Washington State Precast Concrete Barrier

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ABSTRACT

Since the early 1970's, the Washington State Department of Transportation (WSDOT) has used precast concrete barrier for both temporary and permanent installations. The simple design of this barrier makes it easy to install for work zone applications and being constructed of concrete makes it more durable and easier to maintain than other semirigid barriers such as w-beam guardrail. While the barrier can deflect during an impact, sections can usually be pushed back into position with minimal effort. The modular design also allows removal of sections for repair, replacement, or emergency openings. Because of these benefits, the use of this barrier in high impact areas has increased through the years and it is currently one of the primary barriers used on Washington State highways.

The WSDOT design was shown in-service performance comparable to beam guardrail. It has also been evaluated though the use of computer simulations and full scale crash testing. An alternate design was also evaluated through the use of computer simulations and full scale crash testing. Both designs meet the NCHRP Report 350 crash test criteria.

Keywords: concrete, barrier, NCHRP 350, simulation

Washington State Precast Concrete Barrier

Since the early 1970's, the Washington State Department of Transportation (WSDOT) has used precast concrete barrier (as shown in Figure 1) for both temporary and permanent installations. The simple design of this barrier makes it easy to install for work zone applications and being constructed of concrete makes it more durable and easier to maintain than other semirigid barriers such as w-beam guardrail. While the barrier can deflect during an impact, sections can usually be pushed back into position with minimal effort. The modular design also allows removal of sections for repair, replacement, or emergency openings. Because of these benefits, the use of this barrier in high impact areas has increased through the years and it is currently one of the primary barriers used on Washington State highways.

FIGURE 1 Typical precast barrier installation-

A comparison of the accident records for the precast concrete barrier indicate that the injury rate is similar to w-beam guardrail and slightly better than a rigid concrete barrier. However, there had been no crash testing of Washington State's design. Review of literature such as the Portable Concrete Barrier Connectors report (*1*), and crash tests on other designs, suggested that there might be some need to modify this design. To evaluate this need, computer simulation of the impact performance of this design and two alternate designs was performed. The current barrier design and one of the alternate designs were then crash tested in accordance with the National Cooperative Highway Research Program (NCHRP) Report 350 *(2)*.

CONCRETE BARRIER DESIGN

The current Washington State precast concrete barrier (see Figure 2) has a New Jersey shaped face and a pin and loop connection. The barrier segments are 610 mm (24 inches) wide at the base, 810 mm (32 inches) tall, and 3.8 m (12.5 feet) long. The width at the top of the barrier is 150 mm (6 inches). The connection between the segments consists of 2 sets of 2 loops. A connecting pin is passed through the loops to join adjacent barrier segments and transfer the tensile and moment loads from one segment to another. The connection is designed to have “nested” loops, where the loops from one barrier segment are positioned between the loops of the connecting segment. The loops are made of 16 mm (5/8 inch)

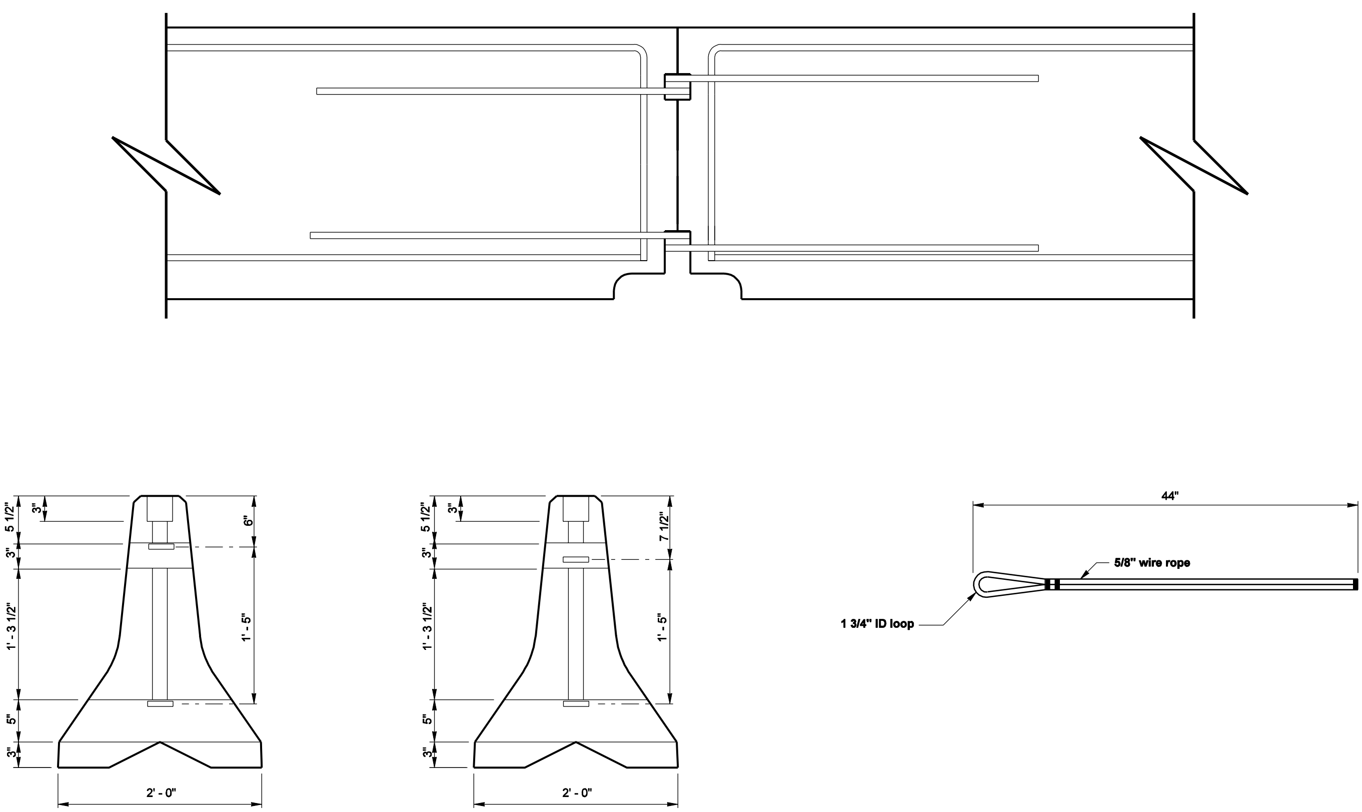


FIGURE 2 Current WSDOT precast barrier details.

diameter wire rope and the connecting pins are 25 mm (1 inch) diameter steel rods. No restraint is provided at the bottom of the pin.

