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Concrete Overlays For Bridges

Interim Report

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16. Abstract

An extensive state-of-the-art review of construction methods and results for latex modified concrete (LMC) and low slump, dense concrete (LSDC) overlays is presented in this report. Recommendations are made for improvements in construction procedures, inspection, and specifications. An analysis and preventative measures for plastic shrinkage cracks in LMC are presented. Other alternate bridge deck protective systems were examined.

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CONCRETE OVERLAYS FOR BRIDGES

by

Washington State Transportation Center (TRAC)
University of Washington
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for

Washington State Transportation Commission
Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

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DISCLAIMER

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SECTION I
INTRODUCTION

This report presents results of an extensive search for the most successful procedures used to protect bridge decks with thin concrete overlays. Important findings from research and testing by governmental agencies and material suppliers will be presented. Discussions with these researchers and users of the research are presented in the report. The research and test reports have been screened to include only those that are pertinent to the conditions in Washington state. Procedures and data related to the use of latex modified concrete (LMC) overlays receives the most attention in the report, although some consideration is given to other methods of constructing concrete overlays.

Interviews with construction personnel from construction companies and state agencies are summarized in the discussion. Valuable insights and experiences from interviews with material suppliers are likewise included.

A variety of specifications were reviewed and analyzed in order to present a consensus of the best practice for successful construction results. Recommendations for changes in the existing Washington State Department of Transportation (WSDOT) specifications are included herein.

Suggestions for a more effective inspection program within the WSDOT are given based on personal interviews and observations of inspection personnel. Recommendations for inspector training to aid the quality assurance program are a part of this report.

Throughout this investigation, focus was placed on the causes and prevention of plastic shrinkage cracks which were evident in many of the LMC overlays constructed in Washington state in 1985. Much of the data and discussion pertains to the seriousness of that problem and procedures which may be used to mitigate cracking in future construction.

New methods for protecting bridge decks were investigated to a limited extent and a brief summary of those possibilities is given here. The benefits and needed research for one new modified concrete overlay are discussed.

A. PROBLEM DEFINITION

WSDOT is at the crossroads in their bridge deck overlay program. The seriousness of deterioration of decks did not require an extensive number of concrete overlays until the late 1970s and 1980s. In the early years of the program, low-slump dense concrete (LSDC) overlays were predominantly used although LMC was an option for most jobs. Today, LMC is the exclusive choice for concrete overlays; however, some experimental applications of thin, polymer/epoxy overlays were performed or are planned.

A moratorium was placed on LSDC as an alternate method of overlaying Washington state bridges based on some poor results in construction and measured higher permeability. The few LMC overlays that had been installed at that time were thought to be superior and would provide longer and more effective protection for bridge decks.

However, the evidence in support of LMC was not as conclusive as WSDOT would have liked and also eliminated the choice of a lower-cost alternate method. This evaluation was undertaken to obtain the measured performance, constructability, and quality control that WSDOT needs before they continue on the large number of remaining bridge deck overlays. The measured performance will be in the form of a physical testing program that will follow this interim report. These tests will be performed on a representative sampling of existing decks to evaluate their condition and predict their future performance.

B. OBJECTIVE

This project will provide insight into the reliability and problems of concrete overlays; namely, LMC and LSDC by evaluating the performance of sampled Washington installations. Additionally, it will review and evaluate the current methods of constructing overlays as well as other related approaches to bridge deck protection. Attempts will be made to integrate the results of this work into WSDOT's current practice.

C. SCOPE

This phase of the evaluation of concrete bridge deck overlays included the following work:

1. State-of-the-art review

2. Review and analyze construction practices for LMC and LSDC overlays in Washington and other selected locales

3. Review mix designs, materials, and specifications of WSDOT and other state agencies

4. Review inspection procedures used by WSDOT and others, and analyze their effectiveness

5. Analyze the plastic shrinkage cracking problem

6. Investigate other concrete overlay methods

The state-of-the-art review was limited to a determination of practices in other states and research pertaining to construction practices. The recommended practices of latex suppliers and equipment manufacturers was also reviewed. An extensive literature review was previously performed and reported in Bridge Deck Program Development, August, 1985, by Khossrow Babaei. (Ref. 7)

The review of construction practices included visits to projects under construction; personal interviews with WSDOT field inspection personnel; meetings with WSDOT bridge, materials, and construction personnel; interviews with materials and equipment suppliers and contractors; and visits to two midwest state highway agencies. This work focused on LMC overlays, but most of the above resource persons also had experience with LSDC since the two procedures are similar.

Mix designs, proportioning criteria, material specifications, and construction specifications were obtained from several sources together with rationale for their origin. No attempt was made to test any of these designs or procedures in the laboratory.

Inspector training and inspection procedures for concrete overlays were investigated by observation during construction and intensive interviews with inspection personnel.

The construction and post-construction history of five selected overlays in Washington state were examined to determine the extent and possible cause(s) of cracking. The experience of other states regarding the frequency and repair of cracks in LMC overlays was considered.

The investigation of new alternate methods to overlay or protect bridge decks was limited to two possibilities. These were only examined sufficiently to determine feasibility and to make recommendations for future work.

SECTION II
EXECUTIVE SUMMARY

A major portion of the bridge deck repair program for Washington state remains to be done in the next 5 to 10 yrs. WSDOT has primarily used concrete overlays on high density routes to protect existing decks which were not in need of complete replacement. Since mid-1984, latex modified concrete (LMC) has been specified as the preferred material for deck protection because of its ability to resist deicing salt (chloride) penetration. WSDOT needed to establish this superior performance to justify the move away from low slump, high density concrete (LSDC) as an overlay material. There was also a need to examine current methods of constructing these overlays and to update them to state-of-the-art procedures. This interim report is primarily intended to answer the latter need.

A review of current practices in at least eight states and provinces was made through a variety of inquiries; telephone, personal interviews, study of reports, and by mail. Resource persons included state transportation personnel, contractors, material suppliers, and concrete experts. The review focused on those who were using concrete overlays and had evaluated the performance of both LMC and LSDC. Many of these resources provided copies of their specifications, training media, test results, research findings, and special provisions.

Results of this survey showed that most agencies preferred LMC overlays because of its lower permeability. One state uses LSDC almost exclusively because they have used it for many years and contractors in that state are prepared to supply it with few problems. Another state is dissatisfied with both methods and is trying to find an alternate. All states have cracking in their overlays to one degree or another, but they do not believe that is a serious problem, provided the cracks are sealed. Construction procedures for LMC overlays are similar in all locales, but the experience of the contractor and DOT personnel dictates the level of success that is achieved, for the most part.

Ten bridge decks in Washington state were selected for inspection and discussion in order to examine the problem of cracking in LMC overlays. District field personnel participating in the construction of these projects were interviewed to aid in the evaluation. The decks were cracked in number from none to very extensive. Construction and inspection procedures on these overlays were compared and suggested improvements were discussed. All district personnel felt that there was a need for better inspection criteria and inspector training.

Construction procedures for LMC overlays are discussed and recommendations are made for improvements and critical items related to successful completion. Lack of contractor preparation and poor aggregate stockpiling practice are major preconstruction deficiencies. Slump control has been very poor on some projects because of poor moisture control in the sand. Lack of timely finishing, delayed application of burlap, and lack of sufficient moisture in the burlap are the biggest contributors to plastic shrinkage cracking. Most experienced contractors in this state and in other states maintain the curing operation within about 10 to 15 ft of the screed in order to minimize evaporation from the concrete surface.

Ambient conditions leading to rapid drying and particularly wind velocity are factors which must be seriously considered in decisions to start or continue overlay construction. Large differences in deck temperature and concrete temperature may lead to plastic shrinkage cracking. Deck surfaces warmer than 75°F or 85°F should be cooled by flooding or allowed to cool naturally before construction begins.

Cracks have been sealed in the past by covering them with a slurry mixture of cement, water, and latex. Research by Michigan and Indiana state research departments has concluded that the latex slurry is not effective in resisting chloride penetration and that cracks should be sealed instead with epoxy resin. If this repair is made following construction, cracking is not considered to be a serious problem.

