Implementation Report

MONTANA
Department of Transportation

BRIDGE DECK CRACKING EVALUATION

https://www.mdt.mt.gov/research/projects/const/deckcracking.aspx

PROJECT NO: 9696-700

MORE INFO:

Principal Investigator

Todd Nelson
tnelson@wje.com
847.753.6583

MDT Technical Contact

Stephanie Brandenberger
stbrandenberger@mt.gov
406.444.9252

MDT Research Project Manager

Vaneza Callejas
vcallejas@mt.gov
406.444.6338

Introduction and Purpose

Montana Department of Transportation (MDT) commissioned WJE in 2016 to investigate the cause(s) of early age transverse bridge deck cracking and provide recommendations on mitigation.

WJE's 2016 investigation consisted of a document review, field investigations, laboratory evaluations, and simple analytical modeling of the bridge decks.

As reported by WJE on April 21, 2017, the most prominent cracking feature observed during WJE's field investigation were closely spaced transverse cracks, which subsequent laboratory testing and analytical studies indicated were initiated at very early ages, primarily due to thermal changes within the bridge deck.

WJE provided recommendations for concrete mix design, construction practices, and design considerations with the intent of reducing early age transverse cracking.

Since implementation of the recommendations, MDT personnel reported a notable decrease in early-age transverse cracking due to these changes, but MDT then observed later age development of transverse cracks in some of their bridge decks.

Therefore, WJE was further commissioned to perform additional investigations to assess the benefits of the previous recommendations and to take a focused look at the later age development of transverse cracking.

WJE implemented a multi-disciplinary approach including literature review, field inspections, bridge instrumentation, laboratory evaluations, and finite element modeling.

Implementation Summary

Findings of this current study suggest that diurnal and seasonal changes in ambient temperature and humidity in the alpine regions of Montana can create significant thermal and moisture gradients within placed bridge decks. These gradients in conjunction with the drying shrinkage of the concrete provide sufficient strain within decks to cause transverse cracking at later ages.

For these reasons, WJE's recommendations can be summarized by three primary goals:

1. Reduction in drying shrinkage.

2. Reduction in thermal gradients.

3. Reduction in moisture gradients.

Implementation Recommendations

CONCRETE MIXTURE PROPORTIONING

Recommendation 1:

Reduction in total cementitious material to less than 600 pounds per cubic yard (lb/yd^3) and ideally below 550 lb/yd^3. This provides two major benefits: 1) reduces thermal heat generation during hydration and associated cooling and 2) reduction in drying shrinkage.

This recommendation is very similar to the 2016 study; however, the goal is to further lower the cementitious content and get below 550 lb/yd³ (Previous recommendation was a maximum of 600 lb/yd³).

This current recommendation is consistent with WJE's completed research findings and associated performance of the decks with cementitious materials below 550 lb/yd³ and consistent with research found during the literature review.

MDT Response:

MDT's current Class Deck concrete mix design specification includes a maximum of 564 lb/yd³ cementitious materials which is consistent with the recommendations.

Recommendation 2:

Target a water to cementitious ratio (w/cm) ratio of 0.42 +/- 0.02 (same as 2016). This w/cm recommendation provides low permeability, durability, and long service life without introduction of autogenous shrinkage.

MDT Response:

MDT's current Class Deck concrete mix design specification includes a w/cm ratio range of 0.42 – 0.45 which is consistent with the recommendations.

Recommendation 3:

Optimized supplementary cementitious materials (SCMs) contents (recommended further research). The goal would be to optimize the mixtures with locally available SCMs for low heat of hydration, low permeability, low shrinkage, and increased cracking resistance while still maintaining strength requirements. WJE encourages this effort in subsequent research combined with optimized aggregate gradations and curing time (easily achieved with laboratory evaluations).

MDT Response:

MDT's current Class Deck specifications includes the use of SCMs consistent with the recommendations. Further research to optimize the concrete mix design, including the use of SCMs, will be considered.

Recommendation 4:

Design consideration for 56-day strength, rather than 28-day. This encourages lower early age strength gain and a lesser heat signature of the mix designs used for bridge deck concrete.

MDT Response:

MDT's current specifications allow the contractor to request 56-day testing for project acceptance, although it is not required. Requiring 56-day strength concrete mix design for bridge decks will be considered as an experimental feature on a future project.

