A Reduced Height Performance Level 2 Bridge Rail

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ABSTRACT

The safety performance of a 737-mm (29-in.) high open concrete bridge railing was evaluated. The evaluation included four full-scale crash tests, investigating two critical impact locations where structural failure was most likely to occur. Each impact location was evaluated with a single-unit truck and a ballasted pickup truck. The safety performance of the 737-mm (29-in.) high open concrete bridge rail was shown to meet the Performance Level 2 (PL-2) requirements specified in the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings*, 1989.

INTRODUCTION

Open concrete bridge railings (OCBR) are widely used by state highway departments across the nation. These barriers offer many advantages over parapet railing systems including, efficient snow removal and improved drainage. The Nebraska Department of Roads (NDOR) has traditionally utilized a 737-mm (29-in.) high open concrete bridge railing design for Performance Level 1 applications and parapet barriers when higher performance bridge rails were required. In addition to the advantages listed above, the 29-in. high OCBR does not obstruct a driver's view from a bridge and could be installed at a height of 813-mm (32 in.) and still accommodate a pavement overlay. In view of the operational and aesthetic advantages of a 737-mm (29-in.) open concrete bridge railing, NDOR and the Midwest States Regional Pooled Fund Program requested that the Midwest Roadside Safety Facility (MwRSF) examine the potential for this barrier to meet the Performance Level 2 standards as outlined in the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings*, 1989 (1).

SUMMARY OF PREVIOUS TESTING

Nebraska's standard open concrete bridge railing was successfully tested to NCHRP Report 230 (2) performance standards by ENSCO, Inc. in 1986 (3). This testing demonstrated that the geometry of the 737-mm (29-in.) open concrete barrier could safely accommodate full-size and mini-size automobiles impacting at speeds up to 96 km/h(60 mph). The bridge rail was then successfully tested according to AASHTO PL-1 standards (4) by the MwRSF. This study demonstrated that the open concrete bridge rail system could safely accommodate pickup truck impacts at speeds up to 72.4 km/h(45 mph).

PL-2 OPEN CONCRETE BRIDGE RAIL DESIGN

NDOR's open concrete bridge rail incorporates a 406-mm (16-in.) deep x 356-mm (14-in.) wide concrete beam mounted on 330-mm (13-in.) high concrete posts. Line posts are spaced 2400 mm (8 ft - 0 in.) except near the end of the bridge and expansion gaps. The posts are typically 279-mm (11-in.) wide which allows the face of the post to be recessed 51 mm (2 in.) from the face of the concrete beam. Line posts are 610-mm (24-in.) long while posts at expansion gaps are increased to 914 mm (36 in.) in length.

In an effort to optimize the design of the open concrete bridge rail for use on high volume highways requiring PL-2 bridge railings, several design changes were made following the AASHTO PL-1 testing (4). These included increasing the expansion gap width, post spacing changes, and reduction of longitudinal steel reinforcement. The expansion gap was increased from 76 mm (3 in.) to 114 mm (4½ in.) in order to accommodate the longer bridges commonly found on high volume and interstate highways. Based on an analysis of computer simulated crash test results, longitudinal reinforcement in the concrete beam was also reduced from six No. 6 bars to six No. 5 bars.

For testing purposes, a 47.1 m (154 ft - 4 in.) open concrete bridge rail was constructed. Note that this length is approximately 100 percent longer than required by the AASHTO *Guide Specifications for Bridge Railings* (1). The extra length was utilized for this testing in order to avoid problems encountered with previous reduced height bridge rail testing wherein a 30.5 m (100 ft) bridge rail proved to be insufficient to definitively ascertain the barrier's capacity to contain single-unit trucks (5). In that test, the truck rolled onto the barrier and slid along the top of the barrier for an extended distance in what appeared to be a "neutral equilibrium" situation. Although the vehicle then righted itself when it came to the end of the bridge rail, there was some concern that the vehicle could have rolled over the bridge rail if the test installation had been longer.

The installation included 9.0 m (29 ft - 6 in.) of bridge rail upstream of an expansion gap and 38 m (124 ft - 6 in.) of railing downstream of an expansion gap. Since the post spacing near the expansion gap was significantly reduced from the spacing away from the gap, the system was constructed to allow full-scale crash testing both at the gap and downstream in the 2400 mm (8 ft) post spacing region. The bridge railing system was constructed with a simulated bridge deck in order to test the post-to-deck connection as well as the rail structural adequacy. The length of the bridge deck was 37.0 m (121 f t - 6 in.). The 203-mm (8-in.) thick deck had a total width of 1.75 m (5 ft - 9 in.), producing a 0.94-m (3 ft - 1 in.) cantilever. A layout of the installation and design details are shown in Figure 1.

