

**MICHIGAN DEPARTMENT OF TRANSPORTATION  
MDOT**

**ANALYSIS OF THE BRIDGE BARRIER RAILING, TYPE 4;  
BRIDGE BARRIER RAILING, TYPE 5; AND BRIDGE RAILING,  
AESTHETIC PARAPET TUBE**

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## EXECUTIVE SUMMARY

Railings used on bridges are required to have passed crash testing according National Cooperative Highway Research Program (NCHRP) Report 350 pursuant to federal regulation. For trunkline bridges, NCHRP Report 350, Test Level (TL4) are the crash test criteria, which requires testing with three different vehicles at specified crash angles and speeds. The Michigan Department of Transportation (MDOT) has a history of using bridge rails that have previously passed crash testing in an effort to decrease the cost of testing new railings. The Federal Highway Administration's (FHWA) policy on the use of bridge rail designs that are similar to a crash tested design essentially allows the use of a modified crash tested bridge railing provided the modified railing precludes snagging problems and meets the requirements stated in Section 13 of the AASHTO LRFD Bridge Design Specifications.

In 2000, the FHWA inquired about the differences in reinforcement configuration between the Bridge Barrier Railing, Type 4 and the crash tested version, along with adequacy of using adhesive anchored steel reinforcement. The Design Division requested the Structural Research Unit to investigate these issues and recommend an action plan to resolve the situation.

The objective of the report is to analyze the capacity of the; Bridge Barrier Railing, Type 4; Bridge Barrier Railing, Type 5; and Bridge Railing, Aesthetic Parapet Tube for conformance with American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Design Specifications. The effectiveness of using adhesive anchors to retrofit the railings to a bridge deck is also analyzed. Findings of the analysis indicate that the Bridge Barrier Railing, Type 4; Bridge Barrier Railing, Type 5; and Bridge Railing, Aesthetic Parapet Tube are adequately reinforced. Adhesive anchors on the Michigan Department of Transportation's (MDOT) qualified products list will perform satisfactorily under dynamic loading for anchoring barriers to bridge decks. The adhesive anchor design procedure used by MDOT needs refined based on specific model testing for the Bridge Railing, Aesthetic Parapet Tube.

## ACTION PLAN

1. Engineering Operations Committee
  - a. Approve Report R-1397, Analysis of the Bridge Barrier Railing, Type 4; Bridge Barrier Railing, Type 5; and Bridge Railing, Aesthetic Parapet Tube
  
2. Design Division
  - a. Revise the details for Bridge Barrier Railing, Type 4 and Bridge Barrier Railing, Type 5 by changing the steel reinforcement that attaches the barrier to the deck from #5 bars spaced at 12 inches to #4 bars spaced at 8 inches.
  
  - b. When needed, perform calculations for anchoring the Bridge Railing, Aesthetic Parapet Tube to existing bridge decks using the method outlined in Report R-1361 Design Procedures for Concrete Anchors (Mechanical Expansion and bonded Anchors). Provide additional reinforcement to anchor the railing to the bridge deck as needed. Compare the cost of this modified railing with that of extending the vertical reinforcement in the railing and bolting to the bottom of the bridge deck. Select the cost effective method for anchoring the Bridge Railing, Aesthetic Parapet Tube to existing bridge decks.
  
3. Structural Research Unit
  - a. Review and refine the design procedure cited by Needham and Juntunen in Research Report R-1361, Design Procedures for Concrete Anchors (Mechanical Expansion and bonded Anchors), based on specific model testing for the Bridge Railing, Aesthetic Parapet Tube. Any national design code published that addresses adhesive anchors should be included in the review.
  
  - b. When needed, assist Design Division-Bridge in performing calculations for anchoring the Bridge Railing, Aesthetic Parapet Tube to existing bridge decks using the method outlined in Report R-1361, Design Procedures for Concrete Anchors (Mechanical Expansion and bonded Anchors).

## INTRODUCTION

Railings used on bridges are required to pass crash testing according National Cooperative Highway Research Program (NCHRP) Report 350 pursuant to federal regulation. For trunkline bridges, NCHRP Report 350, Test Level 4 (TL4) is the crash test criteria, which requires testing with three different vehicles at specified crash angles and speeds. The Michigan Department of Transportation (MDOT) has a history of using bridge rails that have previously passed crash testing in an effort to decrease the cost of testing new railings.

