the experiment.

In addition to these direct benefits, participating agencies will also receive ancillary benefits as a result of direct involvement in this research, including valuable insights and exchange of ideas through interaction with the SHRP team, researchers and personnel from other highway agencies.

## EXPERIMENTAL DESIGN

The recommended experimental design is shown in Table 1. It identifies the primary experimental factors and their relationships with each other. This design incorporates input from a number of highway agencies and interested parties, and is based on the current state of practice for bonded concrete overlays. Table 1 identifies site-related factors across the top and overlay-related parameters down the side. Each column represents one or more project locations each of which incorporates several test sections. Each row represents a series of test sections with specific features to be constructed at each project location.

Table 1. Experimental Design for SPS-7, Bonded Portland Cement Concrete Overlays

| PCC OVERLAY FACTORS WITHIN PROJECTS | | | FACTORS FOR MOISTURE, TEMPERATURE, AND TYPE OF PCC PAVEMENT | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | WET | | | | DRY | | | |
| | | | FREEZE | | NO FREEZE | | FREEZE | | NO FREEZE | |
| | | | TRAFFIC RATE ≅ 200 KESAL/YR | | | | | | | |
| OVERLAY PREPARATION | GROUT (YES/NO) | PCC OVERLAY THICKNESS | JCP | CRCP | JCP | CRCP | JCP | CRCP | JCP | CRCP |
| Cold Milling Plus Sand Blasting | N | 3" | | | | | | | | |
| | | 5" | | | | | | | | |
| | Y | 3" | | | | | | | | |
| | | 5" | | | | | | | | |
| Shot Blasting | N | 3" | | | | | | | | |
| | | 5" | | | | | | | | |
| | Y | 3" | | | | | | | | |
| | | 5" | | | | | | | | |

This experimental design is a coordinated plan intended to produce data and performance information for a variety of concrete overlays constructed with different designs and methods to extend the life of existing jointed or continuously reinforced concrete pavements. The primary factors being studied are surface preparation, bonding material, overlay thickness, and environmental (climatic) factors. Other considerations include type of existing pavement, subgrade soil, and traffic volume and load. In addition, the experiment will include other test sections desired by the highway agency to evaluate local practices or innovative features.

## SITE-RELATED FACTORS

Site-related factors include pavement type (jointed plain, jointed reinforced and continuously reinforced concrete) in the four climatic regions (wet-freeze, wet-no freeze, dry-freeze, and dry-no freeze). These levels of climatic regions and pavement type will result in twelve different study combinations. However, when selecting projects for the study, replicates will be accepted for any pavement type.

### Climatic Factors

The climate factor levels for this experiment are the same as those for the GPS experiments. The wet climatic regions include locations that have a high potential for moisture in the entire pavement structure throughout most of the year, while dry climatic regions include areas that have very little and low seasonal fluctuation of moisture in the pavement structure. The freeze climatic regions include locations with severe winters that result in long-term freezing of the subgrade, while no freeze climatic regions include areas that do not have long-term freezing of the subgrade. However, site specific climatology data will be used to classify candidate projects.

### Existing Pavement Type Factors

The existing pavement types include jointed plain, jointed reinforced, and continuously reinforced concrete pavements. However for experimental design purposes, jointed plain and jointed reinforced concrete pavement are combined and classified as jointed concrete pavements to distinguish them from continuously reinforced concrete pavements. Although joint spacing is expected to influence bonded concrete overlay performance, no specific criteria has been established for acceptable projects. However, details of test sections will be recorded for use in data evaluation and analysis.

Other Site Factors

Other factors that contribute to pavement performance which are not included as study factors will be considered in the test site selection process to keep the experiment within a practical implementable size.

This experiment will allow projects built on fine or coarse grained subgrade, as defined for the GPS experiments, although fine-grained subgrade is generally preferred. Also for this experiment,projects with traffic levels above 200,000 ESAL per year on the outside lane are preferred. Projects with lower traffic levels will be considered, but all test sections in a site should have the same type of subgrade soil and traffic.

