Bridge Deck Program Development

WA-RD 73.1

Final Report

August 1985

Washington State Department of Transportation
Planning, Research and Public Transportation Division
In Cooperation with
United States Department of Transportation
Federal Highway Administration

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. WA-RD 73.1	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Bridge Deck Program Development	5. Report Date August 1985
	6. Performing Organization Code
7. Author(s) Khossrow Babaei	8. Performing Organization Report No.
9. Performing Organization Name and Address Washington State Transportation Center 135 More Hall, FX-10 University of Washington Seattle, WA 98195	10. Work Unit No
	11. Contract or Grant No. Y-2811 Task 24
12. Sponsoring Agency Name and Address Washington State Department of Transportation Transportation Building Olympia, WA 98504	13. Type of Report and Period Covered Final
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report identified, classifies and addresses WSDOT's needs and questions regarding concrete bridge deck deterioration. Included is a state-of-the-art assessment regarding any major areas of concern to the statewide bridge deck program. Recommendations are made to WSDOT regarding future bridge deck research. A proposed work plan is developed for high priority research items as directed by the WSDOT.

17. Key Words Bridge deck, Concrete, Deterioration, Corrosion, Protection, Rehabilitation, Reconstruction	18. Distribution Statement N/A

19. Security Classif. (of this report) None	20. Security Classif. (of this page) None	21. No. of Pages 382	22. Price

Form DOT F 1700.7 (8-69)

BRIDGE DECK PROGRAM DEVELOPMENT

by

Khossrow Babaei
Research Engineer

Washington State Transportation Center
Civil Engineering
University of Washington
Seattle, Washington

Final Report

Research Project Y-2811

Prepared for

Washington State Transportation Commission
Department of Transportation

and in Cooperation with

U.S. Department of Transportation
Federal Highway Administration

August, 1985

ACKNOWLEDGMENT

This work was sponsored by the Washington State Department of Transportation, in cooperation with the Federal Highway Administration, and was conducted by the Washington State Transportation Center (TRAC) at the University of Washington.

The author wishes to acknowledge the supervision and guidance of Dr. G. Scott Rutherford, Director of the Washington State Transportation Center, in conducting this project.

Special appreciation is expressed to the staff of the Bridge and Structures Branch of the Washington State Department of Transportation for its contribution.

The author also wishes to express his appreciation to Ms. Amy O'Brien, TRAC editor, for editing this report.

DISCLAIMER

The contents of this report reflect the view of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of policies of the Washington State Department of Transportation or the Federal Highway Administration. This report does not constitute a standard specification or regulation.

ORGANIZATION OF THE REPORT

Executive Summary

Volume 1 - "Project Design"

Volume 2 - "State-of-the-Art Assessment"

Volume 3 - "Recommendation on Future Research"

Volume 4 - "Introduction of FY 86-87 Research and Work Plan Development"

Volume 1 of the report discusses the relative importance and appropriateness of the various bridge deck treatment concerns and develops a detailed work plan for the Bridge Deck Program Development Project.

Volume 2 presents a literature survey conducted on the bridge deck concerns presented and prioritized in Volume 1 in order to update Volume 1 and to identify sources of pertinent information on the bridge deck treatments.

Volume 3 makes recommendations on future bridge deck research needs based on the state-of-the-art assessment presented in Volume 2.

Finally, Volume 4 of the study develops proposed work plans for high priority bridge deck treatment concerns, as directed by the WSDOT.

EXECUTIVE SUMMARY

State of Bridge Decks

The deterioration of concrete bridge decks poses a major problem to the Washington State Department of Transportation. There are approximately 3,000 bridges in the state system requiring bridge deck treatment. Only 22 percent of those bridges have been treated. Corrosion of embedded reinforcing steel resulting from winter salt applications and moisture has been identified as the main cause of deterioration. Weathering is another environmental factor causing deterioration in bridge structures. Inadequate design practices and improper construction methods have also contributed to the problem. Direct impact of traffic loads has increased the occurrance of deterioration and contributed to its magnitude. Bridge deck deterioration signifi-cantly affects the ride quality of decks. De-pending on its extent and location, deterioration can also impact the load carrying capacity of bridges, primarily in structures such as T-beam and box girder bridges in which decks serve as the top flanges of girders. Fractures in the concrete, loss of bond between the rebar and concrete, and loss of steel through corrosion all can result in loss of strength in reinforced concrete members.

Generally, concrete bridge decks in Washington can be divided into two classes based on their construction. First, there are those which were constructed according to older regulations and which do not offer sufficient protection against premature deteriora-tion. Second, there are those which were constructed with the new regulations and thus have protection or were constructed with the older regulations but received a protection sometime during their service period. At present the first class has attracted the most attention for rehabilitation and/or protection. WSDOT has stipulated that all of those decks need some kind of protection. However, some need additional rehabilitation depending on their conditions. Presently, treatment of the second class of bridge decks has been mainly limited to removing asphalt-concrete/membrane overlay protective systems which have aged after 10 to 15 years of service, rehabilitating the decks, if required, and installing a proper protective system. However, the majority of Washington's concrete overlay protective system installations are relatively new and no major problems with their performance has been reported. In the future bridge deck treatment may be more concentrated on the second class of decks. Since most of the decks will have received some kind of protection the main concern will be the durability of the protective systems. However, the original decks may still need rehabilitation if protective systems do not function effectively.

Concrete Overlays and Need for More Information

WSDOT has recently applied to its bridge decks many special concrete overlays, namely latex-modified concrete and low-slump dense concrete, and will apply more in the future. Special concrete overlays, if proven satisfactory, will play as major a role in the protection of Washington bridges from premature deterioration in the coming years as asphalt-concrete/membrane overlays did in the 1970s. This trend in bridge deck protection is due to different factors among which are the better durability and higher service life of concrete overlays, especially when sub-jected to high traffic volumes, and concrete overlay's being well suited to the repair of highly deteriorated decks. Additionally, ultrathin polymer concrete overlays and superplasticized concrete overlays have been used on a few Washington bridges experimen-tally in order to be able to evaluate their characteristics for future applications, such as the use of polymer concrete where traffic delays or excessive dead loads are a problem, and superplas-ticized concrete where heavy vibrating equipment is not avail-able. WSDOT is also considering sealers, in conjunction with an overlay, for future applications. Despite the advantages of the special concrete overlays, WSDOT is concerned over their constructibility, sensitivity to hot and cold weather concreting, and quality control, which may affect their performance adversely. In order to manage future concrete overlay installations more efficiently, WSDOT plans to fund a bridge deck research program during FY85-87 which will provide insight into the design, construction and performance of these systems. The research will identify potential problems and proper measures can then be taken to prevent those problems in future constructions.

Necessity to Utilize Half-Cell Testing in Practice

Knowledge of the condition of its bridges is essential for the Department to ensure a satisfactorily performing bridge network. Rebar corrosion in bridge decks is a major element affecting their condition. Currently concrete salt content is monitored routinely to determine if the proper environment for rebar corrosion exists. The shortcoming of this procedure, however, is that concrete salt contamination above the threshold value does not necessarily indicate the existence of corrosion. Such is the case in those contaminated bridge decks in which corrosion was arrested by application of a protective system. In addition, chloride content measurement is a destructive and expensive test procedure yielding an insufficient amount of data for condition evaluation of a bridge deck. The half-cell corrosion detection test is a simple and non-destructive procedure which can be used as a supplement to the chloride content test to obtain massive amounts of data on a bridge deck. The data can be used for continuing bridge deck monitoring or it may apply to bridge deck rehabilitation. The WSDOT bridge deck research program will evaluate the half-cell test method and determine its reliability and limitations in order to develop guidelines to employ the test as a routine bridge deck condition survey technique.

Need for a Bridge Deck Management System

The increasing number of bridge decks in need of rehabilitation and/or protection and limitations in maintenance funds are circumstances which require establishment of a systematic approach for logically evaluating and funding bridge deck treatment. Based on historical data on bridge deck conditions, the systematic approach, or "Bridge Deck Management System," would predict when treatment would be needed at the project level and would propose cost effective alternative strategies for that purpose. At the network level, the system would prioritize bridge deck treatments when funds were not available for all of the decks. The bridge deck management system would be a strong tool with which the Department could develop a cost effective bridge deck network with the highest possible level of performance, considering budget constraints. The WSDOT bridge deck research program plans to develop guidelines for a bridge deck management system using the pavement management system recently developed and implemented by WSDOT as a background.

Traffic Delays Caused by Reconstruction

One problem which concerns the public as well as the Department is traffic delays resulting from bridge closure, especially on highly travelled bridges, as a result of the protection, reconstruction or replacement of existing bridge decks. Different operations are involved in bridge deck treatment and each could prolong the construction period. Newly developed construction techniques and materials having the potential to accelerate bridge deck treatment are being introduced to the market. However, their effectiveness needs to be explored before employing them for large scale construction. This includes the effectiveness of different substrate preparation procedures, concrete removal techniques, and accelerated curing methods, as well as fast curing materials. Evaluation of construction alternatives to rehabilitate and protect bridge decks more rapidly is included in the WSDOT bridge deck research program. The research program will determine the effectiveness of different rapid construction techniques and will establish quality assurance standards and acceptance criteria for the most promising techniques.

Microwave Heating for AC/Membrane Placement and Removal

Current procedures using planers to remove aged and deteriorated asphalt overlays from decks result in damage to the concrete substrate and the reinforcing steel in the absence of sufficient concrete cover. New lifts of AC/membrane systems cannot be applied on damaged substrates. In addition, membranes do not stay intact in the process of asphalt concrete removal and are removed as well, regardless of their condition. Microwave heating was originally developed to patch or recycle asphalt concrete pavements. The technology, however, may be used on bridge decks to install new lifts for an AC/membrane system, repair it when cracked, and recycle it when deteriorated without interferring with the concrete substrate. The potential application of microwave heating on bridge decks will be evaluated in the course of the WSDOT bridge deck research. The evaluation will include the advantages of using the technology as well as the potential hazards that microwave heating may have on the properties of reinforced and prestressed concrete.

Need for Further Research

The WSDOT bridge deck research program planned for FY 86-87 will answer questions regarding some of the solutions to bridge deck problems. However, comprehensive and cost-effective management of WSDOT's bridge decks requires further research to make all possible solutions readily available to the Department. Among the areas in which further study is needed are the following.

Cathodic protection could be used to halt the continuing corrosion of contaminated bridge decks. The performance of the system, however, needs to be clearly determined and criteria for its application must be established to fit individual deck conditions.

Greatly needed is the development of thermographic survey or other methods, such as radar, which may have the potential to detect bridge deck deterioration in asphalt covered decks. The ability to determine the conditions of the great number of asphalt covered decks presently in service would allow WSDOT to establish repair priorities and predict future funding needs far in advance of the problem.

Research in the area of tendon protection in prestressed concrete members to prevent stress-corrosion failure is needed. Plastic ducts and epoxy coating could be eva-luated as potential protective systems for this purpose.

The effects of traffic induced vibrations and deflections on the quality of freshly placed concrete should be further evaluated in view of the new high slump concrete mixes recently incorporated into bridge deck repairs.

The influence of concrete removal operations involved in bridge deck repairs on the integrity of different types of bridge superstructures subject to passing traffic during repair periods is worthy of evaluation.

The influence on deck deterioration from native chlorides present in concrete mix components is also worthy of evaluation. The contribution of the native chlorides to rebar corrosion, if any, should be clearly defined.

VOLUME ONE

Project Design
(Task One)
of

Bridge deck Program Development

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 - INTRODUCTION

Premature deterioration of concrete bridge decks poses a major problem to the Washington State Department of Transportation (WSDOT). There are approximately 3,000 bridges in the state system requiring bridge deck treatment. Only 22 percent of those bridges have been treated. The Department needs to synthesize, update, and evaluate information on bridge deck condition survey, rehabilitation, and protection in order to verify performance and improve future protection.

Recently, two bridge deck research projects have been completed through the Washington State Transportation Center (TRAC) for the WSDOT and, accordingly, two reports have been issued (1, 2). In TRAC's September 1982 report entitled "Deterioration of Concrete Bridge Decks and Review of the WSDOT Bridge Deck Program" (1), research efforts concerning the causes of concrete bridge deck deterioration and methods of field appraisal, as well as bridge deck protective systems were reviewed using the available literature and, accordingly, the WSDOT program was reviewed and discussed. TRAC's August 1983 report on "Performance Evaluation of Waterproofing Membrane Protective Systems for Concrete Bridge Decks" (2) was mainly experiment design, field testing, and data analysis regarding the selected test sites protected by membrane systems. Included in this study was also a literature survey related specifically to evaluation of the effectiveness of the membrane systems.

Generally, the goal of the "Bridge Deck Program Development" project is to determine how several bridge deck protection concerns relating to the problem of deteriorating decks should be defined, assessed, and prioritized so that various bridge deck protection treaments may be improved. The purpose of The Project Design Phase (i.e.,Phase I of study) is to determine relative importance and appropriateness of the various bridge deck treatment concerns and to develop a detailed work plan for the Bridge Deck Progam Development Project which will include the most approriate bridge deck concerns as the elements of the overall study. In Phase II of the study, a literature survey will be conducted on the bridge deck concerns presented and prioritized in the Project Design Phase and approved by the WSDOT in order to update that completed previously by TRAC and to identify sources of pertinent information on the bridge deck treatments. Based on the state-of-the-art assessment developed in Phase II, recommendations on future bridge deck research needs will be made to the WSDOT in Phase III of the project. Finally, in Phase IV of the study, work plans will be developed for high priority bridge deck treatment concerns, as directed by the WSDOT for future research projects.

2 - CLASSIFICATION OF BRIDGE DECK TREATMENT CONCERNS

In general, concrete bridge deck treatment concerns could be classified into five major categories as indicated below and in Figure 1.

- I - Causes of bridge deck deterioration
- II - Bridge deck condition survey techniques
- III - Bridge deck repair and restoration procedures
- IV - Bridge deck protection systems
- V - Bridge deck management system

In the following sections each category will be analyzed and the major factors and elements associated with each category will be identified and evaluated so that they can be prioritized.

2.1 - Causes of Bridge Deck Deterioration

This category includes the causes of both deterioration of concrete (namely, delamination, spalling, and scaling) and corrosion of reinforcing steel. Within this category, two major groups can be identified as "Design and Construction Factors" and "Field Factors". These two groups may also be divided into several elements as shown below and in Figure 2.

- A - Design and construction factors
  - 1 - Small rebar depth
  - 2 - High water/cement ratio
  - 3 - Inadequate concrete consolidation
  - 4 - Lack of air entrainment

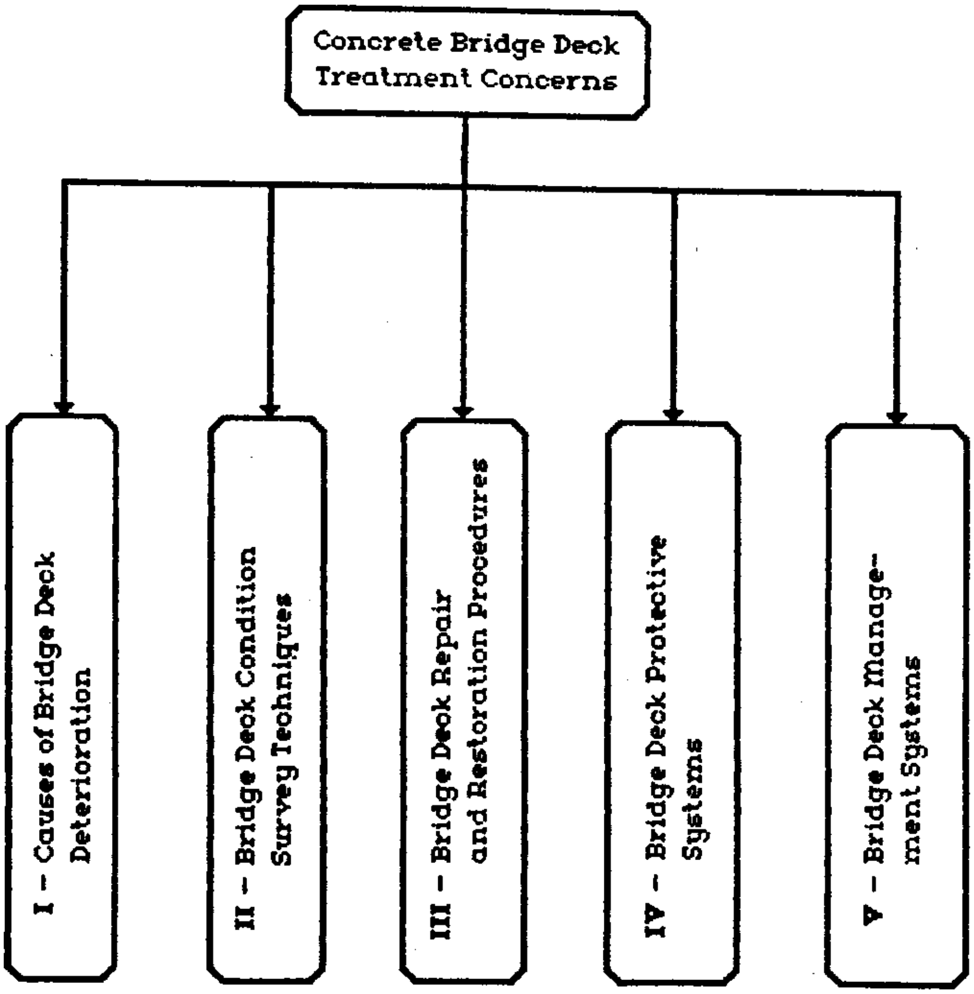


Figure 1. Major Categories of Concrete Bridge Deck Treatment Concerns.

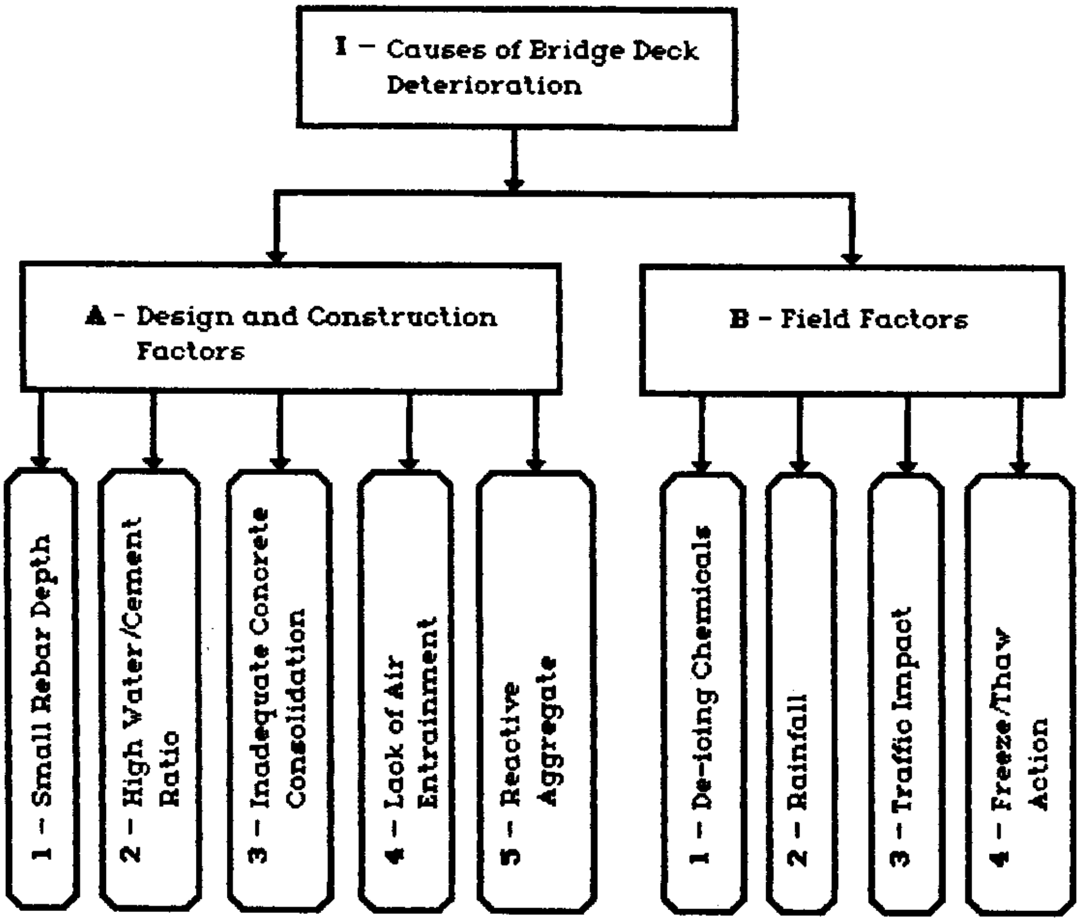


Figure 2. Major Factors and Elements Associated with Causes of Bridge Deck Deterioration.

    - 5 - Reactive aggregate
- B - Field factors
    - 1 - De-icing chemicals
    - 2 - Rain fall
    - 3 - Traffic impact
    - 4 - Freeze/thaw action

2.1.1 - Design and Construction Factors

Research in the past has clearly revealed the importance of large concrete cover over rebar, small water/cement ratio, and high density concrete in preventing corrosion of steel and spalling of concrete. The importance of these factors has been studied in TRAC's previous research efforts for WSDOT (1, 2). Lack of air entrainment in a concrete which is subject to freeze-thaw action could result in scaling and loosening of surface aggregate (3, 12). Scaling is specially severe in the presence of de-icers (12). Today use of entrained air in concrete is recommended for different purposes. Concrete for bridges contain air-entraining admixtures which can markedly reduce the scaling and improve the workability of fresh concrete as well (13, 12). Linseed oil treatment and low water/cement ratio have also been reported (12) effective in reducing scaling of concrete decks. On the other hand, little is known about the effects of different types of Washington state aggregate used in concrete bridges and their contribution to the concrete deterioration. Some aggregates do not possess chemical stability and can react with cement. This reaction, known as alkali-aggregate reaction, may cause expansion and result in a pattern cracking of concrete (13). It has been reported (4) that when using reactive aggregate in concrete the use of low-alkali cement and a smaller size of coarse aggregate could help prevent the pattern cracking.

From this discussion, it is believed that among the "Design and Construction Factors" reactive aggregate is a subject worthy of evaluation. The problem could be associated with the use of some local aggregate. A relevant state-of-the-art assessment could better identify the problem and also provide information for identifying potentially reactive aggregates. Additionally, it could seek solutions to the problem when avoiding their use is not feasible.

2.1.2 - Field Factors

The effects of de-icing chemicals in conjunction with moisture on corrosion of reinforcing steel and subsequent spalling of concrete has long been identified. The nature of the problem and the role of contributing factors has been discussed in two of TRAC's research projects for WSDOT (1, 2) previously. It has also been recognized that traffic impact can hasten the process of bridge deck concrete deterioration. Freeze-thaw action is the fourth field factor causing concrete deterioration as indicated earlier. Scaling of surface concrete in bridge decks has been attributed to freeze-thaw action (3,12). Freeze-thaw has also been reported as a contributing factor to the spalling of concrete decks (12). Some research efforts have even concentrated on the effects of freeze-thaw on durability of stressed concrete members (5). At this time an evaluation of the freeze-thaw action and the problems associated with it is suggested. This could develop new insight into the role of materials, construction procedures, and cyclic stress in contributing to the concrete bridge deck deterioration subject to freeze-thaw action.

2.2 - Bridge Deck Condition Survey Techniques

Under the "Bridge Deck Condition Survey Techniques" category the following concerns can be identified (see also Figure 3).

A - Chloride content measurement
    1 - Wet chemical analysis
B - Chloride permeability test
    1 - Rapid chloride permeability test
C - Rebar depth measurement
    1 - Pachometer survey
D - Delamination detection
    1 - Chain dragging
    2 - Sonic survey
    3 - Radar
    4 - Thermography

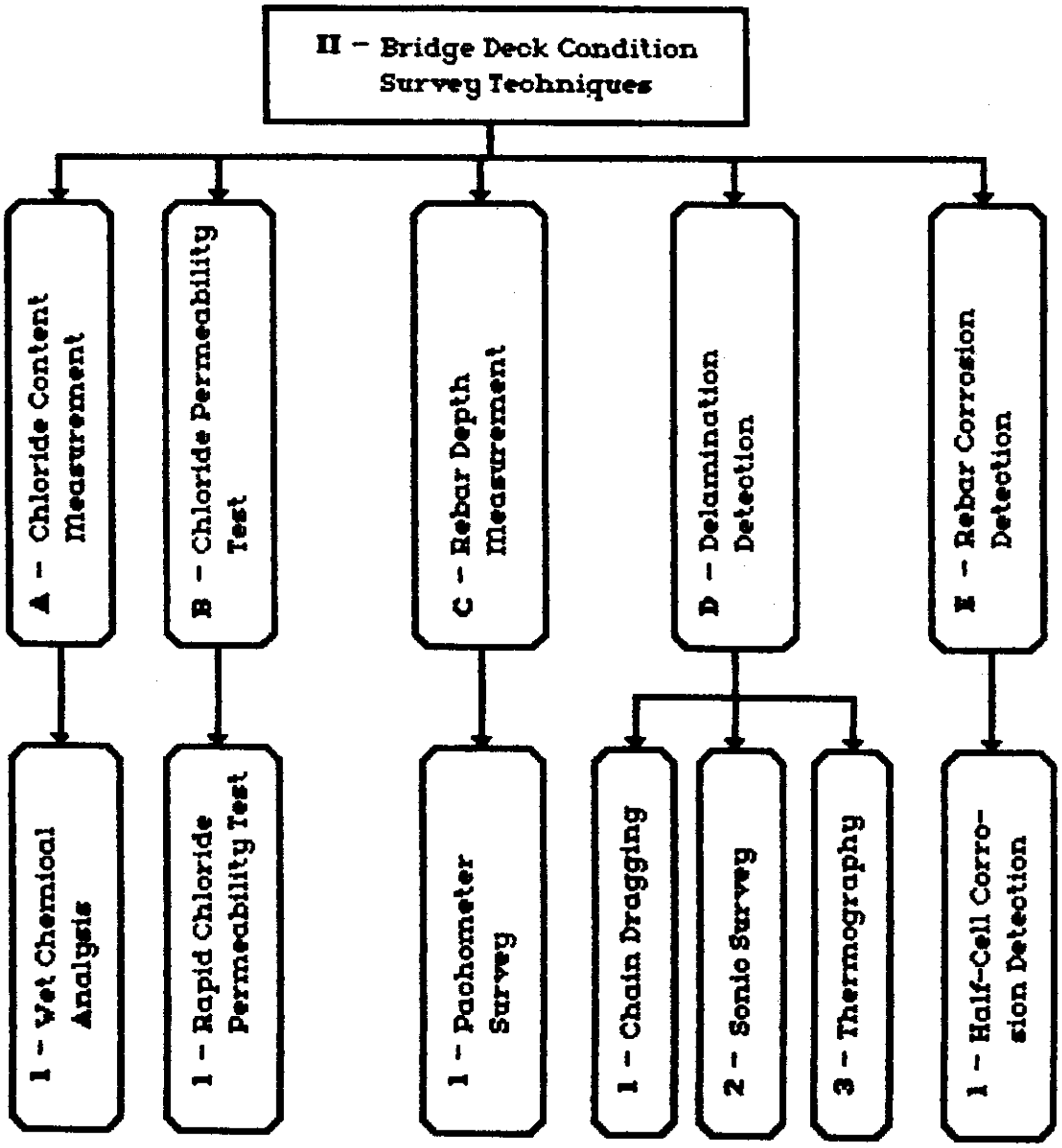


Figure 3. Bridge Deck Condition Survey Techniques

E - Rebar corrosion detection

1 - Half-cell corrosion detection

The above concerns have been the subject of previous TRAC-WSDOT research projects (1, 2). Among the bridge deck condition survey concerns, wet chemical analysis, chain dragging, and pachometer survey have been employed by WSDOT for routine bridge deck condition surveys as well as research projects. These field appraisal methods have proved to be reliable and efficient. Rapid chloride permeability testing has also been used satisfactorily by WSDOT in judging the chloride permeability of different materials and products. Recently, the results from the TRAC-WSDOT waterproofing membrane study (2) indicated that, although very efficient on bare concrete decks, chain dragging is not totally successful in defining concrete delaminations when used on an asphalt covered deck. It has been reported (6) that Sonic Survey of delamination detection of asphalt covered decks would have the same accuracy as chain dragging. Work in Canada (6) has showed that radar and thermography have the greatest potential to be developed for this purpose. Application of radar on bridge decks needs further development of equipment and experience to interpret the results (6). Thermography has been included in WSDOT research activities to a certain degree in the past. It is believed that, in addition to its accuracy on asphalt covered decks, it is better suited to the assessment of large number of decks when a time factor is involved. Bringing present day equipment to the full potential of the theory could make the delamination detection more economical than chain dragging in the future. Considering the great number of asphalt covered decks presently in service, an evaluation of the thermography delamination detection is suggested as part of the state-of-the-art assessment.

Half-cell corrosion detection has been employed by WSDOT on different research projects including the TRAC-WSDOT research project regarding evaluation of the waterproofing membranes (2). The results of the latter work showed correlation between high half-cell readings and concrete deterioration. The results of a previous WSDOT bridge deck deterioration survey (7) have also indicated that local areas on many bridges show good correlation between high half-cell values, high chloride concentrations, and delaminations. However, the results of half-cell survey have not always been consistent in the past. Beside being the only simple corrosion detection tool at the present, half-cell corrosion detection seems to have the most potential for adaptation as a standard test to verify corrosion existance in reinforced concrete. It is suggested that its effectiveness and reliability should be further evaluated in order to improve the procedure for its use as a routine evaluation tool.

2.3 - Bridge Deck Repair and Restoration Procedures

This category deals with the procedures and problems associated with bridge deck repair and restoration. The following major subjects may be outlined under this category (see also Figure 4).

- A - Deteriorating concrete removal
- B - Deteriorating AC removal over sound concrete
- C - Deck patching
  - 1 - Patching followed by a concrete overlay
  - 2 - Patching followed by an AC/membrane overlay or with no overlay
    - a - Use of fast setting mixes
- D - Traffic control's impact on the quality of repair

Generally, repair procedures, when followed by a concrete overlay protective system, require scarifying the concrete surface to a small depth in addition to removing the deteriorated concrete. Concrete surface disturbance is not desirable when an AC/membrane system is applied. However, the current procedures for removing a deteriorating AC/membrane system results in damage to the underlying concrete. The present WSDOT protective system selection criteria for bridge decks (10) (for details see appendix A) prevents using AC/membrane system if it requires removal of an existing AC/membrane system until a satisfactory removal procedure is developed. Further evaluation of the problem may

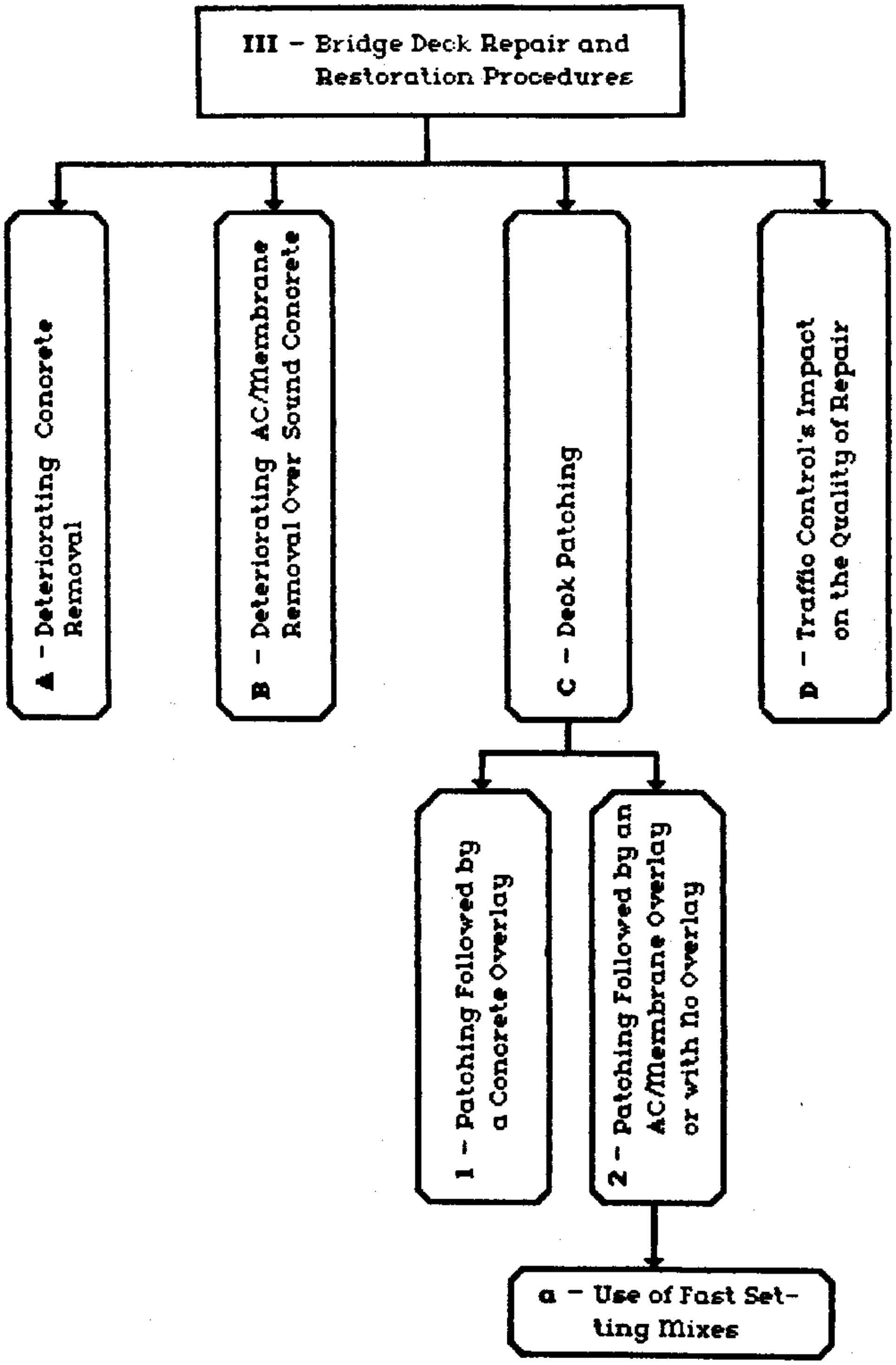


Figure 4. Bridge Deck Repair and Restoration Procedure Concerns.

result in a better method for removal of AC/membrane systems or in modifications to the AC/membrane systems in order to make them compatible with the disturbed concrete substrates.

When using concrete overlays as protective systems a separate patching and concrete placement is not needed since the overlay will fill in areas of concrete removal. However, separate patching in concrete removal areas is needed for temporary repair work or prior to application of AC/membrane systems. Fast setting concrete mixes have normally been used in the latter instances in order to expedite the construction process and minimize disruption to traffic. There are, however, some concerns over compatibility of such products with the underlying conventional concrete. A review of the factors influencing the behavior of fast setting mixes could result in better understanding of these products as well as problems associated with their use.

Finally, in this category traffic control's impacts on the quality of deck repairs is worthy of evaluation. This subject concerns the potential damage to the concrete overlays and patches in their plastic stage of construction. The potential damage is attributed to the traffic induced vibration while traffic is maintained on a bridge during the repair time (11).

2.4 - Bridge Deck Protective Systems

Bridge deck protective systems are divided into two major groups. The first group applies only to the new bridges and the second one applies to both new and existing bridges. Each group in turn is divided into different bridge deck protective methods as shown below and in Figure 5.

A - New bridges only
    1 - Rebar protection
        a - Epoxy coating
        b - galvanizing
    2 - Prestressing steel protection
        a - Plastic ducts
        b - Epoxy coating
    3 - Better concrete
    4 - Double protection
B - New and existing bridges
    1 - Concrete overlays
        a - Latex modified concrete
        b - Low-slump concrete
        c - Superplasticized concrete
    2 - AC overlay and membrane
    3 - Ultrathin overlays
    4 - Cathodic protection

2.4.1 - New Bridges Only

Epoxy coated rebars are normally used by WSDOT for protec-

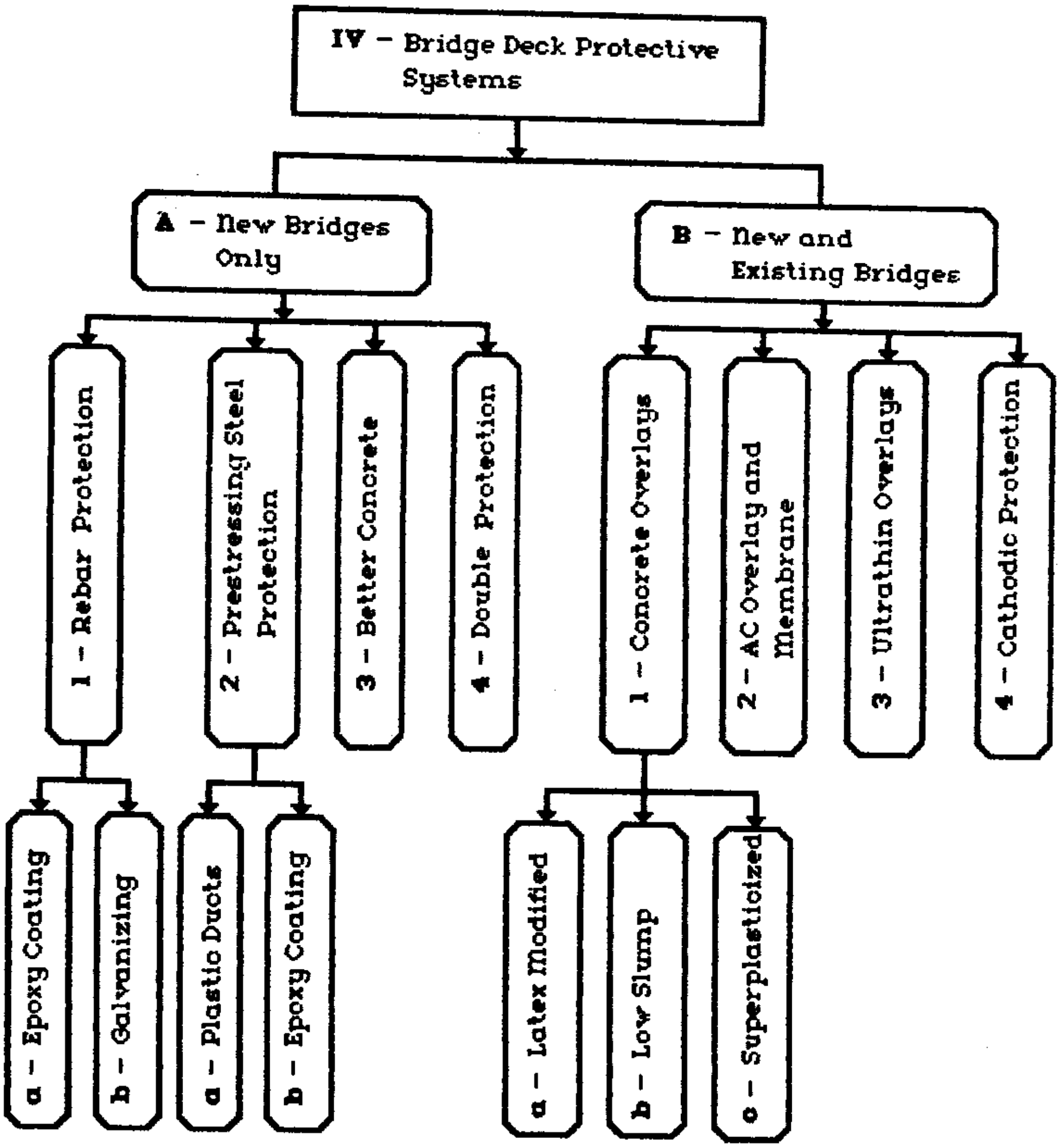


Figure 5. Methods of Bridge Deck Protection

tion of new bridges. Galvanized rebars are not included in the WSDOT's protective systems for bridge decks. Where deck deterioration could compromise structural safety and repairs would be costly due to either the complexity of the repair or traffic volumes, WSDOT specifies double protection (14). This means epoxy coated rebar in combination with a low permeability concrete overlay. Although for protection of post-tensioned tendons, WSDOT has employed galvanized ducts, the use of plastic ducts is recommended by FHWA (8) and considered by WSDOT. There has also been interest within the Department over the use of epoxy coated prestressing steel, especially for protection of pre-tensioned tendons (9), if investigations warrant its application.

Among the above protective systems, only epoxy coated rebar was included in the TRAC research effort for WSDOT (1) previously. It is believed that a literature survey should be conducted to update that completed previously and provide information about those systems in this group which were not included in the past studies.

2.4.2 - New and Existing Bridges

Among the protective systems in this group, latex modified concrete has been approved by the WSDOT's recently issued bridge deck overlay policy for protection of concrete bridge decks, provided the WSDOT criteria (10) (for details see appendix A) are met when using this system. On the other hand, application of AC/membrane systems on Washington State bridges has been restricted only to those decks meeting the WSDOT's policy in this regard. This policy takes factors such as extent of concrete deterioration and contamination, rebar depth, traffic volume, and compatibility of concrete surface with membrane systems under consideration (10). WSDOT's complete protective system selection criteria is presented in appendix A. WSDOT is further evaluating the effectiveness of its protective system selection criteria for concrete bridge decks. Due to some concerns regarding the performance of low-slump dense concrete overlays, the Department will continue to investigate the material to determine whether it should be included in future construction projects (10). The effectiveness of cathodic protection is currently being investigated by WSDOT through an experimental application. Although the characteristics of the before-mentioned protective systems have been evaluated by TRAC for WSDOT in the past, recently there have been rapid changes in the applications and performance of these systems. Superplasticized concrete and ultrathin polymer mortar overlays have not been included in previous TRAC research efforts. The latter systems have been used by WSDOT on a few bridge decks experimentally and the Department needs to evaluate their characteristics for future applications such as the use of ultrathin overlays where weight is a problem and superplasticized concrete where heavy vibrating equipments are not available.

Due to the rapid developments and changes in the bridge deck protection state-of-the-art, further evaluation of all of the protective systems in this group through literature survey is recommended. This could identify application to the WSDOT's recent bridge deck overlay policy and provide information on the systems currently under investigation as well.

2.5 - Bridge Deck Management System

Bridge Deck Management System (BDMS), patterned after the pavement management system already developed by WSDOT, is a methodology which would systematically predict and prioritize rehabilitation and/or protection of the bridge decks at the network level. BDMS would determine the time of rehabilitation and/or protection for a particular bridge deck by evaluating its present condition, predicting its future condition, and comparing it with an established bridge deck quality acceptability level. Thus two necessary aspects of BDMS would be 1) determination of a bridge deck quality index which would use parameters such as structural safety, concrete contamination and deterioration, and steel corrosion under consideration, and 2) the feedback on how well both new and rehabilitated bridges were performing. At the network level BDMS would prioritize rehabilitation and/or protection for those bridge decks whose quality fell below the acceptable level, based on several factors including the rehabilitation and/or protection costs.

As part of the current study, work on development of guidelines to generate BDMS is suggested, since the completed system would be a strong tool for the Department to use in making decisions about expenditure of available maintenance funds.

3 - Relative Importance of the Bridge Deck Treatment Concerns

The relative importance and appropriateness of various bridge deck treatment concerns discussed in the previous sections are given in Table 1. The first priority is given to the bridge deck protective systems, since selecting these systems is the most crucial step in dealing with the deterioration of bridge decks. Next, considerations are given to the bridge deck repair procedures because their effectiveness directly influences the performance of the bridge deck protective systems. Third in importance are the bridge deck condition survey techniques. These progressive techniques could be a supplement to those presently used by WSDOT, thus expediting the deck condition survey process and in some instances providing more accurate information than the conventional methods used routinely presently. The importance of the causes of deterioration is ranked fourth since a knowledge of these subjects could result in better designs for durability of only new bridges. Furthermore, the two items in this category have relatively been studied previously. The bridge deck management system is ranked last in Table 1 since a knowledge of the other bridge deck treatment concerns would be an important and necessary aspect of this system before it can be practiced successfully. The elements of each category in Table 1 are in turn ranked based on their relative importance within their own category. It is recognized,

Table 1. Prioritizing Bridge Deck Treatment Concerns

1 - Protective Systems	1 - Latex Modified Concrete 2 - AC/Membrane Systems 3 - Low Slump Concrete 4 - Cathodic Protection 5 - Epoxy Coated Rebars 6 - Conditions for Double Protection 7 - Plastic Ducts for Prestressing Steel 8 - Ultrathin Overlays 9 - Superplasticized Concrete 10 - Galvanized Rebar 11 - Epoxy Coated Prestressing Steel 12 - Better Concrete for New Bridges
2 - Repair Procedures	1 - AC/Membrane Removal 2 - Fast Setting Mixes 3 - Traffic Control's Impact on the Quality of Repair
3 - Condition Survey Techniques	1 - Half-Cell Corrosion Detection 2 - Thermography
4 - Causes of Deterioration	1 - Reactive Aggregate 2 - Freeze/Thaw Action
5 - Bridge Deck Management System	1 - Bridge Deck Management System

however, that the priorities established in here are relative and the elements of the categories may overlap depending on the Department's present needs for more information. Based on the state-of-the-art assessment and after updating the knowledge about the bridge deck treatment concerns discussed, development work in each area will be further prioritized considering mainly WSDOT's needs for more information at the present time.

4 - Work Plan Development for the Study

Included in the project design (Task I) is development of a detailed work plan for the study. The prepared time schedule for the overall project is shown in Figure 6.

4.1 - Task II, State-of-the-Art Assessment

For the second task of the study, a literature survey will be conducted on the bridge deck concerns presented and prioritized in the project design (see Table 1) and approved by WSDOT. This will be done to update and complete the previous research and identify sources of pertinent information on the bridge deck treatments. The state-of-the-art assessment phase will start upon completion of the project design phase. An interim report will be submitted to WSDOT at the conclusion of Task II which will include the project design and summarize the information obtained during the second task.