Concrete used for all of the above components was a Nebraska 47-BD concrete mix, with a required 28-day minimum compressive strength of 24.1-MPa (3,500 psi) compressive strength. The concrete compressive strength for the simulated bridge deck with monolithic concrete posts, and the attached rail was approximately 49.7 MPa (7,202 psi) and 46.8 MPa (6,765 psi), respectively at the time of the full-scale crash tests.

PERFORMANCE EVALUATION CRITERIA

Performance standards for bridge rails are described in the AASHTO *Guide Specifications for Bridge Railings*, 1989 (1). This document requires that Performance Level 2 (PL-2) bridge rails be tested with an 816-kg (1,800-lb) mini-compact impacting at 96.6 km/h(60 mph) and 20 deg, a 2,449-kg (5400-lb) pickup impacting at 96.6 km/h(60 mph) and 20 deg, and an 8,165-kg (18,000-lb) single-unit truck at an impact speed of 80.5 km/h(50 mph) and 15 deg. As mentioned previously, a very similar open concrete bridge rail system with the same effective railing height and shape of railing face had been successfully tested in accordance with the guidelines set forth in NCHRP Report No. 230 (2). This testing included a mini-size vehicle impacting the barrier under the same conditions as those required by the AASHTO *Guide Specifications for Bridge Rails*, 1989 (1). Therefore, this mini-size vehicle crash test was not repeated with the PL-2 bridge railing system. The impact performance of the open concrete bridge rail system was then investigated with four full-scale crash tests.

TEST RESULTS

Single-Unit Truck Tests

The OCBR was tested with two single-unit trucks. The first of these tests (Test NEOCR-3) involved an 8,165 kg (18,000 lb) truck impacting the bridge rail at a speed of 78.1 km/h (48.5 mph) and an angle of 17.1 deg. This test was designed to examine the effect of the discontinuity at the expansion gap on the barriers performance with single unit trucks. The test vehicle initially impacted the bridge rail 1.5 m (5 ft) upstream of the expansion gap. Upon impact with the barrier, the vehicle rolled toward the barrier and the left front tire slid along the face of the concrete beam. The front tire then snagged on the downstream end of the expansion gap, causing the front axle to become dislodged from the vehicle. The entire vehicle was forced upward as the front tire and axle assembly rolled under the vehicle.

The rear axle assembly then swung into the barrier and snagged on the expansion gap as well. The truck then rolled toward the barrier until the truck box contacted the top of the concrete beam. The truck stabilized with the concrete beam supporting the left front corner of the truck box and the front of the vehicle sliding on the dislodged front axle and wheel assembly. The truck rode down the entire length of the bridge rail in this position and slid off the end. The vehicle came to rest approximately 7.6 m (25 ft) from the end of the barrier. A summary of the test results and sequential photographs are shown in Figure 2.

The bridge rail sustained significant damage in the vicinity of the expansion gap. As shown in Figure 3, two major diagonal cracks were found on the front face and top of the rail at Post. No. 4 and a similar crack was observed at Post No. 3. Extensive concrete spalling was also observed at the end of the upstream rail section. Post No. 4 was cracked along the back as well. Although the test vehicle sustained major damage as shown in

Figure 3, there was no significant deformation of the occupant compartment.

The second single-unit truck test (Test NEOCR-4) involved an 8,165 kg (18,000 lb) vehicle impacting the OCBR at a speed of 76.3 km/h(51.9 mph) and an angle of 16.8 deg. This test was designed to examine the strength of the bridge rail with a 2400 mm (8 ft) post spacing. The test vehicle impacted the bridge rail approximately 356 mm (14 in.) upstream of the center of Post No. 9. Upon impact the vehicle began to roll toward the barrier as the front end was redirected. The vehicle was stabilized when the bottom of the truck box contacted the top of the concrete beam. The vehicle then slid along the front of the barrier until it came to rest approximately 28.7-m (94-ft) downstream from the end of the rail. During this test, the vehicle was smoothly redirected without the severe suspension damage observed during the previous testing. A summary of the test results and sequential photographs are shown in Figure 4.

Bridge rail damage was minor, consisting of only tire marks and superficial concrete spalling as shown in Figure 5. There was no evidence of cracks in either the posts or the rail. Vehicle damage was also relatively minor as shown in Figure 5.