The New Jersey shape barrier was adopted for use by MDOT in 1977 and has had various heights and steel reinforcement patterns since that time. The Bridge Barrier Railing, Type 4 is the current configuration of the New Jersey shape barrier the department is using. It is 40 inches high and has both vertical and horizontal steel reinforcement as shown in Figure 1a. The Bridge Barrier Railing, Type 5 is also a current configuration of the New Jersey shape barrier the department uses at locations where sight distance is a problem. The Type 5 barrier is 34 inches high and has both vertical and horizontal steel reinforcement as shown in Figure 1b. The New Jersey shape barrier has been crash tested using various vehicles throughout its history. In 1988, the New Jersey shape barrier, shown in Figure 2, passed crash testing with a 5,400 pound pickup truck and an 18,000 pound truck, which allowed it to be classified as passing the TL4 crash test criteria.

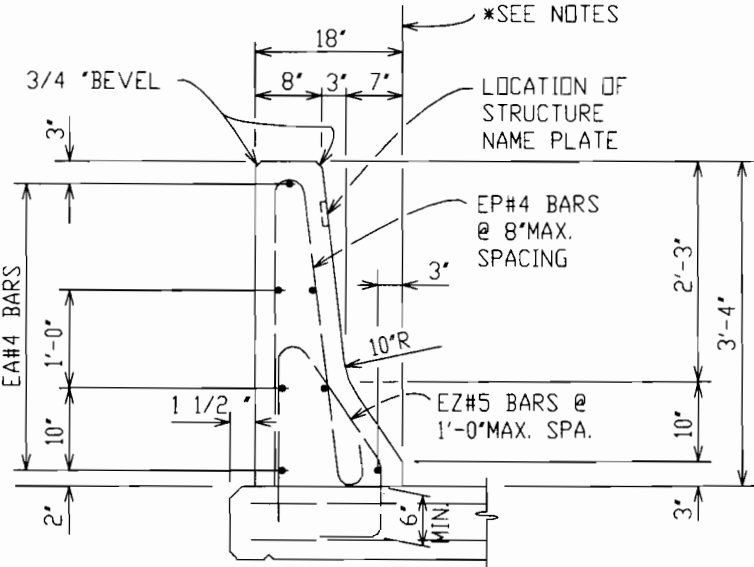
In 1992, the BR27C combination traffic/pedestrian railing, shown in Figure 3, passed crash testing with an 1,800 pound automobile, a 5,400 pound pick-up truck, and an 18,000 pound truck. The BR27C railing was crashed tested both on the bridge deck and on the sidewalk. This crash testing allowed it to be classified as passing the TL4 crash test criteria. The BR27C railing was adopted for use by MDOT in 1997. A minor modification was made to the railing by adding a small steel tube between the top of the concrete parapet and the top steel tube to meet clear opening criteria cited in AASHTO Standard Specifications for Highway Bridges, 16<sup>th</sup> Edition. The Bridge Railing, Aesthetic Parapet Tube is shown in Figure 4.

In most cases, when a railing is replaced on a bridge, the attachment of the new railing to the deck is made by adhesive anchoring the vertical steel in the railing to the bridge deck. Typically, no changes to the railing reinforcement are made and the vertical steel that is usually cast in the deck is instead anchored in the deck using an adhesive. A qualification procedure and qualified products list are used for the adhesive system used for this anchoring.

There is no national code for the design of concrete using adhesive anchored reinforcement. In response to this lack of a design code, the Structural Research Unit investigated various design methods for anchoring reinforcement to concrete and recommended a modified procedure that is commonly used for mechanical expansion anchors. The recommended design procedure for adhesive anchors is found in MDOT Research Report R-1361, Design Procedures for Concrete Anchors (Mechanical Expansion and Bonded Anchors) authored by Needham and Juntunen (1). There have been some concerns regarding the influence of edge distance on the capacity of the