4.2 - Task III, Recommendation on Future Research

Based on the state-of-the-art assessment to be developed in the second phase of the study and its findings, recommendations on future research needs will be made to the WSDOT by identifying specific projects as part of the statewide bridge deck program. Selection of any project for future research will primarily be based on WSDOT's needs and the potential benefits that the

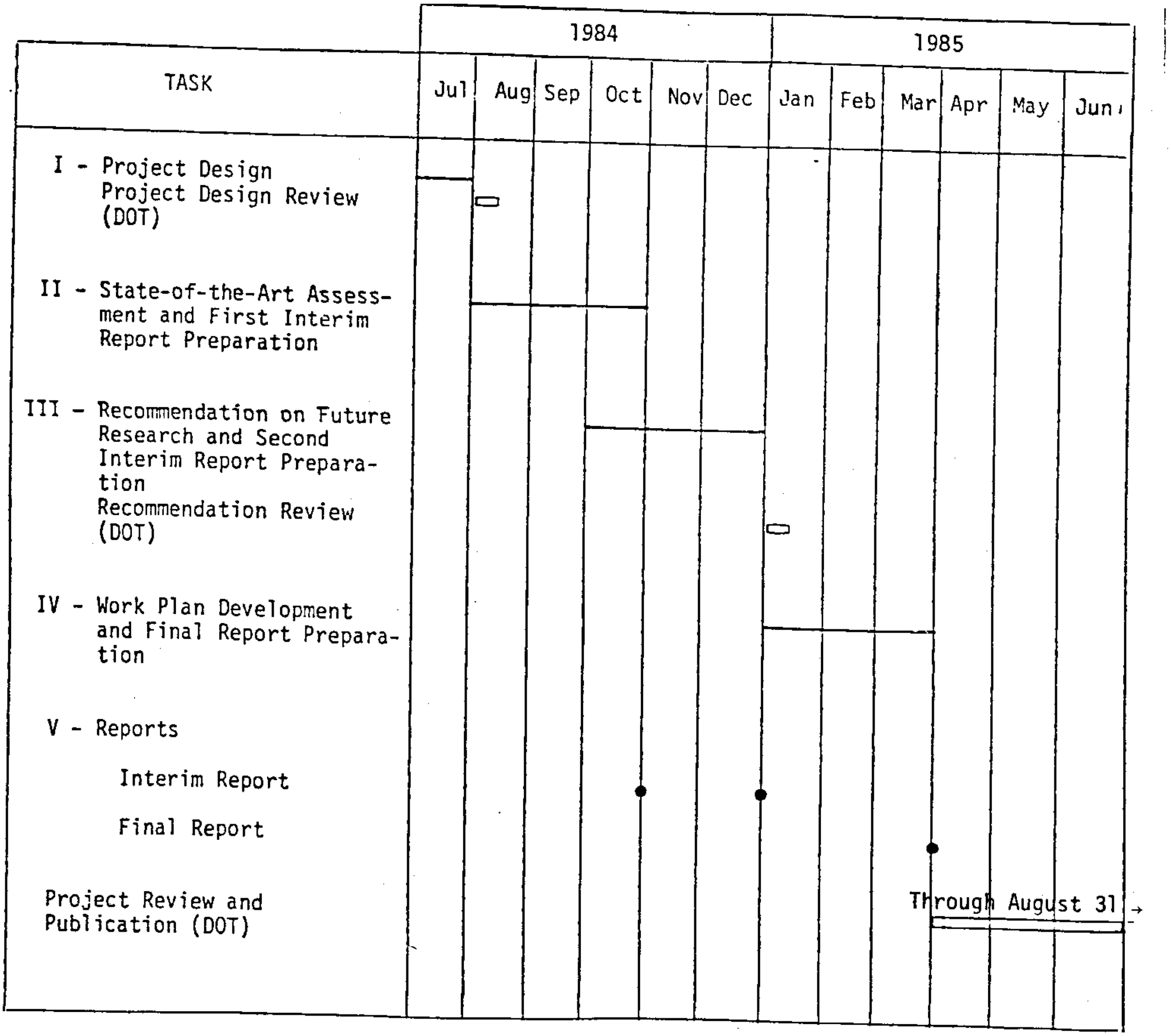


Figure 6. Bridge Deck Program Development Study's Time Schedule

Department could gain by conducting the research. In general, among the areas in which future study would be needed are:

- Evaluation of present systems and methods for bridge deck bridge deck appraisal, rehabilitation, and protection
- Refinement and/or development of new systems and methods for bridge deck appraisal, rehabilitation, and protection
- Fundamental studies
- Development of a systematic approach for bridge deck rehabilitation and/or protection

The second interim report will be submitted to WSDOT at the conclusion of Task III. This report will identify and recommend future research needs and explain the reasons for their selection.

4.3 - Task IV, Work Plan Development for Future Research

Finally, in the fourth task of the study, work plans will be developed for high priority items, as directed by the WSDOT for future research projects. The work plans will provide an overview of how specific research projects will be accomplished as well as the facilities needed for their completion. At the end of this task the final report will be issued which will summarize all work done for the study including project design, state-of-the-art assessment, identification of future research needs, and work plans for selected future research projects.

REFERENCES

1. Babaei, K. and R.L. Terrel, "Deterioration of Concrete Bridge Decks and Review of WSDOT Bridge Deck Program," Washington State Transportation Center, A Report Prepared for Washington State Department of Transportation, (1982).
2. Babaei, K. and R.L. Terrel, "Performance Evaluation of Water-Proofing Membrane Protective Systems for Concrete Bridge Decks," Washington State Transportation Center, A Report Prepared for Washington State Department of Transportation, (1983).
3. "Durability of Concrete Bridge Decks," NCHRP Synthesis 57, (1979).
4. "Cement-Aggregate Reaction," TRB, No. 525, (1974).
5. Callahan, J.P., C.P. Siess and C.E. Kesler, "Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks," NCHRP Report 101, (1970).
6. Manning, D.G. and F.B. Holt, "Detecting Deterioration in Asphalt Covered Bridge Decks," a Paper for Presentation at the Annual Meeting of the TRB, Research Development Branch, Ontario Ministry of Transportation and Communication, (1983).
7. Demich, G.F., "Investigation of Bridge Deck Deterioration Caused by De-Icing Chemicals," Washington State Highway Department Research Program, Report No. 20.1 (1975).

8. FHWA, Region 10 Position Paper on Concrete Bridge Decks, (1981).

9. Moore, D.G., D.T. Klodt and R.S. Hensen, "Protection of Steel in Prestressed Concrete Bridges," NCHRP Report No. 90, (1970).

10. WSDOT Protective System Selection Criteria for Concrete Bridge Decks, April 19, 1984.

11. Manning, G.D., "Effects of Traffic-Induced Vibration on Bridge-Deck Repairs", NCHRP Report 86 (1981).

12. "Concrete Bridge Deck Durability", NCHRP Report 4 (1970).

13. "Design and Control of Concrete Mixtures", Portland Cement Association, Engineering Bulletin (1968).

14. "Bridge Deck Program", Washington State Department of Transportation (1982).

APPENDIX A

WSDOT Protective System Selection Criteria for Concrete Bridge Decks

Washington State
Department of Transportation

INTRA-DEPARTMENTAL COMMUNICATION

DATE: April 19, 1984

FROM: A. D. Andreas

PHONE:

SUBJECT: Protective System Selection Criteria for Concrete Bridge Decks

TO:

R. E. Bockstruck
R. C. Cook
J. D. Zirkle
E. W. Ferguson
R. C. Schuster
W. R. Horning

The Department has developed the following criteria to be used in selecting concrete bridge deck protective systems. These criteria are to be used in developing the six-year program and implementing the current program. Bridges with special problems or unique conditions will be handled as exceptions.

Two systems are currently approved: Latex modified concrete and asphalt concrete with membrane. Latex modified concrete is the preferred system because it provides long-term protection and in most cases it improves the load carrying capacity of the bridge. Conversely, asphalt concrete is a nonstructural component and tends to reduce the load-carrying capacity of the bridge.

These criteria have been developed primarily through the coordinated efforts of the Project Development and Construction Offices. Individuals within the Districts have also provided input. Information has been utilized as best possible to conform to the state-of-the-art for bridge deck overlays. These criteria seem to compare reasonably well with the practices of other states contacted.

A. Latex Modified Concrete

A latex modified concrete system will be used when one or more of the following criteria are met:

1. Delaminated and patched areas of the concrete deck exceed five (5) percent of the deck area.
2. Reinforcing steel is exposed due to wear or insufficient cover.
3. A pachometer survey shows concrete cover of less than one (1) inch over 10 percent or more of deck area (future survey) and the deck has chloride contamination at the rebar level in excess of two pounds per cubic yard for ten percent or more of the samples tested.
4. ADT equals or exceeds 10,000 or the traffic index equals or exceeds 7.5.
5. The structure is on an Interstate route.
6. Chloride contamination at the rebar level exceeds two pounds per cubic yard for 40 percent or more of the samples tested.

7. When removal of an asphalt and membrane system is required.

   (This requirement will remain in effect until such time as a removal procedure is developed which will not result in damage to the underlying concrete.)

8. Concrete in the deck exhibits inferior durability based on visual observation.

B. Asphalt Concrete with Membrane

An asphalt concrete with membrane system <u>may</u> be used when <u>all</u> of the following criteria are met:

1. Delaminated and patched areas of the deck are less than five (5) percent of the deck area.
2. Concrete cover exceeds one (1) inch over 90 percent or more of deck area (future survey).
3. ADT is less than 10,000 and the traffic index is less than 7.5.
4. Chloride contamination at the rebar level is less than two pounds per cubic yard or exceeds two pounds per cubic yard for less than 40 percent of the samples tested.
5. Deck surface must be compatible with the membrane system. A rough or pocked surface will result in damage to or early failure of the protective membrane.

Deck Replacement

In some cases, deck deterioriation will have advanced beyond the point of cost effective rehabilitation and/or protection. Excessive delamination, high chloride content, reactive aggregate and freeze thaw have been the predominant factors contributing to deck deterioration. When deck replacement or bridge replacement becomes necessary, the Bridge and Structures Branch will coordinate with the Districts to develop a replacement schedule and PS&E.

Other

Some structures, such as movable spans, cannot tolerate the added weight of the concrete or asphalt systems. Thin overlay materials are being tested and evaluted for use in these special cases.

Cathodic Protection

An experimental cathodic protection system is being investigated, through a demonstration project, for its practicability and effectiveness. If successful, its potential value lies in saving those decks which are too actively corroding to be preserved with an overlay.

A deck protective system will generally not be required on timber bridges, bridges containing timber structural components, pedestrian structures and bridges with a life expectancy of 10 years or less.

Although latex modified concrete has been specified for the concrete overlay, this does not mean the Department intends to discontinue the use of low slump concrete. Some concerns have arisen this past year over the performance of low slump concrete. It is planned to continue to investigate this material, use it on specific projects, and determine whether it should be included in those projects that will be prepared for the 1985 construction season.

I would appreciate any comments you may find appropriate.

ADA/TH4/211
RHK

cc: C. L. Slemmer
T. L. McLain
T. G. Gray
C. S. Gloyd

VOLUME TWO

State-of-the-Art Assessment
(Task Two)
of

Bridge Deck Program Development

TABLE OF CONTENTS

LIST OF TABLES

1 - INTRODUCTION

This phase of the bridge deck program is directed toward obtaining information developed from previous research relative to the bridge deck concerns presented and prioritized in the first phase of the program, "Project Design". This is done to update and complete the previous work (1, 2) and to identify sources of pertinent information on the bridge deck concerns. The relevant research efforts have been reviewed using available literature. The review is presented in the form of a state-of-the-art report with pertinent references inserted when needed to indicate information source. This state-of-the-art report is prepared specifically for the bridge and materials engineer. Accordingly, the procedures to prevent the corrosion of reinforcing steel and deterioration of concrete in existing and new concrete bridge decks are discussed. This is followed by a review of bridge deck repair and restoration concerns. Next, the discussion is about methods for evaluating the condition of bridge decks. Finally, some consideration of concrete deterioration as well as bridge deck management systems are presented.

2 - SUMMARY OF FINDINGS

In the following, the results of the review of the published literature and other information obtained concerning bridge deck maintenance and repair are briefly summarized. More details regarding each topic as well as the source of the information can be found in the corresponding sections in the main body of this state-of-the-art report.

CONCRETE BRIDGE DECK PROTECTIVE SYSTEMS FOR NEW AND EXISTING BRIDGE DECKS

Latex-Modified Concrete

Latex-modified concrete overlays, in general, have shown satisfactory performance regardless of the existence of some cracking. The bond has been satisfactory, especially with thicker overlays, and virtually no surface scaling has been observed. Although not completely impermeable, the overlays have been able to substantially reduce chloride intrusion in the interface. Delaminations and spalling associated with the latex-modified overlaid decks have been much lower than that of exposed decks. Different authorities have suggested an economic life expectancy in the range of 10 to 20 years for the overlays. Information from the literature survey generally supports WSDOT's selection of latex-modified concrete as the preferred system for rehabilitating highly deteriorated and travelled bridge decks.

Low-Slump Dense Concrete

Like all rigid overlays, this overlay is susceptible to cracking, especially on continuous structures. Although reduction in chloride intrusion and decrease in rebar corrosion activity have been reported after placing the overlay, in some installations delaminations have been detected in the underlying concrete. The exact cause of the delaminations, however, have not been completely determined. It is speculated that they might have occurred during surface preparation prior to overlaying. Despite the problem, at least 12 years of favorable experience with the overlay has been reported in Iowa.

Superplasticized Concrete

Limited experiences with bridge deck application of superplasticized concrete have highlighted that rapid loss of slump or workability is the reason the material has been difficult to handle. On-site batching and continuous mixing using mobile concrete mixing plants have been reported effective in controlling the problem. However, the admixture may adversely affect freeze-thaw durability of the concrete in medium cement content mixes.

Thin Polymer Concrete

Although a number of satisfactory installations of thin polymer concrete overlays have been reported, the majority of the overlays have shown only a few years of useful life. Despite the overlays have shown only a few years of useful life. Despite the concrete's low permeability and high skid resistance, thermally induced cracks may develop in the overlay, the underlying concrete, or the interface as a result of differential thermal expansion between the polymer concrete and conventional concrete. An investigation, in Virginia, suggested a useful service life of least five years for some installations of this type based on their differential thermal expansion.

Asphalt Concrete/Waterproofing Membrane

The wide variation in effectiveness of the protective system could well be the result of different conditions in the substrates on which the system has been applied. Information evolved from research has suggested that highly deteriorated and contaminated substrates having higher traffic use, even after restoration, might not be completely protected by the system. However, on decks with less vulnerability to deterioration and contamination, such as those with a thicker concrete cover and lower traffic use, the system would probably perform satisfactorily. Higher traffic volumes could also seriously impact the integrity of the AC overlay. Additionally, extensive deck patching prior to overlaying may not be economically and practically justified. This theory supports the overall structure of WSDOT's recent membrane application criteria on bridge decks. However, the limits used in the criteria as presented in the membrane policy should be tentatively accepted until further investigations and experience establish more accurate criteria quantitatively.

Cathodic Protection

The performance of "coke-asphalt overlay" systems in some installations has been associated with problems such as overlay wear, cracking and deterioration. In some instances decks covered by the system have shown delaminations possibly due to freeze-thaw action. "Non-overlay" systems, on the other hand, although having some problems with back-fill material, seem to be more promising, especially those with wire anode systems in both directions, similar to the one installed by WSDOT experimentally. Depending on the condition of the bridge deck, a "non-overlay" system in conjunction with a concrete overlay may be required.

CONCRETE BRIDGE DECK PROTECTIVE SYSTEMS FOR NEW BRIDGE DECKS ONLY

Epoxy-coating Rebar

No major deficiencies in the performance of the system have been reported. This is mainly attributed to the resistance of the system to corrosion. However, two factors may have also contributed to this. First, most of the installations have been fairly new. Second, some of the condition evaluation methods, such as chloride measurement and corrosion detection, either are not very useful or cannot be conducted on this type of installation. Chain dragging decks protected by the system is appropriate since it can reveal deterioration caused by sources other than corrosion. Monitoring the level of chloride contamination, however, is necessary to discern the cause of deterioration if it occurs.

Zinc Coating Rebar (Galvanizing)

Although no definite conclusion regarding the effectiveness of this protective system has been reached, indications are that zinc can corrode in chloride contaminated concrete and cause cracking. Although some investigations have demonstrated that concrete containing galvanized rebar cracks later than concrete containing black steel, perhaps a more realistic approach would be to compare the performance of galvanized rebar to that of epoxy-coated rebar. Galvanized rebar installations are presently limited only to experimental projects in order to gather more information regarding their effectiveness.

Double Protection

Due to a lack of long term experience with epoxy-coated rebar, it is inevitable that some structures, such as those whose integrity deterioration would seriously impair or those which are important transportation links to the traveling public, have been protected conservatively. Presently, the question of which conditions warrant the application of double protection can only be answered subjectively. However, with adequate information regarding the useful lives of the protective systems, the answer can be found more accurately by determining a benefit/cost ratio for each alternative.

Post-Tensioned Tendon Protection (Plastic Ducts)

Plastic ducts protect the tendon by blocking the passage of chloride and isolating it from other metallic components. In addition, the duct itself is a noncorroding material in the concrete. However, the plastic material must have certain properties in order to achieve its function. These include resistance to abrasion and ultra-violet light, flexibility at low temperatures and stability at high temperatures, and low creep properties. Additionally the plastic material should not release chloride ions in the concrete environment. Test procedures and specifications need to be developed to prevent using undesireable materials.

Pretensioned Tendon Protection (Epoxy Coating)

Laboratory investigations have indicated that epoxy coating has the potential to protect tendons. Recent development of fusion-bonded epoxy coating technology has suggested that the system should be given further consideration for protecting tendons against corrosion. Investigations, however, are needed to determine the effects of heating and fusion bonding on the engineering properties of the prestressing steel. Additionally, the ability of the system to withstand prestressing elongations and its bonding properties with concrete under application of a certain number of repeated loads needs to be studied thoroughly.

Better Concrete for Bridges

New materials and practices have been developed for concrete bridge decks in order to prevent their premature deterioration. These include use of calcium nitrite as a corrosion inhibitor admixture in the concrete, "low porosity/high strength" concrete containing gypsum-free cement and fly ash, and vacuum dewatering of in-place plastic concrete, resulting in denser and more durable material. In addition, the use of light weight concrete for replacement of older decks has held down the cost of repair in other portions of bridges, and precast concrete deck modules have minimized repair time and traffic disturbance.

BRIDGE DECK REPAIR AND RESTORATION CONCERNS

Deteriorating Asphalt Concrete/Membrane Removal

Worth investigation is an operation combining a few passes of a heater-planer to remove an asphalt concrete pavement whose thickness has been determined by radar with a subsequent sand blasting or flame cleaning to clean the concrete surface of residue. The heater-planer shaves and planes the pavement so that the remaining surface is smooth but abrasive in texture. Flame cleaning a concrete surface is achieved by surface scaling or partially melting the concrete surface.

In the presence of a sound membrane, cold-planing and replacing only the upper layer of the wearing course, with no disturbance to the membrane, is possible by predetermining the asphalt thickness using radar.

An alternative to modifying the currently employed asphalt removal procedure is to use a waterproofing material compatible with the disturbed concrete surface. In this regard, the recent development of an asphalt mix having the characteristics of both a wearing course and a waterproofing course in one layer is worthy of evaluation.

Fast Setting Mixes for Repairing Concrete

Fast setting polymer concrete could be an alternative to cement concrete when patching repair areas on concrete decks. However, although the material can save time for the travelling public and traffic control during the rehabilitation period, it may not be economical when the repair area is large, since it is expensive and difficult to handle when used in large volumes. A shortcoming of polymer concrete is its larger coefficient of thermal expansion than that of conventional concrete which may result in cracking. Repairing concrete decks with the material, therefore, may be acceptable for bridges where it is difficult to close a lane to make more permanent repair.

Traffic Control's Impact on the Quality of Repair

No significant effects from traffic-induced vibration on the quality of partial depth repairs and overlays have been reported. There have been, however, a few documented cases of poor performance with bridge widenings, which, could have been prevented by using good quality concrete and better reinforcement detail. Repairing irregularities in the bridge approach or deck surface has been suggested to minimize the vibration and potential for the problem as well. Speed and weight restrictions would be needed primarily for safety reasons during the repair period.

BRIDGE DECK CONDITION SURVEY TECHNIQUES

Half-Cell Corrosion Detection

Regardless of some inconsistencies experienced with the test results, half-cell corrosion detection shows great potential as a standard corrosion detection test. Half-cell cumulative-frequency distribution curves seem to be the best method to monitor the overall variation of the corrosion activity with time when the readings are taken at certain locations biannually and the results of each season are compared separately. Half-cell equipotential contour maps on the other hand can be used to locate the corrosion activity areas, especially when the overall potential values are small. The suggested ASTM test method must be carefully followed, otherwise the results can be significantly affected.

Thermographic Delamination Detection

In previous research, infrared thermography has demonstrated a great potential for delamination detection in both exposed and asphalt covered decks. The key to a successful survey is an environment proper for the test. The procedure, however, cannot be economically competitive with chain dragging unless a large number of decks are surveyed in a short time. This may be achieved by using a boom truck as a platform for the camera, which is located at a certain elevation above the deck, thus minimizing interference from traffic and expediting the survey. On asphalt covered decks, regardless of the economy, the procedure has proven to be more accurate and efficient than chain dragging.

CAUSES OF CONCRETE DETERIORATION

Reactive Aggregate

In concrete bridges, alkali-reactive aggregate has been identified as the cause of pattern cracking and popouts. Water and sodium chloride both have been reported as contributory elements to deterioration of this type. Currently, there are a few test methods for identifying alkali-reactive aggregate. However, further testing may be required and a final decision may be based on engineering judgment as well. Solutions to the problem when avoiding reactive aggregate is not feasible include specifying low-alkali cement, using a minimum aggregate size, and diluting potentially reactive aggregate.

Freeze-Thaw Action

Freeze-thaw is responsible for concrete scaling and contributes to spalling. Additionally, it may deteriorate concrete by deteriorating frost susceptible aggregate first. The latter deterioration on bridge decks has been reported in the forms of conical shape popouts and pittings. Scaling could well be controlled by air entrainment and by using a low water/cement ratio. Spalling, however, is prevented by providing a thick, dense and impermeable concrete cover over rebar. To prevent the type of deterioration caused by frost susceptible aggegate the size of coarse aggregate should be reduced. Presently, there are a few test methods to identify frost susceptible aggregate.

BRIDGE DECK MANAGEMENT SYSTEM

Due to an increasing number of bridge decks in need of repair, limited maintenance funds need to be carefully directed to those bridges that are important links to the traveling public, providing the most economical treatment in each case. Currently, a method which would systematically predict and prioritize bridge treatment at the network level is needed. This could be achieved with feedback on the performance of different types of constructions as well as a knowledge of their existing conditions. Development of WSDOT's repair priority program and protective system selection criteria by integrating traffic use with existing deck condition is a step toward generating a complete bridge deck management system. A program which incorporated an annual assessment of deck conditions and an inventory rating system would allocate repair efforts where they were most greatly needed. Additionally, it could provide insight into where future bridge treatment would be focused, thus establishing basis for future funding needs.

3 - CONCRETE BRIDGE DECK PROTECTIVE SYSTEMS FOR NEW AND EXISTING BRIDGE DECKS

The following sections discuss the measures that can be taken during bridge design and construction or during restoration of existing bridge decks to help achieve protection against steel corrosion and concrete deterioration.

3.1 - CONCRETE OVERLAYS

The above classification includes rigid-overlays. In most cases these overlays are considered structural components of the bridge deck system and can improve its load carrying capacity. Included in this category are also thin polymer concrete overlays.

3.1.1 - Latex-Modified Concrete

MATERIAL AND CONSTRUCTION

Polymer modified concrete, more commonly known as latex-modified concrete (LMC), is made by incorporating polymer emulsions into fresh concrete. The polymer enters the structure of the concrete and provides supplementary binding. In addition, the water in the emulsion hydrates the cement, thus reducing the water/cement ratio of the concrete while providing sufficient workability. Slump in the range of 5±1 in. (127±25 mm.) has been reported for water cement ratios as low as 0.35 to 0.40 (3). Air entrainment has not been required for LMC and entrapped air has normally been limited to about 6.5 percent (3). The following are the essential steps in the construction of LMC when applying it on existing bridge decks:

a. Scarify deck surface to remove all contaminants.
b. Remove areas of concrete deterioration.
c. Remove loose particles and clean surface by sand blasting.
d. Apply a bonding agent.
e. Place LMC.
f. Cure LMC by combination of wet and dry curing.

In new, two-course construction bridge decks, steps a, b, and c are generally eliminated.

APPLICATION

LMC overlays have been in service for over 20 years. The initial work on latex started with latex-modified motars (LMM) (15). In some states, thin LMM overlays (0.75-1.0 in. or 19-25 mm. thick) were used before 1972. However, it has been reported that since 1972 the majority of the latex overlays have been of the concrete type (1.0-1.7 in. or 25-44 mm. thick)(16). FHWA included latex-modified overlays in its studies in the mid-'70s (17,18). Since 1975, 25 bridges (4 new, 21 existing) in Washington have received LMC overlays. LMC is recommended by WSDOT mainly for protecting existing bridge decks. For new bridge decks, WSDOT prefers the use of epoxy coated reinforcing steel to the LMC. According to the WSDOT requirements for bridge deck protection, a minimum of 1.5 in. (38 mm.) thick LMC will be placed on an existing deck when one or more of the following criteria are met (10):

a. Delaminated and patched areas of the concrete deck exceed five (5) percent of the deck area.

b. Reinforcing steel is exposed due to wear or insufficient cover.

c. A pachometer survey shows concrete cover of less than one (1) in. (2.54 cm.) over 10 percent or more of deck area (future survey) and the deck has chloride contamination at the rebar level in excess of two pounds per cubic yard (1.8 kg/m3) for ten percent or more of the samples tested.

d. ADT equals or exceeds 10,000 or the traffic index equals or exceeds 7.5.

e. The structure is on an interstate route.

f. Chloride contamination at the rebar level exceeds two pounds per cubic yard (1.8 kg/m3) for 40 percent or more of the samples tested.

PERFORMANCE

The effectiveness of a bridge deck protective system relates, in general, to its own durability as well as to the degree of protection that it provides the underlying reinforced concrete by preventing concrete contamination, steel corrosion, and concrete deterioration. The deficiencies of an LMC overlay may be manifested in surface cracking, debonding, and surface scaling. Bishara, in his survey of the field performance of 132 bridge decks overlaid with LMM and LMC in Ohio, Michigan, Kentucky, West Virginia, reported that transverse and random cracking both exist in latex modified overlays and that the development of cracking is rather slow in the first three years of exposure and becomes much more rapid in subsequent years (16). Transverse cracks in the overlay are extensions of cracks which existed in the substrate prior to the overlaying, and their direction is perpendicular to the bridge centerline. On the other hand, random cracks, caused mainly by rapid initial shrinkage and most prevelant in LMM, are limited in depth to the overlay thickness and have random direction (16). Although cracking in overlay is not considered an imminent distress problem, it can contribute to future debonding and separation of overlay as well as deterioraton of the underlying concrete. This occurs when surface moisture and chlorides accumulate in the interface or around the rebar in the presence of freeze-thaw action (16). Some debonding associated with latex overlays has been reported, especially in overlays 3/4 in. (19mm.), but in general the performance has been satisfactory (3). The results of research in Indiana seem to mitigate the concern about the bond between the latex overlays and the substrate concrete (15). However, it should be mentioned that the reported age of the overlays in this study was 1-2 months. In regard to scaling, since virtually no surface scaling had been observed, the survey of 132 latex overlays concluded that latex overlays had provided sufficient resistance to freeze-thaw action (16).

Protection to the underlying concrete deck can be determined in terms of concrete contamination, steel corrosion, and concrete deterioration. The results of research regarding the chloride permeability of latex overlays have not been quite uniform (15,16). However, in general they have shown that latex overlays, although not completely impermeable, are able to reduce the chloride permeability significantly. The rate of chloride intrusion decreases rapidly as a function of the depth between the overlay surface and the interface. At the interface chloride penetration increases gradually as the number of winter exposures increases. Although the interface does not totally prevent chloride penetration, it has been reported that chloride content at the top rebar level in a new, two-course construction has remained below the corrosion threshold value even after six years of exposure (16).

Work in Ontario regarding the corrosion of rebar indicated that there was a sharp decrease in steel corrosion immediately after removing delaminations and applicating LMC (19). However, the initial reduction in corrosion activity was not sustained and the overall level of corrosion in creased gradually with time. In some cases the corrosion increased just after the application of the overlay. Manning and Ryell related the latter variation in corrosion activity to wetting the deck before applying the bonding grout, which can result in rapid rust formation on the exposed reinforcing steel (19). Half-cell data on Ohio bridges overlaid with latex indicated a reduction in corrosion activity with time; however, total cessation of the corrosion was not reported (16). Data on a Michigan bridge showed a slight increase in the corrosion activity with time for a new, two-course construction span, compared with a sharp increase in the corrosion activity of a bare span (16).

Although there have been signs of concrete delamination and spalling associated with the latex overlaid decks, the percentage of deteriorated concrete areas has been reported much lower than that for an exposed concrete deck under similar environmental conditions (16). In general, except for surface cracking, the performance of latex overlay has been reported satisfactory. As mentioned earlier, surface cracking could ultimately cause the deterioration of concrete in the presence of freeze-thaw action and through water and chloride accumulation.

The question of how long latex overlays will perform their function has been the subject of several reports. A 1979 report from FHWA on the performance of Indiana LMC bridge deck overlays suggested that 15 years of service life without maintenance and 20 years with good maintenance of isolated, spalled areas can be expected (15). Manning and Ryell, based on the performance of the overlays in Ontario and elsewhere, concluded that 15-20 years is probably a realistic period for the economic life (19). Bishara, based on the field performance data of 111 rehabilitation decks and 21 new, two-course construction decks, reported that LMC and LMM both should add to a rehabilitated deck a useful life in excess of 10 years and to a new, two-course construction more than 15 years, provided that correct construction practices are observed (16).

3.1.2 - Low-Slump Dense Concrete

MATERIAL AND CONSTRUCTION

Low-slump concrete (LSC) overlays incorporate conventional concrete material, but with a different mix design. A low water-cement ratio, usually around 0.32, is specified in order to ensure low permeability and shrinkage. This is achieved using a high cement content of approximately 800 lb/cy (480 kg/m3) and a maximum slump of 1 in. (25mm.) (3). However, without adequate density a low-slump mix cannot provide low permeability. Thus, special finishing machines are used to provide sufficient density by heavily vibrating the overlay. The density requirement is reported as a minimum consolidation of 98 percent of the compacted unit weight of the mix (3). Although the higher consolidation of LSC significantly minimizes the occurrence of entrapped air in the overlay, the mix should be properly air entrained for durability, and the content of the entrained air should be checked in the final product after consolidation. Whiting and Stark have reported that up to 10 times the normal dose of air entraining agent are sometimes needed to produce specified air contents in low-slump, dense concrete overlays (20). Air content of 6.5±.0 percent is specified for the mix. Proper mix design, good quality control and inspection procedures are essential for the success of LSC overlays. The essential steps in constructing LSC for existing and new bridges are generally similar to those for latex modified concrete overlays (see section 3.1.1), except that LSC only requires wet curing and the bonding agent is normally sand cement grout, which is scrubbed onto a dry bridge deck.

APPLICATION

LSC overlay, or the "Iowa method" of bridge deck protection, was originally used for repairing patches in concrete pavements and was specially developed in Iowa in the early 1960s. In the mid-'60s the process led to the resurfacing of entire deck with thin LSC overlays (21). However, most agencies, including WSDOT, later recommended at least a 2 in. (50mm.) thickness for the LSC overlays. The thickness of the concrete does not substantially affect the cost, but it significantly reduces the rate of chloride penetration into the underlying concrete (3). In 1974, after Iowa evaluated the performance of LSC overlays applied on its bridge decks, which were then at the most nine years old, FHWA gave approval to the use of LSM overlays as an alternative to latex modified concrete (21). Since 1979, 48 existing bridge decks in the state of Washington have received LMS overlays. The use of the overlay was recommended by WSDOT as an alternative to latex modified concrete overlays until 1984. In 1984 WSDOT, due to some concerns regarding the performance of LSC overlays, planned to investigate the overlay, use it on specific projects, and determine whether it should be included in the projects that would be prepared for the 1985 construction season (10).

PERFORMANCE

In 1974, investigation of the conditions of 15 bridge decks overlaid with LSC in Iowa since 1965 showed relatively high concentrations of chloride ions in the underlying old concrete in the vicinity of reinforcing steel (21). However, it was found that the chloride content generally decreased as the depth below the overlay surface increased. Regardless of the high chloride concentrations in some bridge decks, corrosion detection surveys indicated that a very small number of half-cell readings were representing the state of active corrosion in the reinforcing steel. This was attributed to the lack of moisture and oxygen at the reinforcing steel level. Further investigations reported the presence of delamination in about 2/3 of a bridge deck overlaid with LSC (21). The delamination was discovered four years after the completion of the project. It was found that the delamination had occurred below the interface and in the old concrete. Although a chloride content survey showed relatively high chloride contents in the concrete, the corrosion detection survey of the deck included only a small number of half-cell readings to find the existence of rebar corrosion. The possibility of incomplete preparation prior to overlaying was speculated. A more recent investigation by Iowa regarding the performance of LSC overlaid bridge decks indicated the presence of delamination on some of the decks surveyed in that investigation (19,22). The overlays were constructed to specifications that required thinner overlay than existing specifications and the delamination occurred below the interface and in the old concrete. However, regardless of the existence of the delamination the decks did not show any surface distress and performed adequately (19).

Manning and Ryell's investigations in Ontario on the performance of LSC overlaid bridge decks reported corrosion activity on the reinforcing steel in two concrete decks rehabilitated and overlaid since 1977 (19). In general, a sharp increase in corrosion activity was reported immediately after placement of the overlay. However, the initial reduction in corrosion activity was not sustained and the overall level of the corrosion activity gradually increased with time. It was found that the rate of increase in the corrosion activity increased as the magnitude of removed concrete decreased.

Like all rigid overlays, LSC overlays are susceptible to cracking, especially when applied on existing, cracked, concrete bridge decks. This is more pronounced on continuous structures (3). The cracks are probably of a reflective nature and extend into the old conrete. As in the case of latex modified overlays, although the cracking itself is not considered a distress problem, accumulation of moisture and chlorides in the cracks and sufficient cycles of freeze-thaw action might ultimately result in deterioration of the old concrete and the overlay as well.

In regard to the effectiveness of LSC overlays for protecting concrete bridge decks, Iowa reported in 1976 twelve years of favorable experience with this type of bridge deck protection when careful preparation, high quality LSC and good workmanship were stressed features of the repair program (21).

3.1.3 - Superplasticized Concrete

MATERIAL AND CONSTRUCTION

Superplasticized conrete (SC) overlays incorporate high-range water reducer admixtures, or "superplasticizers," into the "Iowa type," or low-slump, dense, concrete mix (see section 3.1.2

for low-slump concrete). This is done to increase the workability or slump of low-slump concrete mixes, thus eliminating the need for heavy vibration and special finishing machines. SC's mixture characteristics, when used for protection of concrete bridge decks, are the same as those for low-slump concrete mixes (i.e., high cement content and low water/cement ratio) except that the superplasticizer is used as an admixture. The dosage of superplasticizer should be carefully determined based on the workability or slump required at the job site since the slump can be lost significantly with time (23,24). Over-dosage should be avoided since it may cause segregation of the mix (24). In his field trial for preparation of SC mixes for bridge decks, Whiting reported a dosage of 0.14 percent cement for an "Iowa type" mixture when using a mobile concrete mixing plant at the job site and for a slump of about 3 in. (7.6 cm.) (23). In ready-mix operations when typical concrete mixtures are prepared at a local yard, a dosage as high as 0.60 percent cement has been reported for an initial slump of about 6 in. (15.2 cm.) (23). Other authorities in their laboratory investigations of SC have reported superplasticizer dosages of 1.2 and 1.0 percent by weight of the cement for the impermeable bridge deck overlay mixtures and general structural construction mixtures, respectively (24). Factors such as characteristics of the cement and the type of superplasticizer can influence the superplasticizer dosage. A "mini-slump" test procedure developed at the Portland Cement

Association has been used to determine the dosage requirements for different mixtures incorporating different types of cement and superplasticizers (23). Fresh SC mixes should also be properly air entrained for their durability, considering a possible loss of entrained air in the hardened concrete.

In regard to preparation of SC mixes for protection of concrete bridge decks, a report by the Portland Cement Association recommended the use of mobile mixing plants at the job site in order to minimize the slump-loss and to have better control over the properties of the mix (23). SC production using central-mix type operations when the mixture is subsequently transported to the job site in non-agitating vehicles has not been recommended since it could result in a significant loss of workability. In cases of ready-mix operation it has been recommended that the superplasticizers be added on-site in order to mitigate the loss of workability problem (23).

APPLICATION AND PERFORMANCE

Application of SC is relatively new since superplasticizer admixtures were introduced in the United States only recently and data on their performance is rare. In the state of Washington two experimental SC bridge deck overlays have been installed. In general, the results have not been satisfactory due to the problems encountered in preparing and constructing the material. Experiences in the Unites States with SC have suggested that loss of slump with time and, to some extent, freeze-thaw durability could be the two major problems with SC mixes. Although high initial slumps can be provided with these admixtures, the rate of slump-loss is much greater for SC mixes than conventional concrete mixes and the higher the initial slump the greater the slump-loss (24). It has been reported that the mixture may lose its workability within 20 minutes after addition of the superplasticizer if the mixture is not agitated (23). Thus, to minimize the slump-loss, addition of the admixture at the job site has been recommended (23).

For controlling the loss of workability, satisfactory results have been achieved by batching on-site and continuously mixing using mobile concrete mixing plants (23). Higher temperatures can increase the rate of slump-loss (23,24). To overcome this problem the use of conventional water reducing/retarding admixtures have been suggested (23). Extensive laboratory tests at the University of South Dakota and investigations by the Portland Cement Association have indicated that the engineering properties of SC are not generally affected by the addition of superplasticizers in the concrete mix, and some of the concrete properties can even be improved (23,24). For example, improvements in strength with time, plastic shrinkage and chloride permeability have been noticed. These investigations have reported that in cases of medium cement content mixes, some deicer-scaling can be expected. This has been attributed to changes in the void spacing factor of these mixes. However, in cases of high cement content mixes of the "Iowa type," resistance to deicer-scaling has been reported satisfactory and the mixes have exhibited good air-void systems.

Recently, some improvements in the engineering properties of SC have been achieved by incorporating steel fibers into the SC mixtures. In their investigation of superplasticized fiber reinforced concrete, Ramakrishnan, et al, reported that a major drawback of high strength SC is its brittle nature, which can lead to a sudden failure if used in a structural member subjected to suddenly applied loads (25). The addition of steel fibers greatly increases ductility and energy absorption capacity as well as flextural strength, impact strength and fatigue strength. Due to its improved physical properties, superplasticized fiber reinforced concrete may have applications in the form of thin bridge deck overlays. In the author's opinion, however, its susceptibility to corrosion deterioration in the presence of deicing chemicals needs investigation.

3.1.4 - Thin Polymer Concrete

MATERIAL AND CONSTRUCTION

Polymer concrete (PC) consists of a monomer mixed with an aggregate which is subsequently polymerized (cured) using an initiator (hardener) (27). Production of PC by mixing and combining the components of the polymer prior to incorporating the aggregate has also been reported (26). Epoxies, polyester, vinyl-esters, and methyl methacrylate have been used as the monomer in PC (27). Due to its superior strength and bonding properties, PC can be used as thin overlays on concrete surfaces. Thin PC overlays, or polymer mortar overlays, can be placed using concrete paving machines (27) or they can be troweled onto the concrete surface (26). Thicknesses as small as 3/8 in. (9.5 mm.) have been reported for polymer mortar overlays (28). Thin polymer overlays have also been used as surface treatment. In this case the components of polymer are combined and distributed on the concrete surface first. Aggregate is then broadcast on the polymer and compacted (27). This type of overlay can consist of alternating layers of polymer and sand. A thickness of 1/2 in. (1.27 cm.) has been reported for three layers (27). The concrete surface should be properly cleaned prior to application of PC. This has been achieved by sand blasting to remove oils and to expose a dry surface (27).

PC can offer compressive strength, tensile strength, and flextural strength higher than those of a typical structural concrete (26). It has also demonstrated good durability under freeze-thaw action and low permeability to salt and water penetration (27). PC cures rapidly at normal temperatures. It has a coefficient of thermal expansion much higher than that of concrete (26). Thus, it may not have a strain compatible with the underlying concrete surface when subjected to high ranges of temperature changes. It has been shown that PC's coefficient of thermal expansion can be reduced by adding more sand in the mixture (26,29). Applying too much sand, however, can affect the other physical properties of PC. Thus, a balanced situation should be provided. PC also has higher creep than concrete which is enhanced at high temperatures (75).

APPLICATION AND PERFORMANCE

Despite PC's relatively high cost, its rapid curing and applicability as a form of thin overlay have made PC suitable for rehabilitation and protection of highly traveled bridges and where additional dead load on the bridge would be a problem. In the state of Washington a few bridges have been either overlaid or scheduled to be overlaid with PC. A number of successfull installations of PC in the form of surface treatment on concrete bridge decks have been reported in New York, Georgia, New Mexico, Idaho, and Oregon since 1978 (27). Satisfactory installations of thin premixed PC overlays have also been reported in California and New York since 1979 (27). On the other hand, it has been stated that the majority of PC overlay installations have lasted only a few years (3). Traffic impact and weathering may affect durability of PC overlays adversely. Another problem with PC overlays on concrete bridges could be their differential thermal expansion. In Sprinkel's laboratory investigation of the thermal compatibility of thin PC overlays (four layers of polyester resin based polymer and sand in total thickness of 1/2 in. or 1.27 cm.) installed in Virginia in 1981 and 1982, Sprinkel showed that despite the overlay's low permeability and high skid resistance, thermally induced cracks can develop in the overlay, the underlying concrete, or the interface bond, depending on the strength of each layer, at temperature changes to which the bridge decks are typically subjected (29). Cracks in the overlay can increase water and salt intrusion, and cracks in the substrate and interface can lead to delaminations under the overlay. Based on his investigation, Sprinkel suggested a useful service life of at least five years for the Virginia installations (29). He reported that the thermally induced stress can be held to a minimum if the overlay is applied at 60 degrees F. (16 degrees C.) to 70 degrees F. (21 degrees C.).

3.2 - AC/MEMBRANE OVERLAY

MATERIAL AND CONSTRUCTION

Asphalt concrete/membrane (AC/membrane) systems consist of a waterproofing membrane applied on a concrete deck, followed by the application of a conventional AC overlay for the purposes of both protecting the membrane and providing a riding surface.

Thus, the most important element in the system, in regard to the protection of the concrete deck, is the waterproofing membrane itself. Products of different types of material have been used as waterproofing membranes. Generally, these materials can be divided into two groups. These are factory laminated sheet membranes and applied-in-place liquid membranes. Both systems are applied on a properly cleaned and prepared concrete deck with all surface defects repaired. For its AC/membrane protective system, WSDOT specifies a minimum of 0.15 feet (4.6 cm.) of AC overlay with any of the membrane systems indicated below (14,2).

System A. A factory laminated sheet composed of either suitably plasticized coal tar or rubberized asphalt reinforced with a polypropylene fabric and primed in accordance with the manufacturer's recommendations.

System B. A hot-applied, rubberized elastomeric membrane with primer if required by the manufacturer.

System C. A hot-applied reclaimed rubber-asphalt membrane.

As it may be noted above, System A is a factory laminated sheet membrane and Systems B and C are applied-in-place liquid membranes. Laboratory investigations have generally shown that the factory laminated sheet membranes can perform better than the applied-in-place membrane systems (30). This may be attributable to the quality control provided during the manufacturing of the factory laminated sheet membranes.

Lower cost and ease of application has made AC/membrane systems attractive for bridge deck protection, especially when overlaying the roadways and waterproofing the bridge decks are done at the same time. However, membranes are susceptible to damage during placement of the hot AC overlay and also during service life under heavy traffic loads (30). To eliminate the problem, some measures have been taken to protect the membranes (30). These protective measures have sometimes challenged the low cost and ease of application of the system. However, simple protective systems for membranes, such as fabrics installed on top of the membranes prior to AC overlaying, have been used with applied-in-place membranes. This type of protection for membranes is specified for WSDOT's System C membrane (2).

APPLICATION AND PERFORMANCE

Different types of materials have been used in the United States and Canada for waterproofing membranes since the early 1970's, and wide variation in service performance of these systems have been reported (2, 31, 32, 33, 34, 35). Since 1971, 864 existing and 57 new bridge decks in Washington State have been treated by AC/membrane systems. The Washington State Transportation Center (TRAC) evaluated the effectiveness of three selected AC/membrane installations in service in Washington in 1983 (2). Generally, based on the results of this limited investigation, the tested protective systems had not completely sealed the passage of salt into the concrete decks. Additionally, they were not very effective in terms of deck protection when installed on a highly deteriorated and rehabilitated concrete deck, which coincide with factors such as shallow rebar depth and higher traffic volume. For example, in one bridge deck, concrete deterioration was found around the repaired concrete seven years after rehabilitating and waterproofing the deck. In 1984, based on its experience with the membrane systems as well as the practices of other states, WSDOT developed criteria regarding the application of AC/membrane systems for bridge deck protection and restricted their application accordingly (10). The WSDOT criteria are presented below.

"An asphalt concrete with membrane system may be used when all of the following criteria are met:

1. Delaminated and patched areas of the deck are less than five (5) percent of the deck area;
2. Concrete cover exceeds one (1) inch (2.54 cm.) over 90 percent or more of deck area (future survey);
3. ADT is less than 10,000 and the traffic index is less than 7.5;
4. Chloride contamination at the rebar level is less than two pounds per cubic yard (1.8 kg/m3) or exceeds two pounds per cubic yard for less than 40 percent of the samples tested;

5. Deck surface is compatible with the membrane system. A rough or pocked surface will result in damage to or early failure of the protective membrane.

In other words, the above criteria justify the application of waterproofing membrane systems only on those concrete decks which are less vulnerable to premature deterioration and more compatible with the membrane systems. Durability of the overlay itself against traffic impact and practicality of construction, in conjunction with deck patching, are also taken into consideration as indicated in items No. 3 and 1 of the criteria, respectively. WSDOT is planning to further evaluate its membrane policy.

A shortcoming of the AC/membrane system is that it is a non-structural component of the deck system and tends to reduce the load-carrying capacity of the bridge. In addition, the system covers the concrete deck so that if the underlying structural components deteriorate, the deficiencies can not be detected easily. For example chain dragging, which is very efficient on concrete surfaces, is not able to completely reveal concrete delaminations under an AC overlay (2,6). Half-cell corrosion detection on AC covered decks is also difficult since the membrane is a dielectric material and has to be punctured for half-cell measurements (2). This, in turn, has made prediction of the performance of decks covered by this system difficult.

3.3 - CATHODIC PROTECTION

BACKGROUND

Cathodic protection has been used for years to prevent steel corrosion in buried pipelines, concrete water tanks, and ship's hulls (3,36). The basic theory behind cathodic protection is that galvanic corrosion of steel is halted when the steel is polarized to a potential equal or higher than the open-circuit potential of the most anodic point on the steel (36,37,38,39). In this case corroding anodes on the steel become non-corroding cathodes, thus the term cathodic protection is applied to the system.

Two systems of applying cathodic protection are: a) the galvanic (sacrificial) anode system (37,41) and b) the impressed current system (37,39,40,42,43,44). In the galvanic anode system, a metal which is anodic to steel, such as zinc and magnesium, is connected to steel, thus providing a natural current which can polorize and protect the steel (37). A drawback of this system is that the natural voltage between the two metals is small and the current output will generally depend on the moisture content or electrical resistance of the electrolyte (i.e., deck concrete) (37,40). In addition, laboratory investigations have indicated that magnesium, and to a lesser degree zinc, are susceptible to corrosion in the process of galvanic cathodic protection. (37). Thus, when buried in a bridge deck's concrete or a conductive medium, they could have the same undesirable effects as the corroding steel would have in the concrete. The impressed current system of cathodic protection is basically the same as the galvanic anode system except that the current to the steel is provided by an external power; thus the current output can be varied depending on the moisture content or electrial resistance of the deck concrete (37.40). Additionally, the anodes can be selected based on their capability to conduct the current and resistance to corrosion. Use of anodes such as carbon and high-silicon cast iron have been reported in conjunction with the impressed current system (37,39). Only the impressed current system of cathodic protection will be discussed in the following sections.

MATERIAL AND CONSTRUCTION

The basic components of a cathodic protection system for bridge decks include the following:

1. conductive medium and anode system,
2. power generating system,
3. controlling and monitoring system.