The proposed experimental design further constrains other factors as follows:

1. Performance period - Because quantification of the existing pavement condition is not possible for previously overlayed pavements, all test sections are to be located on pavements in their first performance period (i.e. no prior overlay). A section can be considered if a thin overlay or maintenance surface patch has been placed but will be removed prior to the rehabilitation and the current condition of the pavement can be determined. Existing open graded friction courses should be removed by milling if the pavement is to be considered as a candidate project.

2. Pavement age - All projects should have been completed between 1965 and 1980 to avoid excessively young or old pavements and unusual performance.

3. Pavement thickness - All pavements shall be at least 7 inches thick over a minimum of 3 inch stabilized or unstabilized subbase.

4. Project uniformity - All test sections in a project should have the same design details, materials, construction quality and should experience uniform traffic movement.

5. Pavement condition - All projects should be in a reasonably good condition, exhibit no significant deterioration, and considered good candidates for bonded concrete overlays based on current engineering judgment.

## OVERLAY FACTORS

The proposed experimental design includes three sets of two-level overlay design and/or construction factors. These are existing pavement surface preparation, bonding grout, and overlay thickness.

### Surface Preparation

The two surface preparation techniques selected for this experiment, based on the consideration of current practices, are cold milling followed with sand blasting and shot blasting.

### Bonding Grout

Most of the bonded overlays constructed to date have utilized a neat-cement grout or a sand-cement grout. Both grout type are expected to provide similar bond strength levels at the interface of the overlay and existing pavement. However, since use of sand-cement grout is more expensive, neat-cement grout is proposed for this experiment.

Use of a bonding grout adds a construction operation and increases the cost of bonded overlays. However, a few highway agencies indicated that a number of bonded overlays built without use of a bonding grout have performed satisfactorily and that this alternative provides a cost saving without sacrificing performance. Therefore, the omission of the grout layer has been recommended for study as the other level for this factor.

### Overlay Thickness

Two thickness levels of bonded overlay are recommended for this experiment. These are 3 inches and 5 inches. The thin level of 3 inches was selected to represent the minimum practical thickness that would be constructed on main line highways. The high level was selected to span the range of thicknesses typically used for bonded concrete overlays. Use of two thicknesses will allow determination of the improvement in the structural capacity due to overlay thickness and also allow mechanistic evaluation of the overlay performance.

## TEST SECTION SEQUENCE

A suggested test section sequence is shown in Table 2. This sequence is based on keeping test sections with the same overlay thickness and surface preparation technique adjacent to each other thus minimize the number of vertical transitions between sections. This sequence may be varied to accommodate local conditions and construction expediency. However, considerations should be given to minimize the experimental bias associated with the ordering of test sections. For example, all test sections should be placed on as uniform subgrade as possible with little variation between cut and fill. Transitions between adjacent sections and vertical elevation run-offs should be of sufficient length to prevent introduction of significant changes in dynamic loadings on the test sections.

Table 2. Test section numbering scheme.

| Section Number | Surface Preparation | Cement Grout | Overlay Thickness inches |
|---|---|---|---|
| 01 | Control Section | - | - |
| 02 | Milling | Yes | 3 |
| 03 | Milling | No | 3 |
| 04 | Shot Blasting | No | 3 |
| 05 | Shot Blasting | Yes | 3 |
| 06 | Shot Blasting | Yes | 5 |
| 07 | Shot Blasting | No | 5 |
| 08 | Milling | No | 5 |
| 09 | Milling | Yes | 5 |
| 10 | Supplemental | Open | Open |

To maintain uniformity, the test section numbering scheme shown in Table 2 should be used regardless of the order of the test sections.

Where possible, each test section should be 600 feet long to allow 500 feet for monitoring and 50 feet at each end for destructive materials sampling. However, as a minimum, each test section should be 550 feet long. Test sections should be separated by an appropriate transition with adequate length to meet practical construction considerations. Therefore, transition lengths will vary depending on site conditions.

## IDEAS FOR EXTENSION OF EXPERIMENT BY PARTICIPATING HIGHWAY AGENCIES

Agencies participating in this experiment are urged to consider the construction of additional experimental sections to evaluate innovative features of local or regional interest in addition to those required. For example, supplemental sections can be constructed as a part of the test site to evaluate the following materials or features:

* Other bonding grouts.
* Different surface preparation methods.
* High early strength, high strength, or special concrete.
* Curing methods.