Recommendation 5:

Limit silica fume use to a maximum of 5% replacement rate (no change from 2016).

MDT Response:

MDT's current Class Deck specifications includes a maximum silica fume replacement rate of 5% consistent with the recommendations.

Recommendation 6:

Optimize aggregate gradation, likely needed for reduction in cementitious content to maintain cohesiveness, pumpability, placeability and finishability. One optimization tool suggested to MDT was developed by Oklahoma State: http://www.tarantulacurve.com/.

MDT Response:

MDT currently allows and incentivizes the use of optimized aggregate gradations. Research results indicate that the use of optimized gradations is effective at reducing early age deck cracking. Modification of the specification language to require optimized gradation for concrete mix designs is proposed.

Recommendation 7:

Increase top sized aggregate to 1 1/2-inch nominal.

MDT Response:

MDT's Class Deck concrete mix design currently allows a top-sized aggregate range of 1-1/2" to ¾". The 1-1/2" top-sized aggregate has been used per special provision. Research results indicate the use of 1-1/2" top-sized aggregate for decks is effective at reducing early age deck cracking.

Modification of the Class Deck concrete mix specification language to require 1-1/2" top-sized aggregate for concrete decks, and ¾" top-sized aggregate for concrete barriers, is proposed.

FURTHER RESEARCH ON MIXTURE PROPORTIONING

Recommendation 8:

Incorporation of shrinkage reducing admixtures (SRAs) into concrete bridge deck mixes. The benefits would include a reduction in stress due to drying shrinkage and a potential reduction in stresses from developed moisture gradients within the decks. SRAs have been used in bridge deck concrete mixes by other states with success. The primary drawback associated with the use of SRAs is cost.

MDT Response:

MDT completed an experimental project using Shrinkage Reducing Admixture and Synthetic Polyolefin Fibers in 2015. Results indicate that early age deck cracking was reduced. Specifying the use of SRAs and fibers in deck mix designs on a trial basis is recommended. Further research to optimize the concrete mix design, including the use of SRAs, will be considered.

Recommendation 9:

Investigation in the use of lightweight aggregates (LWAs) as partial replacement of fines to reduce moisture gradients and potentially for reduction in thermal gradients.

MDT Response:

The use of lightweight aggregates as partial replacement of fines in concrete mix designs for decks will be considered as an experimental feature on a future project.

Recommendation 10:

Characterization and testing of the effect of ambient relative humidity changes on internal bridge deck gradients and associate cracking. This project has shown that additional industry research is needed on how changes in ambient relative humidity affect the internal relative humidity and gradients within the bridge deck concrete and associated stresses that cause cracking. Rapid responses of internal relative humidity and gradients were measured with ambient changes to extents not anticipated. WJE encourages MDT that this research would be very useful to understand the influence of internal deck relative humidity and gradients on cracking.

MDT Response:

This research project has identified that fluctuations in relative humidity may have a significant effect on deck cracking. MDT agrees that further research to understand this phenomenon would be valuable to the industry. This may be a good topic for an NCHRP research project.

Recommendation 11:

Concrete mixture optimization for use of SCMs, SRAs, aggregate gradations (Tarantula Curve), and LWAs for cracking resistance in conjunction with curing times. A lot of variables need to be considered when reducing cracking which need to be balanced with drying shrinkage potential, thermal cooling effect, and early age strength and modulus development, while still maintaining low permeability and durability. A guide document or specification may be helpful.

MDT Response:

Further research to optimize the bridge deck concrete mix design, with the development of a design guide, will be considered.

DESIGN AND CONSTRUCTION PRACTICES

Recommendation 12:

Minimum deck thickness of 8 inches (same as 2016). Research showed limited return on investment for going thicker.

MDT Response:

MDT's bridge design standards include the use of 8-inch minimum deck thickness for new decks, consistent with the recommendations.

Recommendation 13:

Reduction in moisture gradients from the top of the deck with the use of thin-polymer overlays. Mitigation of the moisture gradients within the decks is most effective from the top of the deck based on WJE's research. Additional research is needed to assess the effectiveness of the reduction of the moisture gradients with the use of thin-polymer overlays.