In order to distribute the current evenly to the reinforcing steel in the concrete deck, anodes should be placed in a conductive medium which in turn contacts the concrete deck. Stratfull first developed a conductive medium for cathodic bridge protection by placing a mixture of coke breeze (fine conductive material) and asphalt on a concrete deck (39). Since this layer was not durable enough to be exposed to traffic, it was subsequently covered with a conventional asphalt concrete overlay. Later aggregate was added to the mixture of coke breeze-asphalt in order to make it more stable and resistant to rutting and stripping (3). Anodes used in conjunction with the coke breeze conductive layer have generally been disc-shaped graphite or silicon-iron alloy compositions approximately 10-12 in. (25.4-30.5 cm.) in diameter and 1 1/4-1 1/2 in. (3.2-3.8 cm.) thick. They have been epoxy glued to the deck concrete either on the surface (36,39) or recessed in the concrete flush with the surface (42). The latter case has been more desirable, since if the conductive layer is removed and replaced, the anodes are not damaged and do not have to be removed. The spacing of the anodes is determined by the electrical conductivity properties of the conductive medium as well as that of the underlying concrete. More recent applications of the bridge deck cathodic protection have used a backfill conductive medium in parallel sawed slots (either in a transverse or longitudinal direction or both) in the deck in conjunction with wire type anodes placed in the bottom of the slots (37,40,43,44,45). FHWA guidelines for this system, called the "non-overlay cathodic protection system," specifies the following: transverse and longitudinal anode slots approximately 1/2 in. (12.7 mm.) wide and 1/2 to 3/4 in. (12.7 to 19.1 mm.) deep cut in the deck surface at predetermined spacing; primary wire anodes made of 0.031 in. (0.79 mm.) diameter platinized niobium copper core wire installed in the bottom of each transverse slot; secondary carbon strand anodes placed in the bottom of each longitudinal slot; and conductive polymer concrete, resistant to acid, freeze-thaw, and thermal cycling while bonded to the concrete, as anode backfill material (40).

The electrical power for impressed current systems is provided either from batteries or by a rectifier converting AC power to DC power (3,40). Solar cells have also been considered for the purpose of providing power and have been used in demonstration projects (3).

An effective cathodic protection system is controlled by monitoring the system. In most of the cathodic protection systems the controlling system functions automatically from the monitoring system and maintains the appropriate degree of polarization potential (within the range -0.85 to -1.10 v. measured to a copper-copper sulphate reference half-cell (39)) in order to eliminate the possibility of under protection, which would be inefficient, and over protection, which could damage the bond between the reinforcing steel and the concrete (37). The monitoring system consists of the following: a) reference cells buried in the concrete and near the rebar in order to measure the applied polarization potential; and b) rebar probes burried in the concrete on the level of the rebar in order to determine the rate of rebar corrosion with time (40). Detailed FHWA guide specifications relating to the "non-overlay cathodic protection systems" can be found in reference 40.

APPLICATION AND PERFORMANCE

The first cathodic protection system was installed in California in 1973 (39) and in Ontario in 1974 (42) using coke-asphalt overlay as a conductive layer. Since then many states have installed the coke-asphalt overlay system in demonstration projects in conjunction with FHWA. However, recently the trend has changed and most agencies participating in the FHWA demonstration projects have preferred the "non-overlay" cathodic protection installations. In the state of Washington one bridge has been cathodically protected with a "non-overlay" system since 1981. The protected portion is the lower deck of a pontoon bridge (Hood Canal Bridge) which is not subject to traffic flow.

The performance of the cathodic protection systems installed in the United States have generally been reported satisfactory, except that there have been some problems with shutdown due to lightning strikes, vandalism, non-satisfactory performance of buried reference cells and rate of corrosion detection probes (40). Coke-asphalt overlay systems, which constitute almost all of the installations through 1980, have shown problems with the overlays such as wear, cracking, and deterioration in some installations. The effectivenesss of the coke-asphalt overlay systems may best be determined from Ontario's first cathodic protection installation. As reported by Fromm, one lane of deck was initially protected by cathodic protection in 1974, whereas the other lane was overlaid with a dense asphalt concrete for comparison (40). In the second year of service, random cracks appeared only in the overlay of the protected half of the bridge. This was attributed to the water saturation in the relatively porous, conductive coke-asphalt mixture. The deck was stripped in 1977, after three years of service, for examination. Delaminations were found on both the unprotected and protected portions of the deck. However, the extent of delamination on the protected portion was lower. Some of the delaminations on the protected portion were attributed to corrosion of the steel where the initial delaminations were repaired by injection of a non-conductive epoxy in 1974. The others were believed to be the result of freeze-thaw action.

Although "non-overlay" cathodic protection systems are relatively new, (i.e., 2-3 years old) some cracking and failure of the backfill grout in the sawed slots have appeared in the single-direction, platinized niobium anode systems due to heavy traffic and severe winter weather (40). The grout failure has also been attributed to acid formation around the platinized niobium anode wires surrounded by the grout (1). When polymer concrete is used as backfill grout, thermal compatibility between the materials should be considered. There has not been much information regarding the performance of the newer "non-overlay" systems using a combination of platinized niobium wire anodes and carbon strand anodes installed in both directions. The latter system is believed to be able to polarize the rebar system more evenly, thus eliminating the possiblity of over-protection in some areas of the deck.

APPLICATION GUIDELINES

It should be kept in mind that cathodic protection, when successfully applied, will only halt the corrosion of the reinforcing steel. The system, therefore, is not able to protect concrete decks from deterioration caused by other sources, such as freeze-thaw action or extensive impact from traffic flow. Therefore, decks should be carefully examined prior to installing cathodic protection. For example, a candidate deck for cathodic protection should be properly air-entrained and have enough concrete over the rebar that it is resistant to freeze-thaw action and high frequencies and magnitudes of traffic loads. Generally, existing decks with extensive rebar corrosion but very little deterioration are good examples. In some instances a "non-overlay" cathodic protection system in conjunction with a concrete overlay might be even more effective. Installations of this type have been scheduled by some states participating in the FHWA's cathodic protection demonstration projects (40). In this case the thermal compatibility of the buried backfill grout with the surrounding concrete would need consideration. On the other hand, the use of asphalt overlays with cathodic protection tend to reduce the load-carrying capacity of the bridge. Asphalt overlays can also add to the problems associated with freeze-thaw action, since membranes (di-electric material) can not be used and brine can accumulate under the overlay. Additionally, asphalt overlays cover the concrete decks and if the underlying structural components deteriorate the deficiencies can not be easily detected.

4 - CONCRETE BRIDGE DECK PROTECTIVE SYSTEMS FOR NEW BRIDGE DECKS ONLY

The following sections discuss protective measures to overcome corrosion of steel and deterioration of concrete that can be taken only during the design and construction of bridge decks.

4.1 - REBAR PROTECTION

Under this category, the systems that only protect the rebar and prevent its corrosion, regardless of contamination of concrete with chlorides, are reviewed. The most viable and promising among these systems have been epoxy coating and zinc coating (galvanizing) of rebar.

4.1.1 - Epoxy Coating Rebar

MATERIAL AND CONSTRUCTION

A detailed laboratory investigation of epoxy coatings conducted by the National Bureau of Standards under FHWA sponsorship indicated that some powder epoxies, when fusion bonded to the reinforcing steel and having a thickness in the rage of 7+2 mil (178+51 u), could satisfy the requirements for corrosion protection as well as bonding to concrete (including creep characteristics) and flexibility in fabrication (46,47). The study, however, indicated that handling and fabricating epoxy coated rebars needs special attention in order to minimize damage to the epoxy films. Bundling coated rebars together with nylon rope at the construction site, using bearing rollers, and bending wheels covered with nylon during the fabrication has been recommended (46).

In order to minimize the possibility of corrosion at the locations of damaged epoxy films, FHWA allows only a maximum of 2 percent and 0.25 percent bare, unrepaired, damaged area when coating all reinforcing steel in the deck and when coating only the top mat reinforcing steel, respectively (8). Epoxy coating sitrrups used in conjunction with epoxy coated top bars are not required by FHWA, if the concrete cover over the hook is at least 4 in. (10.2 cm.). The use of non-metalic coated chairs and tie wires when only top mat reinforcing steel is epoxy coated is also recommended in order to minimize electrical coupling between the top and bottom mats (8).

In addition to the FHWA considerations, WSDOT specifies 2-1/2 in. (6.4 cm.) concrete cover over the epoxy coated top mat reinforcing steel (10). According to the WSDOT specifications, traffic barrier bars are also epoxy coated; however, bottom mat rebar and stirrups in conjunction with the top mat when secured with 135 degree hooks do not need to be epoxy coated (10).

As reported by the Concrete Reinforcing Steel Institute (CRSI), in salt-water sea coast locations, all of the bars in a deck and also those in the other parts of a bridge may have to be epoxy coated (48). The following are some of CRSI's design tips in order to help hold down the cost of epoxy-coated reinforcing steel (48):

a) Maximize the use of straight bars.

b) Use the fewest possible bar sizes for a design.

c) Use the largest bar size possible, based upon consideration of the bond, maximum rebar spacing, and flexural reinforcement distribution.

Since concrete deterioration can also be caused by sources other than rebar corrosion, epoxy coating rebar has not relaxed the requirements for adequate concrete cover (2 1/2 in. or 6.4 cm. as indicated in WSDOT's specifications) and high quality, properly air-entrained concrete for a durable structure (3).

APPLICATION AND PERFORMANCE

In 1976, FHWA specified epoxy-coated reinforcing steel in bridge decks. Since that time many states, including Washington State, have adopted the system and used it in the construction of new bridge decks. The author has not been aware of any report regarding deficiencies in the performance of the epoxy-coated rebars. This is mainly attributed to its resistance to corrosion. However, it should be kept in mind that two factors might have also contributed to this. First, most of the installations are fairly new. Second, some of the condition evaluation methods used routinely on the bridge decks either are not very useful or cannot be conducted on this type of installation. For example, the level of chloride contamination does not necessarily indicate a potential for rebar corrosion, and half-cell corrosion detection can not be used to evaluate performance since the reinforcing mat is caoted with a di-electric material (i.e. epoxy). Presently, chain dragging for delamination detection seems to be the best non-destructive and practical method for testing the performance of the epoxy-coated rebar installations. The test can reveal concrete deterioration caused by sources other than corrosion, such as freeze-thaw action and repeated traffic impact. Monitoring the level of chloride contamination of concrete, however, is necessary in order to be able to distinguish the cause of deterioration if it occurs.

4.1.2 - Zinc Coating Rebar (Galvanizing)

In 1976, the FHWA limited the number of zinc-coated installations due to conflicting reports of their performance until a definite conclusion regarding their effectiveness is reached (3). Since then some states have stopped regarding zinc-coated rebars as an alternative to epoxy-coated rebar (50). No protection of this type has been applied to Washington bridge decks and the system has not been adopted by WSDOT as a standard procedure of bridge deck protection. The following briefly reviews the results of different investigations into the performance of concrete containing zinc-coated rebar and exposed to chlorides.

The general concept is that hot-dip galvanizing by zinc can provide protection to steel in a corrosive environment in two different ways (3). First, as a coating, zinc protects the steel from the corrosive environment. Second, when the coating is broken, a natural current is formed between the two metals, making a zinc anode and a steel cathode, thus protecting the steel from corrosion. Investigations have attempted to determine whether the protection of galvanized reinforcing steel is achieved in an alkaline environment of concrete exposed to chlorides. Additionally, the possibility of zinc corrosion and its subsequent effects on concrete have been studied.

Cornet and Bresler, in their laboratory experiments, found taht galvanized reinforcing steel embedded in concrete and exposed to cyclic wetting in chloride solution and drying developed crakcs later, more slowly, and with smaller width than their companion specimens reinforced with black steel (51). Hill, Spellman and Stratfull, on the other hand, in their laboratory testings of concretes reinforced with galvanized steel and black steel, reached the conclusion that zinc can corrode in chloride contaminated concrete and cause cracking in the concrete earlier than black steel (49). The time until cracking was found to be inversely related to the thickness of the zinc coating. The data, however, indicated that relatively porous concretes having a lower cement content and reinforced with galvanized steel cracked later than those reinforced with black steel. The latter authorities also pointed to the possibility that reversed polarity in a concrete having different concentrations of chlorides through which the zinc might act as a cathode might cause the black steel to have accelerated corrosion. Field investigations in Michigan, as reported, have indicated that galvanizing can retard the concrete deterioration, though it can not prevent it (3,25). In this case the concrete protection was less effective were there was a small rebar depth.

4.2 - DOUBLE PROTECTION

Double protection, or two-system protection, based on WSDOT's (14) and FHWA's (8) classifications of bridge deck protective systems, is intended to mean epoxy coating rebar in combination with a low permeability concrete overlay (i.e., latex modified or low-slump dense concrete) or an AC/membrane overlay. Inclusion of the double protection or "belt and suspenders" approach in bridge deck protective systems results from a lack of long-term experience with the relatively new protective systems currently adopted by the highway departments. At this time it is inevitable that some conservatism should be built into certain types of structures. These are generally those structures whose integrity deterioration would seriously impair and those to which repair would be costly, either due to the complexity of the repair of traffic volumes.

WSDOT has identified several factors which influence the decision for double protection of a structure. These are:

a) the type and size of the structure,

b) the geographic location of the structure,

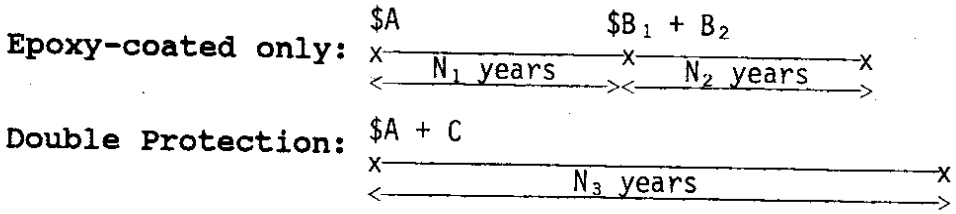
c) the impact of future deck repair on traffic flow, and

d) the anticipated use of deicing chemicals.

Factor "a" generally applies to post-tensioned box girders or decks containing transverse post-tensioned tendons. Additionally, for structures where deck replacement is impractical, epoxy coating all of the deck rebar instead of only the top mat rebar has been suggested (8). Factor "b" represents the importance of the transportation link and the public's dependence on the structure. Factor "c" stands for the cost to the traveling public resulting from the repair work. According to FHWA double protection is warranted for decks with traffic volumes greater than 10,000 ADT (8). Factor "d" represents the severity of the deck exposure to salt and normally is considered in combination with the other three factors.

As mentioned earlier, due to the lack of long term experience regarding the performance of epoxy coated rebars and their useful life, the question of which conditions warrant application of double protection can presently be answered only subjectively by taking the aforementioned factors into consideration for each newly designed bridge deck. However, with solid conclusions about the service lives of different types of bridge deck protective systems, the questions will be better answered objectively by comparing the estimated cost of the additional overlay system with the estimated benefits that can be gained from the additional bridge deck life. This will be achieved by determining the benefit/cost ratio for each alternative and comparing them. A simple mathematical model for benefit/cost ratio determination as adapted from Reference 30 is given below:

Assume that the cost of an original epoxy coated rebar bridge deck is \$A. Without double protection it is expected that the deck will need rehabilitation in N1 years, which would cost \$B1 and add N2 years to the service life of the deck. The cost to the traveling public at the time of rehabilitation is estimated \$B2. On the other hand, if double protection is applied to the original deck with an additional cost of \$C for a low permeability concrete overlay the life of the deck could be extended to N3 years. This is illustrated in the following sketch:



The benefit/cost ratio is then determined as follows:

$$\text{Benefit/cost} = \frac{\left|\begin{array}{l}\text{Avg. annual cost of}\\ \text{epoxy-coated deck in-}\\ \text{cluding the intial}\\ \text{deck construction}\end{array}\right| \quad \left|\begin{array}{l}\text{Avg. annual cost of doub-}\\ \text{ly protected deck includ-}\\ \text{ing the initial deck con-}\\ \text{struction but w/o addi-}\\ \text{tional overlay}\end{array}\right|}{\left|\begin{array}{l}\text{Additional overlay for double}\\ \text{protection as average annual cost}\end{array}\right|}$$

$$= \frac{\left[\begin{array}{l}\text{A+ (B1 + B2)(Present}\\ \text{worth factor for N1}\\ \text{years)}\end{array}\right] \text{ X } \left[\begin{array}{l}\text{Capital recovery factor}\\ \text{for (N1 + N2) years}\end{array}\right] - \left[\begin{array}{l}\text{A(Capital}\\ \text{recovery}\\ \text{factor for}\\ \text{N3 years)}\end{array}\right]}{[\text{C(Capital recovery factor for N3 years)}]}$$

A benefit/cost ratio larger than one would then justify economic application of the double protection. A complete cost determination, however, would take the average annual cost of maintenance, accidents and other factors into consideration for each alternative as well.

4.3 - PRESTRESSING STEEL PROTECTION

The main reason for protecting prestressing steel is to eliminate the possibility of brittle fracturing of prestressing tendons from either stress-corrosion cracking or hydrogen embrittlement. It has been reported that stress-corrosion cracking results from a combination of stress and corrosion, whereas hydrogen embrittlement cracking is caused in stressed tendons by hydrogen entering into the steel structure (9). This may occur by cathodic charging whenever the steel is electrically coupled to a more anodic metal such as zinc or aluminum in a corrosive environment. The embrittlement may also happen in the presence of H2S, which can exist in aqueous environments or be generated from sulfides in a cement or aggregate (9).

Generally, the performance of prestressed concrete members used in bridges or other constructions have been reported satisfactory in the United States (9,54); however, rare incidents of rust stains on the concrete, which might indicate corrosion of pretensioned strands, and spalling of concrete have been reported in some bridges (9,58). In his laboratory investigation of post-tensioned concrete beams, Schupack reported that post-tensioned, air-entrained concrete beams can be designed to have a life expectancy well over 17 years when subjected to an adverse salt-water marine environment and freezing and thawing (57). Although corrosion was found on the post-tensioned wires used in the study, the beams generally performaed satisfactorily under ultimate load testing. As a result, there have been different opinions about the cause and time of rusting (i.e., prior to or after incapsulation of the tendons with the grout).

PROTECTIVE SYSTEMS

Among the different types of prestressed concrete structures, those utilizing unbonded, post-tensioned tendons require most attnetion in order to prevent tendon corrosion. According to specifications, the tendons are coated against corrosion with materials such as grease, epoxies, plastic or galvanizing (55,56). The coated tendons are then wrapped in order to prevent the intrusion of cement and loss of coating material. Spirally wrapped craft paper has been reported in older structures (54), but recent specifications require plastic, fiberglass, metal and impregnated and reinforced paper (55). The most recent recommendations have required use of watertight, continuous plastic tubes for this purpose (53,54).

Unbonded tendons are not normally used in bridge structures; instead, bonded, post-tensioned members, as well as pretensioned members, are used. In both types of constructions, tendons are surrounded by either concrete or grout, thus reducing the potential for corrosion. The surrounding alkaline environment, howver, does not always ensure complete protection against corrosion, especially in a highly contaminated environment such as experienced with reinforced concrete bridge decks. Thus, additional protective measures such as plastic ducts and galvanizing or epoxy coating have been considered.

4.3.1 - Protection of Post-tensioned Tendons (Plastic Ducts)

Although WSDOT has used galvanized ducts in conjunction with bonded, post-tensioned tendons, the use of plastic ducts (polyethylene or polyvinyl chloride) has been recommended by FHWA and considered by WSDOT (8,10). According to FHWA, for decks containing embedded longitudinal or transverse post-tensioned tendons, this type of protection minimizes the potential for chloride-induced stress-corrosion by blocking the passage of chlorides and electrically isolating the tendon from the other metalic components in the deck (8). In addition, the duct itself is a non-corroding material inthe contaminated concrete environment. Additionally, FHWA specifies that in case of smooth wall ducts they should be considered unbonded in design even though grouting is applied (8).

Plastic, watertight, continuous tubes used as sheathing for the unbonded tendons have been the subject of a recently issued report by FIP (Federation International de la Precontrainte) in Europe (53,54). Since plastic ducts for bonded tendons function almost in the same environment as plastic tubes for unbonded tendons, it is appropriate to review the tentatively recommended properties of plastic tubes for unbonded tendons from this report as published in the PCI Journal (53). According to the report, the plastic material should be resistant to damage, abrasion and ultraviolet light. It should remain flexible at low temperatures and stable at high temperatures. It should have relatively low creep properties in order to prevent plastic flow caused by constant pressure exerted on the plastic by a tendon deviated in profile. The use of PVC (poly-vinyl chloride) was not recommended since as reported chloride ions can be released under certain conditions (53).

Another area of concern in protection of post-tensioned members is end anchorage assemblies protection. Flush type anchorage (i.e. a local pocket provided at the end of the member and filled with mortar) has been reported the most effective protection in tests subjecting them to salt-water and freeze-thaw action (57). With regard to unbonded tendons, the FIP report indicates that the end anchorage is the most vulnerable location for a corrosion attack since moisture can reach the tendon through capillary action provided by interstices between the wires or in the strands (53). For such cases, epoxy coating has been recommended for the exposed portion of the tendon and the gripping part of the anchorage. FHWA has also recommended that tendon anchorage assemblies of bonded tendons embedded in the deck should be protected by a field coating with a suitable epoxy (8).

4.3.2. - Protection of Pretensioned Tendons

Strands are the most used tendon for pretensioning in the United States, mainly due to their better bonding properties; bonding is very important in this type of construction, especially when the end anchorages are not used. Laboratory investigations by Moore, et al, indicated that corrosion of pretensioned strands in a chloride environment can occur in the presence of open cracks in the concrete, small concrete cover and voides between steel and concrete (9). During the examination of girder fragments from an out-of-service bridge, mild corrosion was found only in the center wire of the strand near the ends. In this case Moore, et al, reported that the hardened cement, which filled approximately 50 percent of the strand interstices, retarded the moisture penetration. Since there are no known methods for corrosion protection of conventional pretensioned strands, their use in bridge decks has been discouraged (8).

Epoxy coating and galvanizing both have shown potential for protection of prestressing tendons. Moore, et al, studied the characteristics of both systems in laboratory specimens simulating pretensioned and bonded post-tensioned tendons (9). They reported:

> Galvanized coatings lowered steel strength and increased relaxation. Also, the zinc layer was not entirely inert in concrete that contained chlorides. Hydrogen embrittlement by cathodic charging of the steel did not occur for stressed specimens with breaks in the galvanized layer that were tested for long time in a chloride environment.
>
> Epoxy coating provided excellent corrosion protection but were lacking in wear resistance and ease of application.

Regarding the bonding characteristics of strands and wires coated with different permanent type materials and tested in specimens which simulated pretensioned concrete, they reported, "...only the galvanized and the epoxy developed bonding that was comparable to the bare steel," (9).

It is the author's opinion that because of the recent developments in epoxy coating rebar technology which utilizes fusion-bonded coating for reinforcing steel, the system should be given consideration for protection of pretensioned tendons against corrosion if investigations justify its application. The effects of heating and fusion bonding on the strength of prestressing steel and its elastic properities, as well as steel relaxation, need to be determined. Additional research is also needed to identify the behavior of the epoxy coated tendons in pretensioned concrete during prestressing as well as under service conditions. For example, the ability of fusion-bonded epoxy coating to withstand high elongations caused by prestressing and the ability of the system to bond with concrete under application of a certain number of repeated loads should be investigated thoroughly.

4.4 - BETTER CONCRETE FOR BRIDGES

NEW DEVELOPMENTS

"Better concrete for bridges" refers to concrete which would prematurely deteriorate less and which would protect rebar against corrosion and be durable when exposed to freeze-thaw action and traffic impact during the design life of the structure. Research is continuing in an attempt to provide better systems and materials in order to satisfy these requirements.

Different types of materials have been reported as corrosion inhibitors to be used as admixtures in concrete (3). Among them calcium nitrite has been reported as an effective corrosion inhibitor which does not adversely affect the concrete (59). Calcium nitrite has been used in a demonstration project at a bridge in Washington State. The material was used in precast, prestressed piles and slabs by adding it to the concrete batch. WSDOT is evaluating the performance of the material.

A conventional approach to providing better concrete is reduction of the water/cement ratio and entrapped air in the concrete. This can provide a stronger material with a lower permeability to salt and water, thus decreasing the potential for rebar corrosion and concrete deterioration. Although low-slump dense concrete is made according to this concept, its workability has been a problem in construction which requires special finishing machines. Superplasticizers have been used to provide more workable mixes associated with low-slump dense concretes. However, rapid loss of slump in superplasticized concrete needs to be evaluated. Recently an FHWA research project has produced "low porosity" concrete made with gypsum-free cement as a substitute for conventional concrete on bridge decks (63). The properties of the material with and without incorporating fly ash has been determined and compared to those of conventional bridge deck concrete as well as low-slump dense concrete. The results have indicated that "low porosity" concrete, in terms of long-term resistance to chloride penetration, is even superior to low-slump dense concrete (63). "Low porosity" concrete in the study achieved good workability at a water/cement ratio of 0.28 with strengths in the range of 10,000 to 13,000 psi, with excellent freeze-thaw resistance and reduced drying shrinkage (63). It has been reported that due to high inherent alkalinity of the concrete, even in the presence of high concentrations of chlorides, rebar passivation has been maintained for the monitoring period (63). The material, due to its high strength, has shown brittle behavior which should be taken into consideration when it is used in combination with rebar in a deck or as an overlay (63).

A different method to provide denser concrete with lower water content for bridge deck slabs has been vacuum dewatering in-place plastic concrete With vacuum dewatering, excess water is removed from the plastic mix after placing and screeding the concrete. A vacuum is applied over the surface slab which brings excess water to the surface. The operation consolidates and densifies the concrete mass (62). The process can also be applied to bridge deck overlays.

IMPROVING CONVENTIONAL PROCEDURES

Aside from new developments in materials and systems for bridge decks, better concretes can also be provided by carefully designing and constructing conventional concrete bridge decks.

The following are some design and construction tips which can improve the durability of concrete bridge decks:

- In order to control more effectively the transverse cracks in bridge decks, which tend to form over the top primary reinforcing steel, the longitudinal shrinkage and temperature reinforcing steel may be placed on top of the primary transverse bars (60,12).
- In view of the durability of bridge decks, ACI recommends thicker concrete decks over thinner ones since they are stiffer and also result in less reinforcement congestion and fewer problems associated with it. It has been reported that when deterioration starts it is likely to progress more rapidly in thinner decks (60).
- Draingage designs for the removal of small quantities of water from melting snow and brine, in addition to stormwater removal, should be given special attention. The ponding of water and salt on bridge decks could cause serious concrete deterioration (60).
- To resist freeze-thaw action concrete should be properly air-entrained and the amount of entrained air should be specified based on the maximum size of coarse aggregate (14,60).
- Adequate cover thickness over the top mat rebar is essential in preventing spalling. While placing the concrete the variation from design cover thickness caused by flexibility

of screed or differential deflections of girders should be checked and controlled as much as possible in order to provide sufficient cover thickness (3,60). One way to guarantee sufficient cover thickness is to design well bonded, two layer bridge decks constructed in two stages.

- Concrete surface revibration during construction can be effective in repairing surface cracks and horizontal cracks at the top mat rebar level as long as the penetration resistance of the concrete does not exceed 60 psi (61).
- Rapid drying of the concrete surface caused by exposure to sun and wind during the bleeding period should be avoided since it promotes surface crusting. This results in bleed water trapped under the top surface (60,14).

OTHER ASPECTS

Development of new materials and practices for concete bridge decks has not been liminted only to those which provide durability for the decks. For example, light weight concrete was used in construction of a bridge deck after removing the old deck in New York. Because of the lower dead load only 15 percent to 20 percent of the steel truss members needed strengthening (65). Successful use of precast concrete deck modules have also been reported for replacement of deteriorated bridge decks in New York and Indiana (66). Primary advantages included economy and very short construction time.

5 - BRIDGE DECK REPAIR AND RESTORATION CONCERNS

The following sections discuss the major problems associated with the presently adopted procedures for bridge deck repair and restoration and suggest possible solutions to those problems.

5.1 - DETERIORATING AC/MEMBRANE REMOVAL

Asphalt concrete (AC) wearing courses on bridge decks require replacement after a certain period of service. Normally, the underlying waterproofing membrane does not stay intact in the process of AC removal and has to be removed also. Employing AC/membrane removal procedures and equipment such as scarifiers, power shovels or graders usually results in irregularities in and disturbances to the concrete surface. New waterproofing membranes cannot be applied to these irregularities since they are not compatible with them. In view of this problem, WSDOT's bridge deck protective system selection criteria specify only a latex modified concrete overlay for protection of a bridge deck when removal of an AC/membrane system is required, until such time as a removal procedure is developed which will not result in damage to the underlying concrete.

EVALUATION OF AC REMOVAL EQUIPMENT

The New York State Department of Transportation evaluated three different systems for removing AC pavements on roadways by means other than scarification, which results in irregularities in the surface (67). These were heater-planer, hot miller and cold miller. They found in their examinations that the heater-planer planed and cut the pavement surface by creating surface temperatures over 350 degrees F. (176 degrees C.) (67). This was produced by open-flame heat, which penetrated the surface to a depth of only 0.25 in. to 0.40 in. (6.35 to 9.5 mm.). The equipment was able to cut 0.4 in. (9.5 mm.) deep in one pass since the key to planing the pavement was the depth the heat could penetrate. The remaining surface was reported smooth but abrasive in texture. The hot miller milled the pavement surface after heating it with both open-flame and infrared burners. Due to the milling action, it could cut 2 in. (51 mm.) deep in one pass, leaving a waffle textured surface with striations no more than 0.4 in. (9.5 mm.) deep. The cold miller milled the pavement to a depth of 2 in. (51 mm.) without heat. The resulting surface was also waffle textured with striations no more than 0.4 in. (9.5 mm.) deep.

From the above description of the equipment's performance, it seems that the best alternative for removal of AC on concrete bridge decks may be equipment similar to the heater-planer in performance, since it results in minimum surface disturbance and irregularities after the planing action. In using the equipment on AC overlayed bridge decks, the best procedure may be to first determine the thickness of the AC/membrane with a non-destructive method such as radar (see Ref. 6), adjust the number of passes so that a very small thickness of the system is left in place, and remove that layer with another operation such as sand blasting. Sand blasting has been successfully used in the course of a TRAC-WSDOT research project to clean and remove the remainder of a membrane (mainly primer) from a concrete surface after the membrane system had been removed with a jackhammer. However, more investigations, as well as field trials, are needed to verify the feasibility of the suggested procedure.

An alternative to sand blasting may be flame cleaning. According to research conducted by the Swedish Cement and Concrete Research Institute, flame cleaning concrete is done by passing a special multi-flame blow pipe (temperatures approximately 5780 degrees F. or 3100 degrees C.) at a uniform speed over the concrete surface (8). The cleaning is achieved by surface scaling or partial melting of the surface concrete. Any melt residue or loose surface particles are then removed with a rotating wire brush or surface scaler. As reported, flame cleaning is capable of removing paint layers of average thickness and plastic coatings 39-79 mils (1-2 mm.) thick without any problem (68). The research showed that flame cleaning at normal blow pipe speed does not cause any significant deterioration of the basic material properties of the concrete (68). Detailed information regarding the flame cleaning procedure and its effects on the properties of concrete can be found in reference 68. More investigations and field trials, however, are needed to verify the feasibility of the procedure on the concrete bridge decks.

On a sound membrane, cold-planing and replacing only the upper layer of wearing course, with no disturbance to the membrane, may be possible if the asphalt thickness is determined using radar prior to the operation (6).

COMPATIBLE WATERPROOFING MATERIAL

Recently an asphalt mix which offers waterproofing properties has been developed. The waterproofing mix, like any other asphalt concrete mix, can fill holes, low spots, or any other irregularities on the surface. It can then be compacted to the desired thickness. The waterproofing mix incorporates an admixture into the asphalt concrete mix which provides virtually zero voids (69,70). The new product, developed by Royston Laboratories, was first used in 1979 on a Pennsylvania bridge deck at a thickness of 3/4 in. (19mm.). Following this a 3 in. (76mm.) AC wearing course was applied (69). A newer formulation of the waterproofing mix, applied recently on another Pennsylvania bridge deck, formed a wearing course and waterproofing course in one layer 1 in. (25 mm.) thick. The overall performance of the system after 4 winters has been reported satisfactory (70).

Since there are rubber and platicizers in the binder, which can make the mix rubbery in low temperatures, a rolling temperature of 350 degrees F. (177 C.) or better has been recommended (70).

5.2 - FAST SETTING MIXES FOR REPAIRING CONCRETE

Polymer concretes have been used as fast setting mixes for the rapid restoration of concrete bridges when disruption to traffic would have been costly and undesirable. Decks have been restored with fast setting mixes both prior to the application of an AC/membrane system and when the concrete repair has been intended to last only a few years before the deck has been totally replaced or rehabilitated. Although expensive in material cost, the use of polymer concretes has been economically justified because it allows the bridge to be opened to traffic soon after the repair job has been finished (3).

MATERIAL AND CONSTRUCTION

The material characteristics of polymer concretes are discussed in Section 3.1.4 (thin polymer concrete overlays). For preparation of polymer patch material, components of the polymer are first mixed and combined, then aggregate is added, and then the entire mixture is thoroughly blended (73). Both conventional and special mixing systems have been used (73). Removal of unsound concrete is part of the partial depth repair job involving fast setting mixes. The perimeter of the unsound concrete, and delaminations, is first saw cut to a depth of 1 in. to 2 in. (25 to 5 mm.) in order to provide a maximum bond free of feather edges (3,73). During saw cutting a "keying" action can be created by riding one wheel on a plank which cuts the edge of the repair area at a slight angle (73). It is recommended that the saw cut line be located several inches outside the visual limit of the defect to insure removal of all unsound concrete (26). Concrete within the defect is then removed using hammers restricted typically in size to a maximum of a 30 - lb (14 kg) jackhammer above the top rebar and a 15 - lb (7 kg) chipping hammer below the rebar (3). Where unsound concrete should be removed below the rebar level, a clear space of 1/4 in. (6 mm.) plus the maximum size of the aggregate used in repairing the concrete must be provided (3). The bottom of the cutout should not be improperly irregular (26). This situation could prevent wetting the entire concrete surface with polymer material and thus reduce adhesion for good performance (74). After cleaning the concrete surface and exposed rebar and before placing the patch material, a bonding agent for the binder is brushed onto the face of the old concrete (73).

APPLICATION AND PERFORMANCE

Fast setting mixes have been used for patching concrete bridge decks in Washington. Polymer concrete was used in the partial depth repair and restoration of the Methow River bridges in 1976 prior to waterproofing the decks with AC/membrane systems (71). In the case of the Methow River bridges, some difficulties were reported with finishing the patch, since it set rapidly and was hard to strike off and trowel to an acceptable surface (71). Temperatures above 80 degrees F. (27 degrees C.) were reported at the time of repair. Polymer concretes can exhibit a shortened working life and an increase in viscosity at high and low temperatures, respectively. To eliminate this problem, precooling and preheating the components before mixing has been recommended for epoxy concretes (26).

After three years of monitoring a bridge deck in Minnesota which in 1976 had been partially depth repaired with polymer concrete and no overlay, no disbonding was evident when the bridge was surveyed with a DeLam Tech (27). However, the surfaces of the patched areas did show evidence of some peripheral cracks near the bond line and some cracks through larger patches (27).

Polymer concrete can be used as an alternative to cement concrete when repairing bridge decks. The choice of repair concrete depends on different factors including the size of repair job and the volume of traffic. However, although the material can save the travelling public time during the rehabilitation period, it may not be economical when the repair area is large, since it is expensive and difficult to handle when used in large volumes unless special equipment is employed. Among the disadvantages of polymer concrete are: 1) its relatively large coefficient of thermal expansion which can result in thermally induced cracks in either the substrate or the patch itself (29); its creep, which is higher than that of concrete and is enhanced at high temperatures (75); and its sensitivity to temperature during placing (26, 72).

5.3 - TRAFFIC CONTROL'S IMPACT ON THE QUALITY OF REPAIR

Concerns have been expressed in the past over the susceptibility of freshly placed concrete on bridge decks to the effects of traffic-induced vibration. It has been speculated that the vibration caused by the traffic maintained on a concrete bridge deck during patching, overlaying, or widening may cause defects in the plastic concrete such as ingredient segregation, differential settlement, loss of bond between the overlay and underlying concrete, and loss of bond between the rebar and concrete. With the exception of a few detailed, published investigations, there are few reports in the literature regarding the effects of traffic-induced vibration during construction on the performance of concrete decks (11). In his synthesis conducted to determine the effects of traffic-induced vibration on concrete Maning, reporting on the partial-depth repair of bridge decks as well as bridge deck overlays, said (11):

> In not one survey were traffic-induced vibrations found to have a significant effect on cracking, debonding, delamination, or the ride-quality index; nor has a single case study been documented that shows defects to have been caused by traffic induced vibrations at the time of construction.

Regarding bridge deck full-depth repair, widening and replacement, Maning reported (11):

> Concrete in a bridge widening is more vulnerable to the effects of traffic-induced vibrations than concrete in an overlay, especially at the time of inital set....there are few documented cases of poor performance. This is largely explained by the fact that good-quality concrete has been shown to be unaffected by continuous vibrations. Measurements have shown that the maximum curvature in a typical highway bridge is less than that which causes cracking in the concrete.

He concluded in the synthesis that there are only two documented cases of adverse effects on bridge deck widening from traffic-induced vibration: rippling and fracture-plane development in Michigan bridges widened in the mid- and late-'60s, and presence of voids around reinforcing steel near the joint line in a bridge in Texas. In Michigan the problems were caused primarily by excess water in the concrete and small concrete cover over the rebar; in the Texas bridge there was unusual reinforcement detail in which reinforcing steel extending from the old concrete was bent 90 degrees in the new concrete.

In an investigation of the field performances of 132 bridge decks overlaid with latex modified concrete in Ohio, Michigan, Kentucky and West Virginia, Bishara concluded (16):

> Bridges that are open to traffic during placement of a latex overlay generally exhibit a higher degree of surface distress than those that are closed to traffic. Statistically, this increase was found to be insignificant for the sample studied. Thus, it would seem unwarranted to require the closing of decks to traffic during placement of latex overlay. However, it is certainly beneficial to restrict speed or to place the overlay at night or at other times when traffic volume is low.

Regarding traffic control on bridge decks during construction, Maning reached the conclusion that speed and weight restrictions should be established using safety as the main criteria, since the restrictions have only a secondary effect on the magnitude of traffic-induced vibrations (16). He also reported that irregularities in the bridge approach or deck surface are the main cause of vibration; thus consideration should be given to repairing the irregularities (16).

In the state of Washington traffic is usually permitted on bridges during repairing, overlaying, or widening of the decks. However, there are speed restrictions. Depending on the bridge and traffic conditions, speed may be limited to 35-25 miles/hr (56-40 km/hr). Generally, there are no restrictions on vehicle weight unless a structural analysis of the bridge indicates the necessity for weight limitations.

6 - BRIDGE DECK CONDITION SURVEY TECHNIQUES

This section will furnish and update information regarding two bridge deck condition survey techniques, namely half-cell corrosion detection and thermography delamination detection. These progressive techniques have shown potential for supplementing those routinely used by WSDOT. Thus, they could expedite the deck condition survey process, providing additional information which might not be obtained by the conventional methods presently used.

6.1 - HALF-CELL CORROSION DETECTION

Half-cell corrosion detection was first developed in California and has been promoted by FHWA (3). The corrosion detection method has been used by WSDOT on research and special projects for bridge deck condition evaluation. Some authorities consider it a well established testing procedure to detect corrosion activity and use it as a routine evaluation technique for field condition survey (6,87). The results of half-cell testing, however, have not always been consistent and on some occasions additional information may be needed to interpret them. The test method and the suggested criteria for interpretating its results are described in ASTM C876 and will not be repeated here. The following will review the experiences of Washington and of other states and authorities with the half-cell testing method.

WASHINGTON EXPERIENCE (2)

Half-cell corrosion detection has been employed by WSDOT on different research projects in the past, and the reliability of the technique will be further investigated (7,2). The method was used to detect rebar corrosion in the asphalt covered deck of Ebey Slough bridge. Portions of the deck had been deteriorated and subsequently patched with a new asphalt mix, whereas the rest of the deck seemed to be sound. The measured potentials on the deteriorated portion, which had a higher level of chloride contamination, were found significantly higher than those on the sound portion. The corrosion test was also employed on the Columbia River bridge deck after stripping its AC/membrane system. Among the three different test sections in this case the one with the highest level of deterioration showed the highest level of half-cell potential and frequency and the smallest magnitude of concrete cover. At Roza Canal bridge, measured half-cell potentials, although all small in value, showed good correlation with the chloride content in the concrete, which was also small in value.

EXPERIENCE OF OTHER STATES AND AUTHORITIES

A half-cell survey of many bridge decks in California (89) confirmed that half-cell testing could usually be trusted to accurately report active rebar corrosion when half-cell potential values were numerically greater than -0.35 v (CSE). The study, however, indicated that for potentials numerically less than -0.35 v (CSE) additional information, such as plotted equipotential contours that could indicate the anodic or corroded areas, was needed to determine corrosion activity. The work showed that the minimum chloride contamination level associated with the incidence of active corrosion was about 1 lb/cy (0.59 kg/m3). Delaminations generally coincided with the average potential value of -.385 v (CSE). The study also found that repairing delaminations in chloride contaminated concrete reduced the percentage of corrosion potentials by half.

A bridge deck condition survey in Kansas showed that generally older decks have somewhat higher potential values than younger ones (86). However, active potentials were detected even in some new bridges. In one case, half-cell measurements showed active potentials (higher than 0.35 v CSE) when there was no sign of delaminations or spalls. About a year later both types of deterioration were detected in the area of active corrosion.

In Ohio, a condition survey of bridge decks which had been rehabilitated and overlaid with latex modified concrete found that it becomes harder to detect areas of active corrosion, or potential values numerically greater than -0.35 v (CSE), over time (16). However, the survey showed that when measured at crack locations, active potentials can still be obtained. regarding Michigan bridges, the same survey indicated that testing close to expansion joints and the curb lines will yield relatively higher half-cell readings (16). This was attributed to the presence of exposed steel dams at the expansion joints and more concentration of salt brine near the curb lines. It was also found that relatively lower potential values and chloride content existed where the overlay was thicker. The investigation concluded that the cumulative-frequency distribution curves clearly represented half-cell potential values and their evolution over time on the bridge decks.

Work in Ontario using half-cell, cumulative-frequency distribution curves has shown that a significant reduction in corrosion activity occurs immediately after the contaminated, deteriorated concrete is removed from around the reinforcing steel, which usually has the highest corrosion activity (19). Continuous monitoring of this type of rehabilition, however, has indicated that the initial reduction in corrosion activity may not be sustained and that the overall level of corrosion activity may gradually increase. In one case in which a deck was waterproofed after repair and the overall corrosion activity had increased, five cores were taken at those locations where the potential was -0.50 v (CSE) or numerically greater. Three of the cores were found to be delaminated. In a comparison of the pre- and post-paving conditions of a deck which had not been repaired prior to paving, the plotted half-cell equipotential contours showed similar patterns (6). However, the absolute potential values for the post-paving condition were relatively small and included some positive values. This was speculated to be the result of changes in the moisture content of the deck slab after paving. It was also concluded that the range of potential values, including negative and positive values, might have indicated the existance of anodic and cathodic areas on the deck just as the absolute potential values would.

METHODS OF INTERPRETATION

Half-cell, cumulative-frequency distribution curves seem to be the best method to monitor and evaluate overall variations in rebar corrosion activity over time. Shifting of the curves over time to the right or left will indicate a decrease or increase in the corrosion activity of a bridge deck. The procedure is, thus, a relative one and does not totally require the suggested, empirical, active corrosion potential values for interpretation of the overall corrosion activity of a deck. It is believed that the preferred procedure in this regard is to take the potential readings biannually, in winter and summer, and compare the results of each season separately. This procedure can reduce the influence of factors such as the ambient temperature and moisture content of the concrete on half-cell readings. The measurements should be taken at the same locations when conducting each survey in order to eliminate the effects of measuring areas with cracks, areas near curbs, areas close to expansion dams, or areas with thicker concrete cover. Each survey should also utilize the same ground connection.

Another useful method for interpreting half-cell readings is the use of half-cell equipotential contours, especially when the intent is to determine the location of anodic and cathodic areas developed on the deck. In this case the pattern of the contours as well as the range of potential values can be used to indicate the existence of corrosion activity on the deck.

A FEW TIPS REGARDING THE HALF-CELL TEST METHOD

Half-cell corrosion detection was originally a laboratory testing procedure which has been taken to the field. Although the test procedure seems simple, there are a few points which must be carefully observed, otherwise the results can be significantly affected. The following are a few tips regarding a correct half-cell testing.

- Readings should not be taken when the temperature is lower than 40 degrees F. (5 degrees C.) (87). However, the recommended temperature is higher than 50 degrees F. (10 degrees C.) (3).
- The bridge deck surface must be dry for the test (89).
- The concrete must be pre-wetted, if needed, as directed by ASTM C876.
- The copper sulfate solution must be saturated to yield a standard potential. In a saturated solution an ex-

cess of undissolved crystals lies at the bottom of the solution. Diluted solutions can produce erroneous results (88).

- The copper sulfate solution should be renewed either monthly or before each use, whichever is the larger (ASTM C876).
- The porous plug should be covered when not in use for long periods of time so that it will not become dried and dielectric (ASTM C876).

6.2 - THERMOGRAPHIC DELAMINATION DETECTION

Presently there is great need for a technique which can detect concrete deterioration in ashpalt covered decks. Although very efficient on bare concrete decks, chain dragging is not totally successful in defining concrete delaminations when used on asphalt covered decks (2,6). Previous experience has indicated that chain dragging asphalt covered decks may only define highly developed delaminations and those which have reached the concrete surface and turned into spalls under the asphalt pavement (2). This situation has made difficult the assessment of asphalt covered decks presently under service and their performance almost unpredictable.

The technique which has shown the greatest potential for detection of delaminations in exposed and asphalt covered decks is infrared thermography. The technique is based on detecting infrared radiation emitted by the deck. The delaminations which are occupied by trapped air possess different heating/cooling rates than the main mass of concrete and, therefore, are detectable under proper environmental conditions by their different infrared radiation emissions. The temperature difference between the delaminated and solid concrete is the result of the lower volumetric heat of the air than that of the concrete, which means that when the solar heating is active a delaminated concrete will be warmer than the solid concrete and when the solar heat disappears the reverse will occur (87). This difference in temperature can be scanned with a special camera which will produce a thermal image. In a black and white picture the light and dark areas represent warm areas (delamination) and cold areas (solid concrete), respectively. The thermal image can also be colored, with the various colors representing different temperatures or different levels of deterioration (87).

The efficiency of the thermography thus depends on the difference in temperature between the delaminations and the mass of concrete. Tests in Virginia found that on exposed decks under direct solar heating the period between 12:00 noon and 2:00 p.m. provides maximum delamination detectibility as well as a temperature stability profile of the deck area (87). The tests, which used color thermal images, indicated the ability of the technique to disclose even incipient delaminations which were not detected by other methods. The only shortcoming of the technique was its relatively high cost when compared to conventional survey techniques. The study concluded that the use of thermography to rapidly survey a large number of bridge decks should be developed for cost-effectiveness (87).

In the state of Washington a thermographic survey for delamination detection on an exposed bridge deck was conducted in 1982. The study reported that the method worked to some extent under ideal environmental conditions, but it was not competitive with chain dragging from a time or economic standpoint.

A thermographic survey on an asphalt covered deck in Ontario showed that differences in surface temperature in asphalt covered decks develop more slowly than in exposed decks and are more sensitive to weather conditions (6). It was found that a successful thermographic survey needed an air temperature greater than 46 degrees F. (18 degrees C.), a wind velocity smaller than 24 ml/hr (40 km/hr), and a relative humidity less than 50 percent. Under these conditions the delaminations could be identified during the period of 11:30 a.m. to 6:00 p.m. In this study the scanner detected more than 90 percent of the known delaminations on black and white thermal images though the outline of the delaminations were less distinct. Chain dragging asphalt, on the other hand, only disclosed 13 percent of the known delaminations. A boom truck was used as a platform for the camera with a height above the deck between 13 ft. (4 m.) to 20 ft. (6 m.) for the best definition of delaminated areas. The boom truck provided accuracy and speed. The study concluded that the method had considerable potential for evaluating the condition of a large number of asphalt-covered decks in a short time.