Among the alternate choices for deck protection, the use of a modified concrete containing silica fume appears to hold the most promise. Overlays containing this mineral admixture are currently being tested in Ohio and Michigan. Silane coatings may be beneficial on new or slightly damaged decks. It is recommended that further research be conducted on these two alternatives.

Inspection criteria and guidelines need to be established for WSDOT inspectors to aid in the quality control of overlay construction. Training programs for inspectors should be considered as a means of preparing them for these short term construction projects and to assure a continuous supply of trained and experienced personnel.

Some changes are recommended to the current WSDOT specifications. Most of these pertain to procedures recommended for crack control during construction.

SECTION III
STATE-OF-THE-ART REVIEW

A. SURVEY OF THE PROBLEM

Observations of problems with LMC overlays in the State of Washington include cracking, ranging from severe on the east side of the Cascades to minor on the west side of the Cascades, and scaling on the east side of the Cascades.

Interviews of WSDOT personnel and inspections of existing Washington state projects were conducted. Selection of bridges to inspect was based on data sheets selected and submitted by WSDOT. In addition, construction and follow-up observations were made on the Chehalis River Bridge (Aberdeen, Washington) in October 1985 and March 1986.

In summary, weather conditions, placement procedures, and inspector experience had a big influence on the results. More specifically

1. Lack of weather data on most jobs, particularly rate of evaporation

2. Inexperienced contractors on some jobs

3. Slump (water control and sand moisture) was difficult to control

4. Variation between districts on interpretation of the specifications and their application

5. Inspector experience and lack of training (some first timers and some with only two or three LMC paving jobs experience)

B. REVIEW

Data for this report was gathered through various means.

1. Review of various DOT reports and specifications and miscellaneous publications

2. Telephone survey of selected DOTs

3. Telephone survey of suppliers and contractors

4. Meetings with selected DOTs

5. Meetings with selected contractors

Four states and one province were interviewed via telephone surveys and meetings. Comments from the various sources were not restricted to LMC overlays. Summary comments will be grouped into three categories: field performance, construction practices, and specifications.

A literature review was conducted with the aid of the Washington State Transportation Center (TRAC) and WSDOT.

C. LITERATURE REVIEW

Selected highway department reports are summarized. Two reports are summarized for Indiana. Reports on LMC overlays (and other methods) published less than six years ago were selected. Five states were selected; Missouri, Indiana, Colorado, New Mexico, and South Dakota. Although there were good reports written prior to 1980, it is the author's opinion that the state-of-the-art is constantly changing and, hence, only current reports should be summarized here.

1. Missouri

a. Title: "Performance of Latex Modified and Low Slump Concrete Overlays on Bridge Decks," Report 83-1 (Ref. 1)

b. Date: 1983

c. Synopsis: Field performance survey data of LMC, Latex Modified Mortar (LMM), and LSDC overlays. Ninety-one overlays were reported. Minimal cracking and delamination was reported. Favorable on LMC and LSDC overlays.

d. Highlights

(1) Classification of the 91 overlays reported: 60 LSDC, 7 LMM, and 24 LMC.

(2) Some overlays in place for nine years, but majority from one to three years.

(3) New construction and bridge deck rehabilitation projects were surveyed.

(4) No surface cracking observed on 78% of the ~300,000 square feet of deck area surveyed. Generally random and transverse cracking reported.

(5) 0.57% of the deck areas were debonded or delaminated.

(6) Random sampling indicated that percentage of cracks extending into the base concrete were 50% for LMM, 29.6% for LSDC, and 14.3% for LMC.

(7) The depth of crack penetration was found to be independent of the crack width at the surface.

(8) Voltage potential readings obtained on 20 deck driving lanes indicated 90.7% were in passive areas of less than -0.20 volts.

(9) Generally, the overlays were protecting against the migration of chloride ions into the base deck concrete.

(10) Recommended the continued use of both LMC and LSDC overlays but specified minimum thicknesses of 1-3/4 in. and 2-1/4-in. respectively.

2. Indiana

a. Title: "Bridge Deck Protection Systems - Category II - Experimental Features Study;" Fincher, Howard E. (Ref. 2)

b. Date: January 1983

c. Synopsis: Field performance survey data of LMC and LSDC overlays and plain concrete decks with galvanized reinforcement. Thirty-six structures were reported. Generally good performance of LMC and LSDC.

d. Highlights

(1) Classification of the 36 structures reported: 27 LMC, 7 LSDC, 2 galvanized reinforcement. Good data presentation.

(2) LMC in place for 2 to 12 years, LSDC in place for 2 to 4 years, and galvanized reinforcement in place for 5 years.

(3) LMC was used in new construction and rehabilitation projects. LSDC was used only on rehabilitation projects. Galvanized reinforcement was used only in new construction.

(4) Deck condition surveys conducted yearly.

(5) Top 1/2-in. of LMC generally contained highest content of chloride. Content dropped off with depth down to the interface with the base concrete.

(6) "Cracking of bridge decks is not a prerequisite for the penetration of chlorides to the level of the steel. It has been found that the corrosion of steel can occur independently of cracking."

(7) Six to seven LSDC overlays still resisting chloride penetration after three years, remaining deck allowing penetration after four years, but no active corrosion was detected when half cell tested.

(8) Proper densification of LSDC overlays is critical.

(9) The presence of high levels of chlorides at the reinforcement level of rehabilitated decks could be due largely to the original deck contamination.

(10) "Typically, where the existing deck was repaired and overlayed, the higher chloride content remaining in the old parent concrete appears to be diminishing with age."

(11) "(LMC overlays)...allow chloride penetration at a reduced rate and are protecting the reinforcing steel from corrosion chloride levels sometimes 7 to 10 years."

(12) LMC Overlays: Typically "tight" transverse cracking (few cases with wide cracks at the surface) and 7-ft average spacing between cracks (some cases 3 ft or less).

(13) LMC Overlays: Wear noted in wheel paths.

3. Indiana

a. Title: "Investigation of Cracks in Latex Modified Portland Cement Concrete Bridge Deck Overlays," Phases I through IV: Smutzer, R.K; et al. (Ref. 3)

b. Dates: May 1980 through January 1986

c. Synopsis: Field investigations of cracking and comprehensive laboratory studies of cracking, curing procedures, and crack injection reported.

d. Phase I Highlights

(1) Four structures were surveyed. Cores were taken for laboratory testing.

(2) "It appears that the depth of the crack cannot be estimated by the width of the crack on the surface of the overlay."

(3) A polysulfide, Type I, epoxy penetrating sealer and Low Temperature Metaseal were used to seal the deck and cracks.

(4) Remedial crack repair: "The effectiveness of the latex-cement mortar method is highly dependent on the workmanship involved...it appears that shallow penetration of the latex mortar and inadequate coverage was common."

(5) "The effectiveness of the epoxy penetrating sealer appears to be less affected by the workmanship involved...."

(6) Epoxy penetrating sealer should be "worked" into the cracks. Sanding is recommended after each application of sealer. Two separate applications of epoxy penetrating sealer are recommended.

e. Phase II Highlights

(1) Laboratory samples of LMC overlays were prepared. A graphical crack width versus crack depth relationship was presented.

(2) Visual cracks were observed in the slabs exposed to 10 mph wind. Cracking occurred from 5 to 20 minutes after exposure to wind.

(3) Lower slump concrete took longer to crack than higher slump concrete.

(4) Based on limited data, crack depth decreases as the slump increases.

(5) "Plastic shrinkage cracks in LMC overlays can be much deeper than normally anticipated in conventional Portland cement concrete surfaces."

(6) Surface discoloration noted in slabs; darker surface when exposed to wind and lighter surface when moist cured, and not exposed to wind.

(7) Recommended that LMC overlays be covered as soon as possible when wind speed is equal to or greater than 10 mph and relative humidity is less than or equal to 20%.

f. Phase III Highlights

(1) Laboratory investigation of two curing compounds to prevent plastic shrinkage cracking is reported.