## CONSTRUCTION CONSIDERATIONS

Construction techniques and materials should be kept reasonably uniform to minimize influences of variation on performance. Construction guidelines will be developed by SHRP in cooperation with participating agencies to help achieve an adequate level of uniformity.

An important consideration is strength of the concrete used for the overlay. In order to minimize the effect of overlay concrete strength across projects, it is proposed that the concrete mix be designed for a fourteen-day nominal flexural strength (third point loading) of 500 to 700 psi. This proposed range represents the typical strength range for portland cement concrete currently used in pavement applications. High early strength concrete and "fast track" placement methods may be used to expedite overlay construction, provided the strength values are within the proposed limits.

Guidelines will be developed by SHRP to ensure uniform materials and construction at all test sites. These guidelines will address the following considerations:

1. Determination of condition of existing pavement.
2. Specification for bonding grout material and placement.
3. Pre-overlay pavement repair needs and techniques.
4. Concrete placement and curing techniques.
5. Surface preparation methods.
6. Jointing of the concrete overlay on jointed pavements.
7. Special testing needs and procedures.

## PARTICIPATING REQUIREMENTS

Highway agencies considering participating in the SPS-7 experiment must be willing to perform the following activities:

1. Construct all eight test sections described in the experimental design. In addition to these eight test sections, a control test section in which no treatments are applied is needed. All test sections on a project must be constructed during the same construction season. The treatments within the length of the test sections must be applied across all lanes in the direction of travel.

2. Install and operate a traffic data collection station at or near the site to measure the same traffic that passes over the test sections. As a minimum, this station must be operated to obtain continuous automatic vehicle classification and provide for four, one week, sessions of seasonal weigh in motion measurements each

year. However, it is desirable that the station provides continuous weigh in motion.

3. Perform and/or provide for drilling, coring, and sampling and testing of in-place pavement materials and materials used in the overlay. SHRP will provide sampling plans tailored to the site plus directives and standard protocols for laboratory tests. Costs for this work must be borne by the participating agency.

4. Prepare plans, specifications, quantities, and all other documents necessary as a part of the agency's contracting procedures. The agency must also provide construction control, inspection, and management in accordance with their standard quality control and assurance procedures.

5. Provide historical information on pavement inventory features, traffic levels and loads, and maintenance data similar to that required for the GPS test sections.

6. Provide periodic traffic control for on-site data collection activities such as materials drilling and sampling, deflection measurements, and other monitoring activities.

7. Coordinate maintenance activities on the test sections to prevent application of premature treatments which alter the characteristics of the test sections and limit their use in the study. Collect and report all maintenance performed on the test section using the GPS maintenance data collection forms.

8. Perform and report periodic skid resistance measurements in accordance with practices used for GPS test sections.

9. Provide and maintain signing and marking of test sites.

10. Notify SHRP prior to application of overlays or other such treatments when any of the test sections reach an unsafe condition or become candidates for rehabilitation. As much lead time as possible is needed to allow terminal condition of the test sections to be measured.

## SHRP RESPONSIBILITIES

The primary role of SHRP is to provide construction and technical assistance to participating highway agencies to help ensure uniformity and consistency in construction and data collection. Role of SHRP will also include the following activities:

* Development of the experimental design.
* Coordination among participating highway agencies.
* Final acceptance of test sites.
* Development of data collection guidelines and forms.
* Coordination of materials sampling and testing.
* Monitoring of pavement performance.
* Development and operation of a comprehensive nationwide pavement data base and data entry.
* Control of data quality.
* Data analysis and reporting.

## IMPLEMENTATION AND SCHEDULE

The initial step in the implementation of this experiment is the identification and submission by highway agencies of candidate projects for possible inclusion in the study. A total of 12 projects will be required to complete the experiment as planned. Ideally, projects in each of the four climatic regions should encompass the three concrete pavement types. It is anticipated that a few SPS-7 projects will be built during the 1990 construction season. The remaining test sites will be selected from candidate projects scheduled for construction in 1991, or even 1992 if necessary. To assist the highway agencies in identifying candidate projects, guidelines for nominating and evaluating candidate projects for this experiment will be described in detail in a separate report. This report will include nomination forms, identify project selection criteria, and other details.