Pickup Truck Testing

Two pickup truck tests were conducted on the OCBR to investigate the barrier's performance at the expansion gap and in the region with wide post spacing. The first pickup truck test (Test NEOCR-5) involved a 2,447 kg (5,394 lb) pickup truck impacting the bridge rail at a speed of 96.2 km/h (59.8 mph) and an angle of 21.7 deg. The vehicle contacted the bridge rail just downstream of Post No. 11. Upon impact, the test vehicle began to roll approximately 10 degrees toward the barrier. Thereafter, the vehicle was smoothly redirected and came to rest approximately 24 m (79 ft) down stream from the end of the bridge rail. A summary of the test results and sequential photographs are shown in

Figure 6.

Bridge rail damage included superficial concrete spalling and several small cracks in the deck as shown in Figure 7. Although vehicle damage was moderate during this test, there was some occupant compartment damage including deformation of the cab floor pan and moderate buckling of the dash board, as shown in Figure 7. This deformation appeared to be caused when the concrete beam contacted the floor pan area. The maximum occupant compartment crush, located near the center of the cab compartment floor pan, was approximately 133 mm (5¼ in.). The center of the dash buckled upward approximately 64 mm (2½ in.) higher than its original orientation.

The second pickup truck test (Test NEOCR-6) involved examination of the barrier's performance near the expansion gap. Unfortunately, this portion of the bridge rail was severely damaged during the single-unit truck testing and needed to be repaired prior to the pickup truck testing. The retrofit process involved saw cutting the rail just downstream of Post No. 2 and breaking out the concrete around the dowelled vertical reinforcement in Post Nos. 3 and 4, reforming the rail and posts and casting new concrete with a cold joint near Post No. 2.

This test involved a 2,449 kg (5,400 lb) impacting the bridge rail 1.3-m (4.3 ft) upstream of the expansion gap. The impact speed was 98.2 km/h(61.0 mph) and the angle was 20.0 deg. The test vehicle was smoothly redirected and exhibited no tendency to snag on the expansion gap. The vehicle obtained a maximum roll angle of approximately 8 degrees towards the rail before becoming stabilized. Damage to the vehicle's suspension caused it to be steered back toward the bridge rail and recontacted the barrier near Post No. 19. The vehicle came to rest against temporary concrete barriers approximately 34-m (112-ft) downstream of the end of the bridge rail. A summary of the test results and sequential photographs are shown in Figure 8.

Damage to the bridge rail was again limited to minor cracking and concrete spalling as shown in Figure 9. Vehicle damage is shown in Figure 9, and did include some occupant compartment damage but it was not as severe as the previous pickup truck testing (Test NEOCR-5). Maximum occupant compartment crush, located on the left floor pan area was approximately 89 mm (3½ in.) and there was no evidence of dash board deformation.

SUMMARY AND CONCLUSIONS

Nebraska's 737-mm (29-in) high open concrete bridge was successfully tested to the AASHTO PL-2 crash test standards. The barrier successfully redirected two 8,165 kg (18,000 lb) single-unit trucks and two 2,449 kg (5,400 lb) pickup trucks. In fact, when tested away from the expansion gap, the barrier redirected the single-unit truck in a more stable manner than many safety shaped bridge rails. Thus, open concrete railings and possibly vertical concrete parapets can meet AASHTO PL-2 performance standards at a height of 737 mm (29 in.). Based on the excellent performance of testing away from the expansion gap, these barriers may be capable of successfully redirecting single-unit trucks at heights below this level.

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6. *Collision Deformation Classification, Recommended Practice J224 March 1980*, SAE Handbook Vol. 4, Society of Automotive Engineers, Warrendale, Penn., 1985.

7. *Vehicle Damage Scale for Traffic Investigators*, Traffic Accident Data Project Technical Bulletin No. 1, National Safety Council, Chicago, IL, 1971.

LIST OF FIGURES

Test Number	NEOCR-3
Date	6/21/94
Installation	Nebraska Open Concrete Rail
Total Length	47.1 m (154 ft - 4 5/8 in.)
Concrete Material	Nebraska 47-BD Mix
Reinforcing Steel Material	Grade 60 Rebar - Epoxy Coated
Concrete Rail	
Length	47.1 m (154 ft - 4 5/8 in.)
Width	356 mm (14 in.)
Height	737 mm (29 in.)
Depth	406 mm (16 in.)
Concrete Posts	
Length	610 mm (24 in.)
Width	279 mm (11 in.)
Height	330 mm (13 in.)
Concrete Posts Adjacent to Gap	
Length	914 mm (36 in.)
Width	279 mm (11 in.)
Height	330 mm (13 in.)
Concrete Bridge Deck	
Length	37.0 m (121 ft - 6 in.)
Width	1753 mm (5 ft - 9 in.)
Depth	203 mm (8 in.)