7 - CAUSES OF CONCRETE DETERIORATION

Two causes of concrete deterioration, namely "reactive aggregate" and "freeze-thaw action," will be discussed in this section in order to better identify the problems associated with them and to seek solutions to those problems when concrete structures could be affected by them.

7.1 - REACTIVE AGGREGATE

NATURE OF PROBLEM

It has been shown that some aggregate with certain chemical components will react with alkalies in cement (76,78,79,80). This reaction can cause expansion of the aggregate and subsequent pattern cracking of the concrete. Accumulation of water in the cracks can worsen the situation in the presence of freeze-thaw action. Studies in Kansas regarding the deterioration of concrete roadways have shown that fine surface cracking as a result of reactive aggregate can occur first in the vicinity of the transverse joints (80). Later, water enters the cracks and promotes the freeze-thaw deterioration of the concrete and the coarse aggregate. The freeze-thaw deterioration can then extend deep in the concrete. Kansas has reported that reactive aggregate in bridge decks is responsible for formation of small hollow planes above the rebar, which can create popouts if close enough to the surface (86). A survey of reactive aggregate deterioration in Ontario's concrete structures has found that the pattern cracking caused by reactive aggregate is always worse in the following two circumstances: where water is readily chanelled over the face of the concrete, and where there is a source of water available behind or under the concrete which can transpire from its exposed face (76). Investigations of bridge deck deterioration in Virginia have found that reactive aggregate can be a strong determinant of concrete performance (79). A survey conducted on bridges having similar designs and materials, except for differences in their coarse aggregate, indicated that 90 percent of the decks containing aggregates known as non-reactive were free of pattern cracking and scaling. On the other hand, only 15 percent of the decks containing a reactive aggregate were free of those defects. The study concluded that the increasing alkalies in concrete containing reactive aggregate increases expansion and causes cracking, which in turn lowers freeze-thaw resistance. Sodium chloride used for deicing in winter has been reported to contribute to the deterioration by regenerating alkali in the concrete if alkali-aggregate reaction occurred (76,80).

IDENTIFYING REACTIVE AGGREGATE

There are three ASTM test methods for identifying alkali reactive aggregate. The ASTM C277 and C289 test methods are for siliceous type aggregate and the ASTM C586 test method is for carbonate type aggregate. Additionally, the ASTM C295 test method, which is based on optical microscopy, can be used for petrographical examination of aggregates of both types (13). In the ASTM C277 test method, expansions developed in mortar-bar specimens made of siliceous type aggregate are stored under certain laboratory conditions and measured in three to six months. The ASTM C33 appendix indicates that expansions greater than 0.05 percent after three months or 0.10 percent after six months are generally considered expansive. However, recent investigations by Stark and Portland Cement Association have shown that the test period needs to be extended to 12 months with certain types of aggregate. ASTM C289 is a quick test method for siliceous type aggregate and is completed in two or three days (13). The test measures the degree of reaction between a crushed aggregate and a sodium hydroxide solution. The test, however, should be accompanied with a petrographic examination of the aggregate for conclusive results (13). The mortar-bar test (ASTM C227) for siliceous aggregate is reported to give the best correlation of the performance of concretes in pavements and structures (13).

The ASTM C586 test method determines potentially expansive carbonate aggregates based on the expansion of rock cylinder specimens while they are immersed in a sodium hydroxide solution for 28 days. In cases of expansion in excess of 0.10 percent, ASTM requires additional testing, preferably in concrete, in order to identify the exact nature of the carbonate aggregate.

Some specifications clarify carbonate rock specimens having more than 1 percent expansion in alkali solution after 84 days as potentially reactive (77). Concrete prisms are used to identify reactive carbonate rock in Canada. In such cases the expansion of the concrete prisms for 84 days is not to exceed 0.02 percent (76). It has also been reported that the rock cylinder test cannot be used as the sole basis for rejecting concrete material and that material identified as reactive in the rock cylinder test should be evaluated in concrete prisms before a decision is made to accept it (78).

From this discussion it is apparent that the final decision on classifying an aggregate harmless or potentially reactive may ultimately require further information and that engineering judgment may be required as well.

SOLUTIONS TO THE PROBLEM

If possible, aggregates classified as potentially reactive should not be used in concrete of bridge structures and should be avoided with selective quarrying. However, this may not always be feasible. In this cases the following solutions to the problem are reported (77):

- Specify the use of low-alkali cement in the concrete (alkali < 0.45 percent of cement expressed as NA2 0 (76)).
- Specify the minimum aggregate size possible.
- Dilute the aggregate so that the potentially reactive aggregate will be limited to 20 percent of the coarse or fine aggregate or 15 percent of the total if both contain reactive aggregate.

7.2 - FREEZE-THAW ACTION

NATURE OF PROBLEM

Freeze-thaw action affects the durability of concrete bridge decks in two different ways (12). First, a freeze-thaw environment can be the sole cause of surface scaling in concrete decks. Second, it can contribute to spalling in concrete decks. Scaling, or deterioration of surface mortar, has been attributed to different factors including freeze-thaw and deicing chemicals (5,12). The mechanism by which freeze-thaw action causes scaling is postulated to be hydralic pressure. As water freezes in the concrete's surface capillaries, its volume expands and forces the excess water into the adjacent pores. This situation creates hydralic pressure, which in turn induces stress in the mortar fraction of the concrete that can rupture it (5,12). The process of scaling is further aggravated by salt. Freezing water in the capillaries results in a greater concentration of salt in those areas, consequently building osmotic pressure in the cavities, which may be sufficient to rupture the surface concrete and form scaling (82).

The rate of scaling in a freeze-thaw environment can also depend on the character and intensity of the stressed concrete, which might influence the distribution of moisture throughout the concrete (5). Laboratory investigations at the University of Illinois have found that static tensile stresses slightly accelerate the rate of scaling, whereas static compressive stresses retard it (5). On the other hand, cyclic tensile stresses have little influence on scaling, whereas cyclic compressive stresses have an accelerating effect on the rate of scaling.

In contrast to scaling, spalling in concrete decks may not solely occur in a freeze-thaw environment, but that environment can contribute to spalling and expedite the process of deterioration. Water can fill the cracks in the concrete deck, especially the transverse cracks usually formed above the topmost reinforcing steel. Upon freezing, water exerts pressure which results in tensile forces in the concrete. The combination of pressure from the corroded steel and the frozen water, as well as other factors, creates a critical section under the surface that cracks to the surface (12). Pressure from ice lenses formed in these cracks, as well as stress providing mechanical action for initiating and feathering the cracks, expedite the deterioration and form a complete fracture plane or spall (5,12).

Deterioration of concrete in a freeze-thaw environment can also occur by using freeze-thaw susceptible aggregates in the concrete. Freeze-thaw action first deteriorates the coarse aggregate, which in turn causes the deterioration of concrete. The degree of freeze-thaw susceptibility of the aggregate is thought to depend on the pore structure of the aggregate (84). This type of deterioration is generally a phenomenon of concrete pavements and the term "D-cracking" has been used to describe it. D-cracking in pavement slab appears in the surface in an orientation parallel to the transverse and longitudinal joints, and it may later progress into the central area of the slab (83). On bridge decks, deterioration caused by frost susceptible aggregate is reported in the forms of popout and surface pitting (85). Popouts have a conical shape, pittings are irregular voids, and both result from the fracturing and crushing of aggregate near the surface of the structure (85).

SOLUTIONS TO FREEZE-THAW PROBLEMS

Concrete scaling can be controlled by adequate and efficient air entrainment. Air entraining provides disconnected air voids which are extremely small in size and well distributed in the paste (13). Entrained voids remain free of moisture since they are larger than capillary voids (81). As the water freezes in the capillaries and hydraulic pressure is applied, the entrained air provides pockets for water to flow to (12). In other words, they act as resevoirs for the excess water forced into them. This relieves the pressure and prevents damage to the concrete (13).

Current air content limits range from 4 percent to 8 percent of the concrete, with the emphasis on the upper values of this range (20). The optimum air content of concrete is generally the one which corresponds to an air content of 9± percent in the mortar fraction (13,20). However, not only the gross air content contributes to the effectiveness of air entrainment in concrete, but the spacing and size of the air voids are also important factors (13). This means that the air void system should be uniformly distributed in the concrete (12). In hardened concrete, the linear traverse technique (ASTM C457), which is a micrometric analysis of a polished concrete surface, can be used to evaluate the air void system. The technique determines a spacing factor which is an approximation of the true distance between the voids, but it has proven to be useful in determining the durability of concrete (20). The following air void characteristics are reported in the PCA bulletin "Design and Control of Concrete Mixtures" as representative of a freeze-thaw resistant concrete in conjunction with the linear traverse technique (13):

- spacing factor of air voids less than 0.008 in. (0.203 mm.),

- specific surface of air voids 600 sq. in. per cubic in. (236 cm. per cm.) of air void volume, or greater,
- number of voids per linear inch of traverse significantly greater than the numerical value of percentage of air in the concrete.

Aside from proper air entrainment, there are other factors such as water-cement ratio, degree of consolidation, and proper finishing and curing which ensure good concrete durability. It has been reported that for good durability, concrete should be sufficiently air dried after curing and before the deicing salts are first applied (5,20). To insure sufficient air drying, some states have restricted on concreting during certain periods within the year (5).

Although efficient at preventingn scaling, air entrainment is not used to control concrete spalling. Prevention of spalling can be achieved by providing a thick, dense and impermeable concrete cover having proper finishing and curing. Additionally, the use of corrosion resistant reinforcing steel such as epoxy coated rebar is helpful in the prevention of spalling.

To prevent the type of deterioration caused by frost susceptible aggregate in concrete the size of the coarse aggregate can be reduced (83). However, the best procedure is to eliminate the use of frost susceptible aggregate in concrete. The PCA freeze-thaw procedure and the Iowa Pore Index test both have been used to identify frost susceptible aggregate (84). In the former test the aggregate is cast in a concrete beam and subjected to freeze-thaw cycles. Large increases in length indicate the nondurable aggregate. In the latter test the aggregate is placed in an air entrainment pot and water is added. Air is then applied with pressure to force water into the pores of aggregate. The volume of water that is forced into the aggregate indicates the Pore index. A high Pore index indicates a nondurable aggregate. More details regarding the test methods can be found in Reference 84.

8 - BRIDGE DECK MANAGEMENT SYSTEM

Due to the increasing number of bridge decks in need of repair and maintenance, the available funds do not presently permit rehabilitation of all deficient bridge decks. Therefore, the maintenance funds available should be carefully managed and directed to those bridges which are the most important links to the traveling public, providing the most economical treatment in each case. A pavement management system developed by WSDOT has proved to be an efficient tool with which to make rational decisions in dealing with roadway problems. A similar approach to decision making is currently needed to deal with the problems associated with bridges.

The term "Bridge Deck Management System," as used in this report, is meant to describe a methodology which would systematically predict and prioritize bridge deck treatment (i.e., replace ment, rehabilitation, and protection) at the network level. An ideal system would determine the time of treatment for each bridge deck by evaluating its present condition, predicting its future condition, and comparing it with an established bridge deck quality acceptability level. Therefore, two necessary aspects of the system are: 1) determination of a bridge deck quality index which would include parameters such as structural safety, concrete deterioration and contamination, and rebar corrosion; and 2) feedback on how well older decks, new decks, rehabilitated and protected decks are performing. At the network level, the system would then prioritize bridge deck treatment for the group of decks whose quality fell below the acceptable level at any particular time. Additionally, the system should determine the most cost-effective method of treatment for each case.

The establishment of priorities for bridge deck treatment would be based on different factors including safety aspects of the structure, location of the structure, its importance in the highway network, and deferred rehabilitation and protection costs. The latter factor corresponds especially to deterioration prevention. In most cases protecting uncontaminated and sound bridge decks can be more cost-effective than rehabilitating and restoring them later.

Presently, however, due to the lack of sufficient information and feedback on the performance of bridge decks, including those built, reconstructed, and/or protected according to new regulations, predicting the conditions of bridge decks has been difficult, if not impossible. This in turn has limited the system to establishing deck treatment priorities before each construction season based on current deck condition ratings and rough estimates of performance.

BRIDGE DECK CONDITION RATING AND REPAIR PRIORITIES

The first step in establishing repair priorities for bridge decks is to rate and classify their conditions. Classification considers factors such as the levels of concrete deterioration, contamination and rebar corrosion. An FHWA bridge deck condition rating adopted from Ref. 93 is given in Table 1. As shown in the table, four condition categories are classified and each category is divided into three sub-categories having its own code or rating number. FHWA further specifies several restoration options for each bridge deck condition as illustrated in Table 2. The "cost-effective" restoration alternative in Table 2 does not require removal of contaminated concrete but requires buying only about 10-15 years of service until total replacement of the deck is scheduled. This can be an acceptable restoration procedure when a permanent reconstruction is not economically feasible or justified (8).

The Ontario Ministry of Transportation has also developed criterion for selection of bridge deck protective systems when rehabilitating them. Ontario's decision matrix for selecting deck protective methods is illustrated in Table 3. The decision matrix, which is based on deck condition, is built to lead by elimination to the protective system with a minimum of disadvantages (94).

Although FHWA's and Ontario's procedures for bridge deck reconstruction and protection specify different options for restoration, neither of the procedures assigns priority for bridge deck treatment. An approach with which to assign priori-

TABLE 1 - FHWA CONCRETE BRIDGE DECK CONDITION RATING

(Adapted from Reference 95)

Category Classification	Code	Condition Indicators (% deck area)			
	9	no spall	no delamination	0 half-cell	0 #/cy chloride
Category #3 Light Deterioration	8	no spall	no delamination	no half-cell > 0.35 v(CSE)	no chloride > 1.0 #/cy
	7	no spall	< 2% delamination	45% half-cell < 0.35 v(CSE)	no chloride > 2.0 #/cy
Category #2 Moderate Deterioration	6	< 2% spall or sum of all deteriorated and/or contaminated deck concrete < 20%			
	5	< 5% spalls or sum of all deteriorated and/or contaminated deck concrete 20 to 40%			
Category #1 Extensive Deterioration	4	> 5% spalls or sum of all deteriorated and/or contaminated deck concrete 40 to 60%			
	3	> 5% spalls or sum of all deteriorated and/or contaminated deck concrete > 60%			
Structurally Inadequate Deck	2	Deck structural capacity grossly inadequate			
	1	Deck has failed completely. Repairable by replacement only			
	0	Holes in deck - danger of other sections of deck failing			

TABLE 2 - FHWA BRIDGE DECK RESTORATION OPTIONS
(Adapted from Reference 93)

Deck Condition	Permanent Reconstruction	Cost-effective Reconstruction
Structurally Inadequate	A, B	
Extensive Deck Deterioration	A, B, C	D
Moderate Deck Deterioration	A, B, C, E	D
Light Deck Deterioration	C, E	D, F
Uncontaminated Deck	F	

RESTORATION WORK:

A: Complete deck replacement with Protective Sytems 1, 2, or 3.
B: Pour new deck on top of old with Protective Systems 1, 2, or 3.
*C: Install Protective System 4.
*D: Install Protective System 1 or 3.
**E: Install Protective System 1 or 3.
F: Install Protective System 1 or 3.

PROTECTIVE SYSTEMS:

1: Waterproof membrane and asphalt concrete overlay.
2: Epoxy-coated rebars.
3: Latex-modified or two coarse dense (Iowa system) concrete overlay.
4: Cathodic protection system.

* Remove and replace deteriorated concrete
** Remove and replace all contaminated concrete

TABLE 3 - ONTARIO'S DECISION MATRIX FOR SELECTION OF BRIDGE DECK PROTECTION METHOD
(Adapted from Reference 94)

Criterion	Concrete overlay	Waterproofing membrane and paving	Cathodic protection	Rationale
Delamination and spalls exceeding 10% of the deck area.		No	No	Where extensive patching is required it becomes more economical and more durable to construct a concrete overlay.
Corrosion potential more negative than -0.35 V over more than 20% of the deck area.		No		Patch repairs and waterproofing rarely reduce corrosion activity and may accelerate it.
Moderate or heavy scaling exceeding 10% of the deck area.		No	No	The amount of patching becomes too expensive and consequently uneconomical.
Active cracks in deck slab.	No			Cracks active under live load or temperature change are reflected in a concrete overlay.
Remaining life of structure less than 10 years.	No		No	Additional cost of a concrete overlay or cathodic protection is not justified.
Concrete not properly air entrained.			No	Application of a bituminous surfacing (without waterproofing) may accelerate deterioration of the concrete.

TABLE 3 (continued)

Criterion	Concrete overlay	Waterproofing membrane and paving	Cathodic Protection	Rationale
Complex deck geometry. Skew exceeding 45°, curvature exceeding 10°, or changing super-elevation.	No			Concrete finishing machines (especially those used for low-slump concrete) have difficulty accommodating complex geometry.
Limited load capacity of structure*.		No	No	Bituminous overlay is a non-structural component. Concrete overlay can be especially useful where the span/thickness ratio of deck slab exceeds 15.**
Electical power unavailable.			No	Power required for rectifier (unless mains, solar, wind or battery power can be provided economically.
Epoxy injection repairs previously performed and will not be removed.			No	Epoxy insulates underlying reinforcement from cathodic protection.

* Capacity after rehabilitation must be verified. Additional strengthening may be necessary.

** See Reference 94

ties to bridge deck treatments has been developed in Minnesota (91). Minnesota's method classifies the bridge decks not only based on their conditions but also on their traffic use. Minnesota's decision-making matrix for bridge deck repair priorities and restoration methods is given in Table 4. As indicated in the table, four groups of deck conditions based on concrete deterioration and three categories for traffic use are identified. The repair priorities follow the level of traffic volume, i.e., the decks with the higher traffic volume are taken care of first when all other factors are the same. Following this pattern the first and second priorities are assigned to the decks with the most critical level of deterioration. The third and fourth priorities, however, are given to the decks with a slight level of deterioration. The justification for this has been based on economical analysis by determining the cost/benefit ratio for each alternative. The same rationale has been used in completing Minnesota's repair priority matrix. Included in Table 4 are also restoration options for each priority. Concrete overlays generally are recommended unless the traffic volumes are low and bridge deck is not critically deteriorated in which case waterproofing membranes can be applied.

Alaska's bridge deck repair priority program, which was developed after the Minnesota program, is shown in Table 5 (93). The minor changes in the repair priorities of the Alaskan program are the result of the traffic condition of Alaska's bridges. For

TABLE 4 - MINNESOTA'S BRIDGE DECK REPAIR PRIORITY PROGRAM

(Adapted from Reference 91)

		Deterioration		Category A 10,000-100,000 ADT		Category B 2,000-10,000 ADT		Category C <2,000 ADT	
Group	Rating	%	Code	Priority	Procedure	Priority	Procedure	Priority	Procedure
1	Slight	0-5	9	3	Spot removal and concrete overlay	4	Spot removal and concrete or membrane and bituminous overlay	10	Spot removal and concrete or membrane and bituminous overlay
2	Moderate	5-20	7-8	6	Spot removal and concrete overlay	7	Spot removal and concrete overlay	11	Spot removal and concrete or membrane and bituminous overlay
3	Severe	20-40	5-6	8	100% removal to reinforcing bars, minimum spot removal below bars, concrete overlay	9	Spot removal and concrete overlay	12	Spot removal and concrete or membrane and bituminous overlay
4	Critical	40+	4 or lower	1	Program new deck	2	Spot removal and concrete overlay	5	Spot removal and concrete or membrane and bituminous overlay

TABLE 5 - RECOMMENDED ALASKA'S BRIDGE DECK REPAIR PRIORITIES
(Adapted from Reference 93)

Deck Condition	> 10,000 ADT or on major Intercity Route	2,000-10,000 ADT	< 2,000 ADT
Uncontaminated	3	4	8
Slight Deterioration	5	6	13
Moderate Deterioration	9	10	14
Severe Deterioration	11	12	15
Critical	1	2	7

Exceptions should be made for bridges whose decks are part of main structural support (e.g. bulb-tees). These bridges should receive priority over all other bridges in their traffic volume category.

example few bridges in that state, outside of urban areas, carry over 2,000 vehicles per day and few of Alaska's rural bridges have shown serious deck condition problems (93).

WSDOT has developed a bridge deck repair priority program similar to Minnesota's. This is illustrated in Table 6. As indicated in the table, three groups of deck conditions based on concrete deterioration and concrete contamination with chloride, and three categories for traffic use are identified. Although this makes the WSDOT's priority matrix 3 by 3, the pattern and rationale for assigning priorities follow Minnesota's program, i.e. economical analysis and deferred maintenance costs are used as the basis for establishing priorities. The protective system option for each repair priority is then determined based on WSDOT's protective system selection criteria for concrete bridge decks dated April 19, 1984 (see appendix A, Project Design, Task one). As indicated in Table 6, decks rated severely deteriorated or contaminated and those with traffic use in excess of 10,000 ADT are only restored and protected with latex-modified concrete overlay. Decks having other conditions, however, may be protected by asphalt concrete and waterproofing membrane systems. Another factor dictating repair priority in WSDOT' program is the type of span. For example, spans such as box girders, bulb tees, or post-tensioned decks have higher repair priority since dete-

TABLE 6 - WSDOT'S BRIDGE DECK REPAIR PRIORITY PROGRAM

						Traffic Category (ADT)		
	Group	Rating	Code	$\bar{c}l$ >2#/cy	Deterioration	> 10,000 (Priority)	2,000 - 10,000 (Priority)	< 2,000 (Priority)
Deck Condition	1	slight	8	none	<2%	3(LMC)*	4(LMC-AC)**	8(LMC-AC)
			7	none	<2%			
	2	moderate	6	<20%	2-5%	6(LMC)	7(LMC-AC)	9(LMC-AC)
			5	20-40%	2-5%			
	3	severe	4	40-60%	>5%	1(LMC)	2(LMC)	5(LMC)
			3	>60%	>5%			

*Restoration method using latex modified concrete overlay (see Appendix A, Task one).

**Restoration method using latex modified concrete overlay or asphalt concrete and waterproofing membrane (see Appendix A, Task one).

rioration could seriously impair their integrity and later repair could be costly and complex.

REFERENCES

1. Babaei, K. and R.L. Terrel, "Deterioration of Concrete Bridge Decks and Review of WSDOT Bridge Deck Program," Washington State Transportation Center, a report prepared for Washington State Department of Transportation (1982).

2. Babaei, K. and R.L. Terrel, "Performance Evaluation of Waterproofing Membrane Protective Systems for Concrete Bridge Decks," Washington State Transportation Center, a report prepared for Washington State Department of Transportation, (1983).

3. "Durability of Concrete Bridge Decks," NCHRP Synthesis 57, (1979).

4. "Cement-Aggregate Reaction," Transportation Research Record 525, (1974).

5. Callahan, J.P., C.P. Siess and C.E. Kesler, "Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks," NCHRP Report 101, (1970).

6. Manning, D.G. and F.B. Holt, "Detecting Deterioration in Asphalt Covered Bridge Decks," a paper for presentation at the Annual Meeting of the TRB, Research Development Branch, Ontario Ministry of Transportation and Communication, (1983).

7. Demich, G.F., "Investigation of Bridge Deck Deterioration Caused by De-icing Chemicals," Washington State Highway Department Research Program, Report No. 20.1, (1975).

8. FHWA, Region 10 Position paper on Concrete Bridge Decks, (1981).

9. Moore, D.G., D.T. Klodt and R.J. Hensen, "Protection of Steel in Prestressed Concrete Bridges," NCHRP Report 90, (1970).

10. WSDOT Bridge Deck Protection System Selection Criteria (1984).

11. Manning, D.G., "Effects of Traffic-Induced Vibrations on Bridge-Deck Repairs," NCHRP Report 86 (1981).

12. "Concrete Bridge Deck Durability," NCHRP Report 4 (1970).

13. "Design and Control of Concrete Mixtures," Portland Cement Association, Engineering Bulletin, (1968).

14. "Bridge Deck Program," WSDOT (1982).

15. Kuhlmann, L.A., "Performance History of Latex-Modified Concrete Overlays," ACI Publication Sp-69 (1981).

16. Bishara, A.G., "Latex Modified Concrete Bridge Deck Overlays, Field Performance Analysis," Transportation Research Record 785 (1980).

17. Clear, K.C., "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs, Volume 3: Performance After 830 Salting Application," Report No. FHWA-RD-76-70, Federal Highway Administration, (1976).

18. Clear, K.C. and B.H. Chollar, "Styrene-Butadiene Latex Modifiers for Bridge Deck Overlay Concrete," Report No. FHWA-RD-78-35, Federal Highway Administration (1978).

19. Manning, D.G. and J. Ryell, "Decision Criteria for the Rehabilitation of Concrete Bridge Decks," Transportation Research Record 762, (1980).

20. Whiting, D. and D. Stark, "Control of Air Content in Concrete," NCHRP Report 258 (1983).

21. O'Connor, E.J., "Iowa Method of Partial-Depth Portland Cement Resurfacing of Bridge Decks," Chloride Corrosion of Steel in Concrete, American Society for Testing and materials, Publication STP 629, (1977).

22. Brown, B.C., "A Further Evaluation of Concrete Bridge Deck Surfacing in Iowa," Iowa Department of Transportation, Ames, Special Reports, (1979).

23. Whiting, D., "Evaluation of Super-Water Reducers for Highway Applications," Federal Highway Administration, Report No. FHWA/RD-80/132, (1981).

24. Ramakrishnan, V. and W.V. Coyle, "Superplasticized Concretes for Rehabilitation of Bridge Decks and Highway Pavements," Federal Highway Administration, Report No. DOT/RSPA/DPB-50/81/3, (1981).

25. Ramakrishnan, V., W.V. Coyle, P.A. Kopac and T.J. Pasko, "Performance Characteristics of Steel Fiber Reinforced

Superplasticized Concrete," American Concrete Institute, Special Publication, SP68-29, (1981).

26. "Use of Epoxy Compounds with Concrete," Journal of American Concrete Institute No. 9, Volume 70, (1973).

27. Fontana, J.J. and J. Bartholomew, "Use of Concrete Polymer Materials in the Transportation Industry," Application of Polymer Concrete, American Concrete Institute, Publication SP-69, (1981).

28. McConnell, W.R., "Epoxy Surface Treatments for Portland Cement Concrete Pavements," Epoxies with Concrete, American Concrete Institute, Publication SP-21, (1968).

29. Sprinkel, M.M., "Thermal Compatibility of Thin Polymer Concrete Overlays," Bridge Inspection and Rehabilitation, Transportation Research Record 899, (1983).

30. Van Til, C.J., B.J. Carr, and B.A. Vallerga, "Waterproof Membranes for Protection of Concrete Bridge Decks," NCHRP Report 165, (1976).

31. Chamberlin, W.P., R.J. Irwin and D.E. Amsler, "Waterproofing Membranes for Bridge Deck Rehabilitation," Engineering Research and Developing Bureau, New York State Department of Transportation, Research Report 52, (1977).

32. LaCroix, J.E., "Bridge Deck Condition Survey," Illinois Department of Transportation, Bureau of Materials and Physical Research, Physical Research No. 94, (1981).

33. Ross, J.E. and S.M. Law, "The Protection Effectiveness of Waterproof Membrane Systems on Bridge Decks in Louisiana," Louisiana Department of Transportation and Development, Office of Highways, Research and Development Section, Report No. FHWA-LA-78-121, (1978).

34. Swanson, H.N. and D.E. Donnelly, "Evaluation of Bridge Deck Repair and Protective Systems," Colorado Division of Highways, Planning and Research Branch, Report No. FHWA-CO-RD-77-8, (1977).

35. Corkill, J.T., "A Field Study of the Performance of Bridge Deck Waterproofing Systems in Ontario," Ontario Ministry of Transportation and Communication.

36. Fromm, H.J. and G.P. Wilson, "Cathodic Protection of Bridge Decks: A Study of Three Ontario Bridges," Transportation Research Record 604, (1976).

37. Vrable, J.B., "Cathodic Protection for Reinforced Concrete Bridge Decks," NCHRP Report 180, (1977).

38. Brown, R.H. and R.B. Mears, "A Theory of Cathodic Protection," Trans. Electrochem. Soc., Vol. 74, (1938).

39. Stratfull, R.F., "Experimental Cathodic Protection of a Bridge Deck," Federal Highway Administration, Interim Report No. FHWA-RD-74-31, (1974).

40. Jackson, D.R., "Demonstration Project No. 34, Cathodic Protection for Reinforced Concrete Bridge Decks," Federal Highway Administration, Interim Report No. FHWA-DP-34-2, (1982).

41. Whiting, D. and D. Stark, "Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks," NCHRP Report 234, (1981).

42. Fromm, H.J., "Successful Application of Cathodic Protection to a Concrete Bridge Dekc," Transportation Research Record 762, (1980).

43. Nicholson, J.P., "New Approach to Cathodic Protection of Bridge Decks and Concrete Structures," Transportation Research Record 762, (1980).

44. Reckard, M., "Cathodic Protection of Concrete Bridge Decks in Alaska," The Northern Engineers, Vol. 15, No. 1, (1983).

45. Fromm, H.J. and F. Pianca, "Evaluation of Platinized Niobium Wire Anodes for Cathodic Protection of Bridge Support Structures," Transportation Research Record 860, (1982).

46. Clifton, J.R., H.F. Beeghly and R.G. Mathey, "Non-Metalic Coatings for Concrete Reinforcing Bars," Federal Highway Administration, Report No. FHWA-RD-74-18, (1974).

47. Pike, R.G., R.E. Hay, J.R. Clifton, H.F. Beeghly and R.G. Mathey, "Nonmetalic Protective Coatings for Concrete Reinforcing Steel," Corrosion and Corrosion Protection, Transportation Research Record 500, (1974).

48. "Epoxy Coated Reinforcing Bars," Concrete Reinforcing Steel Institute, Engineering Data Report No. 14, (1983).

49. Hill, G.A., D.C. Spellman and R.F. Stratfull, "Laboratory Corrosion Tests of Galvanized Steel in Concrete," Transportation Research Record 604, (1976).

50. Hagen, M.G. and R.G. Tracy, "Performance Evaluation of Bridge Deck Protection Systems, Vol. III," Minnesota Department of Transportation, Report No. FHWA/MN/RD-79/03, (1978).

51. Cornet, I. and B. Bresler, "Corrosion of Steel and Galvanized Steel in Concrete," Materials Protection, Vol. 5, No. 4, (1966).

52. Arnold, C.J., "Galvanized Steel Reinforced Concrete Bridge Decks: Progress Report," Federal Highway Administration, Report No. FHWA-MI-78-R1033, (1976).

53. "Tentative Recommendations for the Corrosion Protection of Unbonded Tendons," PCI Journal, Vol. 28, No. 1, (1983).

54. "Tentative Recommendations for the Corrosion Protection of Unbonded Tendons," Reader's Comments, PCI Journal, Vol. 28, No. 6, (1983).

55. "Tentative Recommendations for Concrete Members Prestressed with Unbonded Tendons," ACI Manual of Concrete Practice (Part 3), (1983).

56. "Post-Tensioning Manual," Post-Tensioning Institute, (1976).

57. Schupack, M., "Behavior of 20 Post-Tensioned Test Beams Subject to up to 2200 Cycles of Freezing and Thawing in the Tidal Zone at Treat Island, Maine," Performance of Concrete in Marine Environment, ACI Publication Sp-65, (1981).

58. Gustaferro, A., M.A. Hillier and J.R. Janney, "Performance of Prestressed Concrete on the Illinois Tollway after 25 Years of Service," PCI Journal, Vol. 28, No. 1, (1983).

59. Resenberg, A.M., J.M. Gaidis, T.G. Kossivas and R.W. Previte, "A Corrosion Inhibitor Formulated with Calcium Nitrite for Use in Reinforced Concrete," Chloride Corrosion of Steel in Concrete, ASTM STP 629, D.E. Tonini and S.W. Dean, Jr., Eds., American Society for Testing and Materials, (1977).

60. "Standard Practice for Concrete Highway Bridge Deck Construction (ACI 345-82)," ACI manual of Concrete Practice, Part 2, (1983).

61. Hilsdorf, H.K. and J.L. Lott, "Revibration of Retarded Con-

crete for Continuous Bridge Decks," NCHRP Report 106, (1970).

62. "Consolidation of Concrete for Pavements, Bridge Decks and Overlays," NCHRP Report 44, (1977).

63. Coleman, S.E., M. Maage and S. Diamond, "Low Porosity High Strength Concrete for Highway Bridge Decks," Purdue University/Indiana Department of Highways, Report No. FHWA/IN/JHRP-82/2, (1982).

64. Montador, A.J., "Comparison of Performance of Concrete Bridge Decks in British Columbia," Concrete, Aggregates, Marking Materials, Corrosion and Joint Seals, Transportation Research Record 651, (1977).

65. "Light Weight Concrete Cuts Bridge Deck Load," Civil Engineering/ ASCE, August 1984.

66. Slavis, C., "Precast Concrete Deck Modules for Bridge Deck Reconstruction," PCI Journal Vol. 28, No. 4, (1983).

67. Vyce, J.M. and R.J. Nittinger, "Milling and Planing of Flexible Pavement," Transportation Research Record 647, (1977).

68. Johansson, L., "Flame Cleaning of Concrete," Swedish Cement and Concrete Research Institute at the Institute of Technology, Stockholm.

69. "Waterproofing Mix Providing to Performance After Three Years Service on Pittsburgh Bridge," Better Roads/November 1982.

70. "Redecking with Special Asphalt Saves Time, Material and Money," Civil Engineering/ASCE, July 1984.

71. Stuart, E.L. and S.K. Delzer, "Bridge Deck Repair, Methow River Bridges and Columbia River Bridge," A report prepared for the Washington State Department of Transportation.

72. Stewart, C.F., "Deterioration in Salted Bridge Decks," Highway Research Baord, Special Report 116, (1971).

73. "Evaluation of Methods of Replacement of Deteriorated Concrete in Structures," NCHRP Report, (1964).

74. Corbett, L.V. and F.B. Alvey, "Patching and Grouting of Concrete with Epoxy Systems," Epoxies with Concrete, Ameri-

can Concrete Institute, Publication SP-21, (1968).

75. Manson, J.A., "Overview of Current Research on Polymer Concrete: Materials and Future Needs," Application of Polymer Concrete, American Concrete Institute, Publication SP-69, (1981).

76. Smith, P., "15 Years of Living at Kingston with a Reactive Carbonate Rock," Transportation Research Record 525, (1974).

77. Mather, B., "Developments in Specification and Control," Transportation Research Record 525, (1974).

78. Ryell, J., B. Chojanacki, G. Woda and Z.D. Koniuszy, "The Uhthoff Quarry Alkali-Carbonate Rock Reaction: A Laboratory and Field Performance Study," Transportation Research Record 525, (1974).

79. Ozol, M.A. and H.H. Newlon, "Bridge Deck Deterioration prompted by Alkali-Carbonate Reaction: A Documented Example," Transportation Research Record 525, (1974).

80. Crumpton, C.F. and J.E. Bukovatz, "Map Carcking in Limestone Sweetened Concrete Pavement Promotes D-Cracking," Transportation Research Record 651, (1977).

81. "Durability of Concrete in Service," Journal of American Concrete Institute, Vol. 59, (1962).

82. "Freezing and Thawing of Concrete - Mechanisms and Control," American Concrete Institute Monograph No.3.

83. Girard, R.J., E.W. Myers, G.D. Manchester and W.L. Trimm, "D-Cracking: Pavement Design and Construction Variables," Transportation Research Record 853, (1982).

84. Traylor, M.L., "Efforts to Eliminate D-Cracking in Illinois," Transprotation Research Record 853, (1982).

85. Ward, P.M., "Bridge Deck Rehabilitation: Methods and Materials, Part I," Oklahoma Department of Transportation, Federal Highway Administration, Report No. 71-04-1, (1977).

86. Crumpton, C.F. and J.E. Bukovatz, "Corrosion and Kansas Bridges," Transportation Research Record 500, (1974).

87. Manning, D.G. and D.H. Bye, "Bridge Deck Rehabilitation Manual, Part I: Condition Survey," Research and Development Branch, Ontario Ministry of Transportation and Communica-

tion, (1983).

88. Marks, V.J., "Detection of Steel Corrosion in Bridge Decks and Reinforced Concrete Pavements," Iowa Department of Transportation, Project HR-156, (1977).

89. Stratfull, R.F., W.J. Jurkovich and D.L. Spellman, "Corrosion Testing of Bridge Decks," Transportation Research Record 539, (1975).

90. Clemena, G.G. and W.t. McKeel, "Detection of Delamination in Bridge Decks with Infrared Thermography," Transportation Research Record 664, (1978).

91. Tracy, R.G., "Priority Assignment for Bridge Deck Repairs," Transportation Research Record 727, (1979).

92. Tracy, R.G., "Scheduling the Bridge Deck Repair Program," Public Works, January, 1980.

93. Reckard, M.K., "Concrete Bridge Deck Corrosion in Alaska," Alaska Department of Transportation, Report No. AK-RD-84-18, (1984).

94. Manning, D.G. and D.H. Bye, "Rehabilitation Manual, Part II: Contract Preparation," Research and Development Branch, Ontario Ministry of Transportation and Communication, (1984).

95. "Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges", FHWA, (1979).

VOLUME THREE

Recommendation on Future Research
(Task Three)
of

Bridge Deck Program Development

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 - INTRODUCTION

The first report from Task I of the research project entitled "Bridge Deck Program Development," categorized bridge deck treatment concerns, prioritized categories and ranked the elements within each category. The author recognized then that ranking was relative and that the elements of the categories might overlap, depending on the Department's needs for more information. This third phase of the research project also suggests overall priorities for specific projects included in the statewide bridge decks program, based on the state-of-the-art assessment conducted on bridge deck treatment concerns in Task II. The author attempts to suggest priorities based primarily on WSDOT's needs and the potential benefit the Department would gain by conducting the research. After WSDOT reviewed the proposed research, specific projects for immediate research were selected. This report provides background on the necessity for the selected projects as well as on the other research recommended for the future. The report also suggests a general scope of activities for each specific research area presented in the bridge deck program.

2 - PRIORITY ASSIGNMENT FOR FUTURE RESEARCH

Table 1 gives the five major categories of bridge deck treatment concerns, research subjects associated with each category, and each subject's relative importance within its category, as determined in the "Project Design" phase. Additionally, Table 1 prioritizes future development work on bridge deck treatment concerns. The categories and their elements were ranked by integrating the previously defined category importance with present needs for more information. The suggested priorities, however, are not meant to be final and are subject to the Department's review.

2.1 - SELECTED RESEARCH FOR THE IMMEDIATE FUTURE

After the Department reviewed the proposed research, it selected specific projects to be conducted in the next biennium (i.e., June 1985 through June 1987). The selected research areas include the following:

A. Protective Systems

  I. Concrete overlays

    - Latex modified concrete overlay
    - Low slump dense concrete overlay
    - Thin polymer concrete overlay
    - Other concrete overlay or sealer alternatives

B. Repair Procedures

    - Rapid construction techniques

Table 1 - Priority Assignment for Future Research Activities

Category Priority	Relative Priority Within Category	Overall Priority for Future Research Activities
1 - Protective Systems	1 - Latex Modified Concrete 2 - AC/Membrane System 3 - Low Slump Concrete 4 - Cathodic Protection 5 - Epoxy-Coated Rebar 6 - Conditions for Double Protection 7 - Plastic Ducts for Prestressing Steel 8 - Ultrathin Overlays 9 - Superplasticized Concrete 10 - Galvanized Rebar 11 - Epoxy-Coated Prestressing Steel 12 - Better concrete for new Bridges	1↓ 0 I 2↓ 5↓ 6↓ 0 II 11↓ 12↓ 13↓ 16↓ 0 III 17↓
2 - Repair Procedures	1 - AC/Membrane Removal 2 - Fast Setting Mixes 3 - Traffic Control's Impact on the Quality of Repair	3↓ 7↓ 14↓
3 - Condition Survey Techniques	1 - Half-Cell Corrosion Detection 2 - Thermography	4↓ 8↓
4 - Causes of Deterioration	1 - Reactive Aggregate 2 - Freeze/thaw Action	9↓ 15↓
5 - Bridge Deck Management System	1 - Bridge Deck Management System	10↓

I - Research conducted previously and continuation scheduled in the current biennium
II - Associated with "epoxy-coated rebar"
III - Added to "plastic ducts for prestressing steel"

  - AC/membrane removal procedures (microwave heating)

C. Condition Evaluation Techniques

  - Half-cell

D. Bridge Deck Management System

  - Bridge deck management system

No research project from the category "causes of deterioration" was selected for the immediate future, since WSDOT recognized that "reactive aggregate" and "freeze-thaw" deterioration, although important, have been studied previously and their primary cause and solutions to them are relatively well known.

The following briefly explains background on the necessity for the selected research.

Protective Systems

Latex modified concrete, due to its relatively better performance and practicality in application, is currently the most preferred protective system for bridge decks in Washington (1). The system has been utilized in Washington since the mid-1970's and its effectiveness needs to be fully evaluated in order to better predict its performance, to suggest improvements to current design, construction, and inspection practices and to justify its future application.

Low slump dense concrete has been applied on Washington bridges as long as latex modified concrete and the system has been regarded as competitive with latex concrete until recently, when tests revealed uncertainty regarding its constructibility, and thus, its performance (1). Research should be conducted to clarify its effectiveness, since at present it is the best potential substitute for latex modified concrete if the latter system is documented non-satisfactory.

Thin polymer concrete overlays have been used for protection of some bridge decks in Washington and are scheduled to be applied on decks where additional dead load would cause structural problems or construction would seriously create traffic delays. The overlay's application will be limited to certain types of structures. An evaluation of past installations could support the use of future applications.

Construction methods other than the concrete overlays need to be considered and their constructibility and effectiveness evaluated by examining the experiences of other agencies as well as WSDOT. Worthy of evaluation in this regard are Low-Cement ratio concrete with superplasticizers, protective coatings, high strength silica fume concrete, and vacuum-dewatered concrete.

Repair Procedures

Traffic delays resulting from reconstruction projects involving deck removal and overlay curing are problems, especially on highly travelled bridges. Newly developed rapid construction techniques and procedures with potential for accelerating bridge deck reconstruction have not been used because their effectiveness has remained unexplored. The effects of different substrate preparation and concrete removal techniques, and the curing condition on the bond, and on the behavior of overlays need to be thoroughly evaluated and criteria established for their acceptance.

A proper AC/membrane removal procedure which caused no disturbance to concrete surfaces would save many bridges to which new lifts of AC/membrane system could be applied from the presently mandatory application of a more expensive concrete overlay during the rehabilitation and protection period. In some instances in which the AC has worn out before the membrane has aged, an appropriate removal procedure could even save the membrane by limiting the operation to only the wearing course.

Condition Evaluation Techniques

The Department has routinely used chloride content measurement for determining a concrete's potential for rebar corrosion. Although efficient and reliable, the test is time consuming and destructive. Non-destructive, half-cell corrosion detection has been used by the Department on special projects with results that have not always been consistent (3,4). A better understanding of the half-cell corrosion detection test method, including its limitations and interpretation of the results, is greatly needed in order to employ it routinely for bridge deck inspection, monitoring and repair, since there is no other simple test method to determine rebar corrosion or to indicate potential for concrete deterioration.

Bridge Deck Management System

Due to the increasing number of bridge decks in need of repair and rehabilitation and maintenance budget limitations , there seems to be a great need for development of a system which would systematically predict and prioritize bridge deck treatments and delegate repair efforts to decks for which the need was greatest. Such a system would be a strong tool with which the department could make rational decisions regarding the expenditure of bridge deck maintenance funds. A similar management system has already been developed and implemented by WSDOT for maintenance of pavements in highway networks (5).

2.2 - RECOMMENDED RESEARCH FOR THE FUTURE

The author believes that relevant investigations on each research item presented below will benefit the Department by helping it maintain satisfactorily performing bridge network. The actual time to conduct each research project, however, will depend on available research funds as well as the importance of each research item.

Protective Systems

Cathodic protection, although presently only experimental in Washington, could be applied efficiently to halt corrosion in rehabilitation projects in which the reinforcing steel is corroding extensively but the concrete shows no considerable sign of deterioration. However, WSDOT should determine the advantage and disadvantages of the system, and establish criteria for determining which decks should be protected by cathodic protection.

Although routine inspections on the fairly new installations of epoxy-coated rebar have given the protective system a good performance record, WSDOT should carefully examine them at this time. Such investigations would reveal the systems performance more clearly in order to better justify the system's future application. Results from this research would also apply to "conditions for double protection," which require epoxy coating rebar as the first element of protection.

Plastic ducts are recommended for post-tensioned tendon protection against stress-corrosion failure. The system could substitute for the galvanized ducts currently used in structures. However, use of plastic ducts would require development of specifications to avoid use of improper materials and applications. The study could also apply to "epoxy coating prestressing steel," which is mainly meant for protection pretensioned tendons. Currently, there is no adopted procedure for protecting pretensioned tendons, and the study could evaluate the feasibility of the protective system.

Superplasticized concrete overlays are presently considered only experimental, but they have the potential to be used as a standard protective overlay for rehabilitating bridge decks. However, criteria must be developed for the proper use of superplasticizers and the field use of the concrete in order to prevent problems such as loss of workability.

Galvanized rebar is an alternative to epoxy-coated rebar intended to prevent the rebar from corroding. Research would be valuable if concrete decks containing epoxy-coated reinforcing steel performed non-satisfactorily.

Research on better concretes and practices being developed in the United States to provide more durable bridges and to eliminate problems associated with the reconstruction of older structures would keep the Department abreast with the state-of-the-art to better understand the new concretes and to learn how they would respond to long-term use.

Repair Procedures

Fast setting polymer concrete is used as an effective method of deck repair for the benefit of the travelling public when closing bridges to traffic for long periods of time is not feasible (6). There are, however, concerns over the compatibility of the system with the conventional concrete substrate and difficulties in handling the material during the construction phase. The constructibility and performance of previous applications of this concrete need to be evaluated in order to justify future applications on highly travelled bridge decks.

"Traffic control's impact on the quality of repair" refers to the susceptibility of freshly placed concrete to the effects of traffic-induced vibration while traffic is maintained on bridges during repair periods. Although a few cases of damage have been documented during bridge widenings, the quality of concrete has been blamed in these cases rather than the traffic (7). Investigation could be conducted to clarify whether traffic-induced vibration has any effect on the quality of the concrete and if so, new regulations could be developed regarding the stiffness of the structures as well as the speed and weight of the vehicles using the bridge during the construction period.

Condition Survey Techniques

Development of thermographic surveys or other methods such as radar which have shown potential for detecting delaminations in both bare and asphalt covered decks is greatly needed (8). The ability to determine the conditions of the great number of asphalt covered decks presently in service would allow WSDOT to establish repair priorities and predict future funding needs far in advance of the development of problems.

Causes of Deterioration

Reactive aggregate has been blamed for deterioration in bridge structures such as map cracking and popouts. The problems could be prevented in future construction if the potentially reactive aggregate could be identified and avoided. Appropriate measures to solve the problem could also be taken if it was not feasible to avoid the material.

Freeze/thaw environments are responsible for different types of bridge concrete deterioration. Concrete air-entrainment, the traditional method of overcoming the problem, should be further evaluated in view of new concrete materials and products recently incorporated into bridge structures. The research should also concentrate on the frost susceptibility of aggregate used in concrete.

3 - RECOMMENDATIONS ON THE SCOPE OF FUTURE RESEARCH

The following recommends scopes and objectives for future research on the bridge deck treatment problems previously discussed. The basis for the recommendations is the extent to which a bridge deck treatment concern has been included in previous research or addressed in practice.