MDT Response:

MDT often installs thin-polymer overlays on new bridge decks ranging in age between 3-months to 1-year. Earlier application of the overlay in a 3- to 6-month window will be specified on a trial basis. Additional research to assess the effectiveness of this placement method will be considered.

Recommendation 14:

Reduction in moisture gradients from bottom side of deck by installation of barrier coatings or stay-in-place forms. Further research recommended into barrier coatings and stay-in-place (SIP) forms and effectiveness of reduction in moisture gradients.

MDT Response:

MDT has allowed the use of stay-in-place forms on a case-by-case basis. SIPs are not desirable due to the limited visibility for deck soffit condition inspections, and potential for water and chloride piping between the deck and forms which create conditions that promote further corrosion.

Transparent forms are available and will be considered on a trial basis. The use of coatings on the soffit will be considered on a trial basis. Further research on the effectiveness of these methods will be considered.

Recommendation 15:

Summer Curing - Continue using curing procedures outlined in WJE's 2016 report with the application of insulated blankets after peak hydration.

WJE further recommended to remove insulation blankets late afternoon or evening and not early morning, as there is added benefit to the compression of the deck due to thermal contraction of the girders during the nighttime cooling.

Recommended further research on the optimization of moist curing length performed in conjunction with previous mix optimization recommendation (Recommendation 11).

MDT Response:

MDT's specifications include the curing procedures outlined in WJE's 2016 report. Specifying removal of blankets in the afternoon is proposed.

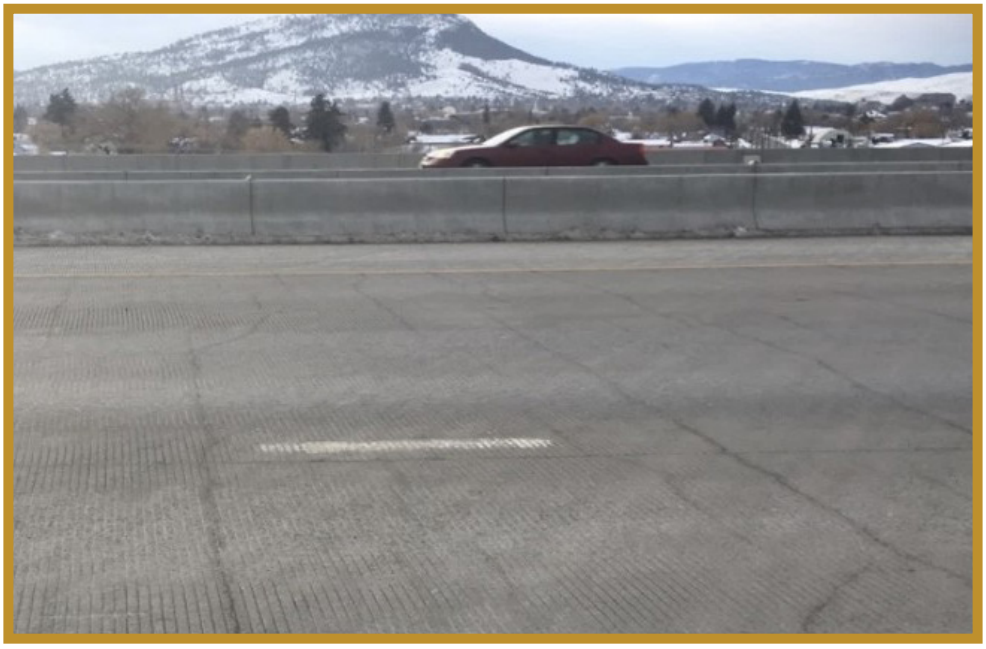
Recommendation 16:

Winter Curing - WJE recommends heat curing from the bottom-side of the deck. A significant benefit was observed in the instrumented bridge deck. After removal of the heating, a pre-compression of the deck occurred once the heating was removed. This provided benefit to overcome the subsequent tensile strains due to drying shrinkage, thermal gradients, and moisture gradients. Top side heating is not recommended unless it is the only option.

The modeling performed by WJE showed that temperature differentials from heating on the topside and subsequent cooling of the girders is sufficient to crack the deck within three days.

MDT Response:

Specifying the use heat curing from underneath the deck, when appropriate, is proposed.



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