Vehicle	
Model	1986 GMC 7000 Series
Box Length	6.7 m (22 ft)
Test Inertial Weight	8165 kg (18,000 lb)
Vehicle Speed	
Impact	78.1 km/h (48.5 mph)
Exit	NA
Vehicle Angle	
Impact	17.1 deg
Exit	NA
Snagging	Moderate
Vehicle Stability	Satisfactory
Occupant Impact Velocities (Normalized)	
Longitudinal	3.0 m/s (9.7 fps) < 9.1 m/s (30 fps)
Lateral	2.0 m/s (6.6 fps) < 7.6 m/s (25 fps)
Occupant Ridedown Decelerations	
Longitudinal	2.1 G's < 15 G's
Lateral	3.0 G's < 15 G's
Vehicle Damage	
TAD (6)	11-LFQ-3
VDI (7)	11LFWS2
Vehicle Rebound Distance	-914 mm (-3.0 ft)
Coefficient of Friction (μ)	0.35 (fair)
Bridge Rail Damage	Concrete Cracking and Spalling at Gap

Test Number	NEOCR-4
Date	8/24/94
Installation	Nebraska Open Concrete Rail
Total Length	47.1 m (154 ft - 4 5/8 in.)
Concrete Material	Nebraska 47-BD Mix
Reinforcing Steel Material	Grade 60 Rebar - Epoxy Coated
Concrete Rail	
Length	47.1 m (154 ft - 4 5/8 in.)
Width	356 mm (14 in.)
Height	737 mm (29 in.)
Depth	406 mm (16 in.)
Concrete Posts	
Length	610 mm (24 in.)
Width	279 mm (11 in.)
Height	330 mm (13 in.)
Concrete Posts Adjacent to Gap	
Length	914 mm (36 in.)
Width	279 mm (11 in.)
Height	330 mm (13 in.)
Concrete Bridge Deck	
Length	37.0 m (121 ft - 6 in.)
Width	1753 mm (5 ft - 9 in.)
Depth	203 mm (8 in.)

Vehicle	
Model	1987 GMC 7000 Series
Box Length	6.7 m (22 ft)
Test Inertial Weight	8165 kg (18,000 lb)
Vehicle Speed	
Impact	83.5 km/h (51.9 mph)
Exit	NA
Vehicle Angle	
Impact	16.8 deg
Exit	NA
Snagging	None
Vehicle Stability	Satisfactory
Occupant Impact Velocities (Normalized)	
Longitudinal	2.4 m/s (8.0 fps) < 9.1 m/s (30 fps)
Lateral	2.3 m/s (7.7 fps) < 7.6 m/s (25 fps)
Occupant Ridedown Decelerations	
Longitudinal	2.9 G's < 15 G's
Lateral	5.4 G's < 15 G's
Vehicle Damage	
TAD (6)	11-LFQ-2
VDI (7)	11LFWE1
Vehicle Rebound Distance	-406 mm (-16 in.)
Coefficient of Friction (μ)	0.41 (marginal)
Bridge Rail Damage	Minor

Test Number	NEOCR-5
Date	9/7/94
Installation	Nebraska Open Concrete Rail
Total Length	47.1 m (154 ft - 4 5/8 in.)
Concrete Material	Nebraska 47-BD Mix
Reinforcing Steel Material	Grade 60 Rebar - Epoxy Coated
Concrete Rail	
Length	47.1 m (154 ft - 4 5/8 in.)
Width	356 mm (14 in.)
Height	737 mm (29 in.)
Depth	406 mm (16 in.)
Concrete Posts	
Length	610 mm (24 in.)
Width	279 mm (11 in.)
Height	330 mm (13 in.)
Concrete Posts Adjacent to Gap	
Length	914 mm (36 in.)
Width	279 mm (11 in.)
Height	330 mm (13 in.)
Concrete Bridge Deck	
Length	37.0 m (121 ft - 6 in.)
Width	1753 mm (5 ft - 9 in.)
Depth	203 cm (8 in.)