When this barrier is hit it is recognized that there will be deflection. A relatively flat, clear area of 0.6 m to 1.0 m (2’ to 3’) in width is provided behind the barrier to accommodate this deflection.

IN SERVICE PERFORMANCE

The reported accident history of guardrail, concrete barrier, and fixed walls on state highways in Washington State for the period from January 1990 to December 1996 (seven full years) was analyzed to compare the relative performance of these barriers. It should be noted that only using accident data of this type will skew the analysis because it does not include unreported accidents. Analyzing only reported accidents will generally result in a greater percentage of higher severity accidents because unreported accidents will generally be lower severity. It was assumed that since this is a comparative analysis, the effect of using only reported accidents was insignificant.

The analysis was performed in two stages. To get an overall understanding of performance, the entire statewide accident data was used. However, since this analysis does not consider the type of guardrail or concrete barrier, further analysis was necessary. There are guardrails on Washington State’s highways that are of a design prior to the current design. Also, concrete barriers could be unrestrained precast barriers or fixed, cast-in-place barriers. Further analysis on specific highway sections allowed for evaluation of the performance of these specific designs.

Statewide accidents involving all types of beam guardrail were compared to statewide accidents involving all types of concrete barrier and all types of fixed walls on the basis of accident severity. The severity of the accidents was broken out into four categories: 1) property damage only, 2) evident and possible injuries, 3) disabling injuries, and 4) fatalities. The accident data is summarized in Table 1.

Accident Severity	Guardrail		Concrete Barrier		Fixed Wall	
	Total	%	Total	%	Total	%
PDO	5,533	62.14%	5,194	59.62%	536	54.47%
Possible or Evident Injury	2,871	32.24%	3,199	36.72%	379	38.52%
Disabling Injury	412	4.63%	274	3.15%	61	6.20%
Fatal	88	0.99%	45	0.52%	8	0.81%
Total	8,904	100%	8,712	100%	984	100%

Table 1 – Overall Accident Severity by Barrier Type

The data showed that accidents with concrete barrier resulted in a higher percentage of injuries than accidents with beam guardrail but fewer severe injuries (disabling and fatal) resulted. In comparison, accidents with fixed walls resulted in a higher percentage of injuries (including severe injuries) than both the guardrail and the concrete barrier.

To evaluate the performance of specific barrier designs, highway sections were identified by barrier type. Sections were selected in which a significant number of accidents for each barrier type could be analyzed and which would represent a diverse cross section of the highway system (different functional classifications and traffic volumes). The accident data for these sections was analyzed and is summarized in Table 2. For this analysis the data for the injury accidents was broken down to show the distribution between possible and evident injury occurrences. This data indicates that impacts with the unrestrained precast concrete barrier resulted in slightly fewer disabling and fatal accidents as compared to w-beam guardrail. The occurrence of evident injuries that resulted from impacts with the unrestrained precast barrier was comparable to the w-beam guardrail and the occurrence of possible injuries was higher. Impacts with rigid concrete barriers and fixed walls generally resulted in a higher percentage of injury accidents.

Accident Severity	Guardrail #	Guardrail %	Unrestrained Precast Concrete Barrier #	Unrestrained Precast Concrete Barrier %	Rigid Concrete Barrier #	Rigid Concrete Barrier %	Fixed Wall #	Fixed Wall %
PDO	261	71.51%	245	66.40%	118	57.56%	214	56.91%
Possible Injury	41	11.23%	61	16.53%	39	19.02%	78	20.74%
Evident Injury	48	13.15%	51	13.82%	41	20.00%	62	16.49%
Disabling Injury	11	3.01%	10	2.71%	7	3.41%	20	5.32%
Fatal	4	1.10%	2	0.54%	0	0.00%	2	0.53%
Total	365	100%	369	100%	205	100%	376	100%

Table 2 – Accident Severity for Specific Barrier Types

This data indicates that impacts with the unrestrained precast concrete barrier resulted in slightly fewer disabling and fatal accidents as compared to w-beam guardrail. The occurrence of evident injuries that resulted from impacts with the unrestrained precast barrier was comparable to the w-beam guardrail and the occurrence of possible injuries was higher. Impacts with rigid concrete barriers and fixed walls generally resulted in a higher percentage of injury accidents.

SIMULATION (*3*)

Prior to full scale crash testing, computer simulations were performed to identify possible failure issues with the current design. The FHWA connection guide (*1*) had indicated that connecting pins should be anchored on both ends to keep them from pulling out of the loops during an impact, resulting in a break in the barrier. Other crash tested designs used a larger, 32 mm (1¼”) diameter connecting pin (*4*). In addition, crash testing conducted by the state of Idaho with a similar wire rope loop connection had caused some speculation that a wire rope allowed too much displacement of the tops of the barriers, resulting in a ramping effect that pitched the vehicle over the top of the barrier (*5*). Five simulations were performed to evaluate the alternate designs shown in Table 3.

All of the simulated designs used the same shape and length of barrier. The first two simulations involved minor changes to the current design (a larger connecting pin and steel loops). The current design was not simulated based on the results of the first simulation with the larger pin. The third simulation was on an alternate design that used steel bar loops and an additional loop was added to each barrier end to create 3 sets of 2 loops as is shown in Figure 3. The fourth simulation was on an alternate design that also used steel bar loops and an additional loop was added to each barrier end to create 2 sets of 3 loops as is shown in Figure 4. The fifth simulation was of the most promising of the alternate designs (simulation 3) with a larger connecting pin. The alternate connection designs with the additional loops were designed to be compatible with the current design to make it possible to connect to existing barrier.