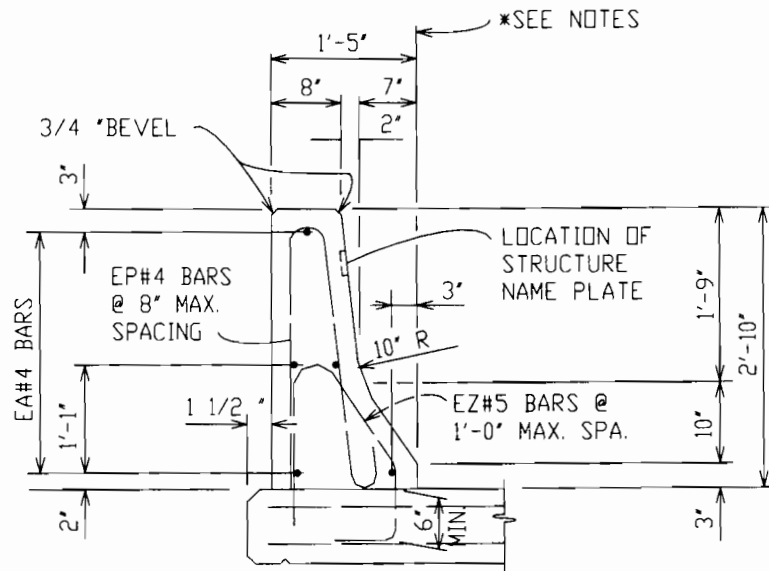
anchoring system when using the procedure cited in Report R-1361 for designing the adhesive anchored reinforcement in the Bridge Railing, Aesthetic Parapet Tube. In one particular instance, some of the vertical reinforcement in the parapet continued through the bridge deck and was bolted to the bottom of the deck.

In 2000, the Federal Highway Administration (FHWA) inquired about the differences in reinforcement configuration between the Bridge Barrier Railing, Type 4 and the crash tested version, along with adequacy of using adhesive anchored steel reinforcement. The Design Division requested the Structural Research Unit to investigate these issues and recommend an action plan to resolve the situation.