3.1 - PROTECTIVE SYSTEMS

3.1.1 - Latex Modified Concrete, Low Slump Concrete and Epoxy-Coated Rebar

The above protective systems have been adopted by WSDOT and many installations have been in service on Washington bridges since the mid 1970's. This has created an opportunity to sample and field test installations in representative areas of the state in order to determine their performance. Although the Department has routinely inspected the systems, it needs to plan and conduct a careful, detailed test to reveal the durability of the systems as well as their effectiveness in protecting the bridge decks. The durability and effectiveness of the systems could be determined by evaluating the following factors:

1 - overlay wear and cracking
Durability 2 - overlay scaling and spalling
3 - overlay bond failure

1 - chloride intrusion
Effectiveness 2 - rebar corrosion

3 - concrete deterioration originated below interface

For decks containing epoxy-coated rebar and built according to the new specifications the sytem's durability is difficult to determine, if not impossible, because the system is an integral part of the deck. However, the .pa effectiveness of the overall construction including the deck and coated rebar is a function of the following factors:

Effectiveness

1 - concrete wear and cracking

2 - concrete scaling and spalling

3 - concrete delamination

4 - rebar corrosion

Rebar corrosion may not be detected easilyusing non-destructive testing methods in a rebar mat coated with a dielectric material. The detection of chloride intrusion, however, could determine the necessity for corrosion detection.

In general, determining the durability and effectiveness of the protective systems requires utilizing different test methods in the field and laboratory. If deficiencies are found attempts should be made to determine their cause and find solutions to them as well. This would certainly improve the quality of future construction. Additionally, such studies should include a review of practices in other states, which explore the feasibility and reliability of the newly developed alternative protective systems such as superplasticized concrete, silica fume concrete, and vacuum-dewatered concrete. Concrete sealers would definitely be worthy of evaluation. The results of such investigations would be implemented to guide current design, construction, and inspection and also provide other alternatives ready for designers. A flow chart showing the sequence of the research activities involved in testing each protective system is illustrated in Figure 1.

3.1.2 - Ultrathin Overlays and Superplasticized Concrete

Installations of ultrathin polymer concrete overlays and superplasticized concrete overlays on Washington bridges have been limited to a few experimental applications. However, more ultrathin overlays incorporating new and improved polymer products are scheduled to be applied. Accordingly, their performance needs to be evaluated carefully by utilizing different condition evaluation techniques. The results would help establish guidelines to determine the effectiveness of different polymer materials and to select systems to fit individual deck conditions. Most important among the factors to be studied is the compatibility of an overlay's strain with a substrate when subjected to thermal cycles. Research should determine the effectiveness of different types of polymer concrete applications such as built-up and pre-mixed construction.

Application of superplasticized concrete on bridge decks, on the other hand, requires techniques yet to be established due to

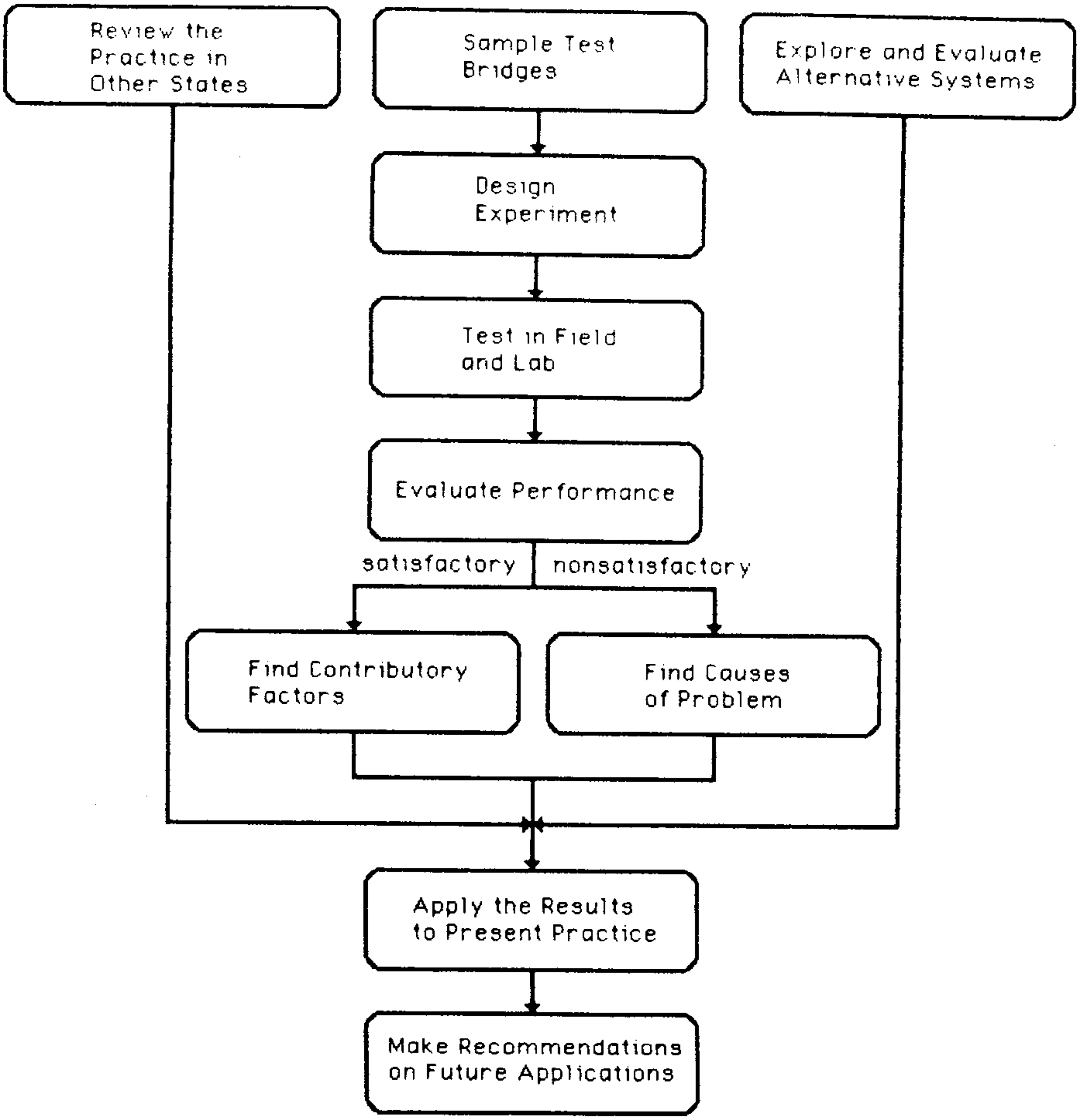


Figure 1. Recommended Research Activities Regarding "Latex Modified Concrete", "Low Slump Dense Concrete" and "Epoxy-coated Rebar" Protective Systems.

the material's short slump-life, encountered with existing practices (9). Furthermore, the effects of mixture characteristics and environmental conditions on the slump-life should be evaluated. A thorough investigation of superplasticized concrete would require laboratory testings and field trials However, as mentioned earlier, overall constructibility and performance could be obtained by examining the experiences of agencies involved in applying the system. The recommended research scheme for ultra-thin overlays and superplasticized concrete can be found in Figures 2 and 3.

3.1.3 - Cathodic Protection

WSDOT has installed one demonstration project of this type on the lower deck of a pontoon bridge in Washington which is not subject to traffic flow. The installation, which is about two years old is the most developed method of "non-overlay" cathodic protection for bridge decks. Two more installations are scheduled for construction in the near future. Future research should include review and examination of this work as well as the other installations nationwide. This would help to determine the performance of the system. The major factors involved in cathodic protection performance are given below.

Performance
1 - Prevention of over- and-under protection
2 - Durability of anod backfill material

However, the application of cathodic protection requires more

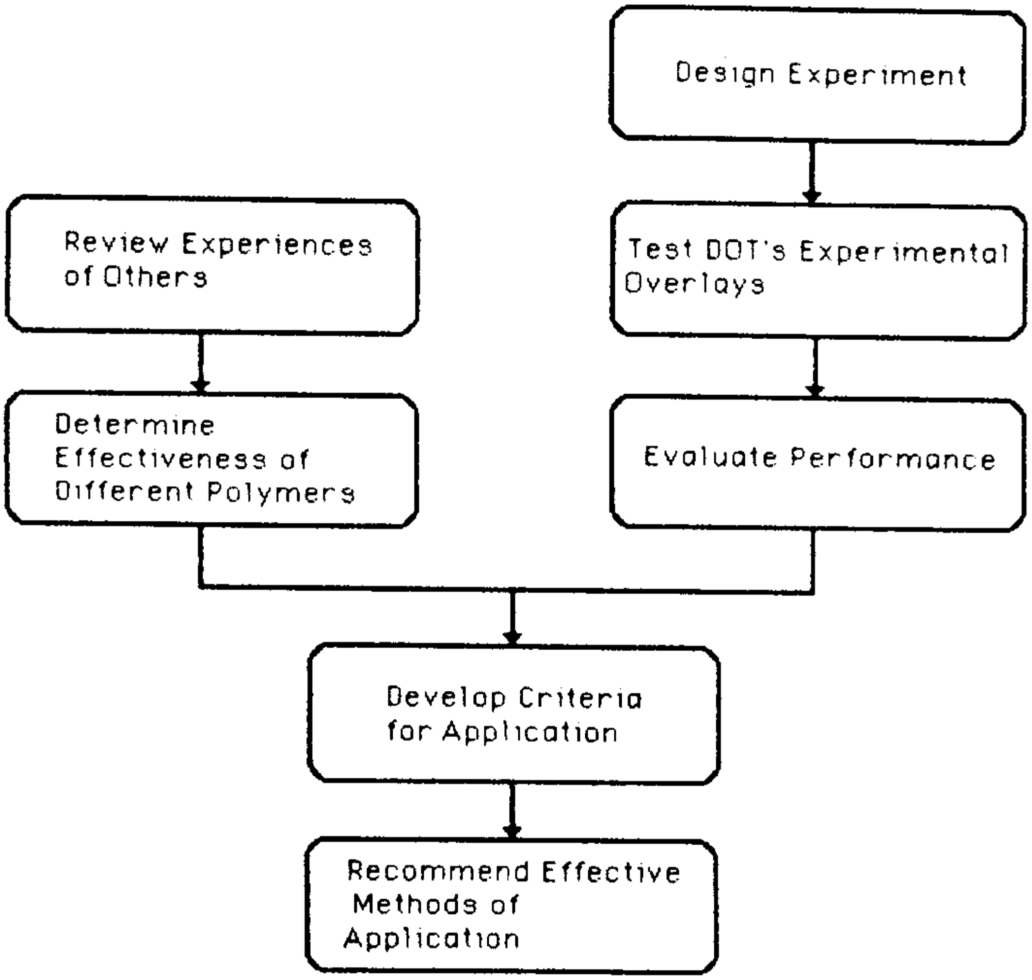


Figure 2. Recommended Research Activities Regarding "Thin Polymer Concrete Overlays".

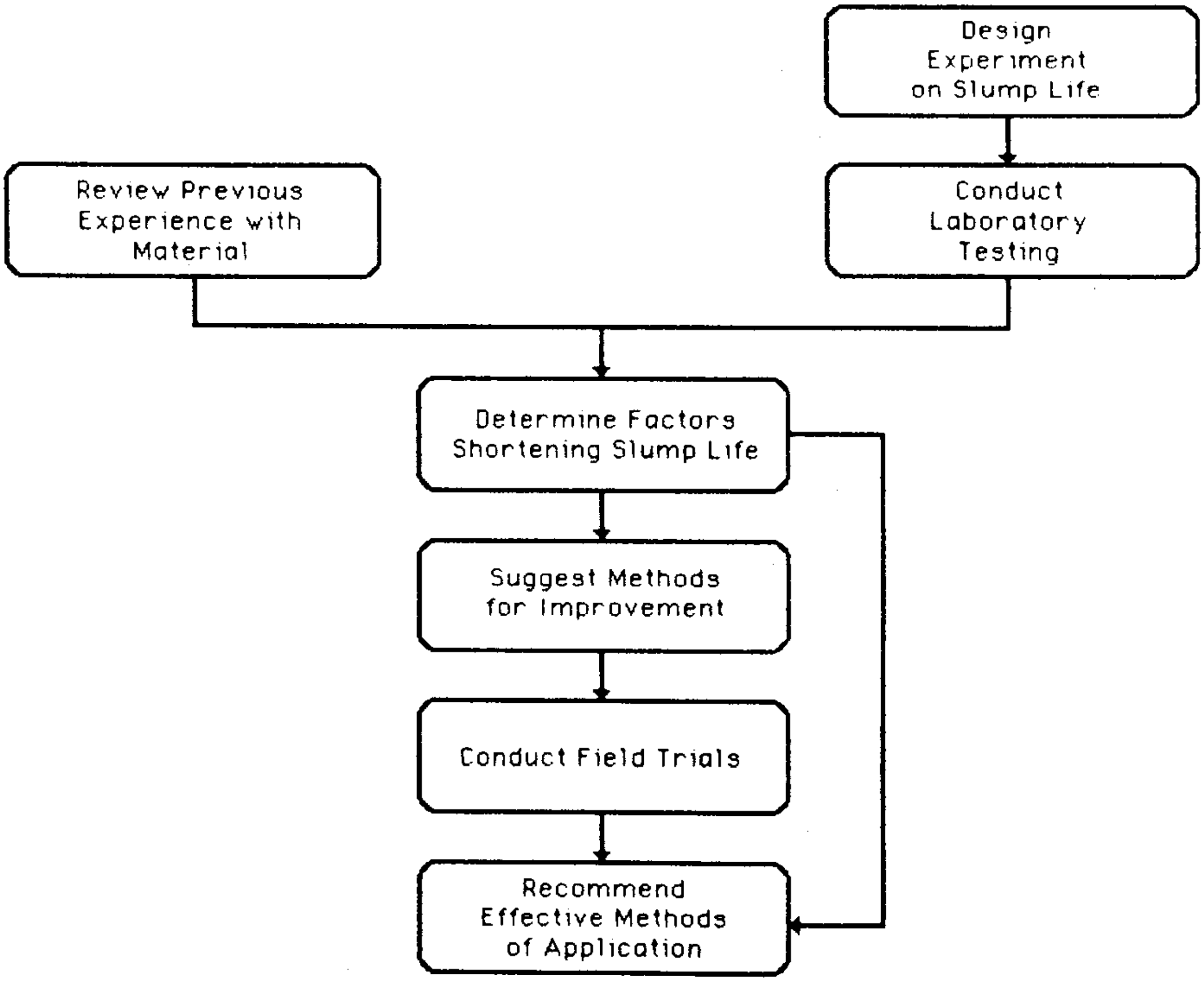


Figure 3. Recommended Research Activities Regarding "Superplasticized Concrete Overlays".

than a satisfactorily performing system. Criteria should be developed to determine which bridge decks should be protected by this method in order to maintain cost-effective protection and prevent future deterioration caused by other sources such as freeze-thaw action and traffic impact. The overall plan for this research is illustrated in Figure 4.

3.1.4 - Prestressing Steel Protection

Prestressing steel in Washington bridges is currently protected with conventional measures such as using galvanized ducts for post-tensioned tendons, providing sufficient concrete cover, and preventing concrete cracking for both post-tensioned and pretensioned tendons. Future research should determine the efficiency of these conventional methods and, if necessary, suggest improvements to them. Additionally, the applicability and effectiveness of the proposed systems, such as plastic ducts and epoxy coating, need to be investigated. The practice of using plastic ducts should be reviewed and if necessary modified in order to screen out undesireable plastic materials. and provide an effective design. The feasibility of using fusion bonded epoxy coating strands is an important factor which needs investigating. The effects of this latter system on the engineering properties of prestressing steel, the extent to which the system can tolerate elongation, and its bonding characteristics with concrete should be examined. The sequence of the activities

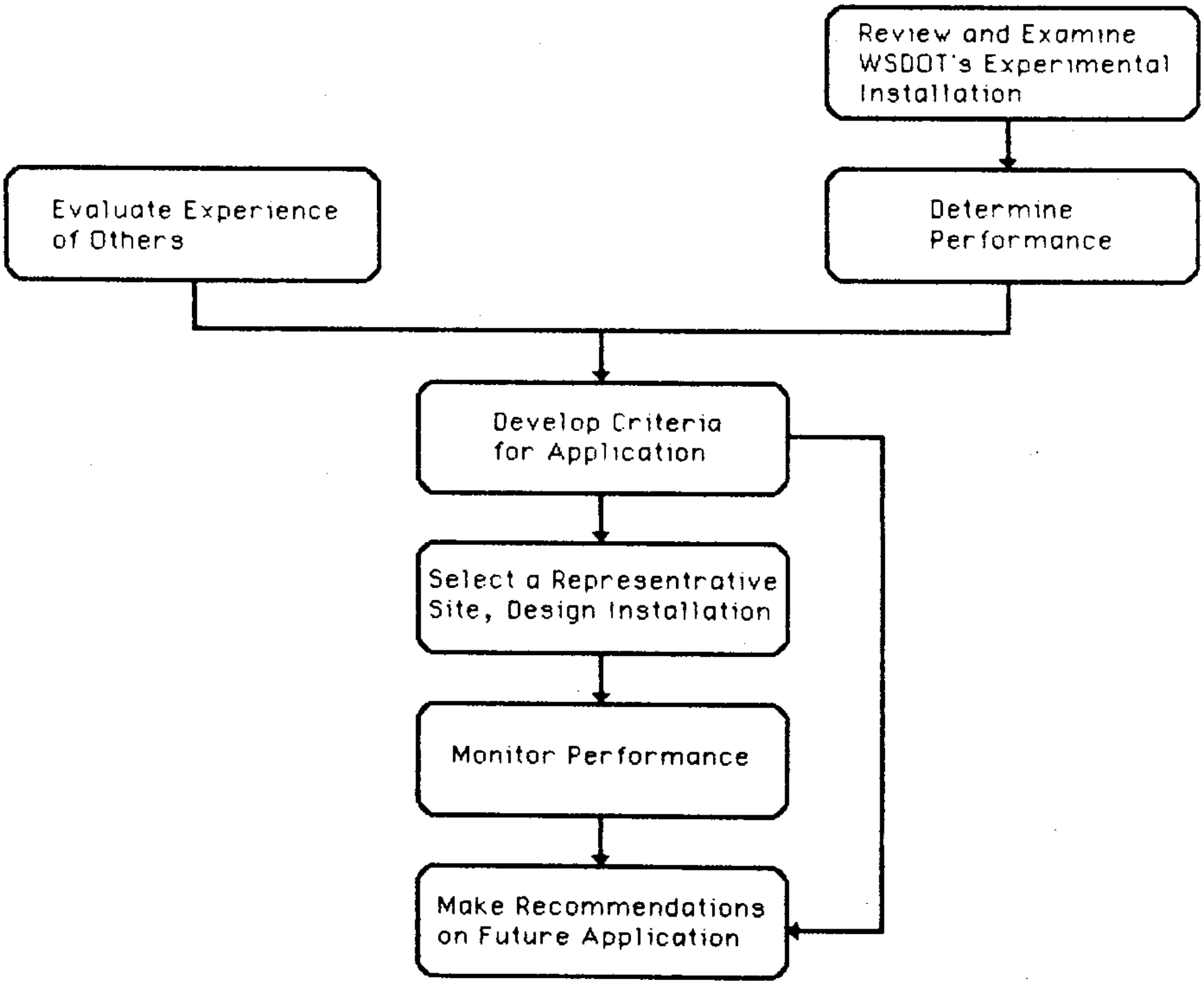


Figure 4. Recommended Research Activities Regarding "Cathodic Protection".

involved in this research is given in Figure 5.

3.1.5 - Galvanized Rebar

The system has not been adopted by WSDOT and the results of previous research have not been very encouraging (10). At this stage it is recommended that the research be limited to keeping abreast with any new developments in the system's performance. However, if a case of a non-satisfactory performance of an epoxy-coated rebar system is documented, research should include laboratory testing and field demonstrations in order to determine the level of protection that galvanizing offers to reinforcing steel as well as zinc's own resistance to corrosion in a chloride contaminated concrete.

3.1.6 - Better Concrete for New Bridges

Generally, this category includes newly developed bridge deck construction material and practices intended to provide more durable structures and to eliminate problems normally associated with the reconstruction and replacement of deteriorated decks in older structures. Examples are: new developments in the production of workable, low porosity concrete containing gypsum-tree cement, vacuum dewatering of in-place plastic concrete, use of light weight concrete for replacement of decks in older structures and use of precast concrete deck modules.

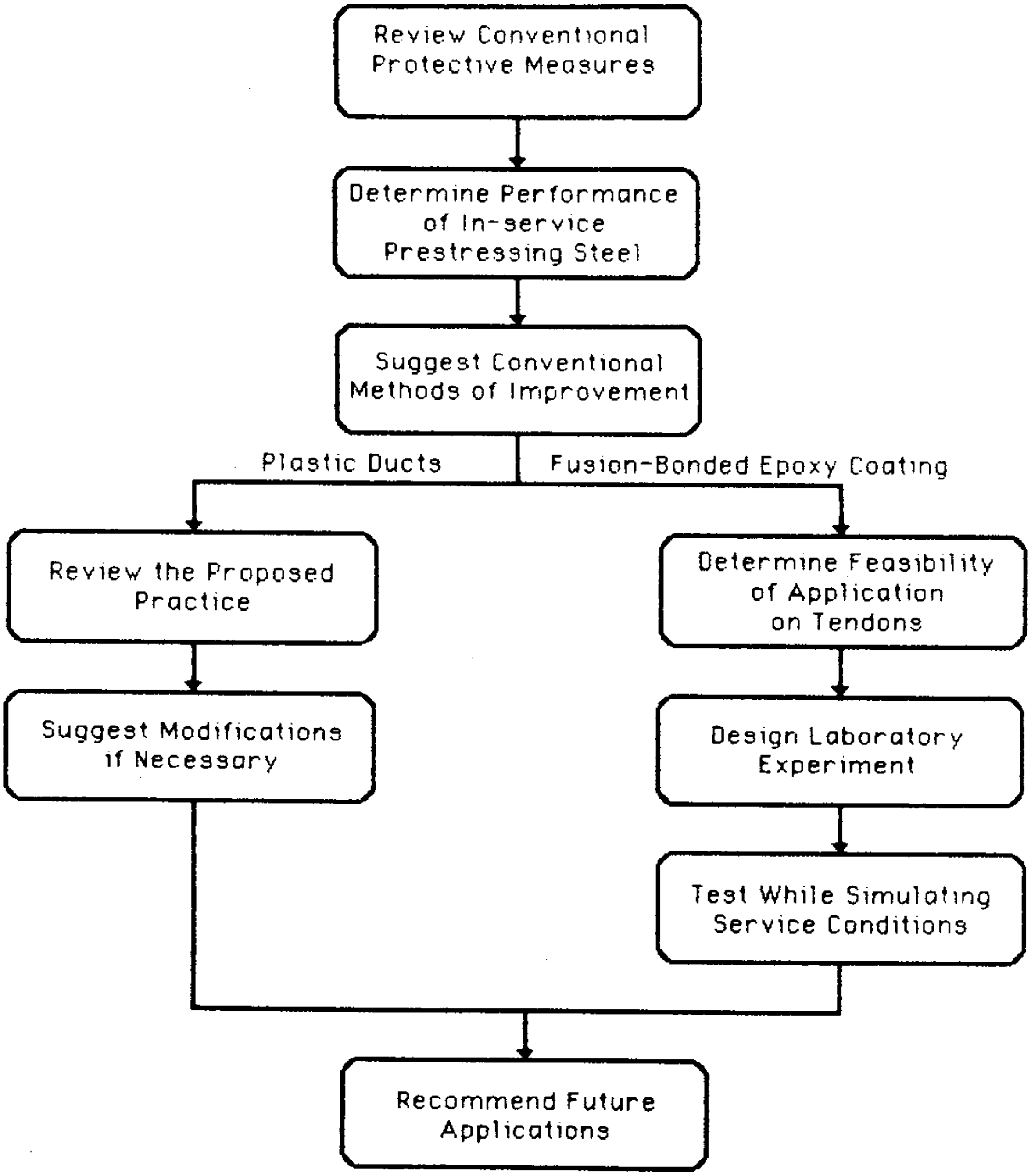


Figure 5. Recommended Research Activities Regarding "Prestressing Steel Protection".

The initial phase of relevant research should include collecting and evaluating information from different sources such as other research groups and industry. This is required to keep abreast of the state-of-the-art and to better understand these materials and practices and to learn how they might respond to long-term performance. Based on the results, the research might subsequently include laboratory testing, field demonstrations and performance monitoring.

3.2 - REPAIR PROCEDURES AND CONCERNS

3.2.1 - AC/Membrane Removal Procedures

The current method of removing deteriorating AC/membrance from concrete bridge decks has been associated with problems such as disturbance to the underlying concrete and, in some instances, to the top mat rebar as well. It is believed that future research should focus on the following two areas: 1) the possibility of employing different removal techniques in order to prevent irregularities in the concrete so that it would be compatible with the new AC/membrane lifts and 2) the possibility of modifying new lifts through application of new materials and procedures in order to make them compatible with the irregularities resulting from currently adopted pavement removal practices. Additionally, WSDOT should explore the possibility of partially removing and replacing asphalt overlays with no damage to the membrane in cases of in-place, sound membranes. The activities involved in such research are shown in Figure 6.

3.2.2 - Fast Setting Mixes for Repair

Polymer concretes, as fast setting patching materials, have been used on concrete bridge decks either with AC/membrane overlays or with no overlays applied on them. Future research should evaluate the performance of both types of installations. This will require sampling and testing bridge decks employing different condition evaluation techniques. Upon evaluation of the bridges' performance, WSDOT needs to developed criteria to help determine which bridges should receive application of polymer concrete over cement concrete for deck patching. In this regard, factors such as environmental conditions, substrate preparation, traffic volume, and repair volume should be considered. Additionally, WSDOT should determine the effectiveness of existing methods of deteriorated concrete removal. The study should focus on the possibility of using newer concrete removal procedures to result in better substrate preparation and bond as well as less impact on the deck concrete.

3.2.3 - Traffic Control's Impact on the Quality of Repair

Traffic is usually permitted on bridges in Washington during reconstruction periods with some restrictions on speed. Previous research has indicated that the effects of traffic-induced vibration on bridge deck repair and widening are insignificant pro-

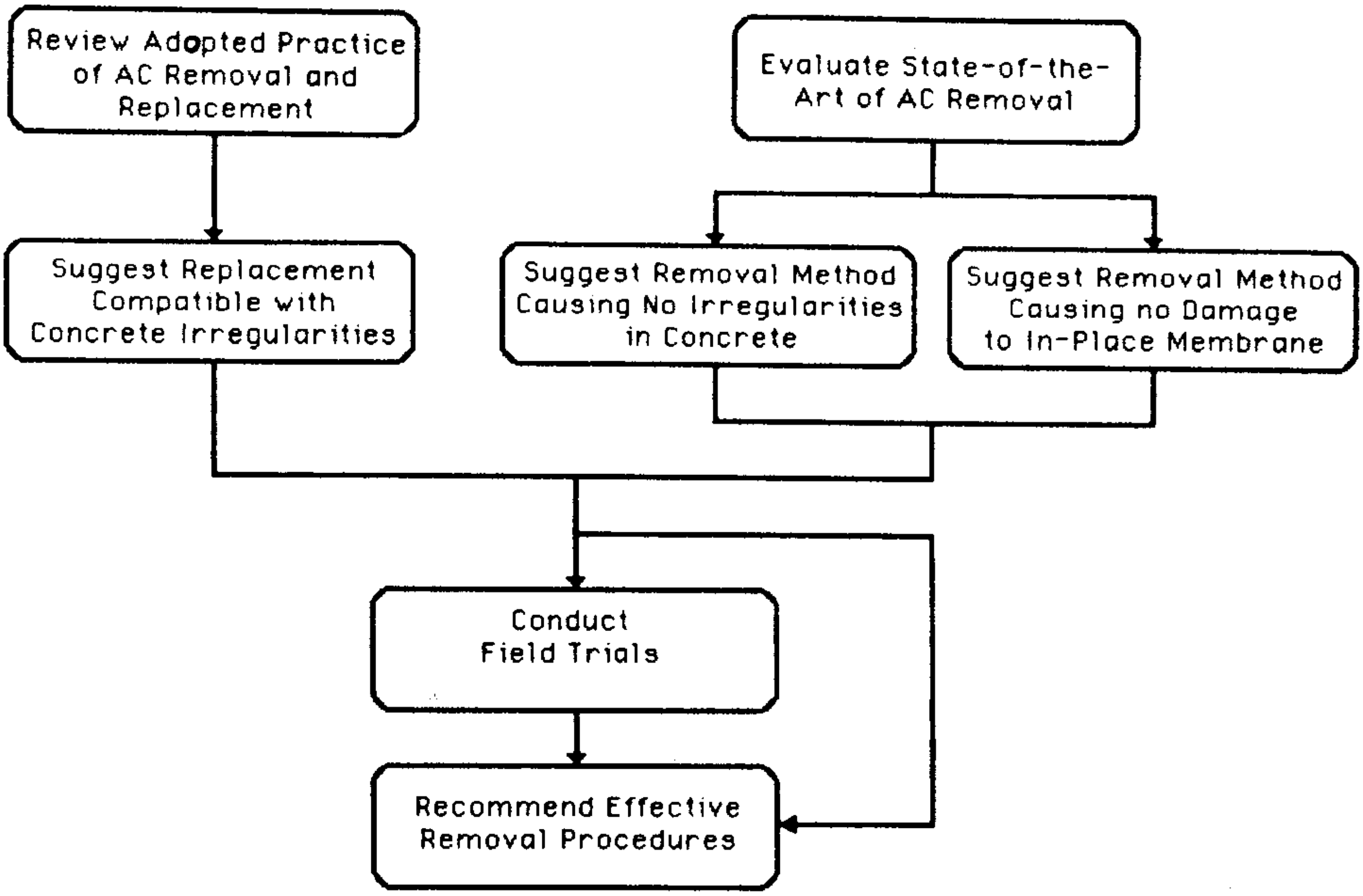


Figure 6. Recommended Research Activities Regarding "AC/Membrane Removal Procedure".

vided good quality concrete is used (7). However, as the process of advancement continues and new materials and techniques are adopted, new information could be found to complete and update that previously obtained. It is recommended that future work focus on collecting and synthesizing the scattered and unevaluated information pertaining to the subject matter. If, in the course of the study, any defects resulting from traffic-induced vibration are identified, recommendations should be made on the type of structures, construction procedures or speed and weight limitations that would alleviate the problem in future constructions.

3.3 - CONDITION EVALUATION TECHNIQUES

3.3.1 - Half-Cell Corrosion Detection

This test method has been used in WSDOT's research and special projects to detect rebar corrosion using current information (3,4). Although some data have also been evolved regarding half-cell testing during the course of these investigations, no research has been conducted solely to evaluate the reliability of the test method. It is recommended that WSDOT design field experiments and sample and test bridge decks for rebar corrosion. The test results should then be interpreted and correlated with concrete deterioration and contamination. Depending on the results of the experiment, inspection procedures could be developed for successful half-cell testing and data interpretation for the following purposes:

1 - monitoring the overall performance of rebar over time, and

2 - locating corroding areas on decks prior to repair.

Figure 7 illustrates the sequence of activities required for the half-cell research.

3.3.2 - Thermographic Delamination Detection

Thermography has been included in WSDOT's research activities to a certain degree. The work, however, was limited and did not include asphalt covered decks. In order to adopt thermography for satisfactory and economical delamination detection, especially on asphalt covered decks, the following three major areas should be investigated:

1 - the environmental condition's limitations on the survey,

2 - the feasibility of a rapid survey, and

3 - the accuracy of the survey.

A research program including the above concerns, as shown in Figure 8, could reveal the unknowns regarding thermography and initiate the test method.

An alternative to thermography is radar. Previous research has also indicated a great potential for radar to rapidly survey bridge decks.

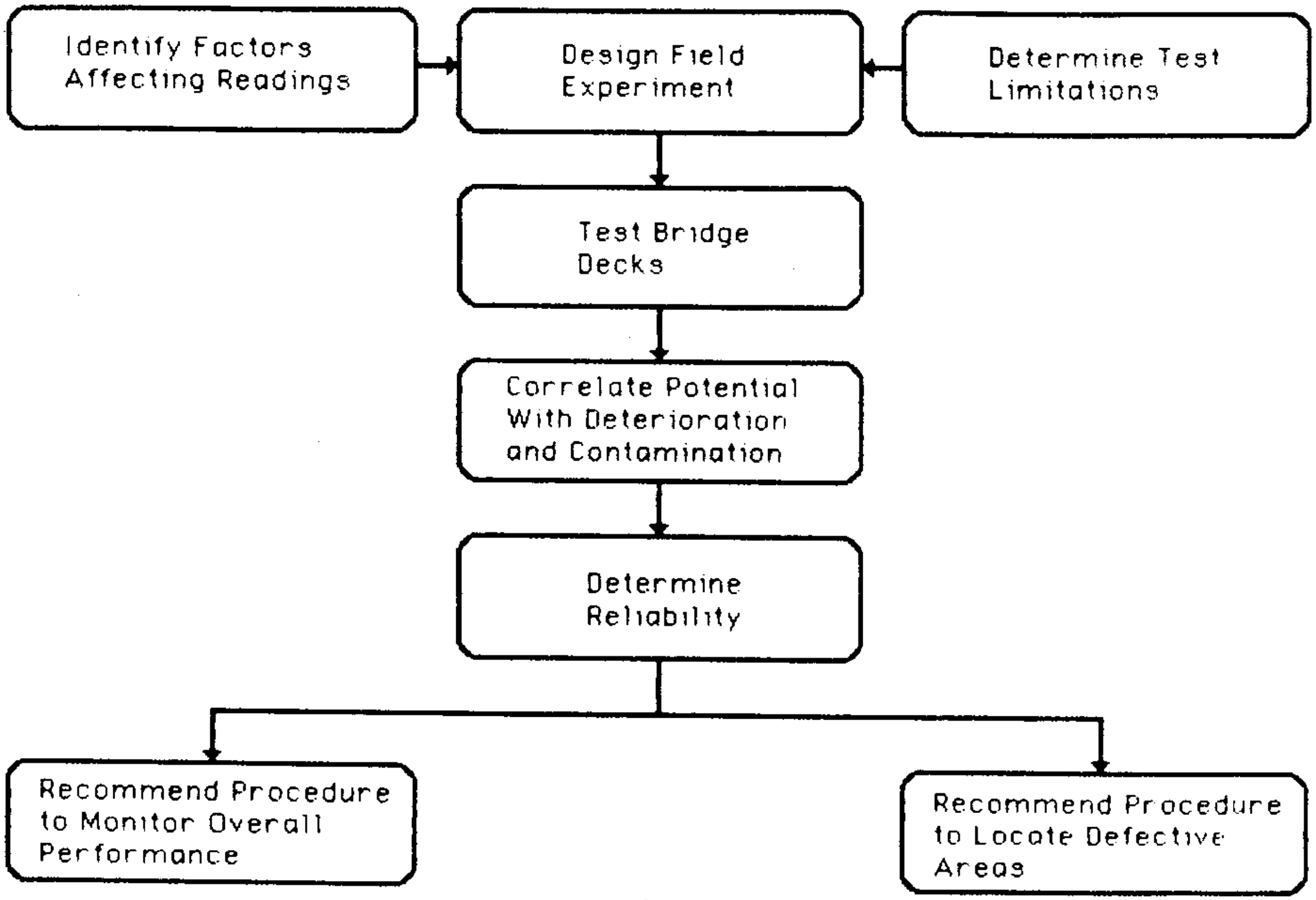


Figure 7. Recommended Research Activities Regarding "Half-Cell Corrosion Detection".

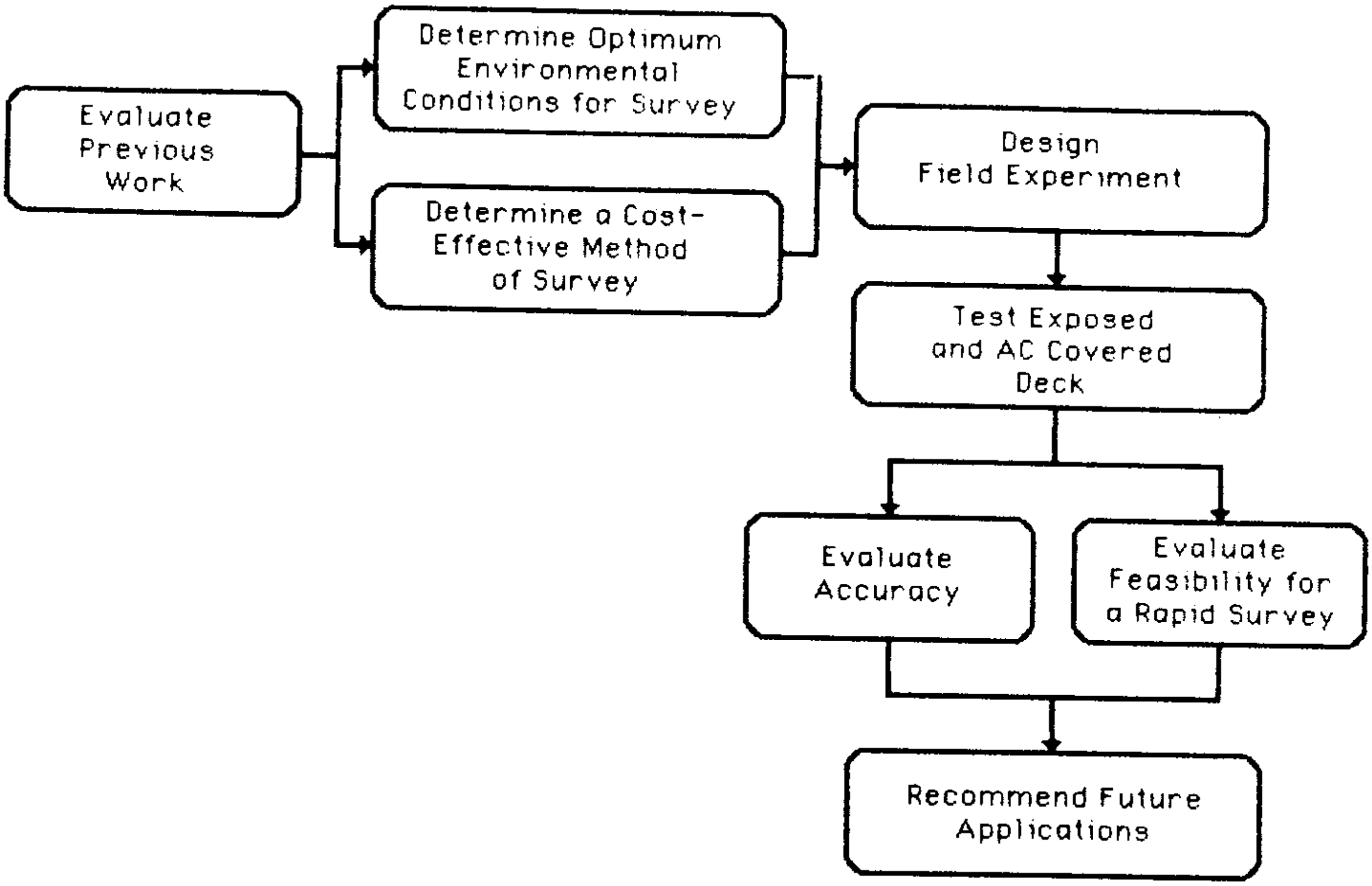


Figure 8. Recommended Research Activities Regarding "Thermographic Delamination Detection".

3.4 - CAUSES OF DETERIORATION (Reactive aggregate, Freeze-thaw)

A considerable amount of information is presently available concerning the effects of reactive aggregate and freeze-thaw action on the performance of concrete. Solutions to the problems have been found as a result of past research and have been utilized in practice. In regard to reactive aggregate, however, improvements in the test methods are needed to conclusively determine the nature of aggregate (11). The long-term effects of alkali in cement on reactive aggregate should be further evaluated and a breakpoint alkali level in cement should be defined based on long-term expansion of reactive aggregate.

As for freeze-thaw action, WSDOT should further evaluate the use of air-entrainment with non-conventional concrete materials such as low slump dense concrete and superplasticized concrete which have either been adopted or could be adopted in the future. Possible loss of entrained air during construction needs to be studied and subsequently proper action taken in practice (12). However, since latex modified concrete usually does not contain entrained air, criteria for the content of entrapped air should be developed based on the durability of the material. Additionally, the effects of a freeze-thaw environment on cracked concrete structures would be worthy of evaluation, especially the possible contribution of freeze-thaw action to spalling and loss of bond between rebar and concrete.

3.5 - BRIDGE DECK MANAGEMENT SYSTEM

WSDOT has initiated a program for prioritizing the rehabilitation and/or protection of those bridge decks built according to old regulations which did not require a protective system. Accordingly, criteria have been developed which consider the conditions of the decks in order to select the best type of protection for them. However, this "management system" is only in its early stages of development and needs to be completed. For example, the basis for bridge deck condition rating could further be developed by incorporating various types of distress such as cracking, scaling, delaminations and corrosion in addition to chloride contamination and spalling. Guidelines for applying protective systems other than latex modified concrete and AC/membrane systems could be generated.

Additionally, the bridge deck "management system" should be extended to those bridge decks which are already protected against premature deterioration. In this regard deck conditions which would warrant future reconstruction should be defined. Accordingly, the time of reconstruction could be determined by using feedback on the performance of the protected bridge decks. The "management system" could then be completed by determining the most cost-effective method of reconstruction for each case as well as by prioritizing bridge deck reconstruction at the network level using criteria such as the public's dependence on the structure and deferred maintenance costs. Selection of reconstruction projects at the network level would require evaluation of two constraints, namely condition-level and budget constraints (5). The proposed activites for future research are shown in Figure 9.

A thorough management system called "bridge management system", however, would consider all the elements of a bridge structure and would not be limited only to bridge decks. In this regard, the structural capacity of the bridges could represent their conditions. Condition surveys would include determination of material and cross-sectional properties to be used for a structural analysis in order to determine load rating. Load ratings warranting strengthening or posting could be defined and priorities could be established for those structures in need of strengthening based on safety considerations as well as the importance of the transportation link. Also included in the "bridge management system" would be maintenance problems related to bridge elements such as expansion joints and bearings, as well as insufficient geometric features of the bridges due to changes in the nature of traffic.

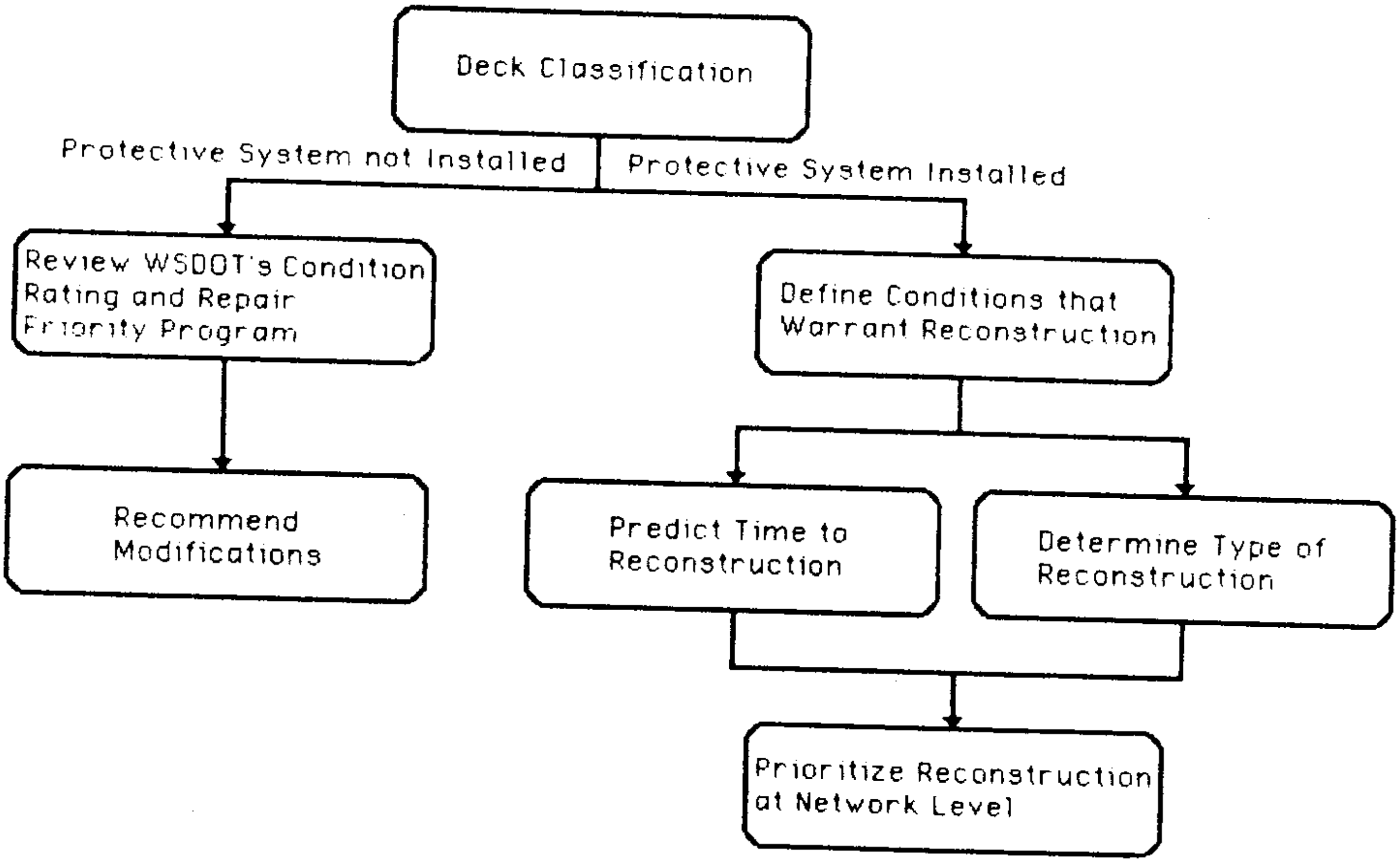


Figure 9. Recommended Research Activities Regarding "Bridge Deck Management System".

REFERENCES

1 - WSDOT Bridge Deck Protection System Selection Criteria (1984)

2 - "WSDOT Bridge Deck Program" Bridge and Structures Branch, Washington State Department of Transportation (1982)

3 - Babaei, K. and R.L. Terrel, "Performance Evaluation of Waterproofing Membrane Protective Systems for Concrete Bridge Decks" Washington State Transportation Center; A Report Prepared for Washington State Department of Transportation, (1983)

4 - Demich, G.F., "Investigation of Bridge Deck Deterioration caused by De- icing Chemicals", Washington State Highway Department Research Program, Report No. 201, (1975)

5 - Nelson, T.L., and R.V. LeClere, "Development and Implementation of Washington State's Pavement Management System", Washington State Department of Transportation (1982)

6 - Stuart, E.L., and S.K. Delzer, "Bridge Deck Repair, Methow River Bridges and Columbia River Bridge", Washington State Department of Transportation.

7 - Manning, D.G., "Effects of Traffic-Induced Vibration on Bridge-Deck Repairs", NCHRP Report 86 (1981)

8 - Manning, D.G., and F.B. Holt, "Detecting Deterioration in Asphalt Covered Bridge Decks", a Paper for Presentation at the Annual Meeting of the TRB Research Development Branch, Ontario Ministry of Transportation and Communication, (1983)

9 - Whiting, D., "Evaluation of Super-Water Reducers for Highway Applications", Federal Highway Administration, Report No. FHWA/RD-80/132, (1981)

10 - Hill, G.A., D.C. Spellman and R.F. Stratfull, "Laboratory Corrosion Tests of Galvanized Steel in Concrete", Transportation Research Record 604, (1976)

11 - Stark, D.C., "Alkali-Silica Reactivity: Some Reconsiderations", Portland Cement Association Research and Development Bulletin RD076.01T

12 - Whiting, D. and D. Stark, "Control of Air Content in Concrete", NCHRP Report 258 (1983)

APPENDIX A

Research Statements
for
Bridge Deck Program Development

Prepared by

Washington State Transportation Center

for

Washington State Department of Transportation

List of Research Statements

PROTECTIVE SYSTEMS FOR NEW AND EXISTING BRIDGE DECKS

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Performance Evaluation of Latex Modified Concrete Overlays for Concrete Bridge Deck Protection.