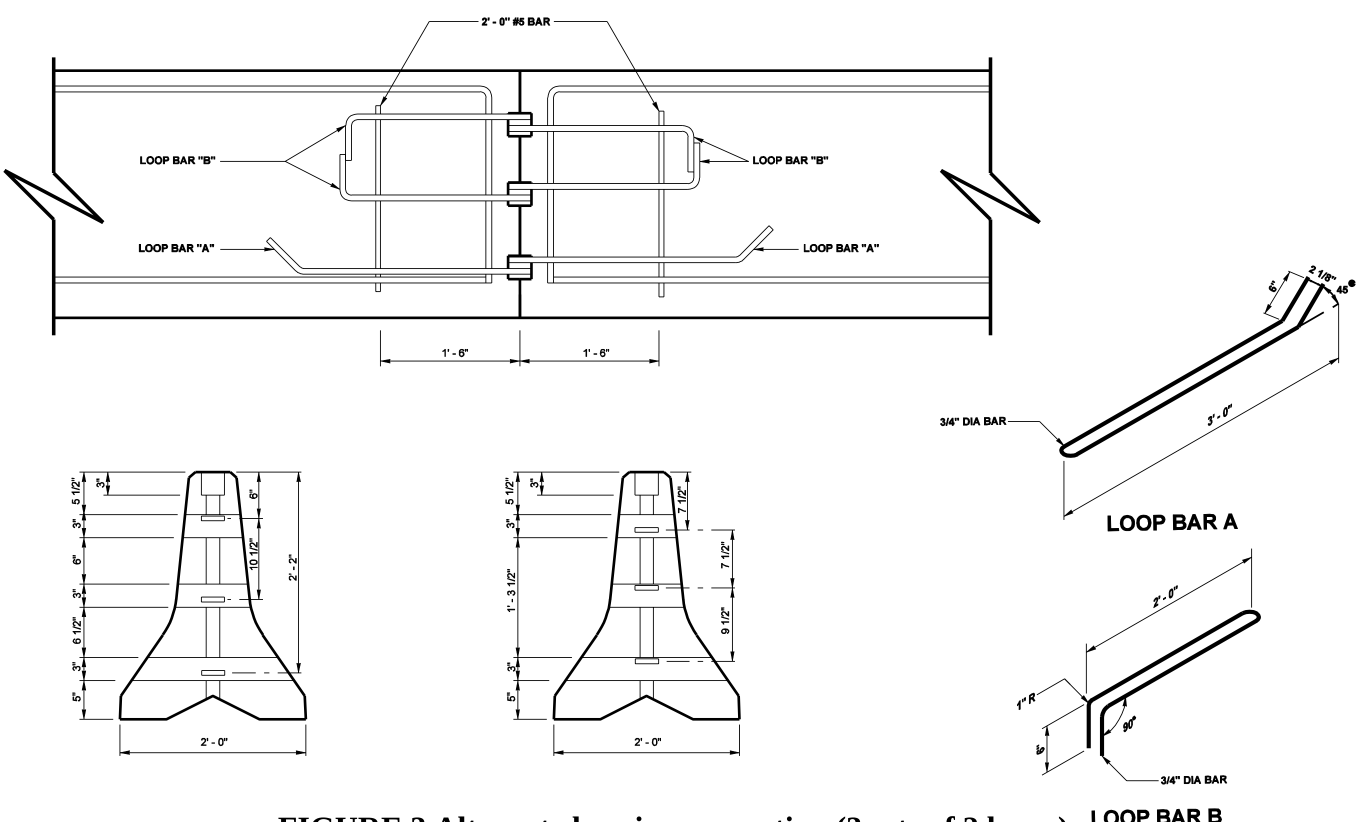


FIGURE 3 Alternate barrier connection (3 sets of 2 loops).

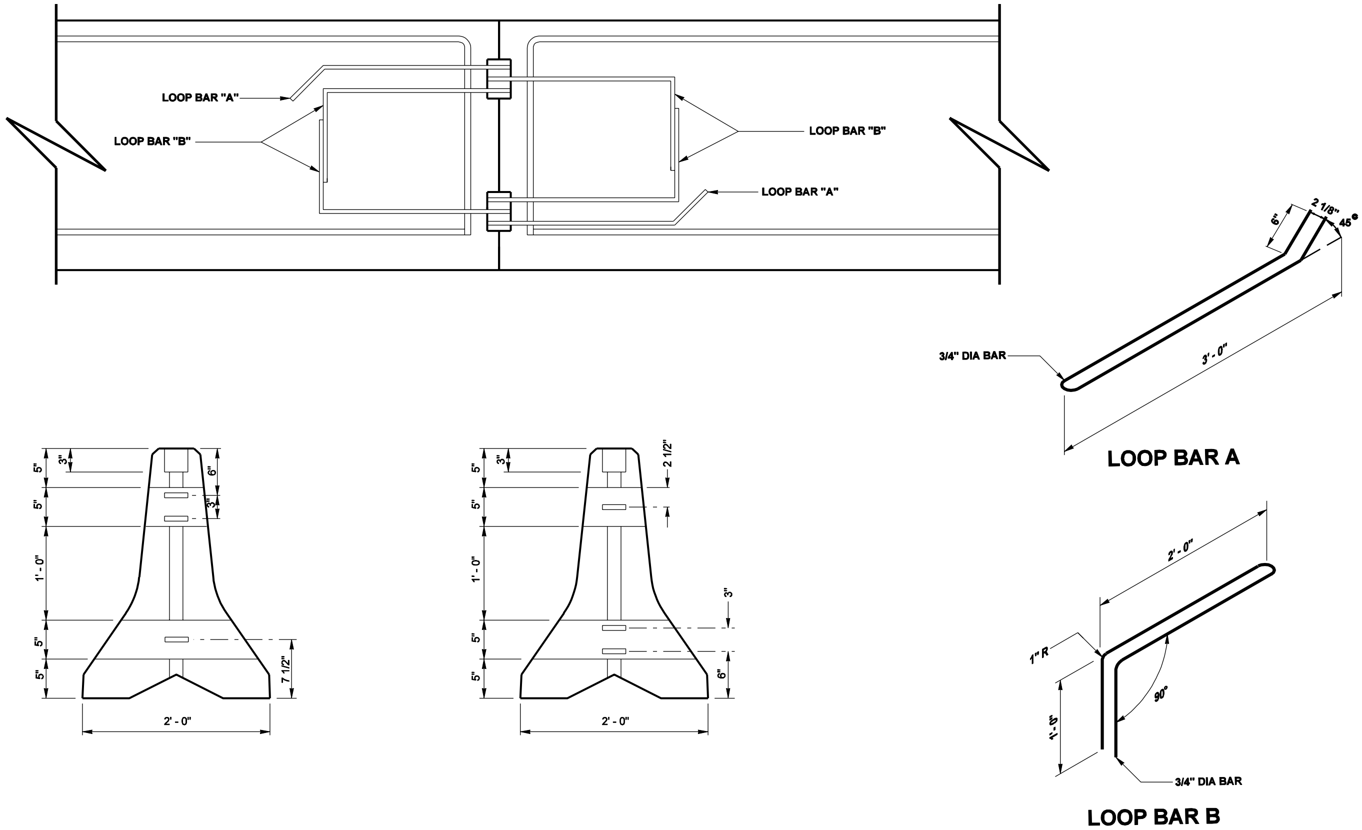


FIGURE 4 Alternate barrier connection (2 sets of 3 loops).