(2) Curing compounds performed better than standard curing method in preventing chloride ion penetration in the top 1/2 in., at greater depths performance was similar.

(3) Curing compounds and the standard curing method performed equally well in preventing cracks.

(4) Curing compounds slightly inhibited strength gain when compared to standard curing method.

(5) Curing compounds are not recommended for use at this time.

(6) Revised recommendation for preventing plastic shrinkage cracking include: cover LMC within 10 minutes when wind speed is equal to or greater than 10 mph and relative humidity is less than or equal to 30%.

g. Phase IV Highlights

(1) Laboratory investigation of three remedial crack repair methods; LMC mortar, polysulfide (Type I) epoxy penetrating sealer, and ISO-FLEX 612 polyurethane sealer.

(2) Freeze-thaw testing conducted.

(3) LMC mortar remedial repair method provided very little benefit in sealing and preventing chloride ion penetration.

(4) Epoxy and polyurethane sealer remedial repair methods performed well in sealing cracks and preventing chloride ion penetration.

(5) A syringe was used to inject the epoxy and polyurethane sealers into certain cracks prior to sealer application.

4. <u>Colorado</u>

a. Title: "Bridge Deck Repair and Protective Systems - Latex Modified Concrete Topping," Interim Report (Ref. 4)

b. Date: July 1984

c. Synopsis: Field survey observations reported on 10 LMC overlays. Cost comparisons made between deck replacement and rehabilitation over a 40-year period. LMC overlays had a 7-year service life. LMC overlays not recommended for Colorado at this time, further evaluation in progress.

d. Highlights

(1) Latest in series of reports begun in 1976.

(2) Cracking appeared on all the overlays within one year.

(3) Very high rate of road salt usage.

(4) "The old concrete is salt contaminated from conditions which existed prior to the repair jobs. Some corrosion of the steel probably continues to occur in the presence of this residual chloride and any residual or new water in the system."

(5) Detailed cost analysis for four overlays based on bid prices.

(6) Assuming 40-year concrete deck service life, LMC overlays are more expensive on an annualized cost basis.

(7) The 10 LMC overlays currently need repair or replacement.

5. New Mexico

a. Title: "A Study of New Mexico Bridge Deck Protective Systems;" Tachau, R.M., et al. (Ref. 5)

b. Date: July 1984

c. Synopsis: Survey of 43 state highway departments reported. Evaluation of 7 bridge deck protective systems on 37 New Mexico bridges reported.

d. Highlights

(1) Presents a good discussion of the different bridge deck protective systems and has an extensive bibliography.

(2) Survey results in tabular form. Good source for information on what different states are using.

(3) Visual survey of 37 bridges and laboratory data from New Mexico State Highway Department reported.

(4) The seven protective systems (and quantity of each) evaluated in New Mexico were: epoxy coated rebar (8), waterproof membranes (3), epoxy-sand seal (8), polymer impregnated concrete (2), LMC (5), LSDC (6), and silane (4).

(5) Minimal deterioration in decks with epoxy coated reinforcing steel. Epoxy coated steel is standard practice in areas with high salt usage.

(6) "Nearly all states that have used waterproof membranes are reasonably satisfied with performance of this protection system."

(7) "Most states that have used epoxy-sand seals are not satisfied and have discontinued use."

(8) Polymer impregnated concrete systems have been discontinued in New Mexico because of application difficulties and cost.

(9) LMC overlays have been in place for eight years. All of the LMC overlays are in good condition with only minor cracking.

(10) LSDC overlays have been in place for three years. Extensive cracking was observed on the six LSDC overlays, some have experienced debonding.

(11) "The construction of low slump concrete overlays are difficult in New Mexico's dry climate. Deck rehabilitation with this material should be discontinued....In lieu of using low slump concrete, latex modified concrete should be specified."

(12) The silane treated bridge decks are in good condition after three years, despite the poor quality of the base concrete. Silane treatments are promising and should be evaluated further.

6. South Dakota

a. Title: "Bridge Deck Overlays with Latex Modified Concrete." (Ref. 6)

b. Date: February 1980

c. Synopsis: Field performance survey data of LMC overlays. Nine overlays were reported. Good results with LMC overlays.

d. Highlights

(1) LMC overlays have been in place for two to three years.

(2) New construction and bridge deck rehabilitation projects were surveyed.

(3) Condensed construction reports included.

(4) Some sampling and laboratory testing.

(5) Chloride contents of fresh concrete overlays ranged from 0.46 to 0.98 pounds per cubic yard.

(6) Cooler temperatures are more favorable for the prevention of crack development.

(7) "Apparently cracking has no relationship to chloride penetration."

(8) Some minor transverse cracking noted after construction, epoxy crack filling used.

(9) No major problems with LMC overlays to date.

D. OTHER STATE DOT INTERVIEWS

1. Telephone Surveys

Telephone surveys were conducted of four state and provincial highway departments. The following highway departments were interviewed: Missouri, Iowa, New York, Ohio, and Ontario. Some of the highlights will be summarized here.

a. Missouri

(1) Favorable recommendation for both LMC and LSDC.

(2) 13 years experience with LMC and LSDC.

(3) No established criteria for overlay performance. Asphalt overlays generally replaced in 10 to 15 years, but hope that LMC and LSDC will last for the life of the bridge.

(4) Shrinkage cracking does occur, as well as local debonding, particularly at pavement joints.

(5) No sealing or epoxying of cracks performed.

(6) One-day wet cure (burlap and plastic) used for LMC.

(7) Manufacturer's representative requirement was a fiasco; expertise of individual varied from job to job, often conflicting and inconsistent recommendations.

(8) State conducts its own inspector training program.

b. Iowa

(1) Only six LMC projects since 1965. One has been replaced, one has been repaired, and four are still serving satisfactorily.

(2) LSDC is primary overlay method. Started in 1965, hope to obtain 20-year service life.

(3) Some cracking due to poor curing practices. Random and alligator cracking observed but causes not identified.

(4) No correlation between crack width and depth. Some delamination has been discovered.

(5) Cracking in the overlay is not considered a problem. Cracking is to be expected. Cracks are not filled.

(6) Debond line was below the overlay in the old deck, typically within 1/4 in. of the bond line.

(7) Wet burlap cure for three days. Plastic covering is not used.

c. New York

(1) Ten years experience with LMC. Favorable on LMC.

(2) Hoping to obtain 30-year service life from LMC overlays.

(3) Cracking and delamination discovered. Four or five decks failed last year.

(4) Crack width and depth could not be correlated.

(5) Cracking versus vibration could be correlated. If bad vibration, cracks go all the way through the overlay. If good vibration, only shallow cracks.

(6) Delamination typically started after five years. State suspects that delamination caused by not removing enough contaminated concrete. Typically all concrete with a potential greater than -0.35 volts is removed. Suggested that a lower limit of -0.25 volts or less be used.

(7) Studying the effects of cracking.

(8) State prefers LSDC paving machines for LMC work; they provide good vibration.

(9) "Astroturf" drag used for finishing. Saw cutting used to provide texturing.

(10) Curing applied within 10 ft or 10 minutes of the paver.

d. Ohio

(1) 12 years experience with LMC.

(2) Very favorable on LMC, 1000+ overlays placed.

(3) Three-day continuous wet cure with soaker hose under the plastic is specified.

(4) ACI rate of evaporation chart used during placing.

e. Ontario

(1) 10 years experience with LMC. Favorable on LMC.

(2) Cracking is a fact of life. Do not expect long-term deficiencies.

(3) Plastic shrinkage cracking and pattern cracking observed. Depth apparently very shallow, but cracks are quite wide.

(4) Crack injection has not been very successful, not recommended.

(5) 24-hour wet cure used.

(6) The Ministry conducts its own construction school during the winter months. Audio-visual training aides are available for duplicating.

2. Personal Interviews

Personal interviews were conducted with the Michigan and Indiana state highway departments and three contractors from Indiana. Some of the highlights will be summarized here.

a. Michigan

(1) 18 years experience with LMC. Most overlays performing well after 15 years.

(2) A few overlays have delaminated in as little as six months because of high chloride content in the substrate concrete.