Vehicle	
Model	1986 Ford F-250
Test Inertial Weight	2447 kg (5,394 lb)
Vehicle Speed	
Impact	96.2 km/h (59.8 mph)
Exit	68.2 km/h (42.4 mph)
Vehicle Angle	
Impact	21.7 deg
Exit	NA
Snagging	None
Vehicle Stability	Satisfactory
Occupant Impact Velocities (Normalized)	
Longitudinal	5.4 m/s (17.7 fps) < 9.1 m/s (30 fps)
Lateral	6.4 m/s (21.0 fps) < 7.6 m/s (25 fps)
Occupant Ridedown Decelerations	
Longitudinal	9.8 G's < 15 G's
Lateral	9.8 G's < 15 G's
Vehicle Damage	
TAD (6)	11-LFQ-4,11-LP-2
VDI (7)	11LFES2, 11LPES2
Vehicle Rebound Distance	-4.7 m (-15 ft - 5 in.)
Coefficient of Friction (μ)	0.31 (fair)
Bridge Rail Damage	Minor

Test Number	NEOCR-6
Date	10/25/94
Installation	Nebraska Open Concrete Rail
Total Length	47.1 m (154 ft - 4 5/8 in.)
Concrete Material	Nebraska 47-BD Mix
Reinforcing Steel Material	Grade 60 Rebar - Epoxy Coated
Concrete Rail	
Length	47.1 m (154 ft - 4 5/8 in.)
Width	356 mm (14 in.)
Height	737 mm (29 in.)
Depth	406 mm (16 in.)
Concrete Posts	
Length	610 mm (24 in.)
Width	279 mm (11 in.)
Height	330 mm (13 in.)
Concrete Posts Adjacent to Gap	
Length	914 mm (36 in.)
Width	279 mm (11 in.)
Height	330 mm (13 in.)
Concrete Bridge Deck	
Length	37.0 m (121 ft - 6 in.)
Width	1753 mm (5 ft - 9 in.)
Depth	203 mm (8 in.)

Vehicle	
Model	1985 Dodge Ram 250
Test Inertial Weight	2449 kg (5,399 lb)
Vehicle Speed	
Impact	98.2 km/h (61.0 mph)
Exit	75.2 km/h (46.7 mph)
Vehicle Angle	
Impact	20.0 deg
Exit	NA
Snagging	None
Vehicle Stability	Satisfactory
Occupant Impact Velocities (Normalized)	
Longitudinal	5.6 m/s (18.5 fps) < 9.1 m/s (30 fps)
Lateral	6.6 m/s (21.6 fps) < 7.6 m/s (25 fps)
Occupant Ridedown Decelerations	
Longitudinal	5.4 G's < 15 G's
Lateral	9.1 G's < 15 G's
Vehicle Damage	
TAD (6)	11-LFQ-4, 11-LP-3
VDI (7)	11LFES2, 11LFES2
Vehicle Rebound Distance	51 mm (2 in.)
Coefficient of Friction (μ)	0.40 (marginal)
Bridge Rail Damage	Minor

LIST OF TABLES

TABLE 1. Summary of Test Results

Test Parameter	Test NEOCR-3	Test NEOCR-4	Test NEOCR-5	Test NEOCR-6
Test Vehicle	Medium Single-Unit Truck	Medium Single-Unit Truck	Pickup Truck	Pickup Truck
Test Vehicle Weight	8,165 kg (18,000 lb)	8,165 kg (18,000 lb)	2,447 kg (5,394 lb)	2,449 kg (5,399 lb)
Test Vehicle Impact Speed	78.1 km/h (48.5 mph)	83.5 km/h (51.9 mph)	96.2 km/h (59.8 mph)	98.2 km/h (61.0 mph)
Test Vehicle Exit Speed	NA	NA	68.2 km/h (42.4 mph)	75.2 km/h (46.7 mph)
Vehicle Impact Angle	17.1 deg	16.8 deg	21.7 deg	20.0 deg
Vehicle Exit Angle	NA	NA	NA	NA
Effective Coefficient of Friction	0.35	0.41	0.31	0.4
Vehicle Rebound Distance (ft)	-914 mm (-3.0 ft)	-406 mm (-16.0 in.)	-4.7 m (-15.4 ft)	51 mm (2.0 in.)
Longitudinal Occupant Impact Velocity	3.0 m/s (9.7 fps)	2.4 m/s (8.0 fps)	5.4 m/s (17.7 fps)	5.6 m/s (18.5 fps)
Lateral Occupant Impact Velocity	2.0 m/s (6.6 fps)	2.3 m/s (7.7 fps)	6.4 m/s (21.0 fps)	6.6 m/s (21.6 fps)
Longitudinal Occupant Ridedown Decelerations	2.1 G's	2.9 G's	9.8 G's	5.4 G's
Lateral Occupant Ridedown Decelerations	3.0 G's	5.4 G's	9.8 G's	9.1 G's
Test Vehicle and Cargo Contained?	Yes	Yes	Yes	Yes
Detached Debris Penetrate Occupant Compartment?	No	No	No	No
Did Snagging Occur?	Moderate	No	No	No
Did Test Vehicle Remain Upright?	Yes	Yes	Yes	Yes