Simulation	Loops	Pin diameter
1	2 sets of two wire rope loops	32 mm (1¼ inch)
2	2 sets of two steel bars loops	25 mm (1 inch)
3	3 sets of two steel bars loops	25 mm (1 inch)
4	2 sets of three steel bars loops	25 mm (1 inch)
5	3 sets of two steel bars loops	32 mm (1¼ inch)

Table 3 – Pin and Loop Connection Simulations

The simulations were performed using the explicit finite element code (LS-DYNA). A modeling strategy was devised to address key performance elements of the system. These key elements are:

1. The concrete segments.
2. The friction between the concrete segments and the ground.
3. The pin and loops.
4. The connection of the loops to the concrete segments.
5. The contact of the pin with the loops.
6. The contact of the vehicle with the barrier system.

The simulation model was set up to represent the *NCHRP Report 350* Test level 3-11. For each simulation, the vehicle impacted the critical impact point (CIP) at 25 degrees and 100 km/hr (62 mph). Finite element simulations indicated a relatively severe impact event between the vehicle and the concrete barrier system for all configurations. As shown in table 4, all of the simulations showed clustered values of Occupant Impact Velocity (OIV) and Ridedown acceleration with values below the acceptable limits.

Both of the simulations with the 2 sets of 2 loops (simulations 1 and 2) showed that the connecting pin was bent and pulled out of the loops. This resulted in lateral deflections in the range of 1.8 (6 feet) to 2.6 meters (8.5 feet) and significant separation of the joint. The simulations of the connections with the additional loops (simulations 3, 4, and 5) resulted in deflections in the range of 1.1 m (3.6 feet) to 1.4 m (4.5 feet) and a dramatic improvement in joint integrity. There were some high stress indications in the steel bar loops and based on this it was decided that the 3 sets of 2 loops design provided more redundancy in the connection and this design (simulation 3) was selected for full scale crash testing. Simulation 5 did not indicate a compelling benefit in using the larger pin. However, a larger pin was considered for testing but it proved to be very difficult to install in either the current or alternate design and its use was abandoned.

	Simulation	1 2 sets of 2 wire rope loops *	2 2 sets of 2 steel bar loops	3 3 sets of 2 steel bar loops	4 2 sets of 3 steel bar loops	5 3 sets of 2 steel bar loops *
Simulated time (seconds)		0.62	0.45	0.5	0.5	0.62
OIV (m/s)	x-direction	8.4	5.8	6.1	6.9	8.5
	y-direction	6.1	1.5	6.1	3.6	4.2
Ridedown acceleration (g's)	x-direction	16.6	-6.9	10.8	7.3	-6.8
	y-direction	15.2	-6.7	-12.1	-15	-15.1
Max 50 msec moving avg. acceleration (g's)	x-direction	-11.5	-12.1	-8.6	-12.1	-13.1
	y-direction	-9.1	-6.8	-10.1	-8.9	-8.5
Maximum lateral movement		1.843 m (6.05 ft)	2.571 m (8.43 ft)	1.102 m (3.62 ft)	1.105 m (3.63 ft)	1.376 m (4.52 ft)

*- 32 mm (1¼ inch) diameter pin used in simulation

Table 4 – Simulation Results

FULL SCALE CRASH TESTING *(3)*

NCHRP 350 compliance tests

According to *NCHRP Report 350*, two tests are required to evaluate longitudinal barriers to test level three (TL-3) and are as described below.

> **NCHRP Report 350 test designation 3-10**: An 820-kg (1800 - pound) passenger car impacting the critical impact point (CIP) in the length of need (LON) of the longitudinal barrier at a nominal speed and angle of 100 km/h (62 mph) and 20 degrees. A rigid New Jersey shaped barrier has previously been successfully tested with a small car (*6*). A deflecting barrier, like the unrestrained precast concrete barrier, can be expected to result in lower occupant impact forces than a rigid barrier. Therefore, the small car test was determined to be unnecessary for these barriers.

NCHRP Report 350 test designation 3-11: A 2000-kg (4400 - pound) pickup truck impacting the CIP in the LON of the longitudinal barrier at a nominal speed and angle of 100 km/h (62 mph) and 25 degrees. This test is intended to evaluate the strength of the barrier and connection and was determined to be the critical test of these systems.

The Critical Impact Point (CIP) was determined to be at the one-third point of the barrier, or 1.2 m (4’) upstream of the joint between segments 6 and 7.

Current Design – 2 Sets of 2 Wire Rope Loops

The current design with the 2 sets of 2 wire rope loops and a 25 mm (1”) connecting pin was crash tested with a 1996 Chevrolet 2500 pickup truck, traveling at a speed of 99.6 km/h (61.9 mph). The vehicle impacted the concrete barrier at an angle of 24.4 degrees. (See Figure 5 for summary information.) During the impact, the vehicle rode up the barrier and all of the tires were lifted off of the road surface. The vehicle was redirected parallel to the barrier installation traveling at a speed of 78.5 km/h (48.8 mph). The undercarriage of the vehicle contacted the

