Development, Field Testing, and Implementation of Improved Bridge Parapet Designs

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Project Background

A previous research project carried out by Cleveland State University (CSU) investigated the occurrence of widespread premature cracking of bridge concrete parapets. ODOT District 12 had identified several bridges exhibiting premature cracking of bridge concrete parapets to varying degrees. Bridge concrete parapets can be replaced without bridge deck replacement, and the decks on which these problem parapets were poured appeared to be performing as anticipated. A cursory review of District 12 parapets showed little correlation between deck characteristics; some were on short spans, while others were on longer spans and/or skews. Also, multiple contractors and concrete suppliers were involved. The District did replace one cracked parapet (without replacing the deck) and the cost was about $140,000. Cracked parapets are a safety concern and the potential cost to the Department to remove and replace parapets could be significant. The overall objective of the study was to determine the reasons for uncontrolled bridge deck parapet cracking, and to provide recommendations to ODOT to prevent such cracking in the future.

This previous project identified the most likely causes of premature bridge parapet cracking. On the basis of the previous work, ODOT District 12 decided to investigate some of the alternatives suggested by the research by conducting field tests on construction projects. This project developed improved parapet designs to mitigate cracking, and monitored test sites constructed in the field during the summer of 2013 and/or 2014.
Study Objectives

The overall objective of this study was to develop improved concrete bridge parapet designs to mitigate cracking. Reasons for uncontrolled bridge parapet cracking were investigated in previous research. Prior to the start of this project, changes were implemented to the current bridge parapet design in an effort to reduce cracking, and these changes were included in the design of the control parapets. Additional design modifications were incorporated on thirteen bridge parapets. In order to fulfill the objective, the following goals were identified:

- Identify all relevant construction procedures potentially contributing to concrete parapet cracking.
- Determine which design modifications, if any, are most significant in preventing premature cracking on ODOT District 12 bridges.
- Provide results of which design modifications mitigate overall cracking of bridge parapets as well as recommendations for future research.

Description of Work

Twenty two test parapets in total were constructed as part of this project to evaluate different approaches to address premature cracking. The experiments included the use of deeper saw cuts through glass fiber reinforced polymer (GFRP) reinforcement or field cut steel reinforcement, with the saw cut depth increased from 1 ½ inches (38 mm) to 3 ½ inches (89 mm). Previous research had indicated that the 1 ½ inch (38 mm) saw cut depth was rarely achieved in the field, with most cuts much shallower. Another experimental modification was the use of polypropylene fibers in the mixture at two different dosage rates, 1 lb./yd³ (0.59 kg/m³) and 2 lb./yd³ (1.19 kg/m³). The higher dosage rate exceeded the manufacturer’s maximum recommendation by 1/3, and led to high air content in the concrete mixture.

The research team monitored bridge parapets during and immediately after construction. This included instrumentation with embedded maturity sensors to capture temperature history of the parapets, using Command Center technology. This instrumentation was used to estimate thermal and shrinkage stresses and assess their potential role in parapet cracking. Researchers also observed and documented parapet construction. The steel reinforcement size and arrangement, fresh concrete properties, and construction processes were recorded through notes and photographs. It was important to note any constructability issues that arose that may be related to the proposed solutions, since they would potentially impact the cost of implementation. Crack surveys were performed once formwork was removed and sawcutting had been completed. The stiffness gain of parapets and joint cracking were monitored using ultrasonic pulse velocity (UPV) technology.

Research Findings and Conclusions

While all of the eight control bridge parapets showed mid-panel cracking, only four of the twelve experimental bridge parapets had mid-panel cracking. Both parapets with Vandal Protection Fence (VPF) posts showed cracks near the posts.

The main purpose of using GFRP or field cut steel reinforcement with the 3 ½ inch (89 mm) deep saw cut was to create a weakened plane at the control joint through the gap provided in the reinforcement, in order initiate cracking at the joints and reduce the risk of cracking elsewhere on the parapet. From the data gathered, this modification allowed more joints to crack at early stages, and prevented uncontrolled
cracking. The 3 ½ inch (89 mm) deep saw cut allowed 15% more joints to crack within the first few weeks of placement than the 1 ½ inch (38 mm) deep cut. This modification is useful to control early age cracking.

The parapets with fibers showed no measurable improvement over the parapets without fiber in regards to preventing shrinkage and temperature cracking. The use of polypropylene fibers may be efficient in extending the service life and safety of parapets as well as reducing life cycle costs. Fibers will enhance fatigue strength, and cracks caused by impact or freeze-thaw cycles will be better controlled. However, it is too early to tell if these long term benefits will be realized.

Reducing the joint spacing over negative tension areas is essential to reduce uncontrolled bridge parapet cracking. As shown by the results of the control parapets, parapets without enough control joints over the negative tension areas of the bridge tended to demonstrate uncontrolled cracking. However, since the experimental parapets with the reduced joint spacing were coupled with other modifications, either the polypropylene fibers or the deeper saw cut, it is hard to determine if this alone would solve uncontrolled bridge parapet cracking.