(3) Have used LSDC overlays but found high chloride permeabilities. Also susceptible to wide, full-depth, and long-term drying shrinkage cracks.

(4) 48-hour wet cure is used.

(5) Wind is a key factor for placing and MDOT will shut down the pour if wind picks up. They limit the bond coat application to 3 to 5 ft in front of the screed.

(6) Most cracks have been verified to be 1/8 to 3/4 in. deep, very few full depth. They fill all cracks with a penetrating epoxy or an epoxy thinned slightly with toluene. MDOT does not permit latex slurry for covering cracks.

(7) MDOT provides no special training for inspectors. They must attend a technicians' class each year; otherwise, LMC inspection in on-the-job training.

b. Indiana

(1) 18 years experience with LMC. Satisifed with LMC, 10- to 15-year service life expected.

(2) Used LSDC as an alternate to LMC but discontinued due to poor quality of work and high permeability.

(3) The LMC is also used as a bond coat. If the concrete is too wet, it is spread out over a wider area or removed and corrected before further placement is allowed.

(4) Recommended covering the concrete as soon as possible behind the screed and water the burlap before covering with plastic film. They seldom, if ever, allow more than 5 to 10 ft of concrete to remain uncovered behind the screed.

(5) Most cracks are filled with a penetrating epoxy sealer and sprinkled with sand.

(6) All inspectors attend a concrete school on a normal basis at the state research center in Lafayette.

3. Summary/Conclusions

a. Some cracking is to be expected. Appears to be related to plastic shrinkage although there may be other causes (i.e., drying shrinkage, structure behavior, thermal stresses, etc.). Plastic shrinkage cracking is usually defined as pattern cracking resulting from rapid drying of the concrete in its plastic state. Often the cracks are wide but shallow. Drying shrinkage cracking is defined as cracks resulting from the drying of the concrete after it has hardened. These are usually finer and deeper cracks than plastic shrinkage cracks and have a random orientation. (Ref. 8).

b. Cracks appear to be cosmetic and do not appear to penetrate through the full thickness of the overlay in most cases.

c. Cracking in itself may not be harmful, but the extent of cracking should be limited by use of good construction practice.

d. Minimum overlay thickness should be 1-1/2 in., 1-3/4 in. would be preferred. Avoid very thick sections -- hard to control consolidation.

e. If possible, pour late at night or under cloud cover with slight or no wind and high relative humidity.

f. "Tining"/texturing of the surface should be accomplished as soon as possible, also consider other methods for texturing.

4. Recommendations

a. Continue to use LMC concrete overlays, but other methods should also be researched.

b. Make specifications more practical. Establish field QA/QC procedures.

c. Provide more training for state inspectors. Develop state training program, can be based on other existing programs. Discuss negative results as well as positive results.

d. Contractor qualification/selection procedures should be adopted. Avoid "on-the-job" training as this will result in a poor quality product unless very strong state inspection can be provided.

e. Uniform method of field data collection should be adopted for 1986.

f. Field data collection for the 1986 construction season should include temperature data, specifically deck and fresh concrete temperature, air and concrete surface temperature (from pour through the end of curing period).

g. Do not let concrete surface dry out. Use misting spray as required prior to applying burlap.

h. Burlap should be in contact with concrete surface, no air gaps.

i. "Thermal shock" should be further investigated as cracking may be a combination of drying shrinkage and temperature of the base concrete.

j. Additional core sampling and testing should be conducted to determine severity of cracking on some existing structures and to determine properties of inplace overlay (i.e., unit weight, permeability, etc.).

SECTION IV
REVIEW AND ANALYSIS OF
CONSTRUCTION PRACTICES

The procedures and recommendations of many individuals and agencies provided the data for our analysis and are presented in Section III, State-of-the-Art Review. This section will highlight the important issues of this research and discuss the background for a recommended practice.

The format of this section will follow the sequence of construction operations, namely

- o Deck preparation
- o Mobile mixer calibration and operation
- o Concrete placement and screeding
- o Concrete finishing
- o Curing
- o Crack repair

A. DECK PREPARATION

Nearly all bridge decks are prepared for overlaying by removing concrete to a depth of 1/4 in., followed by removal and replacement of unsound concrete in select locations. The procedures for accomplishing this are similar for all agencies surveyed.

Scarification is done mechanically with scabblers, shot blasters, or milling machines. Some agencies have experimented with water jet removal of concrete. Michigan, Maryland, Illinois, and others who have used the high-pressure water removal systems report the same findings as WSDOT; namely, that the method is very effective but much slower than mechanical scarification. At least one manufacturer already has produced a faster water jet remover. The advantage of water removal seems to be in its ability to produce a surface that requires no further preparation, hence substantially reducing labor costs; however, Michigan DOT prefers to sandblast the reinforcing steel after water jetting.

When scarification is completed, the deck is sounded with chain drags, steel rods or hammers to determine the location of deteriorated or unsound concrete. Where high chloride penetration is suspected, some agencies sample the deck by coring or drilling and determine the chloride content. Some states such as New York are considering performing routine corrosion half-cell tests at this stage to determine corrosion potential of the substrate concrete. This may be necessitated since a number of new overlays have delaminated due to insufficient removal of chloride-saturated concrete. The extent of this occurrence is not known; however, Michigan, Indiana, and New York all report that a "few" decks have delaminated for this reason.

There is no consensus as to what value of corrosion potential constitutes cause for removal. The currently accepted maximum potential values are -0.30 to -0.40 volts. The New York DOT suggests an upper limit of -0.25 volts while others are saying that the threshold value should be -0.20 volts. Once rebar reaches the -0.20 level, corrosion accelerates rapidly say some experts. The rate of corrosion cannot be monitored by half-cell readings unless they are taken at regular intervals, which is often impractical.

Thus, there is a need for instrumentation or methods which will more precisely determine the extent of corrosion or corrosion protection remaining in the concrete. At least two consultants have devised methods by which the resistivity of concrete can be measured from a bridge surface and thereby measure the likelihood of corrosion.

The procedures for removal of unsound concrete below the scarified surface and patching of these areas are generally similar for all states. Patches are made with ordinary structural concrete, fast-setting proprietary patching concrete, or with the overlay concrete provided it is vibrated into place with hand vibrators. The extent to which the latter may contribue to surface problems in the overlay is a subject of concern and requires more research.

B. MOBILE MIXER CALIBRATION AND OPERATION

With very few exceptions, all LMC and LSDC overlay concrete is mixed on the bridge deck in mobile mixer trucks. Cement, latex, sand, coarse aggregate, and water are all batched volumetrically and mixed for less than 30 seconds in an inclined auger at the rear of the truck. Proper proportioning and yield of the concrete mix are dependent upon proper calibration, cleanliness, and maintenance of the mobile mixer. Calibration is based upon the volumetric flow of cement from a wheel; it then falls onto a conveyor belt and controls the volume of aggregates into the mixture.

The contractor and DOT inspector must understand the significance of the calibration on the concrete performance, as well as changes to that calibration once the pour begins. Calibration procedures among the various states differ only in frequency and the amount of cement used and the number of repetitions during the calibration check.

It is important that the cement wheel be clean for calibration and kept free of build up during the pour. The divider plate between the aggregate bins must be in good condition and free of holes that aggregates could flow through. The divider plate should be close to the conveyor belt and be stiff enough that it does not deflect during calibration, particularly if one of the bins is empty. The aggregate bin vibrators should be checked frequently. Bridging of sand in the bins can occur if the vibrators are not maintaining the flow of material.

The frequency of calibration should be determined as a minimum, every three months or sooner, depending on the relocations of the mobile unit and the quality of concrete as discharged from the mixer. Most authorities agree that the mixer will remain within tolerance after initial calibration as long as the yield remains in tolerance.

Some concrete should be mixed and discharged prior to the start of a deck pour in order to verify proper mix proportioning and operation of the mixer. The contractor and inspector should be aware of the significance of small changes in the aggregate settings as they affect the quality of the finished concrete. Small adjustments of the sand and/or coarse aggregate quantity can improve the ability of the surface finish to be "closed" without seriously affecting the yield. This is particularly important if the source of aggregate changes during the pour from one stockpile to another, or if significant changes in aggregate moisture take place. Of course, these adjustments become unnecessary if proper quality control of aggregate stockpiling and moisture control are performed.