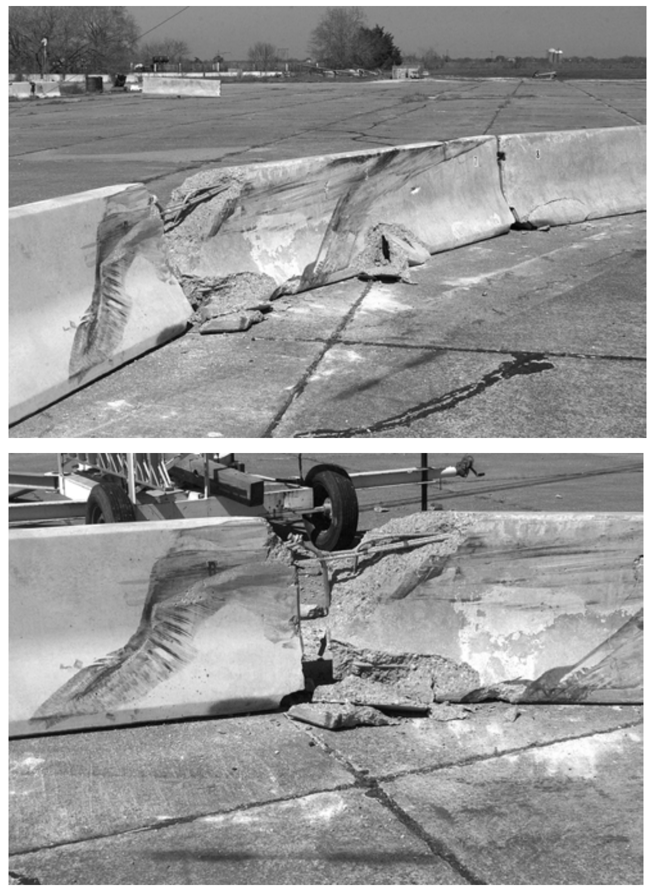
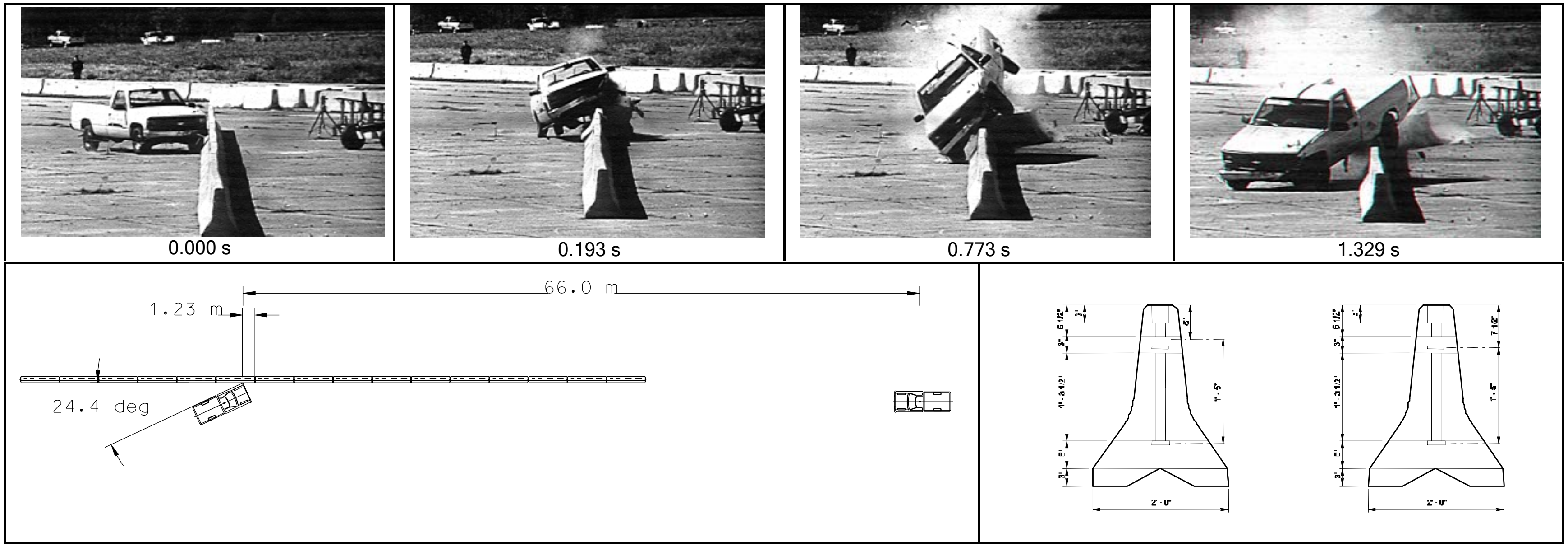


FIGURE 6 Barrier damage – current



General Information	
Test Agency	Texas Transportation Institute
Test No.	400091-WDT1-1
Date	03/05/01
Test Article	
Type	Portable Concrete Barrier
Name	Type 2 Concrete Barrier
Installation Length (m)	61.0
Material or Key Elements	Safety Shape Portable Concrete Barriers with Pin-and-Loop Connection
Soil Type and Condition	Concrete Pavement, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1996 Chevrolet 2500 pickup truck
Mass (kg)	
Curb	2142
Test Inertial	2000
Dummy	No Dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	99.6
Angle (deg)	24.4
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.7
y-direction	4.9
THIV (km/h)	20.9
Ridedown Accelerations (g's)	
x-direction	-4.8
y-direction	-8.5
PHD (g's)	8.6
ASI	0.87
Max. 0.050-s Average (g's)	
x-direction	-5.4
y-direction	7.2
z-direction	-3.8

Test Article Deflections (m)	
Dynamic	1.44
Permanent	1.41
Working Width	1.75
Vehicle Damage	
Exterior	
VDS	11LFQ3
CDC	11FLEK3 & 11LYEW3
Maximum Exterior Vehicle Crush (mm)	380
Interior	
OCDI	LF0000000
Max. Occ. Compart. Deformation (mm)	19
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	67
Max. Pitch Angle (deg)	-12
Max. Roll Angle (deg)	52

FIGURE 5 Crash test summary – current design.

top of the barrier just prior to the left front tire returning to the road surface. The left rear tire and rear bumper contacted the top of the barrier just prior to the left rear tire returning to the road surface. The vehicle lost contact with the barrier and came to rest 66 m (216') from the impact point.

The concrete barrier segments sustained moderate damage as shown in Figure 6. The joint edges of segments 5, 6, 7, and 8 were chipped and spalled. The connecting pin at the joints 5-6, 6-7, 7-8 and 8-9 were deformed. The pin pulled out of the lower loop on the upstream segment at joint 6-7, but remained attached to the lower loop on the end of the downstream segment and both upper loops. The maximum lateral movement of the barriers was 1.41 m (4.6') at the joint between segments 6 and 7. The lateral movement at joints 5-6 and 7-8 was 0.265 m (0.8') and 1.195 m (3.9') respectively.

The vehicle sustained damage to the left front as shown in Figure 7. Structural damage was imparted to the stabilizer bar, upper and lower A-arms, rod ends, rear spring U-bolts and the frame rail. Also damaged were the front bumper, fan, radiator, left front quarter panel, left door, and the left front and rear tires and rims. Maximum exterior crush to the vehicle was 380 mm (15") at the left front corner at bumper height. Maximum occupant compartment deformation was 24 mm (1") in the firewall area.