Cracking near the bolts on VPF post base plates occurred on both the north and south parapets of the South Marginal Bridge. This may be due to the shortened curing time the concrete experienced, but design details for the base plate anchorages, as well as when the base plates were anchored into the concrete may have caused the cracking. It is possible that drilling the bolt holes may have caused enough stress in the concrete to cause it to crack in these specific locations. Redesign of the post anchorage details or installations method may still be necessary to prevent cracking on parapets with vandal protection fences.

Costs of field cut reinforcement or GFRP reinforcement combined with 3 ½ inch (89 mm) deep sawcutting ranged from $ 8.48 to $ 15.81 per linear foot of parapet ($ 26.27 to $ 52.70 per linear meter) based on change orders for this project. The inclusion of fibers in the concrete mixtures was much less costly, at approximately $ 1.35 per linear foot ($ 4.50 per linear meter) for 1 lb./yd³ (0.59 kg/m³) and roughly double the cost for double the fiber dosage. However, the reinforcement alternatives combined with the deeper saw cuts were more effective at controlling cracking.

**Benefits and Potential Application of Research Results**

This research related to ODOT’s mission of “Take care of what we have.” It directly addressed the Strategic Focus Research Area of Transportation Asset Management. This represented an example of “Developing methods to better utilize resources and integrate advances in science, technology, and construction techniques.” It also enhanced Transportation Safety because deteriorated parapet material could potentially pose a risk to the traveling public.

The significance of this work is that uncontrolled concrete bridge parapet cracking has been costly for ODOT, and this trend is expected to continue in the future unless a solution can be found. Bridge deck parapets are replaced when it is necessary to replace the bridge deck itself, as they sit on top of the deck and are constructed after the deck. District 12 had to replace the parapet on a bridge over I-271 in 2002 at a cost of approximately $ 140,000 which did not include sealing, fence and expansion joint repairs. So, if the parapet were to need replacement prior to the deck, that cost is wasted when the deck is ultimately replaced. Overall, the project is likely to result in higher durability, longer service life, reduced life cycle cost, and reduced disruption to the traveling public.
The benefits that are expected to be seen by implementing these recommendations are that the amount and severity of premature bridge parapet cracking will be reduced not only in Northeast Ohio, but throughout all of the ODOT districts. This will also reduce the number of premature bridge parapet repair and replacement projects that ODOT must conduct. The average cost to ODOT is $188,175 per parapet replacement project, or $283 per linear foot ($86 per meter) of parapet. If the amount of premature bridge parapet repair and replacement projects is reduced, then ODOT is able to potentially save hundreds of thousands of dollar per year.

Limitations of this Study

Some potential factors of interest could not be addressed in this study. The use of slipforming to construct parapets has been controversial in Ohio and in other states. However, none of the parapets in the study were slipformed, so this possible effect could not be observed. In the previous CSU research project, cracks were observed propagating from VPF bases into parapets. Since 20 of the 22 parapets in the study did not have VPF, this effect could not be studied either. Finally, it has been suggested that longer bridges are at higher risk for parapet cracking due to their increased flexibility. Two of the bridges in the study had spans over twice as long as the others, but the study sample for bridge length is not sufficient to draw firm conclusions.

Implementation Recommendations

For effective implementation of the results of this research, several actions are recommended. The results and conclusions of this study should be disseminated among relevant industry professionals in order to increase their awareness of this problem. The following changes are suggested for consideration:

1. Use a smaller spacing between parapet control joints over piers, in negative moment regions.
2. Use discontinuous lengths of steel reinforcement, with gaps at the control joints, to allow for 3 ½ inch (89 mm) saw cuts
3. Use GFRP reinforcement, to allow for 3 ½ inch (89 mm) saw cuts

Many of these recommendations have already been implemented in ODOT Standard Drawing ODOT BR-1-13 January 17, 2014 New Jersey Shape Concrete Bridge Railing (ODOT 2014b). These include positive moment joint spacing limited to 15 ft. (4.6 m) and negative moment joint spacing limited to between 5 and 7 ½ ft. (1.5 to 2.3 m). Six inch (150 mm) gaps are to be left in the steel reinforcement for joints. These gaps are crossed with 4 ½ ft. (1.4 m) lengths of ½ inch (13 mm) GFRP stiffening reinforcement. The joint is to be cut into two stages, with an initial 1 ½ inch (38 mm) cut followed by a 4 inch (100 mm) cut.

Recommendations for Future Research

At this time, ODOT is planning to allow slipforming of bridge parapets for future construction. It would be useful to monitor the implementation of slipforming to ensure that it does not lead to new parapet cracking problems. I would also be useful to monitor the implementation of the new parapet standard drawing to ensure that it is performing as anticipated.