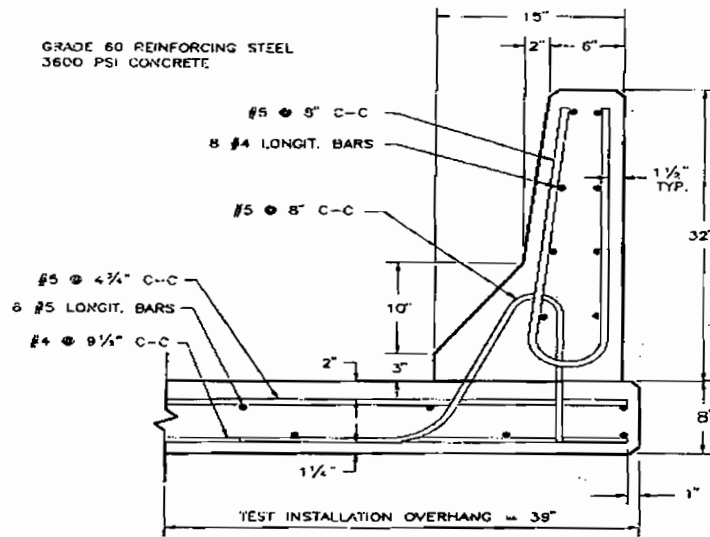


**Figure 1a. Bridge Barrier Railing, Type 4**





**Figure 1b. Bridge Barrier Railing, Type 5**



**Figure 2. New Jersey Shape Barrier**

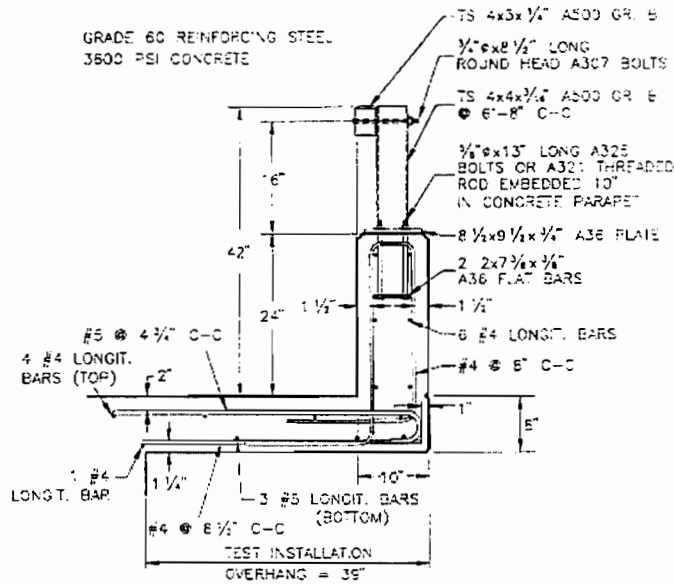


Figure 3. BR27C Combination Traffic/Pedestrian Railing

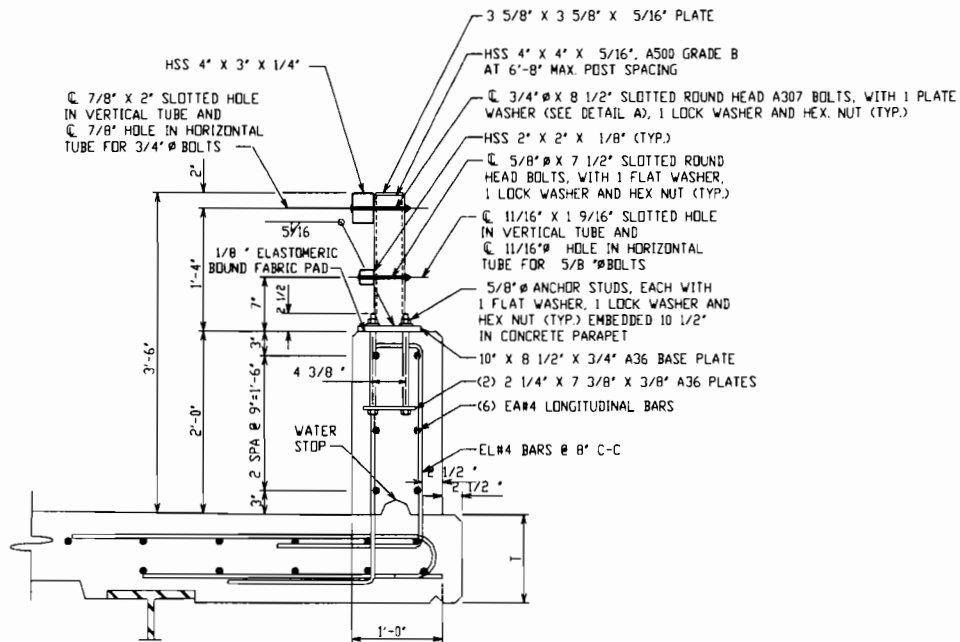


Figure 4. Bridge Railing Aesthetic Parapet Tube

## LITERATURE REVIEW

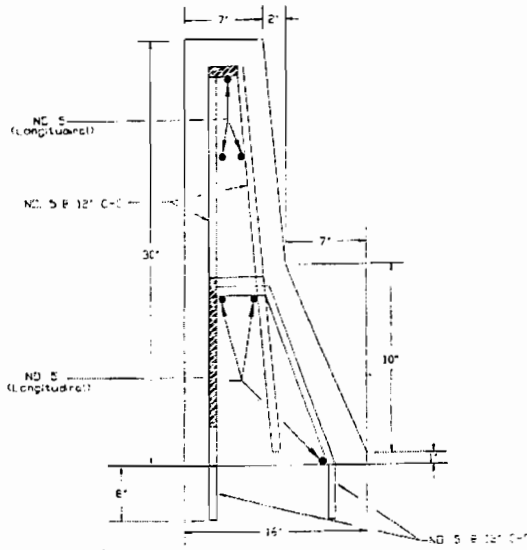
Numerous reports exist on crash testing bridge rails. Reports on testing adhesive anchors also can be found. However, reporting of crash testing barriers using adhesive anchors to attach the barrier to the bridge deck is sparse.