FIGURE 7 Vehicle damage – current design.

Figure 8 shows a comparative sequence of both simulation 1 and the crash test of the concrete barrier design with two sets of two wire loops. The pictures indicate very good correlation between test and simulation up to 0.387 seconds, at which time the dynamics of the vehicle start to differ. In the simulation, the vehicle exhibited less roll than exhibited in the crash test. The simulation of the two sets of wire ropes and a 32 mm (1¼ inch) pin (simulation 1)

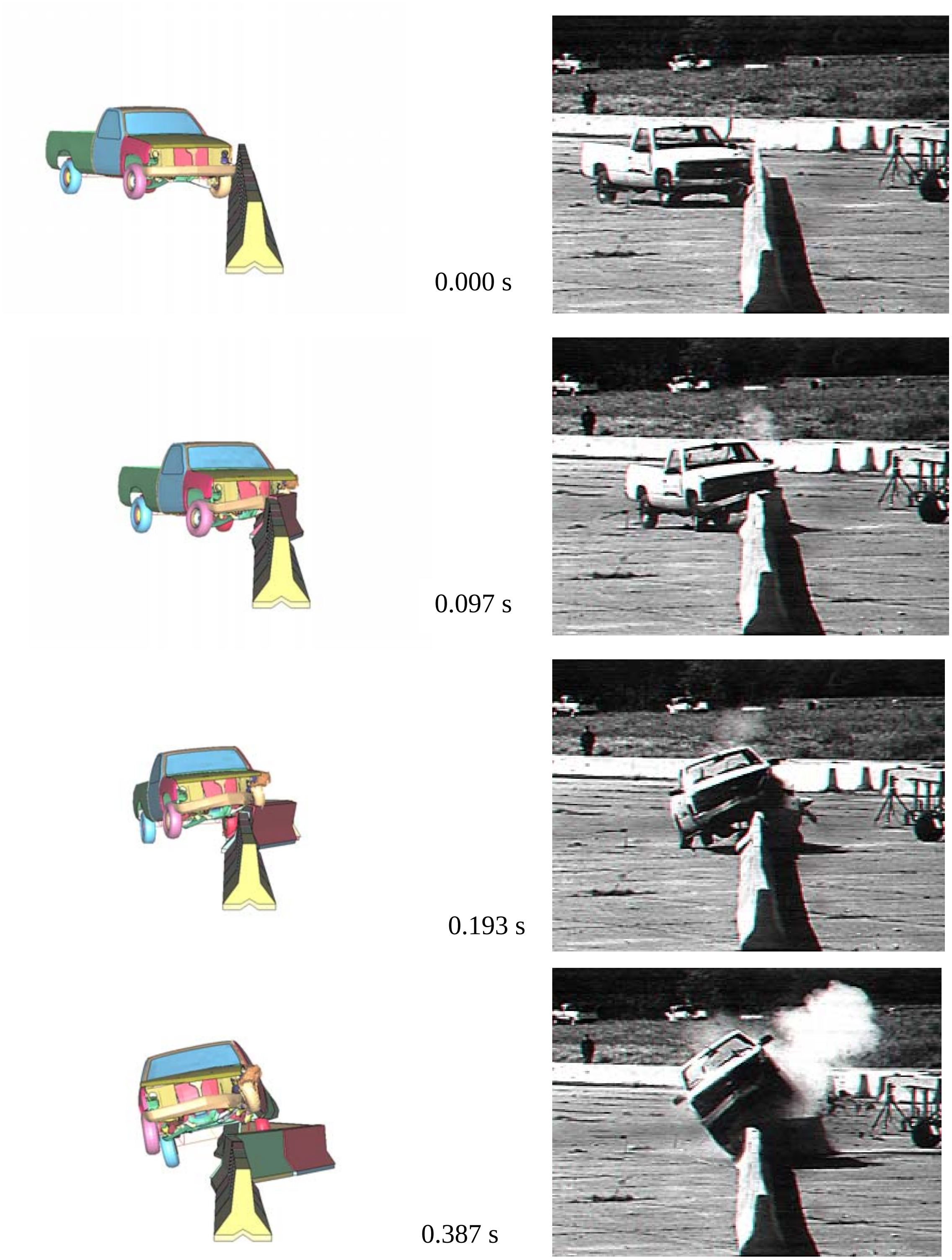


FIGURE 8 Simulation and crash test comparison – current design.

indicated the pin would completely pull out of the bottom loops and the maximum deflection would be approximately 1.8 m (6’). In the crash test with the two sets of wire ropes and a 25 mm (1 inch) pin, the pin did not completely pull out of the bottom loops and the deflection was 1.41 m (4.6’).

Alternate Design – 3 Sets of 2 Steel Bar Loops

The alternate design, which was selected based on the simulations, used a connection with 3 sets of 2 steel bar loops and a 25 mm (1”) connecting pin. This design was crash tested with a 1996 Chevrolet 2500 pickup truck traveling at a speed of 99.6 km/h (61.9 mph) and impacting the barrier at a 24.6 degree angle. (See Figure 9 for summary information.) During the impact, the vehicle rode up the barrier and all of the tires were lifted off of the road surface. The vehicle was redirected parallel to the barrier installation traveling at a speed of 77.4 km/h (48.1 mph). As the vehicle returned to the road surface the right front corner of the vehicle contacted the road surface and the left rear tire contacted the top of the barrier. The vehicle lost contact with the barrier and came to rest 68.4 m (224’) from the impact point.