Water is ordinarily dispensed through flow control devices on the trucks, however, some units are equipped with water meters. In either case, they should be checked during calibration for accuracy. A bypass valve should be installed on trucks to aid this process. Most inspectors or contractors agree that the water control lacks precision, but that slump will control water/cement ratio within the necessary range. If good slump control is lacking, then the control of water/cement ratio within a range of 0.03 is questionable. The WSDOT requirement for more accurate water flow control adjustment appears to be a good specification change.

As with any equipment used for batching and mixing concrete, the maintenance of the mobile mixers is all important. The frequency of mechanical, electrical, or hydraulic malfunctions requires that backup mixers and parts be available for a deck placement if a continuous pour is to be assured.

C. CONCRETE PLACEMENT AND SCREEDING

The most frequent cause of problems on a concrete overlay is probably the lack of readiness of the contractor's crew and equipment at the beginning of the pour. This is evidenced by the observations made in our inspection of existing overlays, observations of placements, and comments from others in our interviews.

The surface finish problems including cracking, poor tining, excessive water and laitance, and rough finish were generally associated with the beginning of a pour. All of these problems were more evident near construction joints at the point of beginning and diminished as the work progressed, until finally there were few problems at the end of the pour. There were exceptions to this as some cracking was randomly spaced, and finish problems were sometimes at points of equipment breakdown, which were scattered.

The lack of readiness causes four types of problems at the start of a pour:

1. Cracking due to delayed covering with burlap, created when the curing crew is not ready or finishing/tining is delayed.

2. High water content in the mix which surfaces and creates laitance or other finish problems. This occurs when sand moisture is high in the bottom of the aggregate bins and creates excessive slump.

3. Poor finish due to shutdown for screed adjustment or mixer adjustment.

4. Lack of properly saturated substrate due to inadequate prewetting of the deck (this will also be discussed under Causes of Cracking).

The inspector must not allow the overlay placement to begin until all of the placing crew are positioned at their proper workstations. A small amount of concrete should be discharged in another location in order to observe that it is of the proper consistency and appearance before using it on the deck. Some DOTs allow the initial discharge to fall onto the deck and they use it exclusively for brooming into the surface, but this is hard to control and may be detrimental to bond.

The screed check prior to the pour should involve a dry run of the screed down the rails to cover the entire length of the pour. Adjustments of the screed rails should be made at that time and further adjustments in elevation of the rails should not be permitted. Some agencies allow screed adjustments, but they agree that it would be better not to. Adjustments to mixer settings should be made prior to the deck overlay pour and should be delayed thereafter until the work is off to a smooth start.

Most states require a one-hour prewetting of the deck, but this may be insufficient to assure penetration of latex into the substrate and keep the latex from drying (i.e., premature formation of polymer film). It is recommended that the deck be wetted and kept wet for at least one hour by continuous sprinkling or by covering the deck with polyethelene film.

Some contractors use a separate mobile mixer or stationary mixer to produce the slurry bond coat for the overlay. There is no evidence that this produces better results than the conventional method of using the overlay mix as a bond coat and removing the coarse aggregate from the deck as it is broomed out. No appreciable delamination of overlays has occurred which can be attributed to a poor bond coat unless it has been broomed on too far ahead of the screed and dried.

The yield, slump, and air content of the concrete should be checked near the start of the pour and immediate action taken to correct deficiencies. The practice of giving the contractor a "free" truck with no quality checks should be discouraged. Proper stockpiling of sand and loading of trucks to prevent pockets of excessively wet sand should

New burlap is usually covered with sizing or other films which impede its ability to absorb water. Michigan DOT specifically prohibits new burlap from use; recommending instead that the contractor launder the material prior to its first use. If used burlap is applied, it should be clean and free of hardened cement paste, dirt, or oil.

At least one contractor and inspector have observed that cracks occur under wrinkles in the burlap. This may be caused from the "greenhouse" effect of high temperature under the burlap and plastic when it is "tented" over the surface. Others have not correlated this phenomenon with cracking, but it is likely to be true and it is advised that the burlap and polyethylene be placed as flat as possible.

The consensus of the authorities polled in our survey is that burlap should be thoroughly saturated in tubs alongside the bridge deck, allowed to reach a drip-free state after removal from the tub, and applied to the concrete surface as wet as possible, such that it will not wash out the texture. They also advise that the polyethylene covering be delayed long enough to allow the burlap to be further wetted by water sprayed from behind the paving train. Others have gone one step further and placed soaker hoses on the burlap before covering with plastic.

The intention of the wet burlap is to prevent further evaporation of water from the concrete and to replace water that has already been lost. These concrete overlays are different from ordinary concrete flatwork in that they are thin and have a very low water/cement ratio. Water in excess of that required for hydration is lost, not only by evaporation, but by self-dessication; the process of internal absorption. The most effective curing process for these thin, low water/cement ratio overlays is to pond water on the surface as is done on industrial floors in commercial applications of overlays. This is impractical on most bridge decks, however, and saturated burlap has been selected as the best substitute for ponding.

The length of time for the wet and dry cycles of the curing process is somewhat controversial and requires some judgment from the decision makers in the field. Most agencies require 24 hrs of wet cure with burlap and polyethylene sheets plus 48 or 72 hrs of dry cure with the cover removed. Michigan researched the effects of longer wet-cure periods in the early days of their overlay program and determined that the benefits of 48 hrs of wet curing outweighed the cost of delayed opening to traffic. They found that the longer cure time produced higher early and ultimate compressive strength and lower permeability. At least one other state, Ohio, has a similar 48-hr, wet-cure requirement.

F. CRACK REPAIR

Three methods of crack repair are currently being used.

1. Cover the crack with a slurry made of latex, cement, and water (occasionally sand is added to produce a mortar).

2. Inject epoxy resin into the crack by use of a squeezable bottle or other low-pressure applicator.

3. Paint an epoxy sealer over the cracks and reapply as necessary to fill the crack. Sometimes a sand is broadcast over the tacky epoxy to improve skid resistance.

Method 1 has been used by nearly all states in the beginning of their overlay programs, but most of them are now using one of the other methods. Nearly all cores of repaired cracks show that the latex slurry provides only a surface cover to the crack, while epoxy penetrates to some depth depending on crack width and depth. The long-term durability of bridge decks with cracks in the overlay repaired with latex slurry has been questionable for some time.

The Indiana DOH report (Ref. 3) presents an excellent comparison of cracks repaired by both latex slurry and epoxy. The ability of the repaired crack to resist penetration of chlorides to the substrate concrete in the deck below was measured.

The Indiana research concluded that the latex slurry or mortar did not provide adequate protection against chloride penetration and that an epoxy penetrating sealer was effective in sealing cracks and protecting the deck.

It is recommended that crack repair be accomplished before opening the overlay to traffic and after some drying of the surface has taken place to promote better penetration of the epoxy into the crack.

G. MATERIALS FOR CONCRETE OVERLAYS

This section will discuss only those aspects of materials which require special consideration or where others have treated them differently from WSDOT standards.

1. Portland Cement

All cement when combined with water tends to false set, i.e., premature stiffening to some degree or another. The one to three minutes of mixing followed by some agitation that most concrete receives is sufficient to mix through this false set and make it unnoticeable. The very short mixing times associated with the mobile mixers used for concrete overlays may not be adequate to prevent noticeable false set. This may create an excessively high rate of slump loss, even greater than that commonly associated with LMC.

Some cements exhibit a stronger tendency toward this apparent slump loss because of choice of gypsum source used as a raw material and grinding mill temperatures among others. The use of an anhydrite versus a dihydrite gypsum may create a difference. When grinding mill temperatures become excessive, some gypsum is dehydrated and reverts to plaster of paris, causing a quick initial stiffening when the cement combines with water.