2 - PROBLEM

Concrete bridge deck deterioration has become a major problem to the Department. Although the depth of the problem is not completely determined, indications are that concern is widespread. According to the Department's present bridge deck protection policy, latex modified concrete (LMC) overlays are the preferred system of bridge deck protection when rehabilitating highly traveled, highly contaminated and deteriorated bridge decks. The Department has inspected the conditions of LMC overlaid decks through routine field condition surveys. However, carefully planned testing and monitoring of the overlaid decks is necessary to reveal the durability of the overlays as well as their effectiveness in protecting the underlying decks from concrete contamination, rebar corrosion and concrete deterioration. WSDOT needs the information to evaluate its policy regarding LMC's application, to predict LMC's service life, and to improve its future applications.

3 - OBJECTIVES

Evaluate the performance of the LMC overlays presently in service by designing experiments and analyzing data to be collected from test bridge decks.

4 - KEY WORDS

Concrete bridge deck,latex modified concrete, overlays, deterioration, corrosion, protective systems.

5 - RELATED WORK

All studies conducted relating to LMC overlays, bridge deck deterioration, rehabilitation and protection.

6 - URGENCY/PRIORITY

The increasing cost of repairing deteriorated concrete bridge decks and the cumulative effects of an ever increasing number of decks in need of rehabilitation and/or protection create an urgent situation commanding immediate attention.

7 - COST

$85,000 for management, information collection, experiment design, testing, data analysis and evaluation, and reporting.

8 - IMPLEMENTATION

The results of the research could be implemented by the Department to distinguish among the conditions of the concrete bridge decks and to decide whether the LMC should be used as a protective system or not.

9 - EFFECTIVENESS/BENEFITS

Information from the evaluation of the LMC overlays could help the Department to determine its performance and effectiveness and to decide how to allocate construction and maintenance funds when protecting concrete bridge decks.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Performance Evaluation of Low-Slump Concrete Overlays for Concrete Bridge Deck Protection

2 - PROBLEM

Premature deterioration of concrete bridge decks poses a major problem to the Department and indications are that concern is rapidly growing. Low-slump concrete (LSC) overlays were recommended by WSDOT for protection of rehabilitated bridge decks until 1984. In 1984 WSDOT, due to some concerns regarding the performance of LSC overlays, decided to investigate the LSC, use it on specific projects, and determine whether it should be included in those projects that would be prepared for the 1985 construction season. An essential feature of this investigation is the carefully planned testing and monitoring of the conditions of the bridge decks overlaid with LSC in the State of Washington. Analysis of data collected from such an experiment could answer the WSDOT's questions regarding the effectiveness of LSC overlays, their service lives, and possibly methods of improving their future applications.

3 - OBJECTIVES

Evaluate the performance of LSC overlays applied on concrete bridge decks in the State of Washington through field experiment design and data collection and analysis.

4 - KEY WORDS

Concrete bridge deck, low-slump concrete, overlays, deterioration, corrosion, protective systems.

5 - RELATED WORK

All studies previously conducted relating to LSC overlays, bridge deck deterioration, rehabilitation, and protection.

6 - URGENCY/PRIORITY

The increasing cost of repairing deteriorated concrete bridge decks and the cumulative effects of an ever increasing number of decks in need of rehabilitation and/or protection create an urgent situation commanding immediate attention.

7 - COST

$85,000 for management, information collection, experiment design, testing, data analysis and evaluation, and reporting.

8 - IMPLEMENTATION

The results of the research could be implemented by WSDOT to decide whether the application of LSC for protection of bridge decks should be continued in the future or not.

9 - EFFECTIVENESS/BENEFITS

Information from the evaluation of LSC overlays could help the Department to determine its performance and effectiveness and to decide how to allocate construction and maintenance funds when protecting concrete bridge decks.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATMENT

1 - TITLE

Evaluation of Superplasticized Concrete Overlays for Bridge Deck Protection.

2 - PROBLEM

As the number of bridge decks requiring rehabilitation and protection increases, the Department is faced more frequently with deciding whether to continue the application of the old protective systems or to try newly developed systems and products promising more simplicity in construction and durability in performance. Past experience has indicated that none of the presently adapted rehabilitation and protection measures has been "zero maintenance". Thus, research is continuing in an effort to improve the current systems or develop new systems in order to overcome the problem.

Introduction of superplasticized concrete is relatively new. In the bridge deck protection field the material has the potential to produce properties similar to (or better than) low-slump dense concrete overlays without resort to heavy vibration and use of special finishing machines usually needed for this type of material. WSDOT has installed a few superplasticized concrete overlays in the past for protection of bridge decks. However, some problems have been encountered in the process of preparing and constructing the overlay. At this time the Department needs detailed information regarding the material's mixture formulation, construction procedures, and expected engineering properties in order to be able to warrant its future applications.

3 - OBJECTIVE

Evaluate the characteristics of superplasticized concrete through information collection and analysis; review the WSDOT's previous experience with the material; and make recommendations regarding future applications of the material for bridge deck protection.

4 - KEY WORDS

Concrete bridge deck, superplasticized concrete, overlay, deterioration, corrosion, protective systems.

5 - RELATED WORK

All studies conducted relating to superplasticized concrete and concrete bridge deck protection

6 - URGENCY/PRIORITY

This work should be given consideration, since the use of the subject protective system could eliminate the construction problems associated with the application of low-slump overlays presently under investigation by WSDOT.

7 - COST

$45,000 for information collection and review, information analysis and evaluation, report preparation, and field trips.

8 - IMPLEMENTATION

Based on the results of this work, the Department could decide whether superplasticized concrete should be included in the future for protection of bridge decks.

9 - EFFECTIVENESS/BENEFITS

The most direct benefit from the study would be that the Department would become familiar with this relatively new material and would be able to treat it well and apply it efficiently for protection of deteriorating bridge decks.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Evaluation of Thin Polymer Concrete Overlays for Bridge Deck Protection.

2 - PROBLEM

Two major problem areas are identified. First, some bridges, due to their original design, cannot tolerate excessive dead loads usually caused by protective overlays. Second, on highly traveled bridges the construction of a protective system can cause long periods of disruption to traffic. The Department needs a system which would overcome the latter problem while efficiently protecting the concrete decks from deterioration.

Despite its relatively higher cost, rapid curing and applications in the form of thin overlays have made polymer concrete suitable to eliminate both of the above-mentioned problems. Wide variations in the service performance of polymer concrete overlays, however, have been reported and determining their effectiveness has been difficult. At the present, the Department needs detailed information regarding the overlay's mixture formulation, construction procedures, and expected engineering properties in order to be able to warrant its future applications.

3 - OBJECTIVES

Evaluate the properties of thin polymer concrete overlays through information search and analysis, review the WSDOT's previous experience with the overlay, and make recommendations regarding the future application of the protective system.

4 - KEY WORDS

Concrete bridge deck, polymer concrete, thin overlay, deterioration, corrosion, protective systems.

5 - RELATED WORK

All studies relating to polymer concrete, thin overlays, and concrete bridge deck protection.

6 - URGENCY/PRIORITY

This research needs consideration since the protective system discussed is the only system suitable for use where excessive dead loads, as well as disruption to traffic, would be a severe problem.

7 - COST

$45,000 for information collection and review, information analysis and evaluation, report preparation, and field trips.

8 - IMPLEMENTATION

The results of the research could be implemented by WSDOT to decide whether thin polymer overlays should be adapted in those special situations where additional loads on highly traveled bridges are a problem.

9 - EFFECTIVENESS/BENEFITS

This work would help the Department become familiar with the properties of thin polymer concretes as well as the problems associated with their use, resulting in better and more predictable performance where their application is essential.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Evaluation of Cathodic Protection of Concrete Bridge Decks

2 - PROBLEM

Research has revealed that none of the overlay systems presently used for protection of concrete bridge decks can completely halt the continuing corrosion of reinforcing steel in chloride contaminated concrete. Cathodic protection has been reported to be the only system capable of totally stopping rebar corrosion in contaminated concrete. Although cathodic protection per se is an old technique used for protection of burried pipelines and ships' hulls, its application on concrete bridge decks is new.

Recently bridge deck cathodic protection has experienced rapid changes and developments in application and performance. The most recent methods of bridge deck cathodic protection are so new that their effectiveness has been difficult to determine. At present the Department needs to evaluate the effectiveness of its experimental cathodic protection installation; to update information in regard to application of the system; to determine its advantages and disadvantages; and to establish criteria for deteriorating decks to be protected through cathodic protection.

3 - OBJECTIVES

Evaluate the effectiveness of cathodic protection of concrete bridge decks through information collection and analysis; review the WSDOT's previous experience with the system; and make recommendations regarding the future applications of the cathodic protection of bridge decks.

4 - KEY WORDS

Concrete bridge deck, cathodic protection, deterioration, corrosion.

5 - RELATED WORK

All studies relating to concrete bridge deck deterioration and cathodic protection

6 - URGENCY/PRIORITY

Research in cathodic protection of bridge decks should be given a high priority, since it is the only system at the present that could halt the corrosion of rebar in contaminated concrete completely. Additionally, the advantages and disadvantages of the system when applied on the bridge decks needs to be carefully studied before adapting the system as a standard procedure.

7 - COST

$45,000 for information collection and review, information analysis and evaluation, report preparation, and field trips.

8 - IMPLEMENTATION

The results of this work could be implemented by WSDOT to decide when and how cathodic protection should be applied for protection of concrete bridge decks.

9 - EFFECTIVENESS/BENEFITS

The most direct benefits from this work are: 1) the Department would become familiar with the benefits and problems associated with the system; and 2) the system would be applied on decks where the maximum efficiency is gained.

PROTECTIVE SYSTEMS FOR NEW BRIDGE DECKS ONLY

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Performance Evaluation of Epoxy-Coated Reinforcing Steel in Concrete Bridge Decks.

2 - PROBLEM

In order to overcome the corrosion-induced deterioration of concrete bridge decks, WSDOT has adopted epoxy coating reinforcing steel as a standard procedure for construction of new bridge decks. The protective system, however, has the potential to develop accelerated corrosion patterns of cracks, holes and damaged areas on the coating caused mainly by fabrication and handling of the coated bars. Additionally, concrete deterioration may still be caused by other sources such as freeze-thaw action rather than corrosion of steel. This requires a carefully planned investigation of the effectiveness of this type of installation in order to verify protection.

3 - OBJECTIVES

Evaluate the performance and effectiveness of epoxy-coated reinforcing steel in concrete bridge decks presently in service through experiment design and data collection and analysis.

4 - KEY WORDS

Concrete bridge deck, epoxy coating, reinforcing steel, corrosion, deterioration, protective system.

5 - RELATED WORK

All studies conducted relating to bridge deck deterioration, rebar corrosion, and epoxy-coated rebar.

6 - URGENCY/PRIORITY

Due to the increasing number of newly constructed bridge decks using epoxy-coated rebars and the need to verify the performance of the installations, a high priority should be given to this research.

7 - COST

$85,000 for managment, information collection, experiment design, testing, data analysis and evaluation, and reporting.

8 - IMPLEMENTATION

Based on the results of this research WSDOT could decide whether to continue using epoxy-coating of rebar alone as a standard procedure for protection of new bridge decks.

9 - EFFECTIVENESS/BENEFITS

The results from this research could determine the effectiveness of epoxy coating rebar in regard to protection of bridge decks, thus helping the Department to predict its performance.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Evaluation of Galvanized Steel Reinforced Concrete Bridge Decks.

2 - PROBLEM

Galvanized steel reinforced concrete bridge decks have been in service in some areas in the United States since the early 1970's. The idea has been to protect reinforcing steel with a zinc coating in order to prevent its corrosion and subsequent concrete deterioration. The low additional inplace cost of galvanized steel has promoted its use as a protective system in concrete bridge decks. However, there have been conflicting reports regarding the system's performance on concrete bridge decks exposed to de-icing chlorides. The Department has not adapted the system as a standard protective measure for bridge decks but is evaluating the possibility of its use in the future. This requires assembling information in this field from different sources and analyzing it in order to justify the application of the system.

3 - OBJECTIVES

Collect, review, and analyze the available information in order to evaluate the effectiveness of galvanized reiforcing steel in concrete bridge decks.

4 - KEY WORDS

Concrete bridge deck, galvanizing, zinc-coated rebar, reinforcing steel, corrosion, deterioration, protective system.

5 - RELATED WORK

All studies relating to bridge deck deterioration, rebar corrosion, and galvanized rebar.

6 - URGENCY/PRIORITY

Priority of this work depends on the performance of the epoxy-coated reinforcing steel, since the protective system is an alternative to epoxy coating rebar presently adopted by WSDOT. In case of non-satisfactory performance of concrete decks containing epoxy-coated reinforcing steel, the research should be given a high priority.

7 - COST

$25,000 for assembling, reviewing, analyzing, and evaluating information and reporting.

8 - IMPLEMENTATION

The results of the research could be implemented by WSDOT to decide if galvanized reinforcing steel should be considered as regular procedure for bridge deck protection.

9 - EFFECTIVENESS/BENEFITS

This work will develop an insight into the effectiveness and performance of concrete decks presently protected by galvanized rebar. This in turn will help the Department to make rational decisions in regard to the use of the system for protection of bridge decks.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Protection of Tendons in Prestressed Concrete

2 - PROBLEM

The main reason for protecting prestressing steel is to eliminate the possibility of brittle fracturing of the prestressing steel, which might result from a combination of stress and corrosion. Generally, the performance of prestressed concrete bridges have been satisfactory in the United States. However, rare incidents of rust on concrete and concrete spalling have been reported.

At the present time plastic ducts are recommended by FHWA for protection of post-tensioned tendons, but there is no known method of protection for pretensioned strands. The Department is considering plastic ducts for protection of future post-tensioned bridge decks and is also evaluating the potential of systems such as epoxy coating for pretensioned strand protection. This requires a thorough state-of-the-art assessment in the area of prestressed tendon protection before justifying the future application of the relavent protective systems.

3 - OBJECTIVES

Collect, review and analyze the available information in order to evaluate the effectiveness of different protective systems recommended and proposed for protection of prestressed tendons.

4 - KEY WORDS

Prestressing steel, prestressed concrete, deterioration, corrosion, protective systems.

5 - RELATED WORK

All studies relating to prestressed tendon protection against corrosion.

6 - URGENCY/PRIORITY

Due to the overall satisfactory performance of prestressed concrete bridges, a thorough study does not require immediate attention. However, a state-of-the-art assessment on the potential problems associated with durability of prestressed concrete and the relavent protective systems, at this time, should be given a high priority.

7 - COST

$25,000 for assembling, reviewing, analyzing and evaluating information, and reporting.

8 - IMPLEMENTATION

The Department, based on the recommendation of the research, may implement the application of the recommended systems for protection of prestressed tendons.

9 - EFFECTIVENESS/BENEFITS

The main benefit from this work is that the Department will become familiar with the potential problems associated with prestressed concrete in corrosive environments as well as the state-of-the-art technology for preventing those problems.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Evaluation of Newly Developed Concretes and Practices for Construction of Concrete Bridge Decks.

2 - PROBLEM

New materials and practices for construction of bridge decks are being developed and used in the United States in order to provide more durable bridge decks and eliminate problems, such as safety and disruption of traffic, usually associated with the reconstruction and replacement of deteriorated decks in older structures. The Department needs to keep abreast of the state-of-the-art to better understand these materials and practices and to learn how they would respond to long-term performance. This requires collecting information from different sources such as other research groups and industry and evaluating them.

3 - OBJECTIVES

Collect and evaluate available information from different sources in order to determine the effectiveness of newly developed systems and materials for construction of bridge decks.

4 - KEY WORDS

Concrete bridge deck, construction, reconstruction, deterioration, durability.

5 - RELATED WORK

All studies conducted relating to bridge deck deterioration, construction, replacement, and durability.

6 - URGENCY/PRIORITY

Consideration should be given to this study since it is needed in order to keep abreast of the rapidly developing bridge deck state-of-the-art in the United States.

7 - COST

$25,000 for assembling, reviewing, analyzing, and evaluating information, and reporting.

8 - IMPLEMENTATION

Any findings of this research considered appropriate by the WSDOT could be implemented. The results of the study could be used as the basis for establishing future research projects.

9 - EFFECTIVENESS/BENEFITS

Acceptable materials and practices could be implemented to add to service lives of the bridge decks and eliminate the problems usually encountered in the process of replacing the decks in older structures.

REPAIR CONCERNS

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Evaluation of Methods for Removal of AC/membrane Systems Applied on Concrete Decks.

2 - PROBLEM

Asphalt Concrete (AC) wearing courses on bridge decks require replacement after a certain period of service. Normally, in the process of AC removal the underlying waterproofing membrane does not stay intact and has to be removed also, however, employing AC/membrane removal procedures and equipment results in irregularities and disturbance to the concrete surface. New membranes cannot be applied on these irregularities since they are not compatible with them.

In view of this problem, WSDOT has specified that only latex modified concrete overlay be used for protection of bridge decks on which removal of AC/membrane system is required until such time as a removal procedure is developed which will not result in damage to the underlying concrete.

3 - OBJECTIVE

Collect and evaluate available information regarding techniques for AC/membrane removal, suggest methods for AC/membrane removal, and conduct field trials to evaluate their effectiveness.

4 - KEY WORDS

Concrete bridge deck, aspahlt concrete, waterproofing membrane, asphalt concrete removal equipment.

5 - RELATED WORK

All studies relating to methods of flexible pavement removal and installation of new AC/membrane systems.

6 - URGENCY/PRIORITY

Employing the present procedure to make the great number of AC/membrane installation replacements that will be necessary in the future will cause irregularities on concrete surfaces and require application of more expensive latex modified concrete overlay for protection of the decks with no exemption. This creates an urgent situation requiring immediate attention.

7 - COST

$90,000 ($55,000 for management, information collection, experiment design, data evaluation, and reporting; $35,000 for field trials of AC/membrane removal and replacement).

8 - IMPLEMENTATION

Any AC/membrane removal method recommended by the research and found appropriate by WSDOT will be implemented.

9 - EFFECTIVENESS/BENEFITS

Acceptable techniques could be adopted to eliminate concrete surface disturbance while removing AC/membrane systems, thus reducing the cost of protection of bridge decks in many cases.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Performance evaluation of fast setting mixes for concrete bridge deck repair.

2 - PROBLEM

Polymer concretes are used in Washington as fast setting mixes for patching and restoring deteriorated concrete bridge decks where disruption to traffic is costly and undesirable. However, their use may not be suitable when the repair job is large, since they are costly and difficult to handle when used in large volumes, unless special equipment is employed. Their incompatibility with cement concrete substrates, when subject to thermal expansion, may also cause deterioration in the vicinity of the interface. At the present, WSDOT needs better understanding of the application and performance of polymer concrete used to restore bridge decks in order to verify their future use over cement concrete patches.

3 - OBJECTIVE

Collect information, review WSDOT's previous experience with the material, design field experiments, analyze data, and evaluate the effectiveness of the applications.

4 - KEY WORDS

Concrete bridge deck, deterioration, restoration, polymer concrete.

5 - RELATED WORK

All studies conducted relating to concrete bridge deck repair and polymer concretes.

6 - URGENCY/PRIORITY

Research in the area of polymer concrete needs special attention since the material is used extensively as an expedient method of bridge deck repair on highly traveled bridges either under an AC/membrane system or with no overlays.

7 - COST

$85,000 for management, information collection, experiment design, testing, data analysis, evaluation and reporting.

8 - IMPLEMENTATION

Based on the results of the research, WSDOT could decide whether the application of polymer concrete should be continued for bridge deck restoration as an alternative to cement concrete application.

9 - EFFECTIVENESS/BENEFITS

The study will head to better understanding of the behavior of polymer concrete patches applied on concrete bridge decks. This in turn could result in selection of the most appropriate patching material for each application (i.e., cement concrete vs. polymer concrete).

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Effects of Traffic-Induced Vibration on the Quality of Concrete Bridge Deck Repair.

2 - PROBLEM

There have been concerns over the susceptibility of freshly placed concrete on bridge decks to the effects of traffic-induced vibration. It has been speculated that the vibration caused by the traffic maintained on concrete bridge decks during the periods of patching, overlaying, or widening the decks may cause defects in the concrete such as segregation of the ingredients, differential settlements, loss of bond between the overlay and underlying concrete, and loss of bond between the rebar and concrete.

Presently, traffic is maintained on the Washington bridges during the periods of repair with restrictions on the speed. WSDOT, however, needs to determine the advantages and disadvantages of permitting traffic on bridges in order to verify the present traffic control regulations.

3 - OBJECTIVE

Assemble, review and analyze available information in order to determine the effects of traffic-induced vibration on the quality of repair.

4 - KEY WORDS

Concrete bridge deck, repair, overlay, widening, traffic, vibration.

5 - RELATED WORK

All studies conducted relating to concrete bridge deck repair and the impact of traffic control on its quality.

6 - URGENCY/PRIORITY

A review of traffic control regulations in other states and the documented cases of effects of traffic-induced vibration on bridge decks will be needed in order to verify the present regulations on traffic control.

7 - COST

$25,000 for collecting, reviewing, analyzing and evaluating information, and reporting.

8 - IMPLEMENTATION

Based on the findings of the research, the Department could either verify the current traffic regulations on the bridge decks or impose new regulations.

9 - EFFECTIVENESS/BENEFITS

This work would benefit the Department, since it would determine whether the traffic-induced vibration could possibly affect the quality of the great number of bridge decks scheduled for reconstruction in the future.

CONDITION EVALUATION TECHNIQUES

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Evaluation of Effectiveness of Half-cell Corrosion Detection Method for Concrete Bridge Decks.

2 - PROBLEM

Concrete bridge deck deterioration due to rebar corrosion in a chloride contaminated environment has become a major problem to the Department and indications are that concern is widespread. The Department has routinely used chloride content measurement for determination of the potential for corrosion of rebar in the concrete. Although efficient and reliable, the chloride content measurement is a time consuming and destructive testing procedure which involves sampling of concrete in the field and subsequent laboratory testing. In addition, the technique is not able to assure the corrosion state of the rebar. Half-cell corrosion detection technique, on the other hand, has been used by the Department only on research and special projects. The previous experience with half-cell method has indicated that the results might not always be consistent. This in turn has resulted in doubts about the reliability of the technique. Presently there is a great need for a rebar corrosion detection technique and half-cell method seems to have the most potential for adaptation as a standard test to verify corrosion existance in reinforced concrete.

3 - OBJECTIVES

Evaluate the effectiveness and reliability of half-cell corrosion detection method through conducting field experiments and data analysis.

4 - KEY WORDS

Concrete, deterioration, bridge deck, corrosion, rebar, half-cell, condition survey.

5 - RELATED WORK

All studies conducted relating to reinforcing steel corrosion and half-cell corrosion detection technique.

6 - URGENCY/PRIORITY

The need for a non-destructive, reliable, and effective technique to detect corrosion of rebar in concrete in advance of corrosion induced deterioration in concrete creates a situation requiring special attention for a relevant investigation.

7 - COST

$85,000 for management, information collection, experiment design, testing, data analysis and evaluation, and reporting.

8 - IMPLEMENTATION

The results of the research could be implemented by the Department to decide whether half-cell corrosion detection technique should be included in the routine field condition survey of the bridge decks.

9 - EFFECTIVENESS/BENEFITS

Adaptation of the non-destructive half-cell corrosion detection technique could help the Department to predict the conditions of the concrete bridge decks long before the concrete deterioration becomes a problem. The technique could also eliminate the need for chloride content measurment in many cases, thus reducing the cost of bridge deck condition survey.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Evaluation of Effectiveness of Thermographic Delamination Detection in Concrete Bridge Decks.

2 - PROBLEM

Presently there is a great need for a technique which could detect the concrete deterioration in the asphalt covered decks. Although very efficient on bare concrete decks, chain dragging or the conventional method of delamination detection is not totally successful in defining concrete delaminations under the asphalt concrete. This has made the assessment of the conditions of the asphalt covered decks, presently under service, difficult and their performance almost unpredictable. One method which has shown the greatest potential from the point of view of accuracy and speed for detection of delaminations in both exposed and asphalt covered decks has been infrared thermography.

3 - OBJECTIVES

Evaluate the effectiveness of thermographic delamination detection through conducting field experiment and data analysis.

4 - KEY WORDS

Concrete bridge deck, delamination, deterioration, thermography, condition survey.

5 - RELATED WORK

All studies conducted relating to bridge deck concrete deterioration detection and thermography.

6 - URGENCY/PRIORITY

The need for assessment of the conditions of the great number of asphalt covered bridge decks in order to be able to establish priorities for their repair creates a situation requiring the development of a suitable technique for this purpose.

7 - COST

$85,000 for management, information collection, experiment design, testing, data analysis and evaluation, and reporting.

8 - IMPLEMENTATION

The results of the research could be implemented by the Department to decide whether thermographic delamination detection should be included in the routine field condition survey of the bridge decks.

9 - EFFECTIVENESS/BENEFITS

The most direct benefit from this work is to be able to assess the conditions of the asphalt covered decks presently under service, predict their performance, and establish priorities for their repair.

CAUSES OF DETERIORATION

3 - OBJECTIVES

Collect, review and evaluate information in order to determine the problem and solutions to it.

4 - KEY WORDS

Concrete deterioration, freeze-thaw action, scaling, bridge deck, air entrainment.

5 - RELATED WORK

All studies conducted relating to the deterioration of concrete in freeze-thaw environments.

6 - URGENCY/PRIORITY

Due to the increasing number of newly constructed concrete bridges,as well as replaced bridge decks and the possibility of deterioration of these structures in freeze-thaw environments, consideration should be given to this research.

7 - COST

$25,000 for assembling, reviewing, analyzing and evaluating information, and reporting.

8 - IMPLEMENTATION

Any findings of this work considered appropriate by WSDOT could be implemented. This will include systems and materials to prevent or retard freeze-thaw deterioration in concrete.

9 - EFFECTIVENESS/BENEFITS

The research will better identify the problems associated with highway structures in freeze-thaw environments and seek methods to protect the increasing number of newly built highway structures from freeze-thaw deterioration.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Concrete Deterioration Caused by Reactive Aggregate

2 - PROBLEM

Some aggregate with certain chemical components will react with alkalies in cement and expand abnormally. This expansion can in turn cause map cracking of concrete. Accumulation of water in the cracks can further worsen the situation in the presence of freeze-thaw action. Sodium chloride used for deicing may also contribute to the deterioration by regenerating alkali in the concrete if aggregate reaction occurs. WSDOT needs to evaluate the causes and effects of the problem, identify the potentially reactive aggregate in Washington, and seek solutions to the problem if avoiding the use of potentially reactive aggregate in concrete is not feasible.

3 - OBJECTIVE

Collect, review and evaluate information in order to determine the problem, solutions to the problem and methods to identify potentially reactive aggregate.

4 - KEY WORDS

Concrete deterioration, alkali, reactive aggregate, map cracking.

5 - URGENCY/PRIORITY

Due to the increasing number of newly constructed concrete bridges, as well as replaced bridge decks, and the possibility of incorporating reactive aggregate in their structures, special attention should be given to this research.

7 - COST

$25,000 for assembling, reviewing, analyzing and evaluating information, and reporting.

8 - IMPLEMENTATION

Any findings of this research considered appropriate by the WSDOT could be implemented. This would include rejection of certain types of aggregate or regulation of their content in concrete.

9 - EFFECTIVENESS BENEFITS

This work will better identify the problems associated with reactive aggregate and seek solutions to those problems. This would ultimately result in regulations on the type of aggregate used in concrete bridges, thus protecting future highway concrete structures from deterioration caused by reactive aggregate.

BRIDGE DECK MANAGEMENT SYSTEM

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

RESEARCH STATEMENT

1 - TITLE

Development of Guidelines for Bridge Deck Management System.

2 - PROBLEM

Due to the increasing number of bridge decks in need of repair and rehabilitation and limitations in maintenance budgets, there seems to be a great need for development of a system which would systematically predict and prioritize bridge deck treatment (i.e., replacement, rehabilitation, and protection) and delegate repair effort to decks where the need is greatest. Such a system would be a strong tool for the Department to make rational decisions regarding expenditure of bridge deck maintenance funds.

3 - OBJECTIVE

Develop guidelines for a system which would systematically predict and prioritize bridge deck maintenance.

4 - KEY WORDS

Concrete bridge deck, deterioration, rehabilitation, protection.

5 - RELATED WORK

All studies previously conducted relating to bridge deck rehabilitation and restoration.

6 - URGENCY/PRIORITY

This research needs considerations since there are too many bridge decks to repair but not enough budget for all. Therefore, it is important to allocate the maintenance funds where they are greatly needed.

7 - COST

$25,000 for assembling and reviewing the relevant research and developing guidelines for bridge deck management system.

8 - IMPLEMENTATION

Any findings of this work considered appropriate could be implemented by the Department to establish a systematic approach for bridge deck maintenance.

9 - EFFECTIVENESS/BENEFITS

Information from the research will help the engineers to predict and allocate the maintenance funds where the need is greatest.

VOLUME FOUR

Introduction of FY86-87 Bridge Deck Research
and
Work Plan Development
(Task Four)
of

Bridge Deck Program Development

TABLE OF CONTENTS

I - CHAPTER ONE
INTRODUCTION

This phase of "Bridge Deck Program Development" introduces the bridge deck related research subjects submitted by researchers and selected by the Washington State Department of Transporation (WSDOT) for FY86-87 and proposes detailed work plans for their accomplishment. The selected research topics are:

Combined
Overlay
Research

1 Performance Evaluation of Latex Modified Concrete Overlays
2 Performance Evaluation of Low-Slump Dense Concrete Overlays
3 Evaluation of Thin Polymer Concrete Overlays
4 Effectiveness of Concrete Overlays

5 Rapid Construction Techniques for Bridge Deck Reconstruction
6 AC/Membrane Placement and Removal on Bridge Decks by Microwave Heating
7 Evaluation of Half-Cell Corrosion Detection Method for Bridge Decks
8 Development of Guidelines for Bridge Deck Management System

Because research topics (1) through (4) are interrelated, WSODT integrated them into one research item entitled "Combined Overlay Research," or "Evaluation of Concrete Overlays for Bridge Applications." This research item includes evaluation of latex modified concrete, low-slump dense concrete, polymer concrete, superplasticized concrete, and concrete sealers as well as field evaluation of Washington installations of the first three overlays. With this combination the total number of selected research items is five. However, the five research items are also interrelated. Therefore, in order to coordinate the activities more efficiently so that maximum benefit could be gained from the overall research, they were further integrated into one major research effort entitled "Concrete Bridge Deck Research Program."

Each of the five research items within this program are then presented as different sub-programs of the overall research. Each chapter of the current report is dedicated to one of those sub-programs. Each chapter presents research backgrounds, objectives, expected benefits, proposed work plans and budgets for the research. Each chapter has been prepared according to the Department's format for research proposal preparation.

There are three major parties involved in the overall bridge deck research program. These are: the Washington State Transportation Center (TRAC), WSDOT Materials Laboratory, and consultants. Research relative to each sub-program will be conducted by one or more of the parties involved. Certain responsibilities are suggested for each party and are explained in the work plan of each sub-program. The following Table summarizes the proposed schedule and budget for the overall bridge deck research program. The work plan provides an overview of how the FY86-87 bridge deck research will be completed. However, the plan is not final and it is subject to review by WSDOT as well as the other parties participating in the research. Thus, all comments are welcome and adjustments can be made to the satisfaction of all agencies involved in the research program.

SUB-PROGRAMS	JUL	AU	MAY	JUN	COST, $ FY 86	FY 87	FY 86-87
1 Evaluation of Concrete Overlays for Bridge Applications TRAC* Faculty, 1 mo Res Eng 10-1/4 mo Prog. Ast, 2 mo 50% Res Ast., 8 mo **WSDOT** **CONSULTANT**	Site Seningtion		TRAC)		**TRAC** 46,935	52,529	99,464
					Mat. Lab+ 13,200	26,400	39,600
					Consult. 30,000	------	30,000
					Sub-Total 90,135	78,929	169,064
2 Evaluation of Half-cell Corrosion Detection for Concrete Bridge Decks. TRAC* Faculty Res Eng 5-1/2 mo Prog Ast, 1 mo 50% Res Ast, 6 mo **WSDOT** **CONSULTANT**		n of od- AC)			**TRAC** 20,203	29,964	50,167
					Mat. Lab+ ------	------	------
					Consult. ------	------	------
					Sub-Total 20,203	29,964	50,167
3 Development of Guidelines for Bridge Deck Management System TRAC* Faculty Res. Eng. 4 mo Prog. Ast, 3/4 mo 50% Res. Ast, 6 mo **WSDOT** **CONSULTANT**		nent of Guide- Management			**TRAC** 16,070	18,288	34,358
					Mat. Lab ------	------	------
					Consult. ------	------	------
					Sub-Total 16,070	18,288	34,358
4 Evaluation of Rapid Construction Techniques for Bridge Deck Reconstruction. TRAC* Faculty 2 mo Res. Eng. 1 mo Prog. Ast., 1 mo 50% Res. Ast., 4 mo **WSDOT** **CONSULTANT**		blishment of e Standards C)			**TRAC** 17,726	12,740	30,465
					Mat. Lab ------	------	------
					Consult. 25,000	25,000	50,000
					Sub-Total 42,726	37,740	80,466
5 AC/Membrane Placement/Removal on Bridge Decks by Micro-Wave Heating. TRAC* Faculty Res. Eng. Prog. Ast, 50% Res. Ast., **WSDOT** **CONSULTANT**		-the-Art ation into sultant)			**TRAC** ------	------	------
					Mat. Lab ------	------	------
					Consult. ------	25,000	25,000
					Sub-Total ------	25,000	25,000
	TOTAL COST ($) Sub-programs				**TRAC** 100,934	113,521	214,455
					Mat. Lab 13,200	26,400	39,600
					Consult. 55,000	50,000	105,000
					Sub-Total 169,134	189,921	359,055

TRAC Staff Total Time* (24 mo.)

Position	FY 86	FY 87	FY 86-87
Faculty	2	1	3
Res. Eng.**	8-3/4	12	20-3/4
Prog. Ast.	2-1/4	2-1/2	4-3/4
50% R.A.	12	12	24

* Con
eng
app

** Res
Bri
mo

+ Tes

II - CHAPTER TWO

Proposed Research for

"EVALUATION OF CONCRETE OVERLAYS FOR BRIDGE APPLICATION"

Table of Contents

1 - Problem Statement

Concrete overlays incorporating various materials and offering properties compatible with the bridge deck environment will play a major role in the protection of Washington bridges. Although the number of concrete overlay installations in Washington is under one hundred at this time, a significant number of the approximately 3,000 bridges in the state highway system requiring deck protection systems may eventually be protected with concrete overlays. However, potential problems with the performance of these overlays may exist as a result of either technology and design practices or the overlays sensitivity to construction practices and the environment. In order to manage future concrete overlay installations more efficiently, information about the performance of these systems is needed now. Potential problems should be identified and the proper measures used to prevent those problems in future constructions.

2 - Background Statement

Many concrete overlays, namely latex-modified concrete (LMC) and low-slump dense concrete (LSC), have been used recently and more will be used in the future. These overlays, if proven satisfactory, will play as major a role in protecting Washington bridges from premature deterioration as AC/membrane overlays did in the 1970s. This trend in bridge deck protection is generally due to the following reasons:

- they have better durability, resulting in relatively longer service life for the overlays;
- they are well-suited to repairing highly deteriorated decks;
- they offer better protection to underlying reinforced concrete decks in terms of steel corrosion and concrete deterioration;
- they contribute to the structural capacity and stiffness of the deck and superstructure in certain types of structures.
- they are an integral component of the deck system, resulting in determination of deck conditions with less difficulties.

Additionally, polymer concrete (PC) overlays have the advantages of curing rapidly and applying in very thin layers, which qualify them for use on heavily travelled bridges or those with lower tolerance for excessive dead loads. These unique properties of PC promise more use of the system in the future.

Despite the aforementioned advantages of the concrete overlays, researchers have been concerned about their constructibility, sensitivity to hot and cold weather concreting, and quality control during construction, which may affect their performance adversely. For example, application of LMC and LSC requires scarifying the concrete deck for bonding. This process can result in damage to the underlying concrete and reinforcement if proper equipment and procedures are not employed. Surface preparation for PC requires sand blasting; however, shot blasting may provide higher shear strength between the overlay and the original concrete. Effective consolidation of LSC needs special equipment and quality control, otherwise the presence of large amounts of entrapped air will result in a chloride permeable overlay. The effectiveness and constructibility of superplasticized concrete (SC) in this regard should be explored. Curing LMC during cold and hot weather also requires special attention. Shrinking and cracking can develop when concreting LMC in hot weather. On the other hand, cold weather does not permit the curing to be completed soon enough. The handling and application of PC can also be difficult in hot and cold temperatures. Depending on the condition of a bridge deck, a sealer may be a simpler and less expensive solution when applied solely or in conjunction with a conventional concrete overlay or asphalt overlay.

Aside from constructibility, the field performance of the concrete overlays needs to be clarified. For example, researchers should determine the effectiveness of concrete overlays in halting corrosion of reinforcing steel, as well as its durability and bonding properties. The propagation and reflection of active cracks originating from an underlying deck may be another problem associated with rigid overlays. PC may not be thermally compatible with the substrate due to its relatively larger volume changes. The possibility of system failure due to this phenomenon should be explored. Concrete sealers, when used alone, must demonstrate skid and wear resistance and must be impermeable to chloride penetration. When used with an overlay they must demonstrate proper bonding abilities.

3 - Objectives

This project will provide insight into the reliability and problems of concrete overlays, namely LMC, LSC and PC by evaluating the performance of sampled Washington installations. Additionally, it will review and evaluate the current use of the overlays mentioned as well as other approaches to deck repair, namely superplasticized concrete and sealers. Attempts will be made to integrate the results of this work into WSDOT current practice.

4 - Benefits

This work will give management insight into the performance of the existing Washington concrete overlays. It will assist designers in foreseeing potential problems and planning more durable decks. It will help inspectors to establish realistic requirements for concrete overlay construction and to identify those aspects of bridge deck conditions which have a significant impact on their performance.

5 - Products

- Draft interim report "Experiment Design for Sampled Washington Overlay Installations," February 29, 1986
- Draft interim report "Evaluation of Current Bridge Deck Overlay Practice," March 31, 1986
- Draft final report "Evaluation of Sampled Washington Overlay Installations," June 30, 1987

6 - Implementation

The Department can implement the conclusions from the field evaluations of existing installations and the results of reviewing the experiences of authorities involved with bridge deck treatment and include them in construction and inspection considerations.

7 - Work Plan Development

Task I. Evaluation of Practice (Consultant and TRAC)

The research team will obtain scattered information regarding current use of bridge deck overlays by contacting a few highway agencies, including WSDOT. Some technical publications not included in the previous research will also be reviewed. The focus of the information collection will be on LMC, LSC and PC overlays. Additionally, the researchers will consider SC overlays and concrete sealers with and without overlays. Two major areas of concern will be: a) material design, construction and inspection considerations, and b) criteria for selection of each system. The team will ask agencies to submit their relevant construction specifications, inspection manuals, and records on the construction, cost, and performance of their overlays. Based on the analysis and evaluation of the generated information as as well as their own experience with concretes subjected to a bridge deck environment, the research team will compare the research results to WSDOT's current overlay practices and make recommendations regarding material design, construction procedures and overlay inspection. Also, criteria for applying each system to fit individual deck conditions cost effectively will be developed. The recommendations may be supplemented upon completion of the field evaluation phase (Task IV) if necessary. The team will issue an interim report at the conclusion of Task I (March 31, 1986) and will document the research conducted during this task.

Task II. Test Site Selection (WSDOT)

From among many bridges in Washington that have already received LMC, LSC and PC overlays, the researchers intend to consider a maximum of 12 bridges for the field evaluation program (5 LMC, 5 LSC and 2 PC installations). Previous research with concrete overlays has disclosed different construction and environmental conditions which may affect the performance of the overlays. When selecting test sites these conditions should be considered in order to determine the extent to which they influence the systems' behavior. However, the availability of base data may be the governing factor in selecting the test sites.

The team prefers that each of five LMC or LSC test sites represent at least one of the conditions listed below:

- Age of installation not less than 7 years (preferrably > 10 years)
- Traffic volume higher than 10,000 ADT (preferrably > 20,000 ADT)
- Extensive deterioration and contamination prior to rehabilitation and protection (preferrably > 5 percent spalls or sum of all deteriorated and/or contaminated concrete > 60 percent)
- Overlay applied and cured during cold weather (preferrably < 45 degrees F.)
- Overlay applied and cured during hot weather (preferrably > 85 degrees F.)

The researchers prefer that each of two PC test sites represent at least one of the conditions listed below:

- Age of installation not less than 5 years
- Traffic volume higher than 20,000 ADT

As mentioned earlier, the nature of the rehabilitation and extent of the data already collected may be the governing factor in selecting the test sites. The following conditions, when present, would be of value to the experiment design (Task III):

- Delaminated concrete is repaired at the test site at the time of the overlay.
- Information regarding chloride contamination, preferrably at the time of the overlay, is available. This includes the location of chloride data points, their sampling depth in the concrete, and the time of sampling.
- the location of concrete repair areas at the time of rehabilitation and protection, and preferrably their depths in the original concrete, is known. Such data could not only help locate the areas of the deck most vulnerable to deterioration but would indicate if the original concrete located where the chloride tests were conducted during the rehabilitation still remained in place.

Additionally, any data collected during the service lives of the overlays, including chloride measurement, rapid choride permeability tests, chain dragging, half-cell tests, pachometer surveys and routine bridge condition inspection reports, would be useful in determining the effectiveness of the installations.

WSDOT will assemble and provide to TRAC all its appropriate data on the bridges selected including design, construction (as-built), maintenance, and rehabilitation, and test data and other appropriate information by September 30, 1985 at the latest.

Task III. Background Information Review and Experiment Design (TRAC)

After selecting the test bridges, WSDOT will present the scattered background data on the test sites to the project staff. The project staff will examine and evaluate the data and determine their significance and suitability for the study. This examination could reveal performance trends as well as any problem areas related to design and construction. Based on the evaluated background data, TRAC will consider areas on the bridge deck representing different repair conditions, as well as other factors, for testing. This process will take full advantage of the testing period and minimize disruption to traffic as well. Accordingly, testing activities will be detailed in sequence for these areas as well as other areas which may be located during the testing. Included in the experiment design will be the logic behind each test and the significance of the results in determining the performance of the overlays. Upon completion of the experiment design, TRAC will submit an interim report containing the background data and the testing methodology developed to WSDOT for its consideration (February 29, 1986).

The details of such an experiment cannot be ascertained until actual sites are known. However, the testing plan should include at least the following general features:

Field Activities:

- Visual inspection and mapping of various types of distress such as cracking, scaling and spalling
- Electrical resistivity testing (only on PC installations)
- Half-cell testing (on PC installations either small holes will be drilled to the original concrete for this purpose or core location will be used)
- Chain dragging to locate debonding or delaminations
- Coring concrete to verify debonding or delaminations, depth of cracking and depth of overlay
- Coring sound concrete to provide samples for rapid chloride permeability tests
- Test to measure bond between old and new concrete
- Pachometer survey to determine the depth of rebar
- Obtaining powdered chloride samples for chloride content testing (core samples may be used for this purpose)

Laboratory Activities:

- Chloride content determination (powdered and cored samples)
- Rapid chloride permeability testing (cored samples)

- Shear testing to measure bond on cored samples, if the bond cannot be determined in the field.

Pretesting meetings with the parties involved in the project will assure efficient operation and will clarify each party's function and duties during the testing program. In some cases an inspection of the test site in advance of the testing phase may be required.

Task IV. Data Collection Through Field and Laboratory Testing (WSDOT and TRAC)

The WSDOT Materials Laboratory will conduct all field and laboratory tests according to the experiment design. WSDOT will provide traffic control and protection for the condition survey. Although the Mat. Lab. will collect all physical data, a representative for TRAC will be present at each test site to assist with obtaining appropriate data. The Mat. Lab. will provide TRAC with the data obtained during the field testing upon completion of each bridge deck testing. However, the Mat. Lab. will submit the results of laboratory test within 2 weeks - at the latest from the conclusion of each field test.

Coordinating all the activities will be most important if the team is to maximize data acquisition and minimize traffic problems. The actual testing day for each bridge must follow the project's time schedule but must also be appropriate for the weather. In order to comply with the project's time schedule, four bridges must be tested in FY86 (i.e., during the months of May and June 1986) and eight bridges in FY87 (i.e., during the months of July, August, September and, perhpas, October 1986).

Task V. Data Analysis and Evaluation of Washington Installations (TRAC)

The TRAC project staff will analyze and interpret the field and laboratory data collected during the testing phase, as well as those submitted by WSDOT as background construction and test in-formation, in order to accomplish the following:

- determine the durability of the systems and their effectiveness in protecting of the decks;
- attempt to determine the cause of any problems documented;
- recommend solutions to those problems, if possible;
- recommend modifications to the testing program, if needed, for future investigations.

Additionally, TRAC will incorporate the results from TASK I, Evaluation of Practice whenever possible, interpret the overall findings and make final conclusions regarding the performance of LMC, LSC and PC installations. The activities of Task V will be included in the final report which will be issued at the conclusion of Task V (June 30, 1987).

Task VI. Reports

As mentioned earlier in the Work Plan, the consultant and TRAC will issue interim reports at the end of Task I (March 31,

1986) and Task III (February 29, 1986) which will include recommendations regarding the use of concrete overlays and document the development of the test program, respectively. TRAC will issue the final report at the end of Task V (June 30, 1987) which will document the overall activities of the project and include the conclusions regarding the performance of the test installations.

Responsibilities:

The team intends that all the parties participating in the project work closely to achieve the desired end results of this research. However, certain responsibilities are assigned to each party and are outlined in the following so that no oversight occurs and the project advances on schedule.

Task	Responsibility
I	The consultant will have the main responsibility for accomplishing of this task. The consultant will contact agencies, review and evaluate current practices, and make recommendaitons regarding design, construction and inspection procedures. TRAC will contribute one faculty-month, one research engineer-month, and one research assistant-month (one staff-month is approximately 155 staff hours) and will assist with the

evaluation of the generated information. The consultant will prepare an interim report to be submitted March 31, 1986.

II WSDOT will select test bridges possibly according to the criteria presented. WSDOT will assemble and provide to TRAC its appropriate data on the selected bridges by September 30, 1985, at the latest.