### Crash Testing

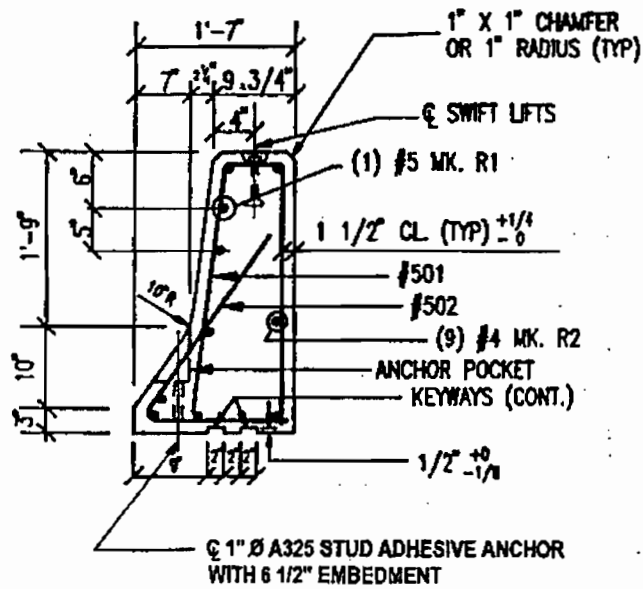
Buth et al., (2) reported on crash testing the New Jersey shape barrier with a 5,400 pound pickup truck and an 18,000 pound truck. The barrier was 32 inches tall and was anchored to the bridge deck using cast-in-place #5 bars spaced at 8 inches. Eight horizontal, longitudinal #4 bars were used in the barrier as shown in Figure 2. Grade 60 steel reinforcement and concrete with a compressive strength of 3,600 psi was used in the barrier. It should be noted that a non-standard hook was used for the anchorage of the #5 bar in the bridge deck. The barrier passed the crash testing, which allowed it to be classified as passing the TL4 crash test criteria. Strength analysis using the yield line theory, as stated in the AASHTO LRFD Bridge Design Specifications (3) (AASHTO LRFD Code), was done on the railing. The calculated strength of the barrier is 73.9 kips applied at the top of the barrier (32 inches).

Holloway et al., (4) reported on crash testing the New Jersey shape barrier with an 1,800 pound automobile, a 5,400 pound pickup truck and an 18,000 pound truck. The barrier was 30 inches tall and was anchored to the bridge deck using #5 bars spaced at 12 inches. The anchorage to the deck was done using 8-inch deep adhesive anchorage of the #5 bars. Six horizontal, longitudinal #5 bars were used in the barrier as shown in Figure 5. Grade 60 steel reinforcement and concrete with a compressive strength of 6,000 psi was used. The barrier passed the crash testing, which allowed it to be classified as passing the TL4 crash test criteria. Strength calculations were not presented by Holloway. However, strength analysis on the railing by the author using the yield line theory, as stated in the AASHTO LRFD Code (3), indicates the strength of the barrier is 69.3 kips applied at the top of the barrier (30 inches). No analysis was done on the anchorage of the barrier to the bridge deck.

Buth et al., (5) reported on crash testing the New Jersey shape barrier with an 18,000 pound truck. The barrier was part of a proprietary system developed by L. B. Foster. Height of the barrier was 34 inches and was anchored to the bridge deck using 1-inch diameter A325 studs spaced at 24 inches. The anchorage to the deck was done using a 6½-inch deep adhesive anchorage of the A325 studs. Vertical reinforcement in the barrier was #5 bars spaced at 12 inches. Ten horizontal, longitudinal #5 bars were used as shown in Figure 6. Grade 60 steel reinforcement and concrete with a compressive strength of 5,000 psi was used. The barrier passed the crash testing, which allowed it to be classified as passing the TL4 crash test criteria. Strength calculations for the barrier were not presented by Buth.



**Figure 5. New Jersey Shape Barrier with Anchorage to the Deck Using 8- Inch Deep Adhesive Anchors.**



**Figure 6. New Jersey Shape Barrier Developed by L. B. Foster**

Crash testing of the BR27C combination traffic/pedestrian railing, shown in Figure 3, is reported by Buth et al., (6). Testing of the barrier included an 1,800 pound automobile, a 5,400 pound pickup truck and an 18,000 pound truck with the barrier on the bridge deck and on the sidewalk. The barrier passed the crash testing, which allowed it to be classified as passing the TL4 crash test criteria. The barrier was 42 inches tall and was anchored to the deck/sidewalk using cast-in-place #4 bars spaced at 8 inches. Six horizontal, longitudinal #4 bars were used in the barrier as shown in Figure 3. Grade 60 steel reinforcement and concrete with a compressive strength of 3,600 psi was used in the barrier. Strength analysis using the yield line theory, as stated in the AASHTO LRFD Code (3), was done on the railing. The calculated strength of the barrier is 18.0 kips for the steel railing portion and 73.0 kips for the concrete barrier portion. The strength of the barrier system is stated as 91 kips applied at 27 inches above the deck/sidewalk.