The significance of this problem in placing concrete overlays is not well known and requires some research. In the meantime, it would be advisable for the Materials Laboratory to observe slump loss while qualifying mix designs and materials to determine the tendency of a particular brand of cement to be highly false setting with very short mix times (i.e., 10 to 30 seconds).

2. Latex

No agency expressed a strong preference for one brand of latex over another. There seemed to be some agreement that Polysar latex does not form a polymer film as rapidly as does Dow latex, resulting in Polysar requiring a lower placing slump to hasten the film formation. Likewise, for the same reason, the Dow material is more susceptible to finishing problems if finishing is delayed too long. The differences are subtle and provide no reason to prefer one brand over the other.

One contractor finds it simple to cool the latex by icing the center compartment of his three compartment bulk tanker, thereby making the LMC easier to place under hot weather conditions. Others try to avoid excessively high (or low) latex temperature by using insulated tankers, shading the storage vehicle during construction, or other means.

3. Aggregates

There seems to be equal preference for crushed coarse aggregate as there is for smooth, rounded aggregates. The choice, if it exists, should be based on suitable gradation and density. Michigan DOT specifies a higher coarse aggregate content than do most other agencies. They have determined from tests that a sand-to-total aggregate ratio of 53 to 58% results in lower shrinkage and lower permeability in LMC than does the same concrete with 60% sand. The optimum sand content can be estimated from density measurements of various combinations and verify that this will result in workable concrete.

The most significant problem with aggregates is the free moisture content of sand as it combines with other materials in the mobile mixer. Pockets of wet and dry material are easily distinguished, because they result in an immediate slump change. The "batch" size is so small that it cannot average the local differences out as readily as larger, conventional mixers. Excessively high free moisture in the sand must be avoided to maintain slump within tolerable limits and to permit adjustment of slump by the ability to add some water to the mix.

Most agencies try to control sand moisture by specifying a minimum time period that stockpiling must be performed before paving begins and by covering the stockpiles. They find that this coupled with limitations on slump are sufficient. However, all agencies agree that the control of initial moisture content, the retrieval of sand from proper locations in the stockpile and maintenance of uniform moisture content in the mobile mixer are sometimes a problem. An upper limit of 3 to 5% free moisture in the sand appears to be a suitable criteria for control. More attention needs to be given to uniformity in stockpiling and stockpile location to provide drainage.

H. SPECIFICATIONS

All specifications that we reviewed were similar to the original ones that Dow Chemical Company recommended when LMC was first used, because they were the primary source of material and experience. Some variations and improvements have been made by some users, with some being somewhat more restrictive. All specifications are prescriptive in nature as opposed to performance because of the specialized construction methods used.

Suggested changes or additions to WSDOT specifications for LMC are presented under the Recommendations section of this report.

I. ANALYSIS OF CRACKING PROBLEM IN LMC OVERLAYS

Ten bridge decks in Washington were examined as part of this phase of the study, primarily to develop background for determining the cause and seriousness of cracking in the overlays. All overlays were constructed of LMC and all but one were performed in 1985. Two overlays were in the western part of the state while the others were in eastern Washington on I-90 between Spokane and Snoqualmie Summit and in the Tri-Cities area. It is considered by WSDOT personnel that cracking was more common in the 1985 construction season. Western Washington had a warmer and drier summer than usual, but the eastern part of the state is normally quite warm and dry in the summer.

The most serious cracking exists on the SR 240/12 bridge in the Tri-Cities and is well documented in a report prepared by the district field personnel. Other cracking is typically oriented in the longitudinal direction of the bridges although there may be more transverse cracking than can be observed because it is hidden in the grooving. Crack frequency varies from 2 or 3 ft of width to 2 or 3 per structure. As stated previously, the frequency generally is greater at the start of a pour and diminishes toward the end, although there were several exceptions to this.

Cores from two of these sites and those from other bridges in Michigan, Indiana, Ohio, and Ontario reveal that cracks are generally not full depth of the overlay, but are 3/8 in. to 3/4 in. deep. The crack width ranges from wide, say 0.10 in. to hairline, say 0.004 in. with an average width of around 0.025 in.

One overlay exhibited a much different crack pattern and crack appearance. The cracks on I-182 over the Columbia River were "alligator" type of crazing cracks as opposed to wide plastic shrinkage cracks. It was reported that they did not appear until several months after construction was completed, whereas all other overlay cracking appeared in the early life of the overlay; 3 to 72 hrs after pouring. This overlay was placed on a long-span, post-tensioned, box girder bridge and it could be that cracks were caused by differential shrinkage and creep in the roadway surface. In any event, the cracks do not appear to be an immediate problem, but it is recommended that the cracks be sealed to minimize chloride penetration.

Plastic shrinkage cracking occurs to some degree on overlays in all the states and provinces included in our survey. None of these agencies reported cracking to the extent that occurred on the SR 240/12 bridge, but instead indicated that cracks were widely scattered. Indiana found it a serious enough problem that they initiated the four-phase investigation summarized in the state-of-the-art review. The results of this study have helped them to mitigate the problem, but they have not completely eliminated it.

The makeup of the concrete overlays is such that they are very susceptible to plastic shrinkage cracking. Those factors that contribute to this cracking are listed below.

1. Thin concrete overlays have a high surface to volume ratio and promote rapid evaporation under drying conditions.

2. Low water/cement ratio concrete has a low bleed rate and self-dessicates, making very little bleed water available to replace the evaporated water.

3. LMC forms a polymer film as the latex coalesces. This feature is beneficial for water retention as it cures, however, it causes surface tearing and cracking if it forms prior to finishing.

4. Ambient conditions and restrictions for LMC application require that LMC overlays generally be applied under adverse drying conditions in the summer. These conditions also create high differential temperatures between bridge decks and overlays.

Rapid loss of evaporable water and high differential temperature between the deck and overlay are the two most significant contributors to the cracking problem. Other influences, such as type of superstructure, vibration from nearby traffic, and substrate preparation contribute much less to the problem, if at all.

The most effective ways of mitigating the cracking problem may be summarized as follows:

1. Longer prewetting of the deck prior to overlaying in order to promote evaporable cooling. Deck temperatures should be reduced to at least 85°F and possibly 75°F. This may require that the deck be continuously flooded for several hours before the pour.

2. Paving should be done in the coolest hours of the day or night. Midwestern states have found that beginning the pour at 4:00 or 5:00 a.m. provides a cool deck, allows them to do most of their work in daylight, and to finish the work before the hottest part of the day.

3. Fog spraying of the surface behind the screed should be performed, if controlled properly.

4. Finishing must be completed before the surface films over.

5. Burlap should be applied wet, dripfree and wetted again before covering with polyethylene sheeting.

6. No more than 10 to 15 ft of overlay should remain uncovered with burlap behind the screed if drying conditions are present.

Most agencies that have "lived" with the cracking in overlays for several years feel that it is not a serious problem, if minimized. Many overlays with cracks have been in service for 15 to 20 years without delaminating due to corrosion of the deck reinforcement. There has been some concern about the ability of latex slurry to repair the cracks and provide adequate resistance to chloride penetration. The Indiana study supports this concern and recommends that cracks be sealed with epoxy resin.

J. OTHER SURFACE DEFICIENCIES

It was noted on the SR 90/121 overcrossing at Easton, Washington, that surface scaling had begun after only a few months of winter exposure. Cracks that had appeared significant in the surface immediately after pouring in the summer of 1985 were barely noticeable in February 1986. No other decks exhibited this kind of blemish. The scaling pattern suggested that some batches of concrete were placed with excessive water or water was applied after placing concrete.

Two bridge deck overlays near Ritzville (SR 90/21 and SR 395/90) were crackfree, but had some slightly rough, burlap-wrinkled indentations. These were probably a result of excessive water used to wet the burlap and hold it down necessitated by high winds towards the end of the pour. The surface, although rough, was very dense and should have a long service life.

More serious deficiencies are apparent on other decks where breakdowns or stoppage of a pour took place and apparently the concrete was not covered or finished allowing a white laitance to form. These areas are poorly textured and appear to be porous.