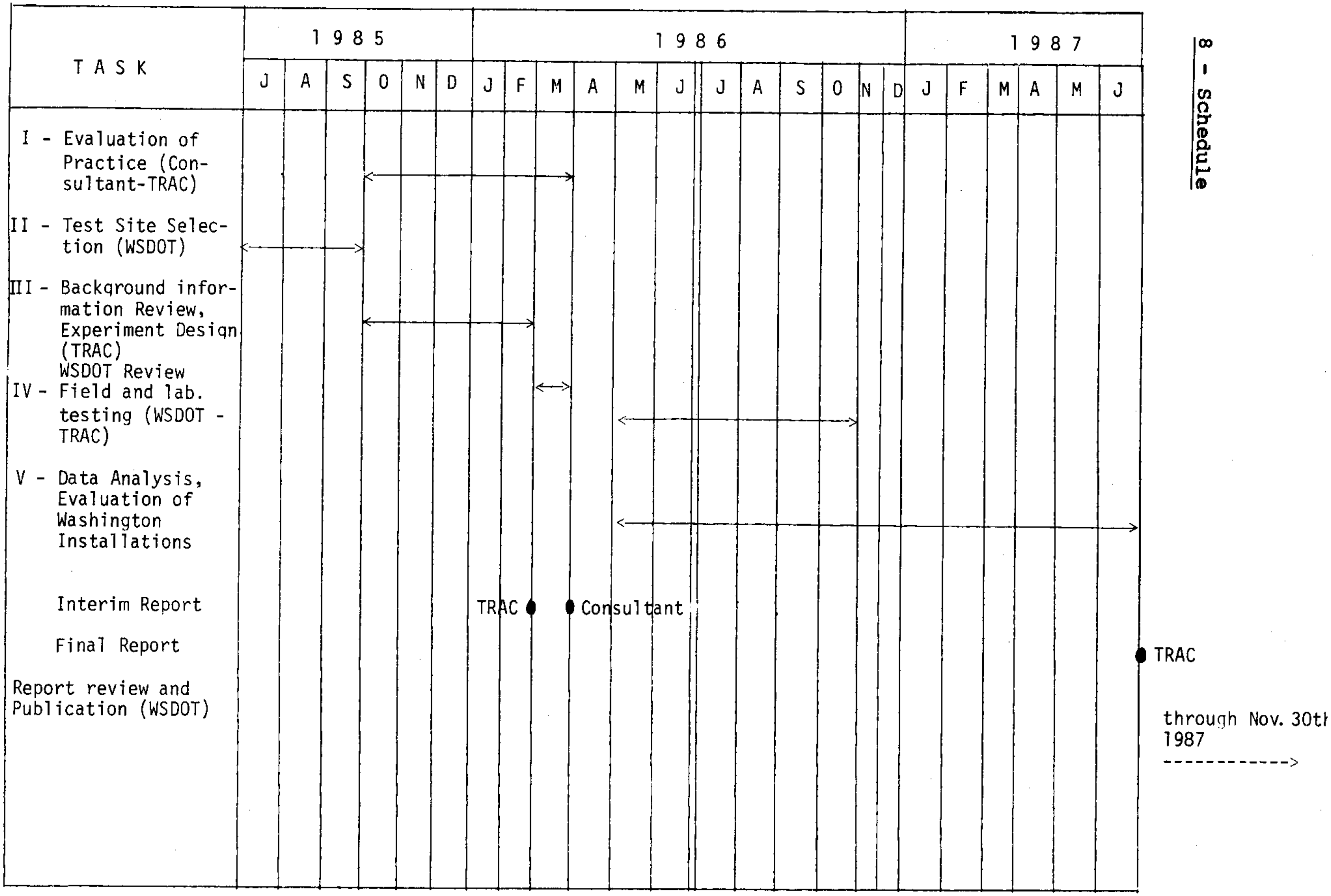
III TRAC will evaluate the background data and will accordingly develop a plan for testing the bridges in conjunction with the WSDOT Materials Laboratory. TRAC will prepare an interim report to be submitted February 24, 1986.

IV The WSDOT Materials Laboratory will conduct all field and laboratory tests according to schedule and will provide TRAC with the complete results within 2 weeks from the conclusion of each field test at the latest.

V TRAC will analyze and evaluate the data to determine the durability and effectiveness of the test installations. The results will be included in the final report to be submitted June 30, 1987.

VI. The reports will be prepared by the responsible parties as per the schedule.

8 - Schedule


TASK
1985
1986
1987
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
I - Evaluation of Practice (Consultant-TRAC)
II - Test Site Selection (WSDOT)
III - Background information Review, Experiment Design (TRAC)
WSDOT Review
IV - Field and lab. testing (WSDOT - TRAC)
V - Data Analysis, Evaluation of Washington Installations
Interim Report
Final Report
Report review and Publication (WSDOT)
TRAC
Consultant
TRAC
through Nov. 30tł 1987
------------>

9 - Staffing Plan

The individuals who will work on the project are as follows:

TRAC

Dr. Neil Hawkins, Chairman of Civil Engineering, will be principal investigator and project coordinator. He will contribute to the evaluation of practice of concrete overlays. Professor Hawkins is a well known researcher. He has taught and carried out research and consulting work in structural and construction engineering, with emphasis on reinforced concrete.

Khossrow Babaei, Research Engineer, will serve as co-principal investigator. He will design the experiment and coordinate the data collection and its input into the final report. Mr. Babaei is a registered professional engineer with experience in construction, design, and inspection. He has carried out research on concrete and concrete materials, including materials used in bridge structures and subjected to bridge environments.

Other TRAC staff will include Amy O'Brien as support services coordinator and a graduate student as research assistant.

10 - Budget Estimate

	FY86	FY87	FY86-87
TRAC	46,935	52,529	99,464
MAT. LAB.	13,200	26,400	39,600
CONSULTANT	30,000	---	30,000
TOTAL	90,135	78,929	169,064

TRAC, FY86

(12 months)

Salaries		
Faculty		
1 mon. @ 6,076 (1.08)**	6,562	
Khossrow Babaei, Research Eng.		
*3-3/4 mos. @ 2,445 (1.08)**	9,902	
Amy O'Brien, Supp. Services Coord.		
*1 mon. @ 1,495 (1.08)**	1,615	
Research Assistant, 50%		
4 mos. @ 872 (1.08)**	3,767	
		21,846
Benefits		
Faculty (6,562) 20%	1,312	
Exempt (9,902 + 1,615) 21%	2,419	
Student (3,767) 7%	264	
		3,995
Miscellaneous		
Photocopy	250	
Telephone, Postage, etc.	250	
Drafting	1,500	
Report Production	500	
C.E. Department Service	528	
		3,028
Travel		
Local Travel, Olympia, etc.	500	
Project Site Visit	2,000	
Per diem, 20 days @ 50/day	1,000	
		3,500
Total direct cost	32,369	
Total indirect cost @ 45%	14,566	
GRAND TOTAL		46,935

* Time includes approximately 11%, for vacation and sick leave
** Possible salary adjustment

TRAC, FY 87
(12 months)

Salaries

Khossrow Babaei, Research Engineer *6-1/2 mos. @ 2,445 (1.08)(1.08)**	18,537	
Amy O'Brien, Supp. Serv. Coord. *1 mon. @ 1,495 (1.08)(1.08)**	1,744	
Research Assistant, 50% 4 mos. @ 872 (1.08)(1.08)**	4,068	
		24,349

Benefits

Exempt (18,537 + 1,744) 21%	4,259	
Student (4,068) 7%	285	
		4,544

Miscellaneous

Photocopy	250	
Telephone, Postage, etc.	250	
Drafting	1,500	
Report Production	500	
C.E. Department Service	586	
		3,086

Travel

Local Travel, Olympia, etc.	500	
Project Site Visit	2,000	
Per diem, 30 days @ 50/day	1,500	
		4,000

Total direct cost	35,979	
Total indirect cost @ 46%	16,550	
GRAND TOTAL		52,529

* Time includes approximately 11% for vacation and sick leave
** Possible salary adjustment

TRAC, FY86-87

(24 months)

Salaries

Faculty 1 mon.	6,562	
Khossrow Babaei, Research Engineer *10-1/4 mos.	28,439	
Amy O'Brien, Supp. Serv. Coord. *2 mos.	3,359	
Research Assistant, 50% 8 mos.	7,835	
		46,195

Benefits

Faculty (6,562) 20%	1,312	
Exempt (31,080 + 3,359) 21%	6,678	
Student (7,835) 7%	549	
		8,539

Miscellaneous

Photocopy	500	
Telephone, Postage, etc.	500	
Drafting	3,000	
Report Production	1,000	
C.E. Department Service	1,114	
		6,114

Travel

Local Travel, Olympia, etc.	1,000	
Project Site Visit	4,000	
Per diem, 50 days, @ 50/day	2,500	
		7,500

Total direct cost	68,348	
Total indirect cost	31,116	
GRAND TOTAL		99,464

* Time includes approximately 11% for vacations and sick leave

* WSDOT   MAT. LAB.

Field and Laboratory Testing

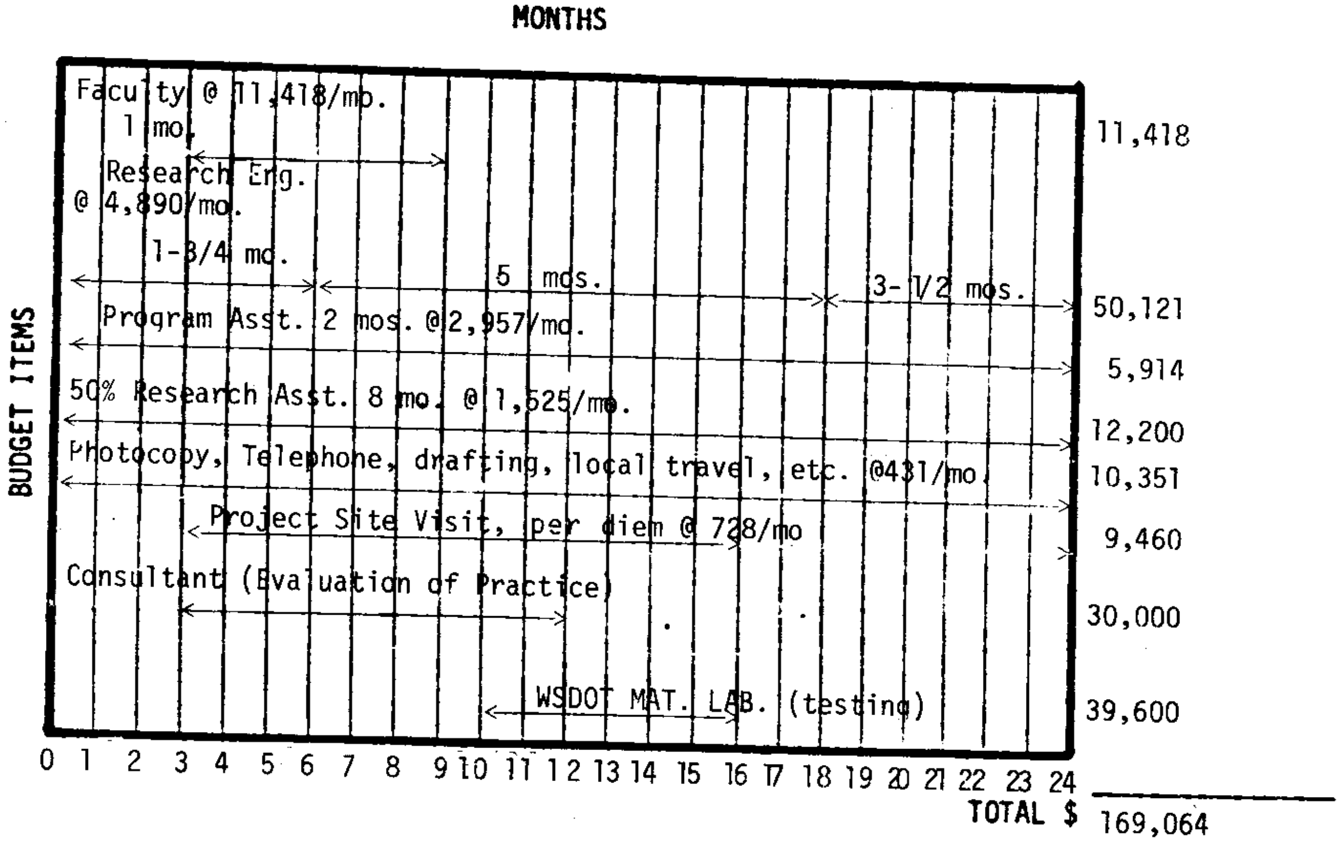
FY	No. of Bridges Tested	Cost *
86	4	13,200
87	8	26,400
86-87	12	39,600

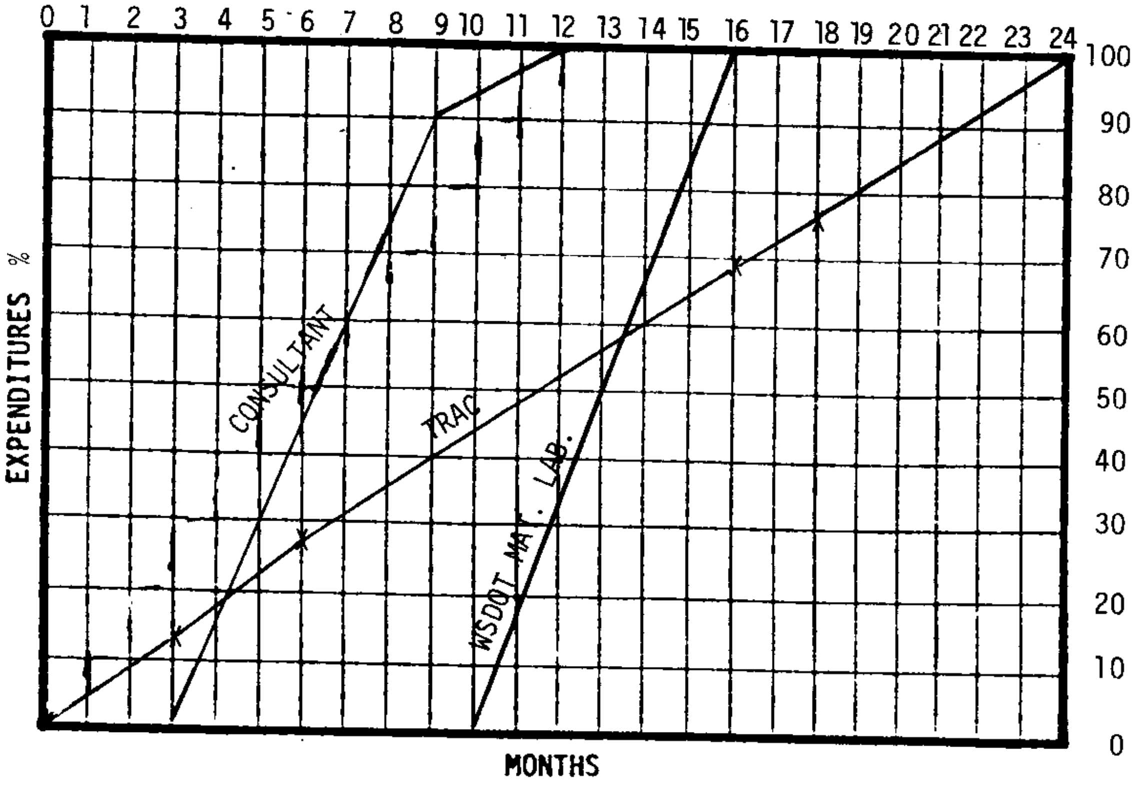
* Cost estimate for testing one bridge is $3,300

Consultant

$30,000 in FY86

WSDOT Research Office
Budget Planning and Monitoring Program





PROJECT: "Evaluation of Concrete Overlays for Bridge Applications"

11 - Level of Effort

TASK	% OF TOTAL COST			FRACTION OF TOTAL COST, $		
	TRAC	CONSULTANT	MAT. LAB.	TRAC	CONSULTANT	MAT. LAB.
I - Evaluation of Practice, Second Interim report Preparation	25	100	---	24,866	30,000	---
II - Background Information Review, Experiment Design, First Interim Design Preparation	18	---	---	17,903	---	---
III - Testing Phase	17	---	100	16,909	---	39,600
V - Information Analysis, Evaluation of Washington installations, Final Report Preparation	40	---	---	39,786	---	---
TOTAL	100	100	100	99,464	30,000	39,600

12 - Facilities Available

The research will be conducted through the Washington State Transportation Center (TRAC), located at the Department of Civil Engineering, University of Washington; the consultant; and the WSDOT Materials Laboratory, located in Olympia, Washington. Offices and telephones of the department of Civil Engineering and the consultant, as well as testing facilitates at the WSDOT Materials Laboratory, will be available for this study. Additionally, the University of Wash-ington libraries and the WSDOT library in Olympia will be available to the project.

13 - Report and Documentation

The two interim and final reports will be prepared by the responsible parties as indicated in the work plan development.

III - CHAPTER THREE

Proposed Research for

"EVALUATION OF THE HALF-CELL CORROSION DETECTION METHOD FOR CONCRETE BRIDGE DECKS"

Table of Contents

1 - Problem Statement

Knowledge of the condition the of bridges is essential for the Department to ensure a satisfactorily performing bridge network and manage a comprehensive bridge maintenance program. Rebar corrosion has been blamed for a large portion of the problems associated with concrete bridge decks. Rebar corrosion can affect the integrity of reinforced concrete in the following two ways:

a) It can deteriorate concrete by expanding corrosion products, causing fracture planes or delaminations. This phenomenon may also affect the rebar concrete bond adversely. The final result can be loss of the deck's ride quality as well as strength.

b) It can deteriorate the steel in the rebar cross-section, thus reducing the the rebar's strength.

Currently WSDOT routinely monitors the concrete chloride content in bridge structures to determine if the proper environment for rebar corrosion has been reached. However, the shortcomings of this procedure are the following: a) the fact that a concrete is chloride contaminated above the threshold value does not necessarily indicate the existance of rebar corrosion, but indicates only the potential for corrosion; b) corrosion may occur as a result of other factors in addition to chloride contamination, such as exposure of the rebar to moisture and air through open cracks directly oriented above the rebar; and c) chloride content measurement is a destructive and expensive test procedure yielding insufficient data for evaluating the condition of bridge deck.

Previous experience with the half-cell corrosion detection test method in Washington has indicated that there is a potential for employing this simple and non-destructive procedure in the field as a supplement to chloride content tests to obtain massive amounts of data on the state of bridges' rebar corrosion activities. As example, the results of a half-cell survey on five SR-90 bridges in Washington in 1979, before the rehabilitation, when superimposed with the actual concrete removal areas, indicate that the highest readings are mainly concentrated in the removal areas. There is, however, an exception to this. For example, in one case, extremely small and uniform pattern readings located only in one lane suggest that the ground for that lane may not have been satisfactory. Whereas, in the adjacent lane removal areas coincide with high potential values. The SR-90 half-cell survey also indicates active corrosion in sound concrete. An explanation for this is that the steel can be actively corroding, although not necessarily to the point of causing cracking. Also, contribution on deterioration from traffic impact might have not been sufficient on those areas. The latter is evident on the survey of some SR-90 bridges when deterioration of passing lanes are compared to that of the driving lanes.

Half-cell tests, when conducted properly and the data is interpreted correctly, should indicate the potential for future problems. They may or may not coincide with the deterioration at the time of testing. Before adopting the test, however, its limitations should be understood and its reliability outside of laboratory, on bridge decks, fully established.

2 - Background Statement

The most important feature expected from the half-cell corrosion detection test is its possible contribution to a bridge deck management system by providing on-going information regarding the condition of bridge decks. Corrosion of rebar in a concrete, although not considered a distress, could eventually cause deterioration of the concrete as well as a loss of steel. Thus, corrosion could be used in combination with actual distress to identify bridge deck distress problems. Monitoring the level of corrosion activity as well as other measurable distresses and translating them into a combined rating would reveal performance trends for decks and their protective elements so that the amount of time until reconstruction would be needed could be predicted.

Another potential benefit that could be gained from establishing the corrosion detection test is the location of areas vulnerable to deterioration during bridge deck rehabilitation so they may also be repaired prior to application of a protective system. This procedure may prolong the service life of the rehabilitation. Areas vulnerable to deterioration in a bridge deck are those which could turn into actual deterioration before the expected service life of the rehabilitation was over. Corrosion could be used as an element in identifying those areas. For example, an area having half-cell potentials indicating active corrosion, an insufficient cover depth and to be subjected to extensive traffic impact might disintegrate within the life of the rehabilitation. Thus, it might be prudent to locate these areas, if possible, and repair them if it could be done economically. Or, depending on the magnitude of such areas, prescribe a protective system which could alleviate the problem more effectively instead of repairing them.

In order to take advantage of the aforementioned features of half-cell testing, WSDOT should fully evaluate the procedure and determine its feasibility in the fields. Evaluation would include experimentally verifying corrosion on concrete decks and the corrosion's correlation with chloride contamination, moisure content and other factors such as cracking. Additionally, corrosion induced distress may be correlated with contributing factors such as cover thickness and traffic impact.

3 - Objectives

This project will review half-cell corrosion detection and evaluate the test method. The research team will attempt to experimentally verify the reliability of the test method on sampled Washington bridges. Depending on the results, guidelines may be developed to employ half-cell corrosion detection as a routine bridge deck condition survey technique for continuing bridge deck monitoring or bridge deck rehabilitation.

4 - Benefits

The benefits expected from this work are as follows:

- WSDOT could use an established half-cell test procedure and data interpretation system as a tool for monitoring bridge deck condition, and it would thus contribute to a continuing bridge deck management system.

  Knowledge of the existence of rebar corrosion could be applied to bridge rehabilitations to add to their service lives.

5 - Products

- Draft interim report "Evaluation of Half-Cell Method and Criteria for Sampling Data from WSDOT Bridge Condition Survey Program," December 31, 1985

- Draft final report "Evaluation of Data and Half-Cell Methodology Development for Bridge Condition Determination," March 31, 1987

6 - Implementation

Evaluation and experimental verification of the half-cell test method will determine the test's limitations and help develop a data interpretation system. WSDOT could implement such a system to distinguish among service conditions and contribute to a bridge deck evaluation program.

7 - Work Plan Development

Task I. WSDOT Bridge Deck Condition Survey Program (WSDOT)

WSDOT has scheduled a comprehensive bridge deck condition survey program to start about April 1985 which will encompass all districts. District one, however, has already started the program and has surveyed a number of bridge decks. Bare concrete decks are tested in the course of this program employing different condition survey techniques including half-cell. The following tests are included in the field condition survey:

- half-cell corrosion detection,
- visual inspection and mapping of deck distress such as spalling and cracking,
- chain dragging for delamination detection,
- surveying depth of cover using a pachometer,

- measuring chloride content,
- core sampling concrete to determine the nature of distress (if needed).

Presently the raw data obtained in the study are stored in a computer and translated into ratings representing general deck conditions. However, the availability of the raw data makes it possible to study each bridge deck condition individually. The WSDOT bridge condition survey program creates a great opportunity because the WSDOT bridge deck research program can conduct an in-depth analysis of the data and attempt to correlate the half-cell readings with different types of distress, environmental factors, and other factors related to bridge deck conditions, and determine the nature of potential problems with half-cell testing which WSDOT may encounter in practice.

Task II. Evaluation of the Half-Cell Test-Method and Criteria for Sampling Data (TRAC).

Sufficient information will be assimilated from literature and other sources to enable the research team to evaluate the half-cell test method. TRAC will consider factors such as the condition of the test instument, type of ground, temperature, moisture in the concrete, cracks in the concrete, and size of the grid. Subsequently, TRAC will develop criteria for selecting 8 sites included in the WSDOT bridge deck survey program, so their collected data can be available to TRAC. The criteria will consider factors such as the level of contamination and deterioration, age, traffic volumes, and climatic conditions in which the half-cell tests were conducted. An interim report will be issued at the conclusion of this task (December 31, 1985).

Task III. Field Trips

The research team will coordinate field trips with WSDOT and make them to a few bridge decks while WSDOT is surveying them. The research team will observe the testing phase and make recommendations, if necessary, for improvement of the test procedure.

Task IV. Data Analysis and Half-cell Test Methodology Development (TRAC)

WSDOT will provide to TRAC in two stages the results of its survey of the 8 selected sites. WSDOT will provide to TRAC the results from 4 sites by January 31, 1986, and the other 4 sites by September 30, 1986. Additionally, WSDOT will provide other information regarding the design and construction of the bridges. TRAC will analyze and interpret the information collected during the survey program. Additionally, TRAC will incorporate information in TASK II regarding the half-cell test method and the relevant information from the research entitled "Evaluation of Concrete Overlays for Bridge Applications" whenever possible, and interpret the overall findings to evaluate the feasibility of half-cell testing. Subsequently, TRAC will develop methodology for the following purposes:

1. to employ the test as a routine condition survey technique to monitor overall conditions of bridge decks; and
2. to integrate the half-cell survey into bridge deck rehabilitation, if possible.

TRAC will document the activities and results of TASK IV in the final report which will be issued on March 31, 1987.

Task V. Reports

The study team will issue an interim report, including evaluation of the test procedure and criteria for sampling data at the conclusion of Task II (December 31, 1985). A final report will be issued at the conclusion of Task IV (March 31, 1987), which will document all the activities conducted in the course of the investigation.

Responsibilities:

Task	Responsibilities
I	WSDOT will have already surveyed bare decks and has scheduled to survey more according to its bridge deck condition survey program. WSDOT will provide to TRAC its sampled survey results on January 31 1986 and September 30, 1986.
II	TRAC will evaluate the half-cell test procedure and will develop criteria for sampling data from WSDOT's inventory of bridge deck condition data. TRAC will

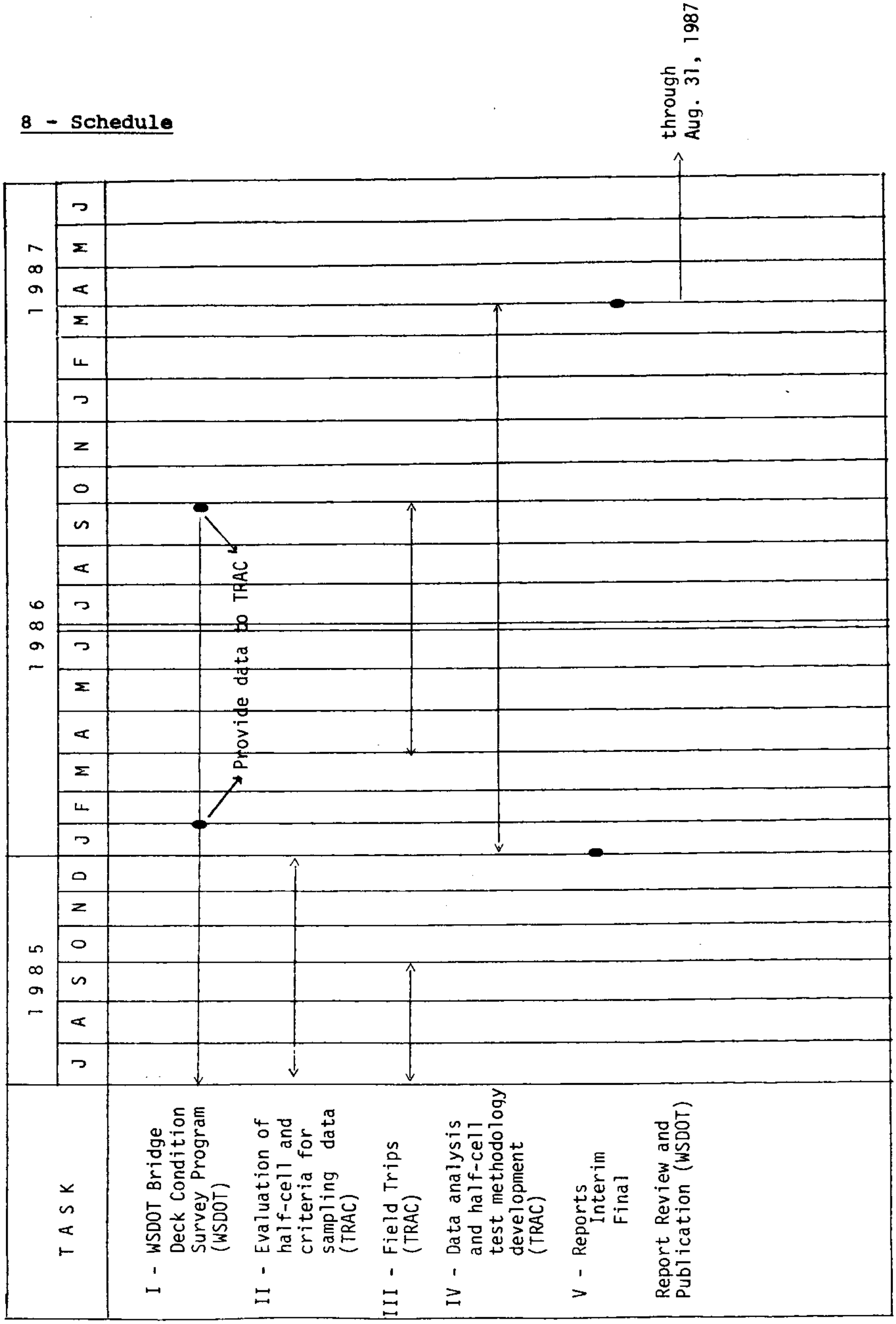
prepare and interim report to be submitted December 31, 1985.

III TRAC will make field trips to a few sites to observe the WSDOT's bridge deck survey method.

IV TRAC will analyze and evaluate the data to determine the usefulness and practicality of half-cell testing. The results will be included in the final report to be submitted March 31, 1987.

V TRAC will prepare the reports according to the schedule.

8 - Schedule



TASK
1985
J A S O N D
1986
J F M A M J J A S O N
1987
J F M A M J
I - WSDOT Bridge Deck Condition Survey Program (WSDOT)
II - Evaluation of half-cell and criteria for sampling data (TRAC)
III - Field Trips (TRAC)
IV - Data analysis and half-cell test methodology development (TRAC)
V - Reports
Interim
Final
Report Review and Publication (WSDOT)
Provide data to TRAC
through Aug. 31, 1987

9 - Staffing Plan

The individuals who will serve the project are as follows:

TRAC

Dr. Neil Hawkins, Chairman of Civil Engineering, will be principal investigator and general coordinator. Professor Hawkins is a well known researcher. He has taught and carried out research and consulting work in structural and construction engineering, with emphasis on reinforced concrete.

Khossrow Babaei, Research Engineer, will serve as co-principal investigator. He will design the experiment and coordinate data collection and its input into the final report. Mr. Babaei is a registered professional engineer with experience in construction, design and inspection. He has carried out research on concrete and concrete materials, including materials used in bridge structures and subjected to bridge environments.

Other TRAC staff will include Amy O'Brien as support service coordinator and a graduate student as research assistant.

10 - Budget Estimate

	FY86	FY87	FY86-87
TRAC	20,203	29,964	50,167
MAT. LAB.	---	---	---
CONSULTANT	---	---	---
TOTAL	20,203	29,964	50,167

TRAC, FY86

(12 months)

Salaries

Khossrow Babaei, Research Eng. *2 mos. @ 2,445 (1.08)**	5,281	
Amy O'Brien, Supp. Serv. Coord. *1/2 mos. @ 1,495 (1.08)**	807	
Research Assistant, 50% 3 mos. @ 872 (1.08)**	2,825	
		8,913

Benefits

Exempt (5,281 + 807) 21%	1,279	
Student (2,825) 7%	198	
		1,477

Miscellaneous

Photocopy	250	
Telephone, Postage, etc.	250	
Drafting	500	
Report Production	500	
C.E. Department Service	243	
		1,743

Travel

Local travel, Olympia, etc.	300	
Survey Site visit	1,000	
Per diem 10 days @ 50/day	500	
		1,800

Total direct cost	13,933	
Total indirect cost @ 45%	6,270	
GRAND TOTAL		20,203

* Time includes approximately 11% for vacation and sick leave

** Possible salary adjustment

TRAC, FY87

(9 months)

Salaries

Khossrow Babaei, Research Engineer		
*3-1/2 mos. @ 2,445 (1.08)(1.08)**	9,981	
Amy O'Brien, Supp. Serv. Coord.		
*1/2 mos. @ 1,495 (1.08)(1.08)**	872	
Research Assistant, 50%		
3 mos. @ 872 (1.08)(1.08)**	3,051	
		13,904

Benefits

Exempt (9,981 + 872) 21%	2,279	
Student (3,051) 7%	214	
		2,493

Miscellaneous

Photocopy	250	
Telephone, postage, etc.	250	
Drafting	1,000	
Report Production	500	
C.E. Department Service	326	
		2,326

Travel

Local travel, Olympia, etc.	300	
Survey Site Visit	1,000	
Per diem 10 days @ 50/day	500	
		1,800

Total direct cost	20,523	
Total indirect cost @ 46%	9,441	
GRAND TOTAL		29,964

* Time includes approximately 11% for vacation and sick leave

** Possible salary adjustment

TRAC, FY86-87

(21 months)

Salaries

Khossrow Babaei, Research Engineer *5-1/2 mos.	15,262	
Amy O'Brien, Supp. Serv. Coord. *1 mon.	1,679	
Research Assistant, 50% 6 mos.	5,876	
		22,817

Benefits

Exempt (15,262 + 1,679) 21%	3,558	
Student (5,876) 7%	412	
		3,970

Miscellaneous

Photocopy	500	
Telephone, Postage, etc.	500	
Drafting	1,500	
Report Production	1,000	
C.E. Department Service	569	
		4,069

Travel

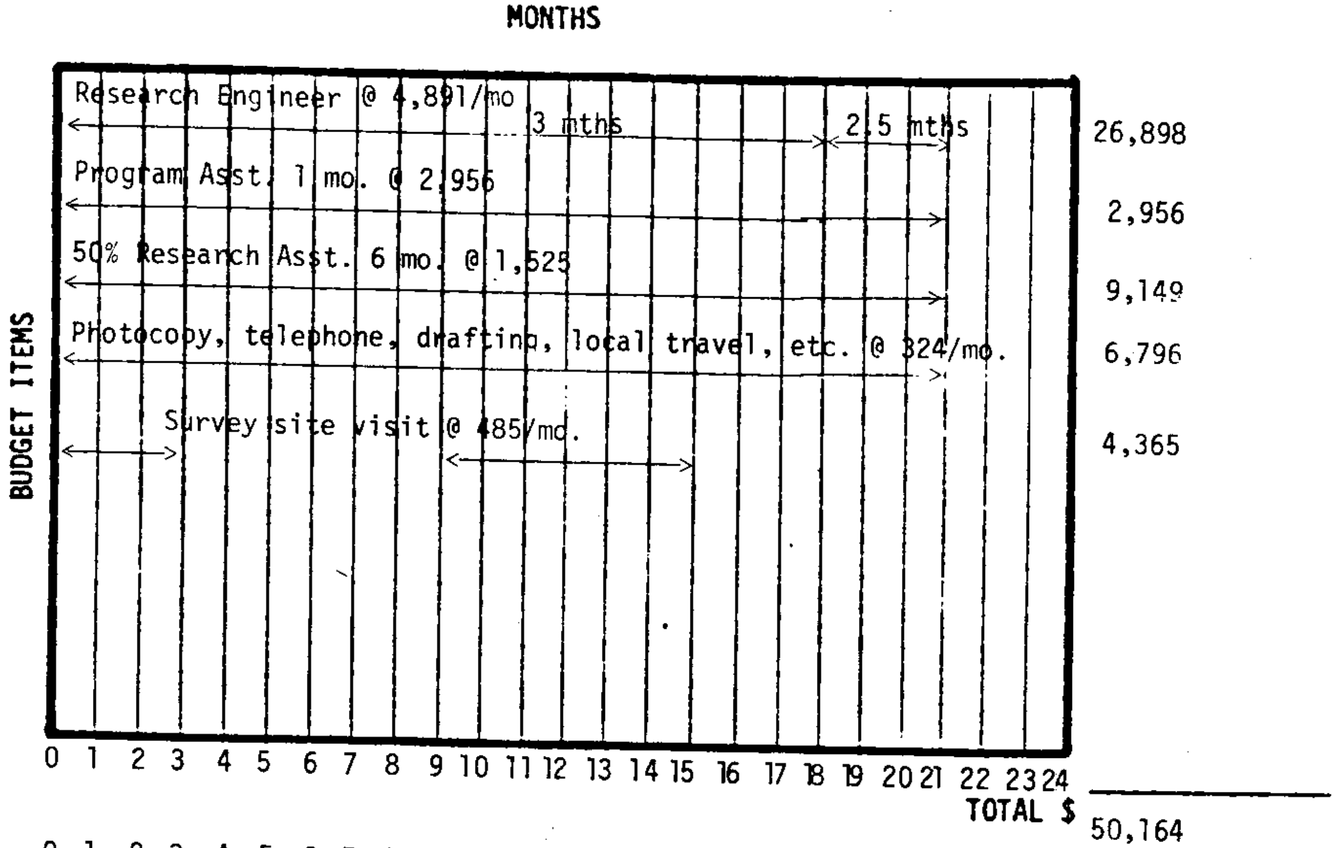
Local travel, Olympia, etc.	600	
Survey Site Visit	2,000	
Per diem 20 days @ 50/day	1,000	
		3,600

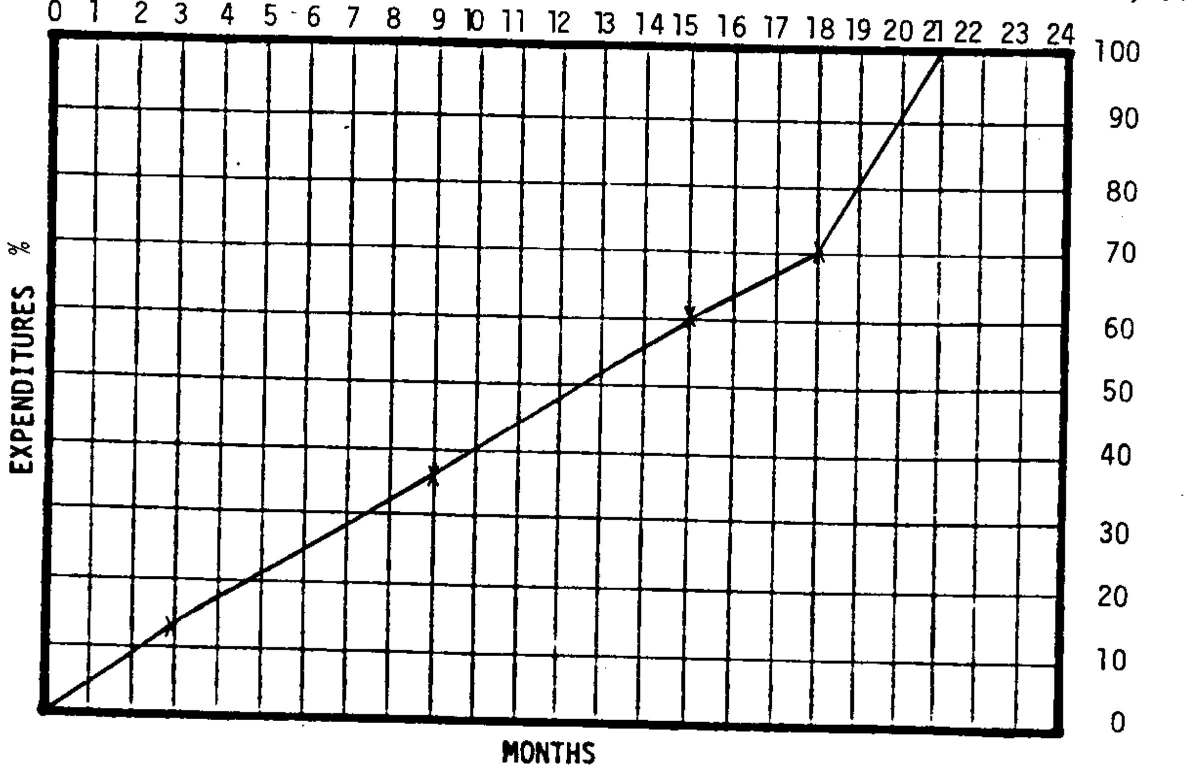
Total direct cost	34,456	
Total indirect cost	15,711	
GRAND TOTAL		50,167

* Time includes approximately 11% for vacation and sick leave.

WSDOT Research Office

Budget Planning and Monitoring Program





PROJECT: "Evaluation of Half-Cell Corrosion Detection for Concrete Bridge Decks"

11 - Level of Effort

TASK	% OF TOTAL COST			FRACTION OF TOTAL COST, $		
	TRAC	CON-SULTANT	MAT. LAB.	TRAC	CON-SULTANT	MAT. LAB.
II - Evaluation of half-cell and criteria for sampling data	25			12,542		
III - Field Trips	10			5,017		
IV - Information analysis, Half-cell test methodology, Development, Final Report Preparation	65			32,609		
TOTAL	100			50,167		

12 - Facilities Available

The research will be conducted through the Washington State Transportation Center (TRAC) located at the Department of Civil Engineering, University of Washington. Offices and telephones of the Department of Civil Engineering will be available for this study. Additionally, the University of Washington libraries and the WSDOT library in Olympia will be available to the project.

13 - Report and Documentation

TRAC will prepare the interim and final report as indicated in the work plan development.

IV - CHAPTER FOUR

Proposed Research for

"DEVELOPMENT OF GUIDELINES FOR A BRIDGE DECK MANAGEMENT SYSTEM"

Table of Contents

1 - Problem Statement

The increasing number of bridge decks needing repair and limitations in maintenance funds pose a major problem to the Department. In order to manage a comprehensive bridge deck maintenance program, WSDOT needs to establish a systematic method to logically evaluate its bridges and fund such a program. WSDOT needs guidelines to develop such a system. The systematic approach, based upon use of factual data, should enable management and engineers to answer the following questions:

- What conditions warrant rehabilitation?
- When would those conditions appear in a deck?
- What measures should be taken at that time to cost-effectively rehabilitate the deck?
- When would deterioration prevention be warranted?
- How many decks would need repair in a fiscal year?
- If funds are not available for all decks in need of rehabilitation, what criteria should be used for priority assignment?

Such a system would be a strong tool for the Department, for with it WSDOT could develop a cost effective highway system with the highest possible level of performance.

2 - Background Statement

In general, bridge decks could be divided into two classes based on their construction. The first group would be those bridge decks built according to older regulations and not offering sufficient protection against premature deterioration. The second group would be those bridge decks built with new regulations and offering a protection or those built with older regulations but having received protection sometime during their service life. At present the first group has attracted most attention for rehabilitation and/or protection. It has been stipulated that all of those decks need some kind of protection. However, some may need additional rehabilitation depending on their condition. Therefore, the Department has concentrated its management systems mainly in this area and has prioritized rehabilitation and/or protection of these decks based on factors such as traffic volumes and deck conditions while considering deferred maintenance costs. Furthermore, it has started a program to select the most cost effective protection alternative for each case. WSDOT has also considered factors such as traffic volume and the volume of repair so that it could install a compatible and more durable protective system.

As for decks in the second category, generally there has not been any systematic management system to deal with their reconstruction. Presently, reconstruction of this class mainly consists of removing AC/membrane overlays which have aged after 10 to 15 years of service and rehabilitating them if needed, and installing a proper protective system. Concrete overlay protective systems, on the other hand, are relatively new and there have not been any major problems with their condition. It is predicted that reconstruction will become more concentrated on the second class of decks, since most of the decks will have received some kind of protection and the main concern will be the service lives and durability of the protective systems. However, the original decks may still need rehabilitation if their protective systems do not effectively function. The latter problem, however, should not be large due to the better quality and more effective protective systems introduced to the market and adopted recently by highway agencies.

A comprehensive bridge deck management system (BDMS) would systematically predict and/or prioritize treatment of both classes of bridge decks. The pavement management system (PMS) recently developed and implemented by WSDOT could be used as a model for the BDMS. The PMS would be especially useful in providing guidelines for managing the second class of bridge decks since they more closely resemble pavement because durability of the overlay would be the main concern rather than corrosion and deterioration of the underlying reinforced concrete. Many techniques for developing the PMS would be applicable to the BDMS.

3 - Objectives

This project will develop guidelines for a systematic methodology to facilitate management of bridge deck treatment. This will enable administrators and engineers to predict and prioritize bridge deck treatment based upon use of their factual data.

4 - Benefits

An established, systematic methodology for bridge deck treatment will assist administrators and engineers to manage a comprehensive program to predict bridge deck problems in advance of their occurrance, allocate sufficient funds for bridge deck treatment, and more efficiently manage the maintenance funds so they will be used where the need is greatest.

5 - Products

- Draft final report "Development of Guidelines for Bridge deck Management System," December 31, 1986

6 - Implementation

The Department could implement the findings of this work to establish a systematic approach for bridge deck maintenance and funding.

7 - Work Plan Development

Task I. Review of Research and Practice (TRAC)

The research will encompass background research and practice which could impact the development of the system. The project will especially concentrate on the related PMS developed by the Department. This will reduce the research effort necessary to develop the BDMS. The Department's current practices relative to BDMS will also be reviewed.

Task II. Development of Guidelines for the BDMS (TRAC)

Based on the analysis and evaluation of the information TRAC generates, TRAC will establish a rationale for the development of the BDMS. To develop a model BDMS the following steps adapted from the WSDOT PMS will be addressed:

1. Inventory: TRAC will identify the data required to track the progression of distress over the service life of the deck to inventory historical and current data.
2. Condition Interpretation: TRAC will define methods for translating raw information into a combined average rating to identify the general condition of a deck. TRAC will assign weighted values for each distress category for this purpose. Methds will be developed to obtain performance curves and equations based on regression analysis of historical data to predict future conditions.
3. Project Optimization: Using hypothetical performance curves TRAC will define how to predict the amount of time until treatment will be needed for a project, has to consider a set of alternative treatment strategies,

and how to evaluate them on the basis of economic so that the optimum alternative can be selected.

4. Network Level Activities: TRAC will develop methods for scheduling anticipated cost and performance at the network level. keeping in mind budget and condition level constraints, TRAC will also establish criteria to prioritize bridge deck treatment.

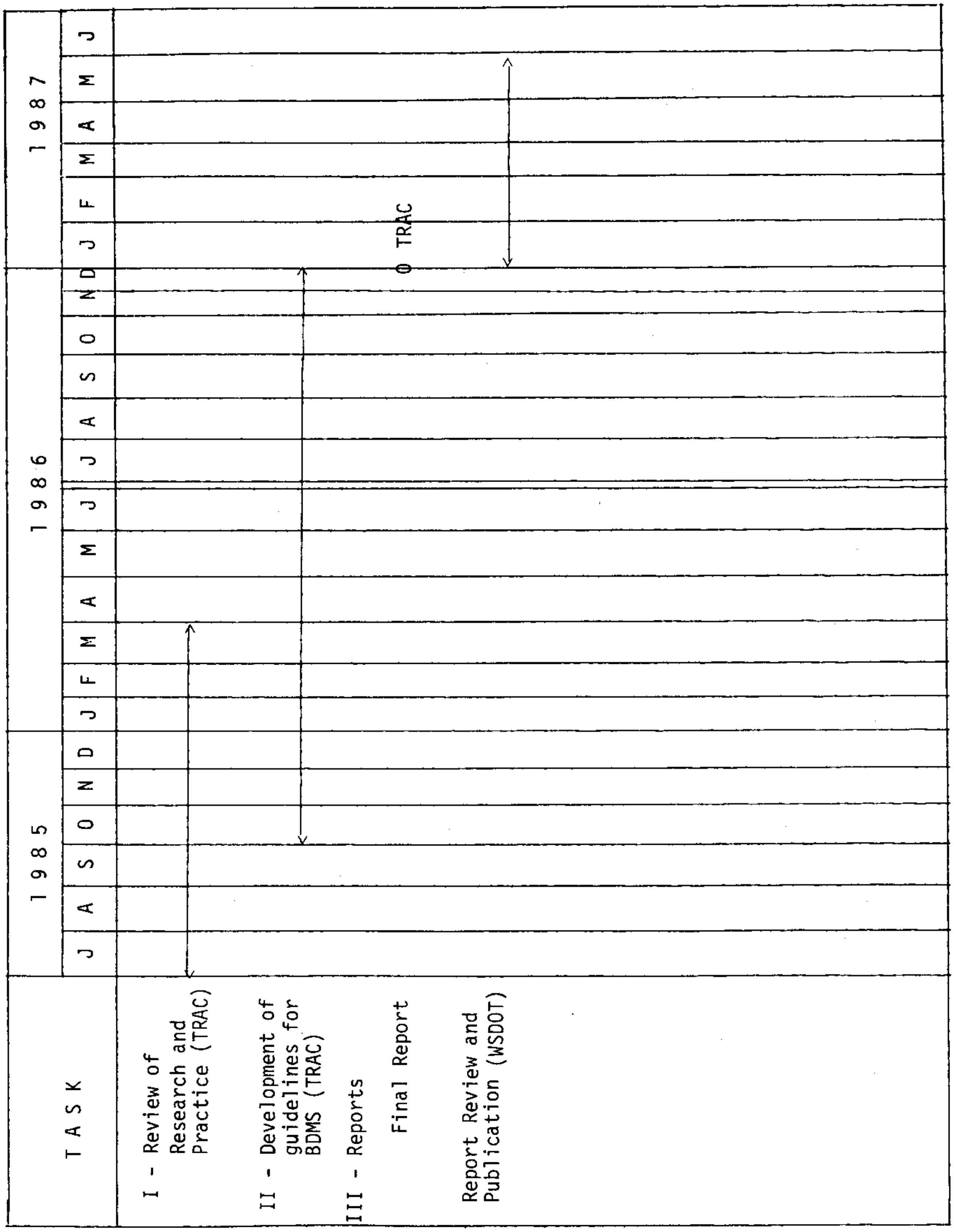
Task III. Report (TRAC)

TRAC will prepare a final report which will document the research it conducts. The final report will be issued on December 31, 1986.