### **Adhesive Anchors**

Impact testing of threaded rods anchored to concrete using an epoxy grout adhesive was reported by Arnold et al., (7). A Charpy Impact testing machine was used to provide the impact loading. The load impulse (zero to peak to zero) was applied to the anchor within 0.002 seconds. Static testing of the threaded rods was also performed. Room temperature and -14 F were used as the test temperatures. Shear bond stress at the concrete-epoxy interface for the impact loading was found to be 150 percent greater than that of the static loading. Arnold concluded that impact does not seem to be a problem with these materials, even at winter temperatures.

Collins et al., (8) reported on impact testing of threaded rods anchored to concrete using epoxy, polyester and vinylester adhesives. Three triangular pulse loads approximately 0.25 seconds long (zero to peak to zero) were used with the specified yield point of the material being the maximum load. Static testing of the threaded rods was also done. Room temperature was used for the testing. Embedment length was 7 inches and 8 inches for the 5/8-inch diameter rods. Collins concluded that impact loading to yield had no effect on the anchor strength compared with static loading.

Dynamic testing of threaded rods anchored to concrete using Hilti HVU adhesive was obtained from Hilti Corporation (9). Ten triangular shock loads approximately 0.04 seconds long (zero to peak to zero) were applied after 2 million cycles of graduated fatigue cycles were applied. The rod was then tested to failure under static loading. The maximum stress in the rod during the shock loading was 36,000 psi to 40,000 psi. Room temperature was used for the testing. Embedment length was 4.3 inches for 0.47-inch diameter rods and 8.3 inches for 0.94-inch diameter rods. No failures occurred during the shock loading. The failure load during static testing after the dynamic loading was at least 98 percent of the failure load when only static testing was done.

## **ANALYSIS**

### **Bridge Railing**

The FHWA policy on the use of bridge rail designs that are similar to a crash tested design is contained in Mr. Frederick Wright's letter dated May 16, 2000, and is based on an analytical comparison. Essentially, the policy allows the use of a modified crash tested bridge railing provided

the modified railing has a similar geometry that precludes snagging problems and meets the requirements stated in Section 13 of the AASHTO LRFD Code (3).

An analysis was done on both the Bridge Barrier Railing, Type 4 and Type 5 barriers using the yield line method cited in the AASHTO LRFD Code (3). Basically, the yield line analysis uses energy principles to calculate the ultimate strength of the barrier. The ultimate load the barrier can resist is calculated using the principle that external work must equal the internal energy absorbed by the barrier. Strain energy of the yielded steel reinforcement in the barrier is used in determining the internal energy absorbed by the barrier. Flexural resistance of the barrier in both the vertical and horizontal directions are used in the yield line method. The variable section condition is not thoroughly addressed in the AASHTO LRFD Code(3), which is the case for the New Jersey shape barrier since the thickness of the barrier varies from top to bottom. In this case, a weighted average of the flexural strength was used for calculating the barrier's ultimate strength. For Railing Test Level 4, TL4, the minimum transverse resistance of the barrier is 54 kips with a load factor equal to 1.0.

## **Results**

**Bridge Barrier Railing, Type 4:** The computed ultimate cantilever moment,  $M_c$ , is 12.0 k-ft/ft. The ultimate moment capacity in the longitudinal direction,  $M_w$ , is 5.2 k-ft/ft. Length of the yield line pattern is 8.2 feet. Total ultimate capacity of the barrier is 59.2 kips placed at the top of the barrier (40 inches), which exceeds the minimum TL4 resistance of 54 kips.

**Bridge Barrier Railing, Type 5:** The computed ultimate cantilever moment,  $M_c$ , is 11.5 k-ft/ft. The ultimate moment capacity in the longitudinal direction,  $M_w$ , is 4.6 k-ft/ft. Length of the yield line pattern is 7.1 feet. Total ultimate capacity of the barrier is 57.7 kips placed at the top of the barrier (34 inches), which exceeds the minimum TL4 resistance of 54 kips.

**Bridge Railing, Aesthetic Parapet Tube:** No analysis was done on this railing since the geometry and reinforcement details meet or exceed the crash tested railing.