K. OTHER BRIDGE DECK PROTECTION SYSTEMS

During this study, we noted any other methods that were in use or under study by other agencies for alternate methods to LMC or LSDC overlays. Most states using either or both of these methods seemed to be satisfied that they had an adequate solution, but were seeking lower cost or more constructable methods.

One system which is getting an increasing amount of attention is a concrete overlay containing silica fume. Ohio has completed at least one installation and Michigan is planning to construct two overlays early this summer using silica fume concrete. Silica fume is an extremely fine particle size mineral admixture, sometimes sold in liquid form, which increases the density and resistivity of concrete.

It is hoped by these DOTs that the silica fume overlay can be more easily constructed with conventional equipment, be lower in cost, and at least equal to LMC in resisting chloride penetration. No data is available yet about their performance, although considerable research and construction has been performed with silica fume concrete for saltwater resistance and for high-strength concrete.

L. INSPECTION OF CONCRETE OVERLAYS

The construction of LMC and LSDC overlays is a process that is sensitive to many subtle influences and demands that strict adherence to established construction methods be enforced. The specifications for application of these overlays is highly prescriptive and has many parts which are dependent on proper compliance to other parts. The DOT inspector should be familiar with the specifications and the intent of the specification, as well as the background for some aspects of their inclusion.

In order to properly administer the quality assurance of concrete overlays, the inspector should become familiar with the construction equipment, some of which is unique to this industry. He or she should be prepared to know how the mobile concrete mixer functions and how to calibrate it. The inspection of concrete for overlays is done entirely by DOT personnel, so it is imperative that the inspector force changes to concrete that is out of specification in a timely manner. This requires a highly coordinated inspection activity because concrete quality may change very rapidly from the mobile mixers. Poor concrete may affect a substantial deck area in these thin overlays.

The quality of overlay is dependent on maintaining a low water/cement ratio. The only practical method of assuring this is to enforce a maximum slump in the concrete. Slump loss occurs rapidly with these concretes and, therefore, slump must be measured using consistent procedures at the specified time after sampling. The reliability of slump measurements directly influences the contractor's willingness to change his procedures and the inspector's confidence that he/she is right.

Perhaps the most important function of an inspector begins before the pour starts. Preconstruction activities such as aggregate stockpiling, concrete trial mixes, and screed check are critical to a successful overlay application. The inspector should not allow paving to begin until the contractor has all of the equipment and personnel in position and readiness.

The inspection function as it existed on WSDOT overlay construction in 1985 was not prepared to perform as outlined above. This was evident in observing some of the construction and in discussions with the inspectors. They did not feel well prepared when an overlay project began and in many cases it was a matter of on-the-job training. Since a bridge overlay requires only a few days to complete, this type of training is not effective, at least for primary inspection personnel.

The importance of having a trained inspection staff is particularly acute in Washington, where there are few experienced and well-qualified contractors performing this work. Much of the success of overlays in Michigan, Indiana, Iowa, and other agencies is due to the availability of many experienced contractors and inspectors.

The inspectors participating in our interviews felt a definite need for inspection guidelines to establish tolerances, action items for out-of-tolerance construction steps such as concrete yield, data collection forms, and acceptance criteria. They felt ill-prepared to begin an overlay project and are concerned about the continuity of inspection knowledge if there is a long time between projects as will exist in some districts this year. Some inspectors felt that some specification items were difficult to enforce and this input is included in our recommendations for changes to the specifications. Areas of difficulty which were typically mentioned included aggregate moisture, total water content, and evaporation rate. In at least one district, the instruments needed to measure and enforce evaporation limits were not available.

We found only one agency which had a significant training program; namely, the Ontario Ministry of Transportation. They have a coordinated slide/cassette program that covers the entire construction process. The Indiana DOH, Division of Research and Training has published a Bridge Deck Repair Course Workbook, which includes procedures for both LMC and LSDC.

SECTION V
CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The following conclusions may be made regarding the relative performance of concrete overlays for bridges.

1. Both LMC and LSDC overlays have some history of satisfactory performance.

2. The majority of state DOTs which have compared the two systems and analyzed performance of existing overlays report that LMC is more impermeable to chlorides and has a longer life.

3. The satisfaction of state DOTs with existing overlays is dependent on capabilities and experience of contractors doing the work. Even though the conclusions above are true, the predominant method in any state is the one which contractors are prepared to do.

4. In many states, LSDC has been removed as a viable alternate method and LMC or other protective systems are used.

5. All states would like to have another protective system which is equal to or better than LMC at a lower cost.

These conclusions pertain to construction methods with an emphasis on LMC overlays.

6. The state-of-the-art for constructing LMC overlays has changed little in the past 10 years.

7. The proper application of concrete overlays requires a contractor that is knowledgeable about the special materials and equipment that are used. They must understand the limitations of both.

8. Proper stockpiling of sand and protection of stockpiles are a major source of success or problems for concrete overlays.

9. Plastic shrinkage cracks are common during construction under drying ambient conditions. Cracks appear in the first 24 hours and extend to 3/4 in. deep.

10. High deck temperatures and prolonged exposure of fresh concrete are the major reasons for plastic shrinkage cracks in LMC and LSDC.

11. There is new evidence that cracking in concrete overlays is related to poor vibration (hence low compacted density.)

12. 48 hours of wet curing provides stronger, more impermeable LMC than does 24 hours.

13. Repair of cracks with latex slurry or mortar is not effective in preventing or reducing chloride penetration through the cracks. Epoxy resin has been found to be effective.

The following conclusions relate to quality control and other bridge deck protective systems.

14. Quality control of concrete overlays is generally performed by DOT personnel

15. Contractors perform little or no quality control on a formal basis.

16. Results of quality control tests and observations must be incorporated into the construction process in a timely manner due to the nature of the short duration of construction.

17. Inspector training is inadequate in Washington. Few states have formal training for concrete overlays. Most agencies depend on field experience as an educator.

18. Dense concrete modified with silica fume and high range water reducers is a new material for bridge deck protection that is receiving much attention. At least two states have or will apply some experimental overlays with silica fume.

19. Liquid sealers, primarily silane or silane related are in use on many new or slightly damaged decks as a protection system.

B. RECOMMENDATIONS

1. WSDOT should continue to use LMC as the material for concrete overlays on primary structures.

2. Criteria for selecting alternate overlay types has been prepared by the Ontario Ministry of Transportation (Ref. 8) and should be included in the currently used process.

3. Some changes in WSDOT specifications for LMC overlays are recommended in the section entitled "Recommended Specification Changes".

4. False-setting cement should be eliminated during the selection of material combinations before construction.

5. Considerable effort should be made to reduce substrate deck temperatures at the time of overlaying. Continuous flooding of the deck prior to the pour and nighttime pours are two of the most practical methods.

6. Contractors should not be allowed to begin overlay placement until all equipment and personnel are ready.

7. No pour should begin until sand stockpiles are properly located on a draining surface and moisture content is within specification.

8. The initial discharge of concrete at the start of the pour should be wasted until mix consistency is within specification.

9. Contractor and DOT personnel should verify proper screed vibration at the beginning of and randomly throughout the pour.

10. Proper density of overlays should be verified by nuclear densometer, coring, or other means. Reference previously mentioned: Indiana Course Book and current NCHRP studies.

11. No overlay placement should be permitted to continue when wind velocity or drying conditions increase to the point where plastic cracking cannot be prevented.

12. Fog spraying of concrete behind the screed, under drying ambient conditions, should be permitted if the contractor has good control.

13. The surface should be sealed to form a membrane behind the screed. Some hand floating may be necessary.

14. Burlap must be kept thoroughly saturated to the point of being just drip-free. It shold be placed in direct contact with the concrete surface. The burlap should be further wetted with a water spray prior to covering with polyethylene sheeting.

15. No more than 10 to 15 ft of exposed concrete should be permitted behind the screed when drying ambient conditions exist.