Responsibilities:

TRAC will be the only research agency participating in the research project and all responsibilities are assigned to TRAC.

8 - Schedule


TASK
1985
1986
1987
J A S O N D J F M A M J J A S O N D J F M A M J
I - Review of Research and Practice (TRAC)
II - Development of guidelines for BDMS (TRAC)
III - Reports
Final Report
O TRAC
Report Review and Publication (WSDOT)

9 - Staffing Plan

The individuals who will serve the project are as follows:

TRAC

Dr. Neil Hawkins, Chairman of Civil Engineering, will be principal investigator and general coordinator. Professor Hawkins is a well known researcher. He has taught and carried out research and consulting work in structural and construction engineering with emphasis on reinforced concrete.

Khossrow Babaei, Research Engineer, will serve as co-principal investigator. He will conduct the project and develop guidelines for the BDMS. Mr. Babaei is a registered professional engineer with experience in construction, design, and inspection. He has carried out research on concrete and concrete materials, including materials used in bridge structures and subjected to bridge environments.

Other TRAC staff will include Amy O'Brien as support service coordinator and a graduate student as research assistant.

10 - Budget Estimate

	FY86	FY87	FY86-87
TRAC	16,070	18,288	34,358
MAT. LAB.	---	---	---
CONSULTANT	---	---	---
TOTAL	16,070	18,288	34,358

TRAC, FY86

(12 months)

Salaries

Khossrow Babei, Research Engineer *2 mos. @ 2,445 (1.08)**	5,281	
Amy O'Brien, Supp. Serv. Coord. *1/4 mos. @ 1,495 (1.08)**	404	
Research Assistant, 50% 3 mos. @ 872 (1.08)**	2,825	
		8,510

Benefits

Exempt (5,281 + 404) 21%	1,194	
Student (2,825) 7%	198	
		1,392

Miscellaneous

Photocopy	200	
Telephone, Postage, etc.	200	
Drafting	300	
C.E. Department Service	181	
		881

Travel

Local Travel, Olympia, etc.	300	
		300

Total direct cost	11,083
Total indirect cost @ 45%	4,987
GRAND TOTAL	16,070

*Time includes approximately 11%, for vacation and sick leave
**Possible salary adjustment

TRAC, FY 87
(6 months)

Salaries

Khossrow Babaei, Research Engineer *2 mos. @ 2,445 (1.08)(1.08)**	5,704	
Amy O'Brien, Support Srvcs Coord. *1/2 mos. @ 1,495 (1.08)(1.08)**	872	
Research Assistant, 50% 3 mos. @ 872 (1.08)(1.08)**	3,051	
		9,627

Benefits

Exempt (5,704 + 872) 21%	1,381	
Student (3,051) 7%	214	
		1,595

Miscellaneous

Photocopy	100	
Telephone, Postage, etc.	100	
Drafting	200	
Report Production	500	
C.E. Department Service	204	
		1,104

Travel

Local Travel, Olympia, etc.	200	
		200

Total direct cost	12,526
Total indirect cost @ 46%	5,762
GRAND TOTAL	18,238

---

* Time includes approximately 11% for vacation and sick leave.

** Possible salary adjustment.

TRAC, FY 86-87
(18 months)

Salaries

Khossrow Babaei, Research Engineer * 4 mos.	10,985	
Amy O'Brien, Support Srvcs Coord. *3/4 mo.	1,276	
Research Assistant 6 mos.	5,876	
		18,137

Benefits

Exempt (10,985 + 1,276) 21%	2,575	
Student (5,876) 7%	412	
		2,987

Miscellaneous

Photocopy	300	
Telephone, Postage, etc.	300	
Drafting	500	
Report Production	500	
C.E. Department Service	385	
		1,985

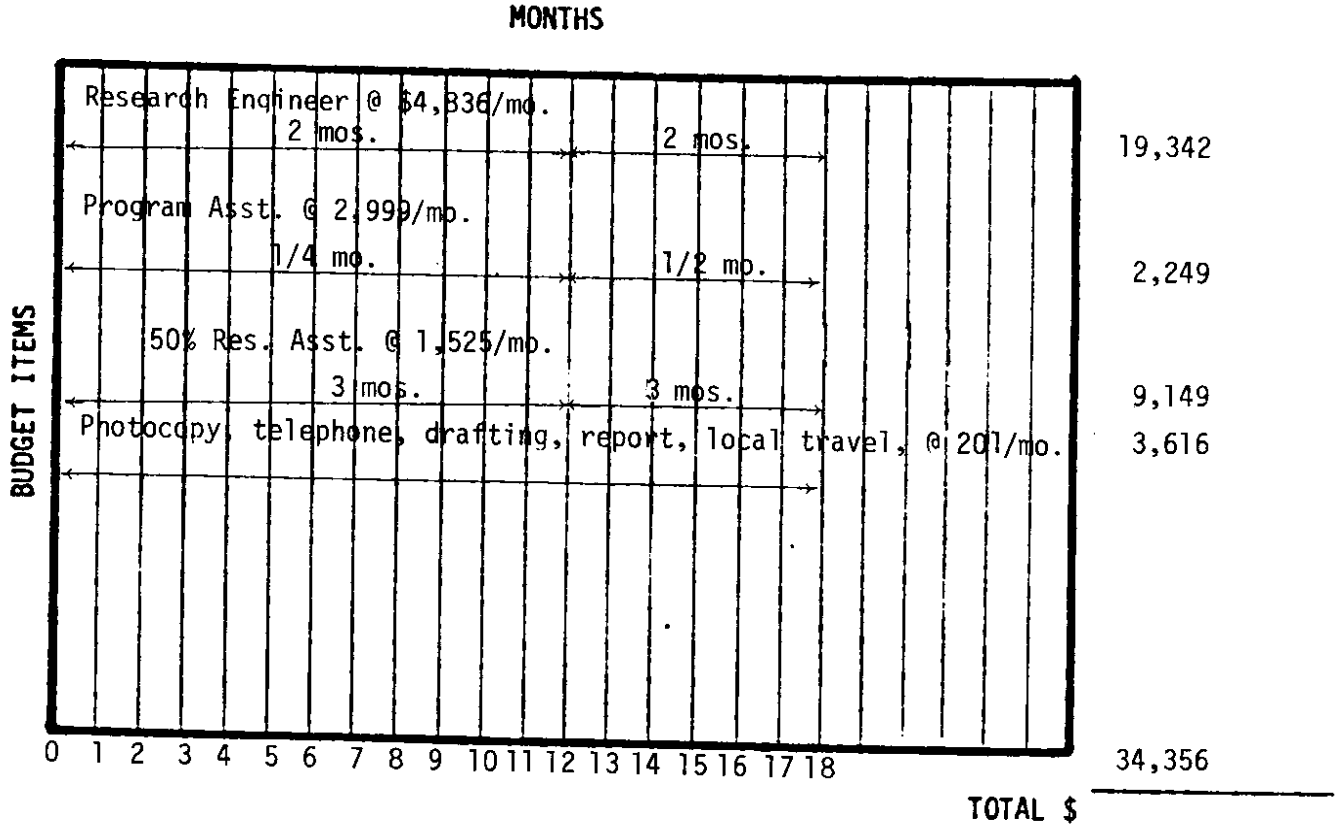
Travel

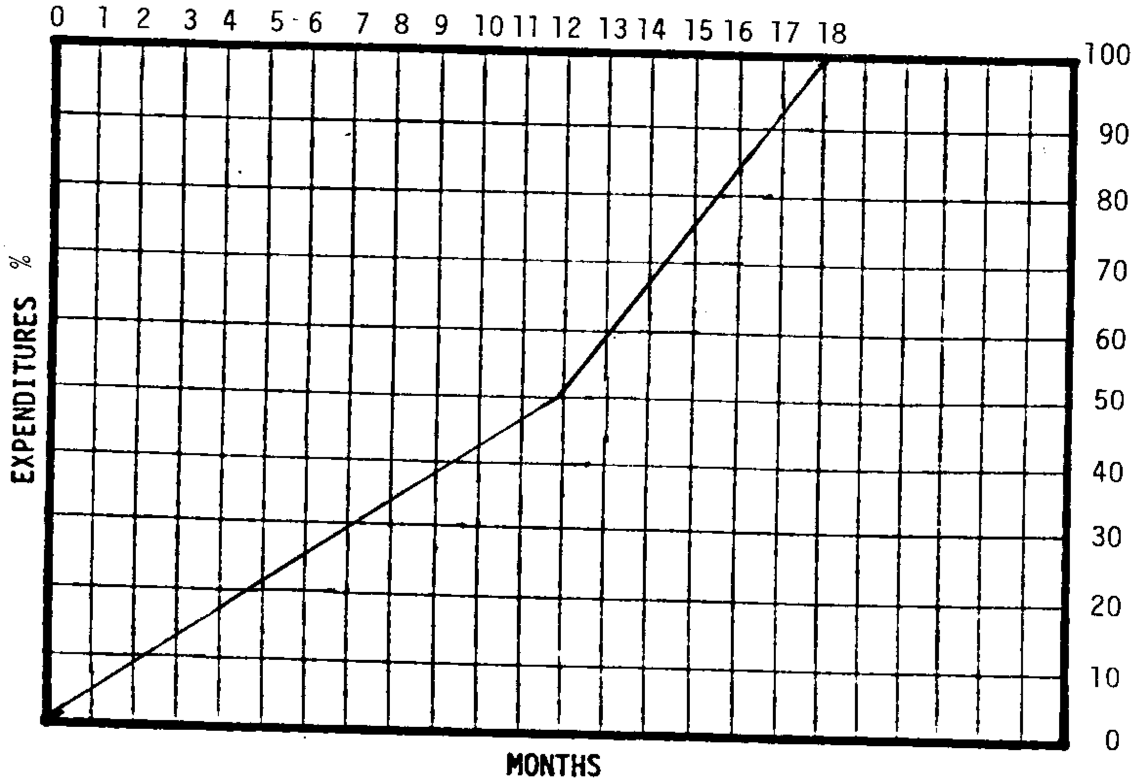
Local Travel, Olympia, etc.	500	
		500

Total direct cost	23,609
Total indirect cost	10,749
GRAND TOTAL	34,358

* Time includes approximately 11% for vacation and sick leave.

WSDOT Research Office
Budget Planning and Monitoring Program





PROJECT: Development of "Guidelines for Bridge Deck Management System"

11 - Level of Effort

TASK	% OF TOTAL COST	FRACTION OF TOTAL COST, $
	TRAC	TRAC
I. - Review of Research and Practice	25	8,590
II. - Development of Guidelines for BDMS, Final Report Preparation	75	25,768
TOTAL	100	34,358

12 - Facilities Available

The research will be conducted through the Washington State Transportation Center (TRAC) located at the Department of Civil Engineering, University of Washington. Offices and telephones of the Department of Civil Engineering as well as the University of Washington libraries and WSDOT library will be available to the project.

13 - Report and Documentation

TRAC will prepare the final report as indicated in the work plan development.

V - CHAPTER FIVE

Proposed Research for

"RAPID CONSTRUCTION TECHNIQUES FOR BRIDGE DECK RECONSTRUCTION"

Table of Contents

1 - Problem Statement

The problem is that bridge closures resulting from the reconstruction and replacement of deteriorated bridge decks cause traffic delays, especially on highly travelled bridges. Different operations are involved in bridge deck reconstruction and replacement and each can prolong the construction period. Newly developed construction techniques and materials which have the potential to accelerate bridge deck reconstruction are being introduced to the market. However, their effectiveness needs to be explored before employing them for large scale construction. This includes evaluating the effectiveness of different substrate preparation procedures, concrete removal techniques, accelerated curing methods, and as fast curing materials. Use of precast concrete bridge deck modules may also be considered for rapid replacement and widening of bridge decks instead of cast-in-place construction.

2 - Background Statement

In general, operations involved with the rehabilitation and protection of bridge decks may be classified as follows:

- Removing deteriorated concrete
- Patching concrete removal areas (mainly for AC/membrane system)
- Preparing the substrate

- Placing the overlay
- Curing the overlay (for concrete overlays)

Highway agencies have traditionally removed deteriorated concrete by using jackhammers above the rebar and chipping hammers below the rebar with subsequent sand blasting or water blasting. This is a time consuming process which requires special care to avoid striking the rebar and damaging the concrete or the bond between the rebar and the concrete. Hydro-demolishing concrete using high pressure water jets has been done experimentally and has demonstrated the ability to rapidly remove concrete. Some of the present equipment, however, is more cost-effective on large volume repair jobs.

Highway agencies patch areas where the concrete has been removed using cement concrete or rapid curing materials of different formulations including polymer concretes. Generally, cement concrete is preferred because of its better durability and compatibility; however, rapid curing materials are used when traffic conditions do not permit the curing of cement concrete. For example, polymer concretes can cure and reach the minimum acceptable strength in hours. The constructibility of fast setting materials, however, may depend on ambient temperature and the volume of repair as well. Their durability depends mainly on their bond to the substrate.

Substrate preparation when using concrete overlays requires scarification of the deck to a small depth in order to provide sufficient bond. Scarifiers have been used for this purpose and their removal rate is competitive with the newly introduced high pressure water jets in this regard. However, they may damage the top mat reinforcing steel if the concrete cover is not thick enough. This problem can be eliminated using the latter system. Flame cleaning concrete has also been suggested for this purpose.

The minimum curing period for LMC and LSC overlays is generally four days, the time required to gain the acceptable strength. Depending on the weather condition, curing may require more time. Admixtures such as superplasticizers and silica fume may accelerate the strength development of cement concrete. The most important breakthrough in this regard is the use of polymer concretes. Overlays made with polymer concrete could develop the required strength in less than one day when proper weather conditions exist. The cost and durability of the system, however, should be taken into consideration.

3 - Objectives

This project will explore and evaluate alternative construction techniques to more rapidly rehabilitate and protect bridge decks. It will determine the effectiveness of concrete removal and substrate preparation techniques, concrete curing conditions, and rapid setting materials, and will establish their quality assurance standards.

4 - Benefits

The project will investigate alternate construction techniques involving different phases of bridge deck treatment and minimizing the overall construction time and establish criteria for their acceptance. Such alternate construction techniques could prevent costly traffic delays, traffic control and accidents during bridge deck rehabilitation.

5 - Products

- Draft interim report "State-of-the-Art Assessment of Rapid Construction Techniques," June 30, 1986
- Draft final report "Establishment of Quality Assurance Standards and Acceptance Criteria," December 31, 1986

6 - Implementation

Based upon quality assurance and acceptance criteria developed in the course of this project, the Department could implement the new rapid construction techniques for bridge deck rehabilitation.

7 - Work Plan Development

Task I. Information Collection and Review (Consultant-TRAC)

The research team will review the available literature in an effort to determine current and future bridge deck construction techniques. The work will focus on the effectiveness and possible time gains resulting from alternative substrate preparation procedures, concrete removal techniques, accelerated curing methods and fast curing materials. The research team will undertake a telephone survey (as necessary) to obtain information from appropriate sources. A summary of such information is not known to exist at this time. The team will interview appropriate personnel from WSDOT so that their input can be obtained. Field trips will be coordinated with the normal WSDOT reconstruction that will be occuring at that time to gather information regarding the construction techniques.

Task II. Evaluation of Rapid Construction Techniques (Consultant-TRAC)

Analysis of the information generated during Task I will allow the research team to evaluate the effectiveness of rapid construction techniques relative to their cost, improved construction time, and maintained durability. As a result, the team will identify and recommend the most promising techniques. This will be documented in an interim report to be submitted by the consultant on June 30, 1986.

Task III. Establishment of Quality Assurance Standards (Consultant-TRAC)

The research team members, based on their field experience with bridge construction procedures and materials, will determine the constructibility and practicality of the recommended rapid construction techniques in order to integrate them into the Department's current reconstruction program. This evaluation will lead to the establishment of quality assurance standards for the rapid construction techniques recommended in Task II. The quality assurance standards will include the effects of adverse conditions which might normally be encounterd. The team will determine acceptance criteria for WSDOT construction inspections which will assure the quality of construction while preventing traffic delays.

Generally, WSDOT would like to be able to do two things when working with rapid construction techniques:

1. Specify any precautions which could be taken during construction to prevent undesirable conditions which might occur either during the construction period or later during the service period.
2. Identify and specify any practical testing methods to assure the quality of the construction before its acceptance.

The results of Task III will be included in the final report which will be issued by the consulant on December 31, 1986.

Task IV. Reports

The consultant will submit an interim report, or state-of-the-art assessment, on June 30, 1986, which will recommend the most effective rapid construction techniques for consideration.

The final report will summarize the overall study and present quality assurance standards for the recommended techniques. The final report will be issued by the consultant on December 31, 1986.

Responsibilities:

Certain responsibilities are assigned to each party and outlined below:

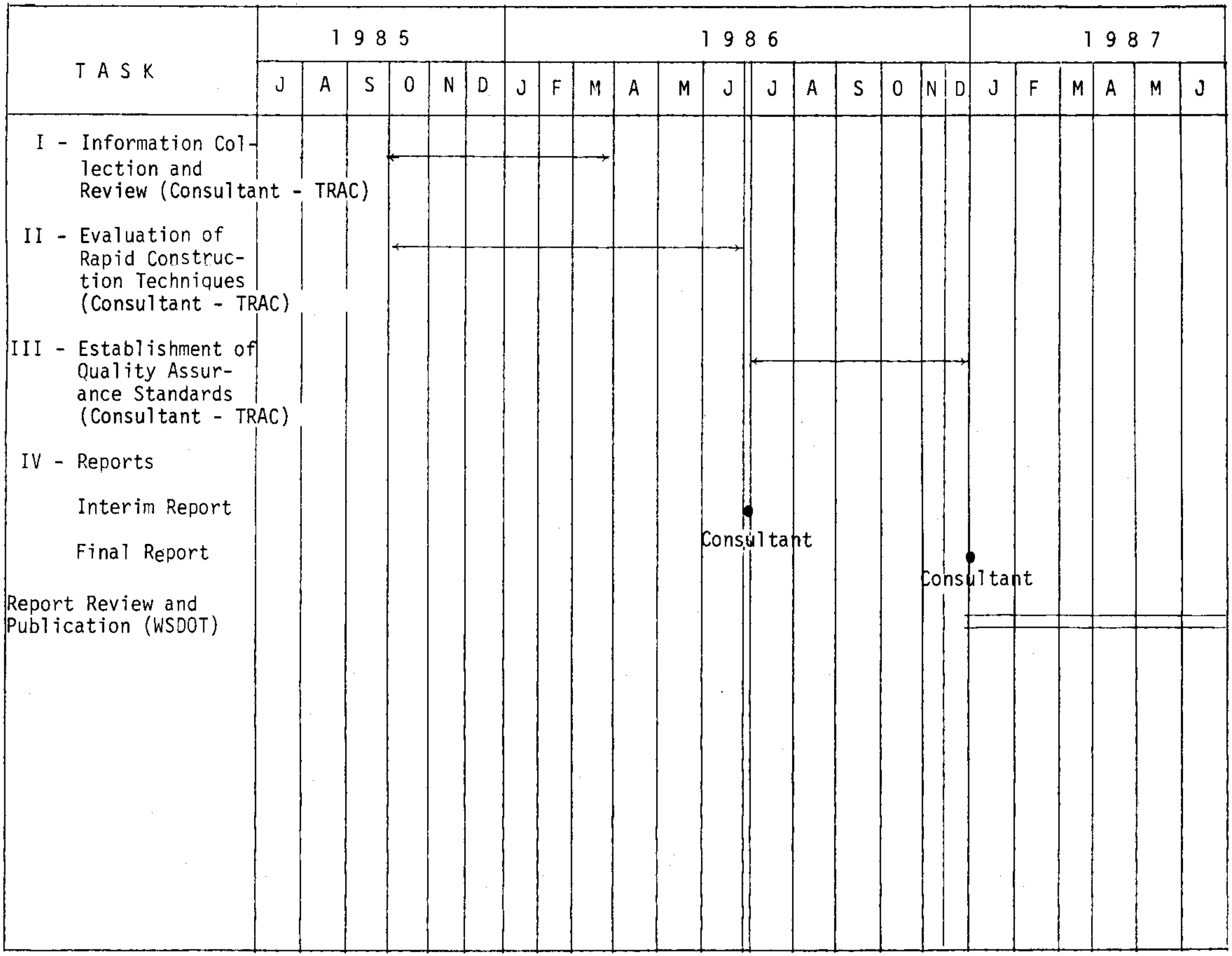
Task	Responsibilities
I.*	The consultant will obtain sufficient information to evaluate the effectiveness of the construction techniques relative to improving construction time. TRAC will contribute one-half a research engineer month and one research assistant month and assist with the collection of information.
II.*	The consultant will analyze the information and will recommend the most promising techniques. TRAC will contribute on faculty month and one-half a research engineer month and assist with the analysis of the information. The consultant will prepare and issue an interim report on June 30, 1986.
III.*	The consultant will determine the constructibility of the techniques recommended and will establish quality assurance standards and acceptance criteria. TRAC will

contribute one faculty month and one research assistant month and will assist with the development of the quality assurance standards. The consultant will prepare the final report to be submitted on December 31, 1986.

IV. The reports will be prepared by the consultant as per the schedule.

* One staff month is approximately 155 staff hours.

8 - Schedule


TASK
1985
1986
1987
J A S O N D J F M A M J J A S O N D J F M A M J
I - Information Collection and Review (Consultant - TRAC)
II - Evaluation of Rapid Construction Techniques (Consultant - TRAC)
III - Establishment of Quality Assurance Standards (Consultant - TRAC)
IV - Reports
Interim Report
Final Report
Report Review and Publication (WSDOT)
Consultant
Consultant

9 - Staffing Plan

The individuals who will serve the project are as follows:

TRAC

Dr. Neil Hawkins, Chairman of Civil Engineering, will be principal investigator and project coordinator. He will direct and conduct the state-of-the-art assessment of rapid construction techniques. Professor Hawkins is a well known researcher. He has taught and carried out research and consulting work in structural and construction engineering, with emphasis on reinforced concrete.

Khossrow Babaei, Research Engineer, will serve as co-principal investigator. He will contribute to the state-of-the-art assessment of rapid construction techniques. Mr. Babaei is a registered professional engineer with experience in construction, design, and inspection. He has carried out research on concrete and concrete materials, including materials used in bridge structures and subjected to the bridge environments.

Other TRAC staff will include Amy O'Brien as support service coordinator and a graduate student as research assistant.

10 - Budget Estimate

	FY86	FY87	FY86-87
TRAC	17.726	12,740	30,466
MAT. LAB.	-	-	-
CONSULTANT	25,000	25,000	50,000
TOTAL	42,726	37,740	80,466

TRAC, FY 86
(12 months)

Salaries

Faculty 1 mos. @ 3,038 (1.08)**	3,281	
Khossrow Babaei, Research Engineer *1 mo. @ 2,445 (1.08)**	2,641	
Amy O'Brien, Support Srvcs Coord. *1/2 mo. @ 1,495 (1.08)**	807	
Research Assistant, 50% 2 mos. @ 872 (1.08)**	1,884	
		8,613

Benefits

Faculty (3,281) 20%	656	
Exempt (2,641 + 807) 21%	724	
Student (1,884) 7%	132	
		1,512

Miscellaneous

Photocopy	300	
Telephone, Postage, etc.	300	
Drafting	300	
C.E. Department Service	200	
		1,100

Travel

Local Travel, Olympia, Field Trips, etc.	700	
Per diem 6 days @ 50/day	300	
		1,000

Total direct cost	12,225
Total indirect cost @ 45%	5,501
GRAND TOTAL	17,726

* Time includes approximately 11% for vacation and sick leave
** Possible salary adjustment

TRAC, FY87

(6 months)

Salaries

Faculty 1 mo. @ 3,038 (1.08)(1.08)**	3,544	
Amy O'Brien, Support Srvcs Coord. *1/2 mo. @ 1,495 (1.08)(1.08)**	872	
Research Assistant, 50% 2 mos. @ 872 (1.08)(1.08)**	2,034	
		6,450

Benefits

Faculty (3,544) 20%	709	
Exempt (872) 21%	183	
Student (2,034) 7%	142	
		1,034

Miscellaneous

Photocopy	200	
Telephone, Postage, etc.	200	
Drafting	200	
C.E. Department Service	142	
		742

Travel

Local travel, Olympia, Field trips, etc.	300	
Per diem 4 days @ 50/day	200	
		500

Total direct cost	8,726
Total indirect cost @ 46%	4,014
GRAND TOTAL	12,740

* Time includes approximately 11% for vacation and sick leave

** Possible salary adjustment

TRAC, FY86-87

Salaries

Faculty 2 mos.	6,825	
Khossrow Babaei, Research Engineer *1 mo.	2,641	
Amy O'Brien, Support Srvcs Coord. *1 mo.	1,679	
Research Assistant, 50% 4 mos.	3,918	
		15,063

Benefits

Faculty (6,825) 20%	1,365	
Exempt (2,641 + 1,679) 21%	907	
Student (3,918) 7%	274	
		2,546

Miscellaneous

Photocopy	500	
Telephone, Postage, etc.	500	
Drafting	500	
C.E. Department Service	342	
		1,842

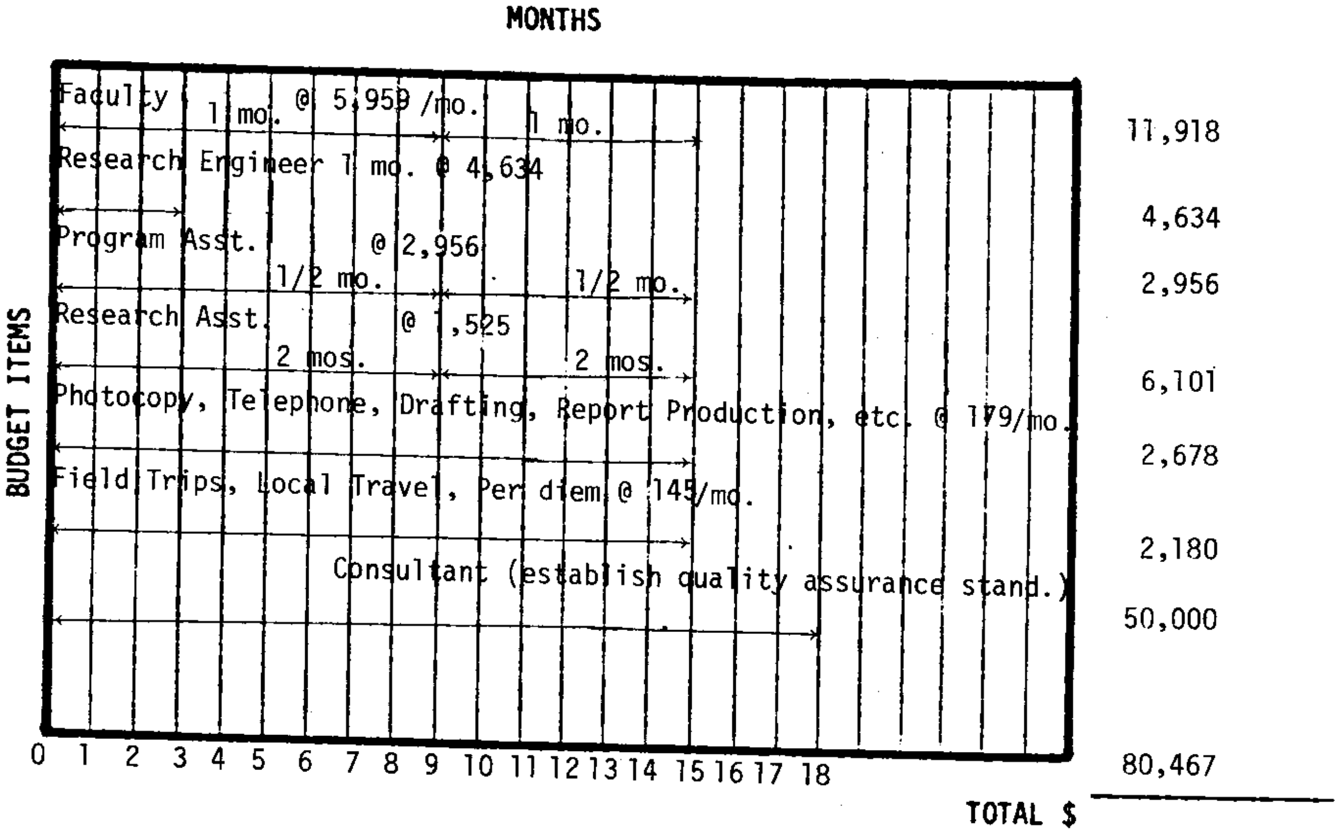
Travel

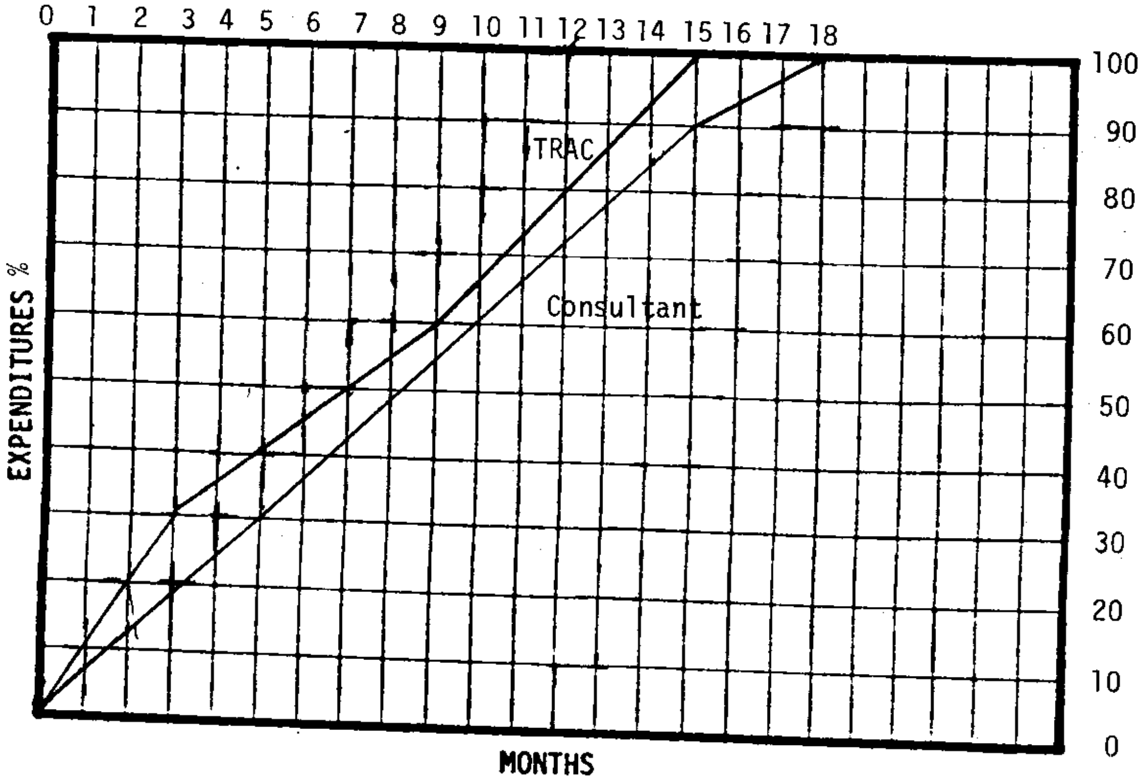
Local travel, Olympia, Field trips, etc.	1,000	
Per diem 10 days @ 50/day	500	
		1,500

Total direct cost	20.951
Total indirect cost	9,515
GRAND TOTAL	30,466

* Time includes approximately 11% for vacation and sick leave.

WSDOT Research Office
Budget Planning and Monitoring Program





PROJECT: "Evaluation of Rapid Construction Techniques for Bridge Deck Reconstruction"

11 - Level of Effort

TASK	% OF TOTAL COST		FRACTION OF TOTAL COST, $	
	TRAC	CONSULTANT	TRAC	CONSULTANT
I. Information Collection and Review	29	25	8,835	12,500
II. Evaluation of Rapid Construction Techniques, Interim Report Preparation	29	25	8,835	12,500
III. Establishment of Quality Assurance Standards, Final Report Preparation	42	50	12,796	25,000
TOTAL	100	100	30,466	50,000

12 - Facilities Available

The research will be conducted through the Washington State Transportation Center (TRAC) located at the Department of Civil Engineering, University of Washington. Offices and telephones of the Department of Civil Engineering will be available for this study. Additionally, the University of Washington libraries and the WSDOT library in Olympia will be available to the project.

13 - Report and Documentation

TRAC will prepare the interim and final report as indicated in the work plan development.

VI - CHAPTER SIX

Proposed Research for

"AC/MEMBRANE PLACEMENT AND REMOVAL ON BRIDGE DECKS BY MICROWAVE HEATING"

Table of Contents

1 - Problem Statement

The following two problem areas are identified:

1. Current procedures using planers to remove deteriorated asphalt overlays from bridge decks damage the concrete substrate and the reinforcing steel in the absence of sufficient concrete cover. New lifts of AC/membrane systems cannot be applied to damaged substrates.
2. Membranes do not stay intact in the process of asphalt concrete removal and are removed as well, regardless of their condition.

Microwave heating may be used on bridge decks to install new AC/membrane lifts, repair when cracked, and recycle when deteriorated with no interference with the concrete substrate. However, the overall effectiveness of the operation, including the effects of microwave heating on the concrete, reinforcing steel and prestressing steel need to be explored.

2 - Background Statement

The system was originally developed to patch or recycle asphalt concrete pavement. It provides complete asphalt concrete recycyling by heating and mixing it with rejuvenators. The whole process is done on-site with no need for additional materials. Microwave heating may also be useful for concrete bridge deck

AC/membrane protection. The following operation has been recommended in an article published in Better Roads, September 1982, for this purpose:

- The first pass of the equipment heats the concrete
- A sealer binder coat of thermoplastic material (membrane) is applied which will penetrate into warm concrete
- The second pass of the equipment overlays a hot asphalt concrete.

Later when cracks develop in the AC, the equipment passes over the deck, heats the system, and recompacts it so that it seals the cracks. When AC has lost its effectiveness completely through aging, the equipment can recycle AC by heating and mixing it with rejuvenators. However, it may be that the recycling process damages the sealer or membrane. Therefore, some measures may be needed during the initial construction to avoid this problem. One alternative may be installation of heat reflectors over the membrane.

3 - Objectives

This project will evaluate the potential application of microwave heating for the installation, maintenance, recycling and replacement of AC/membrane systems on bridge decks. It will determine the advantages and disadvantages of using this technology on bridge decks and compare the system with the conventional

AC/membrane protection.

4 - Benefits

An acceptable microwave heating technique could be adopted to install waterproof membrane bridge decks and to maintain them more cost-effectively, since the system could be re-set and recycled after aging with no disturbance to the concrete surface.

5 - Products

- Draft final report, "State-of-the-Art Assessment of AC/Membrane Placement/Removal by Microwave Heating and Integration into the Current Program," December 31, 1986.

6 - Implementation

The results from this work, including evaluation of the procedure and definition its requirements, may be implemented by WSDOT into the current bridge deck waterproofing program.

7 - Work Plan Development

Task I. State-of-the-Art Assessment

The consultant will assimilate sufficient information to evaluate microwave heating as a means of installing and maintaining AC/membrane systems on bridge decks. Additionally, the consultant will explore the practicality of the operation to remove existing AC/membrane systems from bridge decks with no damage to the concrete substrate. The consultant will also evaluate the use of new membranes having reflectors to prevent heating and damaging the membrane while removing and replacing only the top portion of the AC. The consultant will consider the following when assessing the operation on bridge decks:

- The safety aspects of the operation on bridge decks
- The effect of the operation on the rebar/concrete bond from possible different rates of microwave heat absorbency between steel and concrete
- The effect of microwave heating on the aggregate/cement paste bond.
- The effects of microwave heating on the properties of the rebar and prestressing steel
- The waterproofing properties of the system built by the operation
- Operation time and cost as compared to conventional AC/membrane removal and replacement

Task II. Integration into Current Practice

The results of this evaluation will be integrated into the current program, if justified, by defining the requirements and specifications for microwave heating on bridge decks for an effective operation. The consultant will issue the final report documenting the overall study at the conclusion of Task II on December 31, 1986.

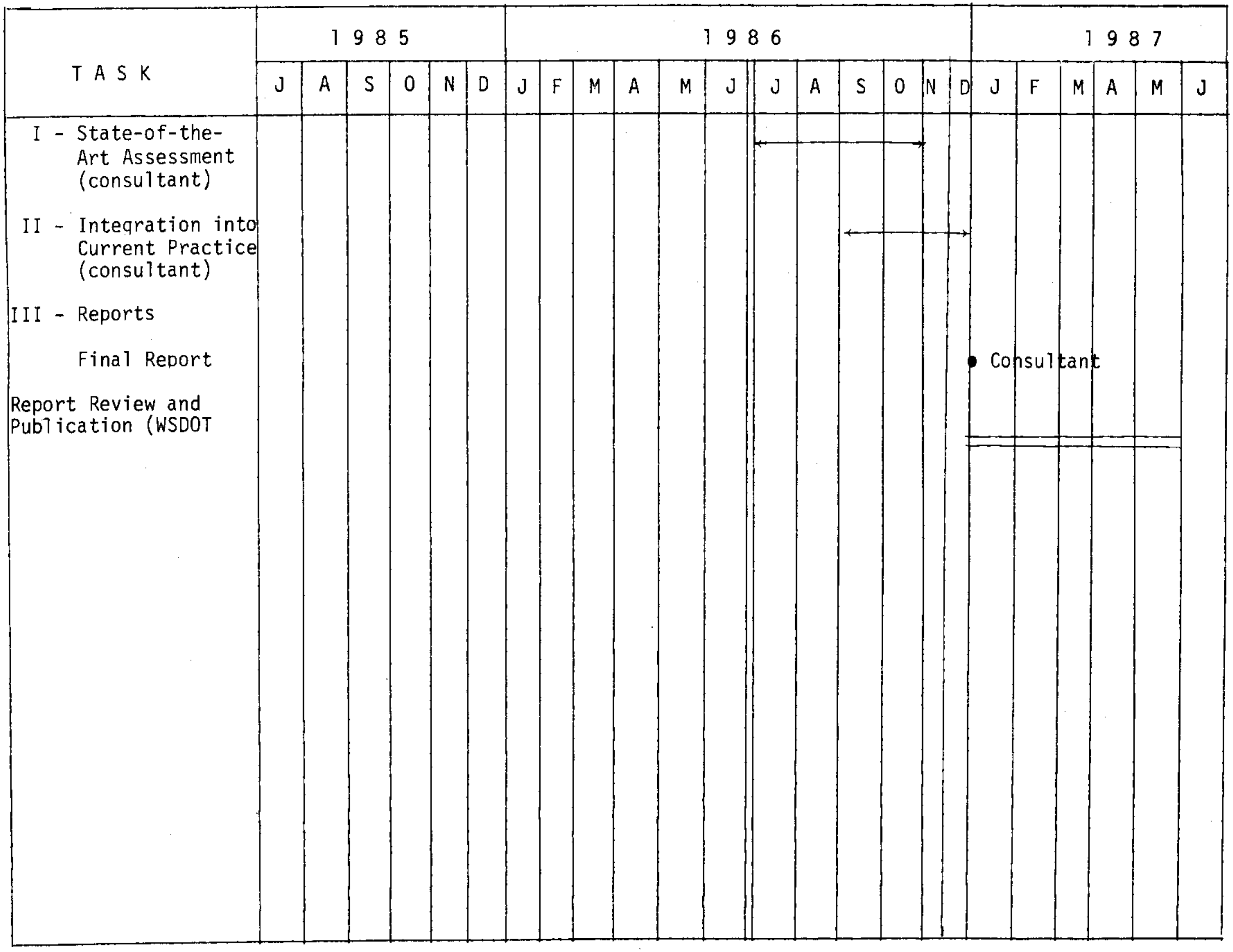
Task III. Report

The final report will be prepared by the consultant and submitted on December 31, 1986.

Responsibilities:

The consultant will be the only party participating in the research project and all responsibilities are assigned to the consultant.

8 - Schedule

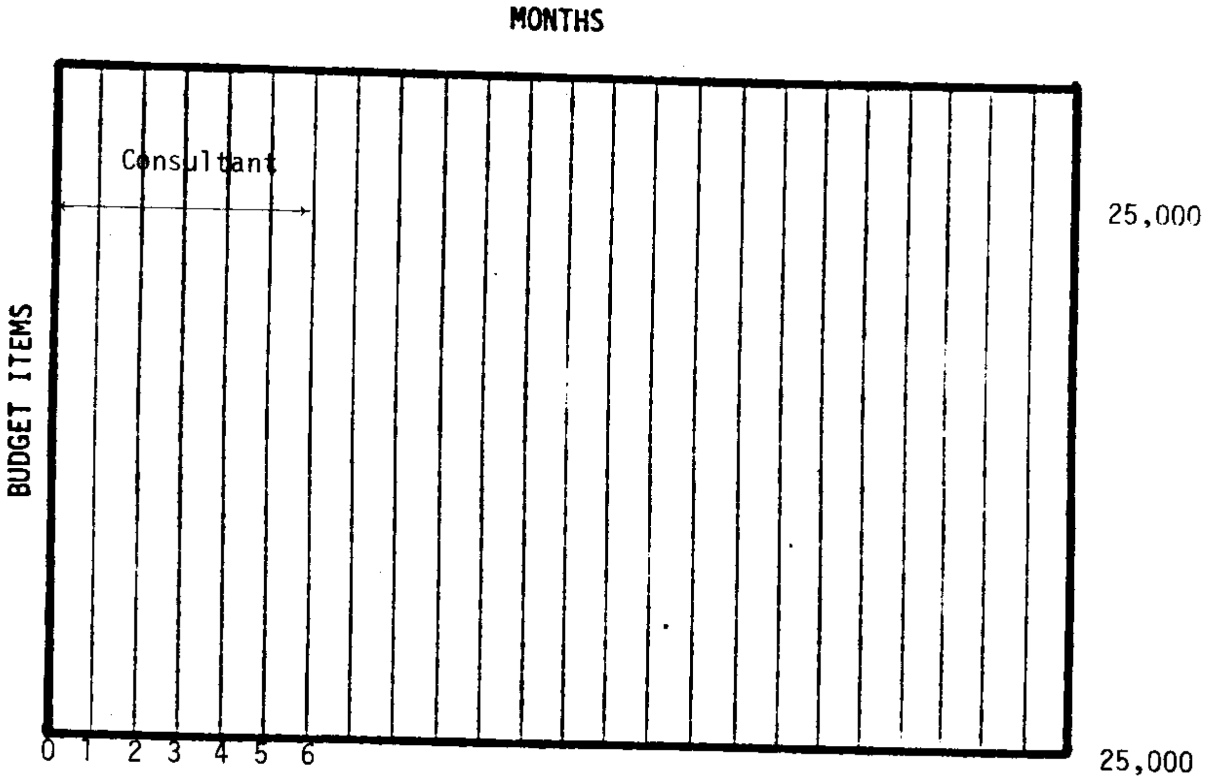

TASK
1985
1986
1987
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
I - State-of-the-Art Assessment (consultant)
II - Integration into Current Practice (consultant)
III - Reports
Final Report
Consultant
Report Review and Publication (WSDOT

9 - Budget Estimate

	FY86	FY87	FY86-87
TRAC	–	–	–
MAT. LAB.	–	–	–
CONSULTANT	–	25,000	25,000
TOTAL	-	25,000	25,000

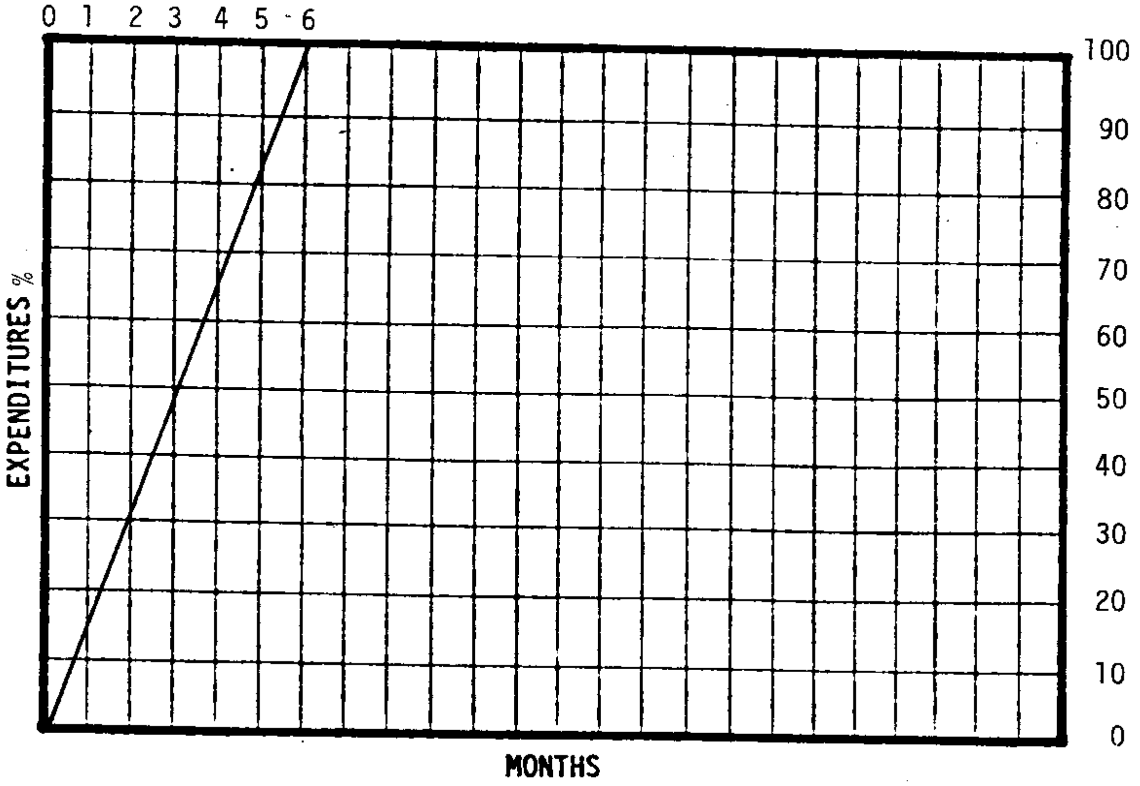
WSDOT Research Office

Budget Planning and Monitoring Program



25,000

TOTAL $



PROJECT: "AC/Membrane Placement/Removal on Bridge Decks by Microwave Heating"

10 - Level of Effort

TASK	% OF TOTAL COST	FRACTION OF TOTAL COST, $
	CONSULTANT	CONSULTANT
I. State-of-the-Art Assessment	50	12,500
II. Integration into Current Program, Final Report Preparation	50	12,500
TOTAL	100	25,000