## **Adhesive Anchors**

Review of the lateral accelerometer trace from crash testing the New Jersey shape barrier with an 18,000 pound truck, as reported by Buth et al., (2), reveals that the maximum load on the barrier occurs over an approximate 0.2 second interval (zero to peak to zero). Damage to the barrier after the crash test was reported as cosmetic with some scraping and gouging in the barrier. There were no reported cracks in the concrete. The maximum stress the steel reinforcement could have sustained is the yield point of the steel, but this is not likely since no cracking in the concrete was reported. The more likely upper bound of steel reinforcement stress would be that which is just below the cracking load of the concrete barrier. Conservatively, assuming the concrete modulus of rupture equals  $7.5\sqrt{f'c}$ , and concrete compressive strength,  $f'c$ , equals 5,000 psi (reported  $f'c$  was 3,600 psi), the controlling concrete cracking moment is 5.65 k-ft/ft located 19 inches from the top of the barrier with a corresponding cracking load of 3.6 k/ft at the top of the barrier. Using the cracking load of 3.6 k/ft at the top of the barrier, the reasonable upper bound load in a single #5 bar

reinforcement is calculated to be 8.0 kips. The load rate on the #5 bar is 80 kips/second during the crash test, since the reinforcement is loaded in about 0.1 seconds (zero to peak load time).

A similar analysis was done for the New Jersey shape barrier crash tested with an 18,000 pound truck as reported by Holloway et al (4). Damage to the barrier after the crash test is reported as concrete spalling at the point of impact and the top of barrier. There were no cracks in the concrete reported. In this case, the anchorage to the deck was done using 8-inch deep adhesive anchorage of the #5 bars. Assuming the concrete modulus of rupture equals  $7.5\sqrt{f'_c}$ , and concrete compressive strength,  $f'_c$ , equals 6,000 psi (as reported), the controlling concrete cracking moment is 7.83 k-ft/ft located 19 inches from the top of the barrier with a corresponding cracking load of 5.0 k/ft at the top of the barrier. Using the cracking load of 5.0 k/ft at the top of the barrier, the reasonable upper bound load in a single #5 bar reinforcement is calculated to be 13.7 kips. The load rate on the #5 bar is 137 kips/second during the crash test, since the reinforcement is loaded in about 0.1 seconds (zero to peak load time). Using the 8-inch deep adhesive anchorage, the load rate on the adhesive-concrete interface would be 7.27 k/in<sup>2</sup>-second.

Hilti Corporation's data (9) from their shock load testing most closely resemble the loading that would be experienced by adhesive anchors used to attach a retrofit barrier to the bridge deck. In this case, 10 shock loads were applied at a load rate of 238 kips/second and 909 kips/second for the 0.47-inch and 0.94-inch diameter rods, respectively. Using the hole size of 0.55-inch diameter x 4.33-inch deep and 1.10-inch diameter x 8.27-inch deep, the load rate on the adhesive-concrete interface is calculated to be 31.8 k/in<sup>2</sup>-second for the 0.47-inch and 0.94-inch diameter rods, respectively. This load rate far exceeds that experienced by the crash tested railing. No failures occurred during the shock loading and the failure load during static testing (after the dynamic loading) was at least 98 percent of the failure load when only static testing was done.

## DISCUSSION

MDOT has been using the New Jersey shape barrier since 1977 with satisfactory performance. Some changes to the barrier have occurred over the years; however, the geometry and reinforcement pattern in the current Bridge Barrier Railing, Type 4 and Bridge Barrier Railing, Type 5 have basically remained the same since 1990. There have been instances where the top of the barrier has been detached from an apparent vehicle collision, but no major damage or penetrations of the bridge barrier railing have been reported after vehicle collisions. This satisfactory performance, along with the analysis showing that the bridge barrier railings exceed the needed resistance cited in the AASHTO LRFD Code (3), indicates that the reinforcement used in the Bridge Barrier Railing, Type 4 and Bridge Barrier Railing, Type 5 is sufficient.

Attaching new railings to an existing bridge deck is typically made by adhesive anchoring the vertical steel in the railing to the deck. Usually, no changes to the railing reinforcement are made and the vertical steel that is normally cast in the deck is instead anchored in the deck using an adhesive. The qualification procedure used for including an adhesive anchoring system on MDOT's qualified products list requires the adhesive system to develop 125 percent of the yield strength of Grade 60 reinforcing steel in tension at a maximum embedment of 12 times the bar diameter. The anchor displacement must be less than 1/16-inch when placed in concrete with a