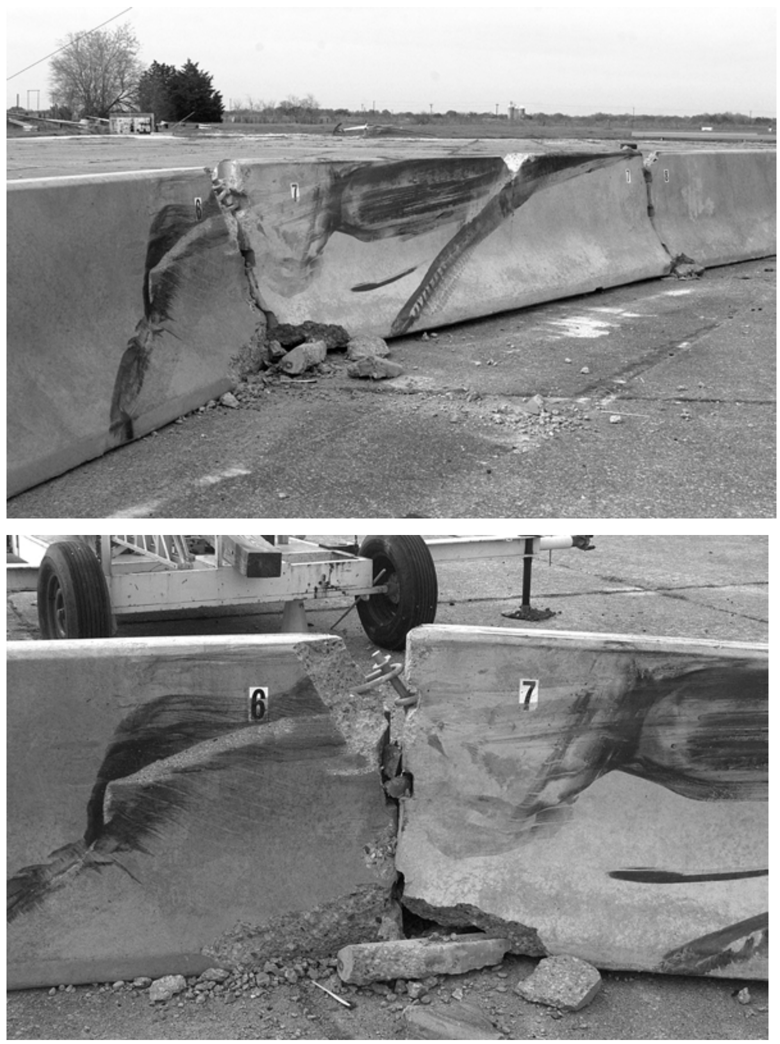
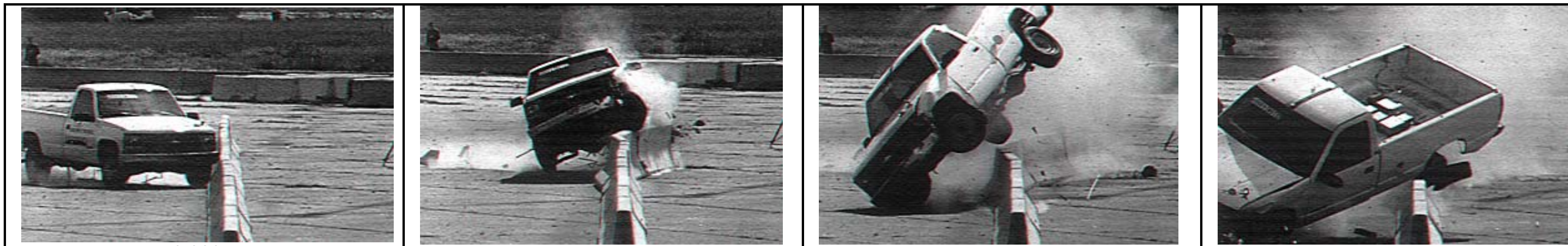
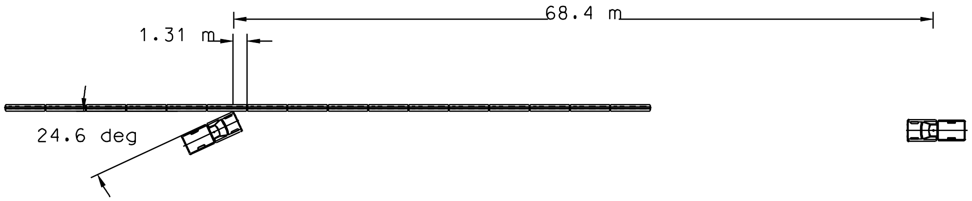
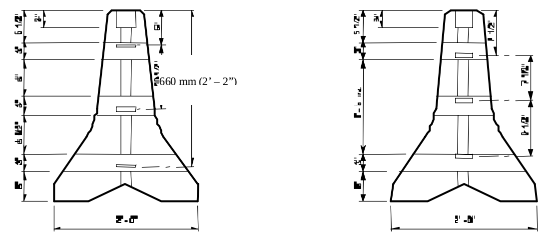


FIGURE 10 Barrier damage – alternate design.







General Information	
Test Agency	Texas Transportation Institute
Test No.	400091-WDT1-2
Date	03/06/01
Test Article	
Type	Portable Concrete Barrier
Name	Modified Type 2 Concrete Barrier
Installation Length (m)	61.0
Material or Key Elements	Safety Shape Portable Concrete Barriers with Pin-and-Loop Connection
Soil Type and Condition	Concrete Pavement, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1996 Chevrolet 2500 pickup truck
Mass (kg)	
Curb	2142
Test Inertial	2000
Dummy	No Dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	98.9
Angle (deg)	24.6
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.1
y-direction	5.6
THIV (km/h)	24.1
Ridedown Accelerations (g's)	
x-direction	-5.8
y-direction	-7.1
PHD (g's)	7.8
ASI	1.01
Max. 0.050-s Average (g's)	
x-direction	-5.5
y-direction	8.4
z-direction	-4.1

Test Article Deflections (m)	
Dynamic	1.25
Permanent	1.17
Working Width	1.87
Vehicle Damage	
Exterior	
VDS	xxxxx
CDC	xxxxxxx
Maximum Exterior Vehicle Crush (mm)	420
Interior	
OCDI	xxxxxxxxxxx
Max. Occ. Compart. Deformation (mm)	20
Post-Impact Behavior	
(during 1.0 s after impact)	
Max. Yaw Angle (deg)	72
Max. Pitch Angle (deg)	-22
Max. Roll Angle (deg)	59

FIGURE 9 Crash test summary – alternate design

The concrete barrier segments sustained moderate damage as shown in Figure 10. The joint edges of segments 5, 6, 7, 8 and 9 were chipped and spalled. The connecting pin at the joints 5-6 and 7-8 were deformed but none of them pulled out of the loops. The maximum lateral movement of the barriers was 1.17 m (3.8') at the joint between segments 6 and 7. The lateral movement at joints 5-6 and 7-8 was 0.510 m (1.7') and 0.790 m (2.6') respectively.

The vehicle sustained damage to the left front as shown in Figure 11. Structural damage was imparted to the stabilizer bar, upper and lower A-arms, rod ends, and the frame rail. Also damaged were the front bumper, fan, radiator, left front quarter panel, left and right doors, the left front and rear tires and rims, and the left side of the floor pan. Maximum exterior crush to the vehicle was 420 mm (16.4") at the left front corner at bumper height. Maximum occupant compartment deformation was 20 mm (¾") in the firewall area.