16. Continuous wet curing should take place for 48 hours after completion of overlay placement.

17. Cracks should be filled and sealed with epoxy resin. No latex slurry should be permitted for crack repair.

18. A systematic, well-planned inspector training program should be started as soon as possible.

19. A formal inspection plan and list of special procedures for inspection should be written. It should include action to be taken when changes should be made.

20. A uniform method of field data collection should be adopted for 1986 construction of overlays.

21. Testing and research programs should be initiated to study cement/latex combinations regarding slump loss and simulating very short field mixing time.

22. Additional cores should be drilled in the latter phase of this study on the test bridges to correlate density of cracked versus uncracked sections of overlay.

23. Trial mixes should include effect of lower sand content on density of concrete. A target of 55-58% should be examined.

C. RECOMMENDED CHANGES TO SPECIFICATIONS

1. Section 1.02: Paragraphs A and B should be restricted to those requirements for the contractor only. References to procedures for inspectors should more properly be included in an inspector's manual. The yield test should specify container location at the mixer discharge point. The upper and lower limit of yield should be discussed as well as necessary actions when these are exceeded.

2. Paragraph B. 1 & 2

The location of testing near the bridge deck but free of vibration should be addressed in the inspector's manual. It should permit testing within the 4-1/2-minute delay period. The sample placed in the wheelbarrow should be larger.

3. Paragraph C

This should be removed after 1986. It was originally intended to provide technical assistance in the early years of LMC construction, but is no longer enforceable or always helpful.

4. Section 1.03

The contractor should submit a list of equipment to be used and its present location, a list of backup equipment, a list of primary construction personnel and their qualifications.

5. Section 1.04

Paragraph 1. A maximum variation of sand moisture of at least 1% should be permitted.

6. Section 2.01

a. Paragraph 3: This section should also permit sand gradations complying to AASHTO M6-65 or ASTM C 33. The higher fineness would be beneficial for finishing without significant reduction of density or strength.

b. The moisture limits should include a minimum of 1% and a maximum of 4.5%. This would ensure that the sand is saturated and would still permit some water to be added at the mixer.

7. Section 2.02

Paragraph B: The slump target should be raised to 5.5 in. ± 1.5 in.

8. Section 3.04

The contractor should have a minimum of two pressure washers, one ahead and one behind the screed.

9. Section 3.05

a. Paragraph A.3: The mobile mixer should be equipped with a bypass valve to enable calibration of the water valves or flow meters.

b. Paragraph B.4: Should also verify that the sand bin vibrators operate satisfactorily.

10. Section 4.05

a. Paragraph B.1: The deck should be soaked with water for a period of two hours and be kept wet from then throughout the pour. Longer presoaking and/or sprinkling periods may be required in hot weather.

b. Paragraph B.4: Maximum temperatures should be 85°F and falling or 75°F.

c. Paragraph B.5: If concrete placement is stopped temporarily for more than five minutes, all concrete behind the screed shall be covered with wet burlap. No concrete should be allowed to remain in front of the screed.

d. Paragraph B.7: Within 30 minutes of, but prior to dispensing any concrete from the mixing chamber on to the bridge deck, the contractor shall mix and discharge at least 1/4 cu. yd. to verify proper consistency and yield. This concrete shall be discarded.

11. Section 4.06

a. Paragraph A: The final product shall be a dense, uniform, and sealed (or closed) surface.

b. A fine mist, fog spray shall be permitted if the fresh concrete is drying rapidly. The engineer shall determine if the contractor has proper spray equipment and control of spraying before this will be permitted.

12. Section 4.07

a. Paragraph A: A single layer of clean burlap which has been laundered prior to its first use. Burlap shall be placed so as to eliminate wrinkles and large air gaps between concrete and the burlap.

b. Burlap should be thoroughly saturated and drip-free.

c. The concrete shall then wet cure for a minimum of 48 hours.

13. Section 4.08

All cracks shall be thoroughly sealed, with a low viscosity epoxy resin.

SECTION VI
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result in uniform concrete throughout the pour. However, an occasional change in aggregate mosture may justify a mix adjustment. The contractor and inspector should agree before the pour as to the degree of change in gate settings that will be permitted at any one time. Any change should be accompanied by a yield check.

The New York DOT and Ontario Department of Highways have correlated some cracking with low-density concrete which they attributed to poor vibrator performance on the screed. The New York DOT suggests that the vibrating screed have a frequency of vibration of 3500 to 5000 vibrations per minute (vpm) in air to obtain a frequency of 1500 to 2500 vpm when operating in concrete. All vibrators should be checked for proper frequency and amplitude of vibration while in concrete. This can be accomplished with a Vibrotak instrument -- a simple reed device that gives direct readings of frequency and indirect measurements of amplitude.

Some agencies have used nuclear density gauges to measure density of the fresh concrete behind the screed and have had varied degrees of success. There is a National Cooperative Highway Research Program (NCHRP) project in progress for determining the reliability of the nuclear gauge as a quality control instrument on highway paving.

The practice of adding water to the concrete after it has been placed is a sensitive issue. In general, it should be prohibited when it is used as a means of increasing the workability or to increase working time of the concrete caused by poor timing of the finishing operations. However, when conditions are present for possible plastic shrinkage cracking, the addition of a fine mist of water as applied with a fogging nozzle, is considered good practice by many authorities. The fog spray is most successfully applied from the top deck of the screed where the operator has access to the entire width of the overlay. The intent of the fog spray is to replace moisture which is already evaporating from the surface. The inspector should not permit spraying with a "garden hose" nozzle, a finisher's brush, or other means which would increase the water/cement ratio at the surface and promote future scaling.

D. CONCRETE FINISHING

Some localized hand finishing of the concrete surface becomes necessary if the finishing rollers and/or pans on the screed fail to close the surface. This hand work with bull floats or small hand floats should be minimized to avoid weakening the surface with excessive fines. However, if a continuous membrane of cement and fines is not created in finishing, the subsequent formation of a polymer film will be discontinuous, permitting moisture loss and cracking.

The presence of tears or discontinuities in the surface behind the screed may indicate a lack of consolidation or a shortcoming in the aggregate blend. The cause can usually be determined from observation of the location of the surface blemish relative to the width of the overlay. If it occurs in the same location, it may be due to a vibrator problem, while a mix problem tends to be widespread and randomly located. Indiana DOH recommends to find the source of the open surface and avoid the need to perform a lot of hand finishing. In any case, it is important to avoid substantial areas of open surface behind the screed.

Timely finishing, which includes the handwork above and texturing (usually with a wire rake called tining), is one of the most critical operations in placing overlays. If done too soon, the grooves from the tines will collapse, but more importantly, if done too late, the latex may film over prematurely. Surface tears and cracks are likely to form if the surface is raked after this film formation. The tining creates strain in the crusted surface which upon further drying exceeds the membrane strength and creates a plastic shrinkage crack. Delayed finishing also prevents application of wet burlap on the surface before excessive surface drying takes place.

E. CURING

The single most important step in constructing either LMC or LSDC overlays is the proper application of positive curing materials. There are a number of significant safeguards to be followed, as listed below.

1. When drying conditions exist due to ambient conditions, the burlap must be applied as soon as possible behind the placement of concrete.

2. The burlap must be capable of absorbing sufficient moisture such that it can release some water to replace evaporated water in the concrete surface.

3. The burlap must be laid flat with no wrinkles such that an air gap exists under it.

4. The burlap must be thoroughly saturated when the polyethylene sheeting is applied.

5. The polyethylene should be laid in contact with the burlap as much as possible to avoid large air pockets underneath it.

WSDOT specifications provide for a maximum evaporation rate depending on wind velocity, temperature, and humidity under which work on overlays can be performed. This specification should be observed and enforced, but it should also be noted that wind velocities over 10 mph can be detrimental in combination with less severe temperature and humidity (see Indiana DOH research report, Ref. 3). Therefore, if wind velocity picks up during the overlay construction, the contractor should tighten up his paving train. Indiana DOH, Michigan DOT, and other contacts all advised that this means that the curing bridge carrying burlap, polyethylene, and the workers should be no more than 10 to 15 ft behind the screed. In other words, there should be no more than 15 ft of uncovered overlay at any time under drying conditions.