compressive strength of 4,000 psi. Test results must be submitted from an independent laboratory for verification of the tensile capacity, along with passing confirming tests performed by MDOT before the adhesive system is placed on the qualified products list. It should be noted that Hilti Corporation's HVU adhesive system is included in MDOT's qualified product list for adhesive anchors. The Standard Specifications for Construction require the contractor to select an adhesive system from the qualified products list and perform proof testing of the selected system to a load equal to the yield strength of the reinforcement, along with field testing to a load equal 90 percent of the yield strength of the reinforcement. All this screening and testing is done to ensure the integrity of the adhesive anchor's performance. The literature indicates that dynamic loading of adhesive anchors does not adversely affect the anchor's capacity when they are properly embedded for the yield strength of the reinforcement. In light of MDOT's qualification procedure and construction specifications for adhesive anchors, along with the analysis of adhesive anchors above, there is reasonable confidence that adhesive anchors will satisfactorily serve the purpose of anchoring barriers to bridge decks.

There are two additional issues that need to be addressed regarding the use of adhesive anchors for attaching railings to bridge decks: reinforcement bar size and group action of anchors. The qualification procedure for the adhesive anchors allows a maximum of 12 bar diameters for the embedment depth and contract plans are detailed using an embedment depth equal to 12 bar diameters. For a #5 bar, an embedment depth of 7½-inches would be specified and for a #4 bar a 6-inch embedment depth would be specified. Historically, MDOT has had problems with punching through the deck when drilling holes for adhesive anchors in 7-inch thick bridge decks built prior to the 1960s. To mitigate this problem, the depth of embedment for the adhesive anchors has been limited to around 5½ inches when anchoring the barrier to the deck. From this viewpoint, it would be best to use #4 bars for the vertical reinforcement in the Bridge Barrier Railing, Type 4 and Bridge Barrier Railing, Type 5 to avoid violating the criteria cited in the qualification procedure for adhesive anchors. The 6-inch embedment for adhesive anchoring the #4 bar would minimize the resurrection the problem of punching through the deck when drilling the hole for the adhesive anchor. This could be accomplished by changing the steel reinforcement that attaches the barrier to the deck from #5 bars spaced at 12 inches to #4 bars spaced at 8 inches, which maintains the reinforcement area on a per foot basis.

Group action of post-installed adhesive anchors is difficult to address. The work by Needham and Juntunen (1) included recommended design methods to account for anchor spacing and edge distance. Unfortunately, there is no national code to follow for post-installed adhesive anchors concerning group action and edge distance. Needham and Juntunen (1) based their design recommendations on proposed and existing ACI specifications for fastening to concrete, which all exclude adhesive anchors. Refinement of the design procedure through specific model testing could be done until such time as a national design code addressed this issue for adhesive anchors.

## CONCLUSIONS

Bridge Barrier Railing, Type 4; Bridge Barrier Railing, Type 5; and Bridge Railing, Aesthetic Parapet Tube are adequately reinforced.



Adhesive anchors on MDOT's qualified products list will perform satisfactorily under dynamic loading for anchoring barriers to bridge decks.

## **RECOMMENDATIONS**

### **Design Division-Bridge**

Revise the details for Bridge Barrier Railing, Type 4 and Bridge Barrier Railing, Type 5 by changing the steel reinforcement that attaches the barrier to the deck from #5 bars spaced at 12 inches to #4 bars spaced at 8 inches.

When needed, perform calculations for anchoring the Bridge Railing, Aesthetic Parapet Tube to existing bridge decks using the method outlined in Report R-1361, Design Procedures for Concrete Anchors (Mechanical Expansion and Bonded Anchors). Provide additional reinforcement to anchor the railing to the bridge deck as needed. Compare the cost of this modified railing with that of extending the vertical reinforcement in the railing and bolting to the bottom of the bridge deck. Select the most cost-effective method for anchoring the Bridge Railing, Aesthetic Parapet Tube to existing bridge decks.

### **Structural Research Unit**

Review and refine the design procedure cited by Needham and Juntunen (1) based on specific model testing for the Bridge Railing, Aesthetic Parapet Tube. Any national design code published that addresses adhesive anchors should be included in the review.

When needed, assist Design Division-Bridge in performing calculations for anchoring the Bridge Railing, Aesthetic Parapet Tube to existing bridge decks using the method outlined in Report R-1361, Design Procedures for Concrete Anchors (Mechanical Expansion and Bonded Anchors).

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