FIGURE 11 Vehicle damage – alternate design.

Figure 12 shows a comparative sequence of both simulation and test of the concrete barrier design with three sets of two steel bar loops. The pictures indicate very good correlation between test and simulation until 0.476 seconds at which time the vehicle begins to exhibit more roll in a the crash test than in the simulation. The predicted deformation pattern in the simulated pin was observed in the full-scale test. Simulation 3 predicted a maximum deflection of approximately 1.1 m (3.6'). The actual deflection was very close to the simulation.

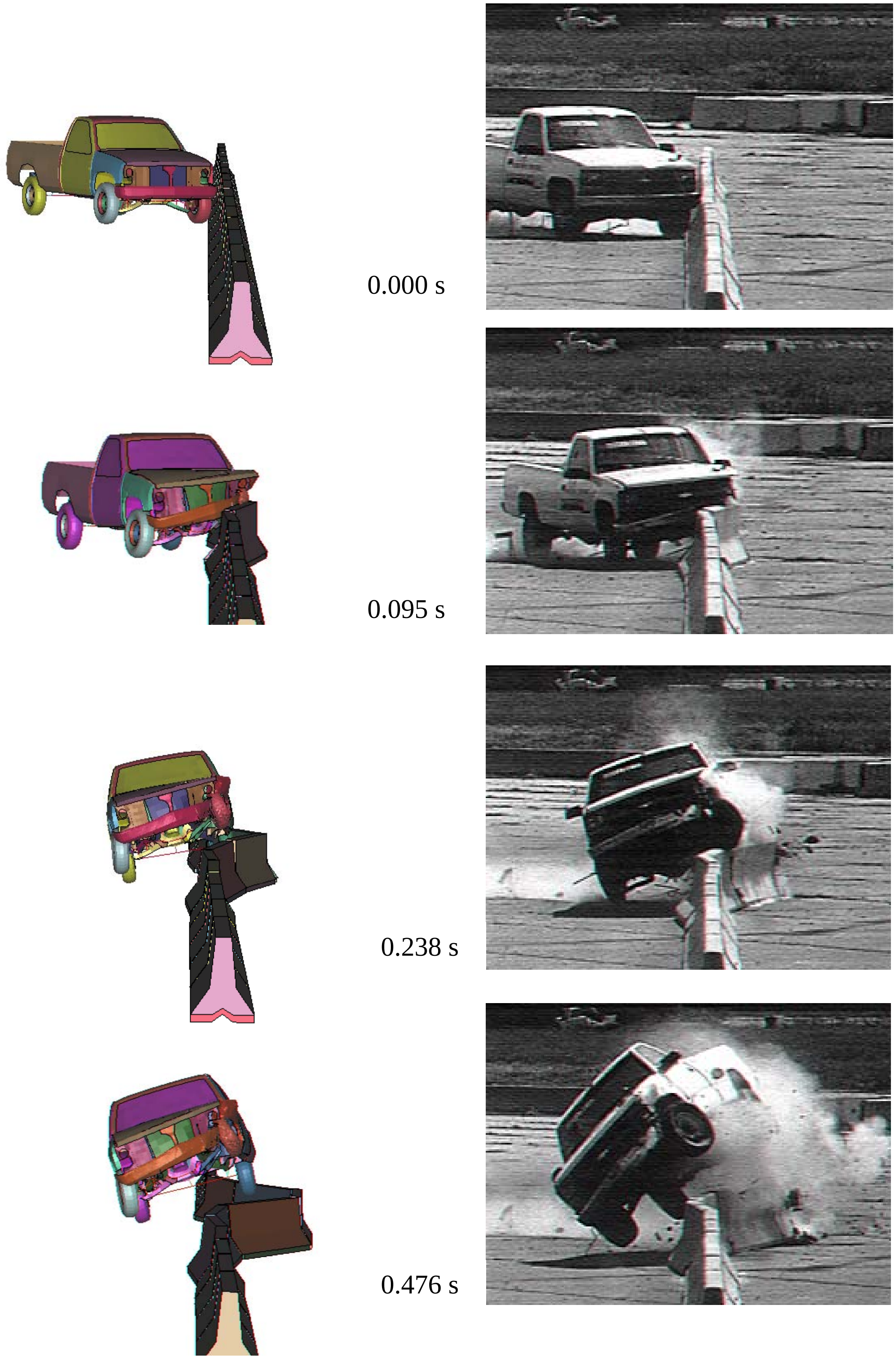


FIGURE 12 Simulation and crash test comparison – alternate design

CONCLUSIONS

Two precast concrete barrier designs were tested and found to meet the NCHRP Report 350 crash test criteria. Both designs used freestanding 3.8 m (12.5’) long segments with the New Jersey shaped face and pin and loop connections. Computer simulations were used to evaluate alternate designs prior to the testing and they showed fairly good correlation with the full scale crash tests.

The roll angle in both tests was higher than predicted and higher than was observed in tests of other barriers. However, it is recognized that the NCHRP Report 350 test conditions represent an extremely severe impact condition and research shows that the in-service performance of this type of barrier is comparable to other commonly used barriers.

The maximum deflection predicted for the current WSDOT design was more than the actual crash test maximum deflection. However, the crash test deflection was approximately 1.41 m (4.6’) for the current design and 1.17 m (3.8’) for the alternate design, which is more than what is currently being provided for in project design, typically 0.6 m to 1.0 m (2’ to 3’). It was noted that the maximum deflection occurred at one joint and the adjacent joints had less deflection. It was also noted that in the crash tests, the vehicle projected over the top of the barrier. This performance suggests a couple of possible design considerations for placement of this type of barrier.

- Rigid objects should be placed beyond the deflection distance of the barrier or, when this isn’t practical, the barrier should be restrained to act as a rigid barrier.
- When placed in front of a dropoff or negative slope, the deflection of the adjacent joints may be more appropriate as a guide because it is unlikely that the deflection of one joint would cause the run of barrier to drop over the edge.

The crash test performance of the alternate barrier design was similar to that of the current design. The integrity of the connection was improved with the addition of the extra set of loops. There was no evidence of a significant difference in the overall performance between the wire rope loops and the steel bar loops. There are some maintenance concerns with removal of the damaged pins from the alternate 3 loop design that may make this design less desirable.

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Figure List