Development of an NCHRP Report 350 TL-3 New Jersey Shape 50-inch Portable Concrete Barrier

Final Report

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16. Abstract

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17. Key Words

Portable Concrete Barrier, PCB, Full-Scale Crash Test, Finite Element Analysis, NCHRP Report 350, Test 3-11, TRC Test 060412

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DEVELOPMENT OF AN NCHRP REPORT 350 TL-3 NEW JERSEY SHAPE 50-INCH PORTABLE CONCRETE BARRIER

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ABSTRACT

For roadside work-zones in areas that have opposing traffic flow, safety is enhanced if the temporary barriers incorporate a “glare-shield” that blocks headlight glare from opposing traffic. Currently-available 32-inch portable concrete barriers require the use of an add-on glare shield attached to the top of the barrier. The add-on glare shields are an extra expense and complicate barrier set-up and handling. An alternative solution was to develop a 50-inch high portable concrete barrier which is tall enough to serve as its own glare-shield. Finite element analysis was used to investigate various barrier shapes and connection schemes to identify a successful crashworthy design that would meet requirements of NCHRP Report 350 Test level 3. A 50-inch portable concrete barrier design was developed based on the results of the finite element analyses and was crash tested at the Transportation Research Center in East Liberty, Ohio. The system successfully met all safety criteria of NCHRP Report 350 and has been approved by the Federal Highway Administration for use on the National Highway System as a test level 3 device.

KEYWORDS

Portable Concrete Barrier, PCB, Full-Scale Crash Test, Finite Element Analysis, NCHRP Report 350, Test 3-11, TRC Test 060412

INTRODUCTION

The Ohio Department of Transportation (ODOT) is in need of a 50-inch (1.27 m) high Portable Concrete Barrier (PCB) that will pass National Cooperative Highway Research Program (NCHRP) Report 350 Test Level 3 (TL-3).[1] ODOT desires that the upper portion of this new PCB function as an integral, low maintenance glare screen. An original 50-inch (1.27 m) PCB design that was proposed was an outgrowth of a 32-inch (0.813 m) high PCB. The 32-inch PCB design was approved for use on the National Highway System (NHS) per Federal Highway Administration (FHWA) Approval Letter B-93. The FHWA, however, was not willing to approve an extended (18 inches to total height of 50 inches) version of the PCB because of fear that the 50-inch configuration may have a snagging problem.

The potential snagging problem was inferred from the results of a full-scale crash test conducted on the ODOT 32-inch New Jersey Shape PCB. The test was conducted at the Transportation Research Center (TRC) in East Liberty, Ohio in the Fall of 2001 under impact conditions corresponding to NCHRP Report 350 Test 3-11, in which a 4400-lb (2000-kg) ¾-ton pickup truck impacts the barrier at 62.2 mph (100 km/hr) at an angle of 25 degrees. The test was (marginally) successful because the test vehicle rode up on top of the barrier during impact and came to rest on top of the barrier near the downstream end of the barrier string. Since the test vehicle did not penetrate the area behind the barrier, the test was deemed a pass.

FHWA was concerned that the increased height of the 50-inch PCB design might result in increased deformation of the pin-and-loop joints causing excessive opening of the joint. In essence, the impacting vehicle might ride up a barrier segment causing it to rotate such that the top of the next sequential barrier would be exposed, thereby setting up the snagging potential. Nonetheless, ODOT still wants to eliminate add on components that are used to create a glare screen (e.g. individual plastic paddles, 18 inches high) affixed to the top of their current 32-inch PCB because of maintenance and handling problems typically encountered with such add on devices. Additionally, the 50-inch PCB would need to be structurally robust so that, in the event of an impact, the additional 18-inch height would not spall and create potential for another harmful event. Thus a new design for a 50-inch PCB that is structurally robust and has a significantly improved connection scheme is warranted. As such, Battelle was selected to perform this project to produce a 50-inch PCB that would achieve NCHRP 350 TL-3 approval.

RESEARCH OBJECTIVES

The primary objective of this project was to develop a 50-inch high portable concrete barrier (PCB) that would meet the requirements of NCHRP Report 350 for test level 3. The currently approved PCB used in Ohio is the 32-inch New Jersey shape with pin-and-loop connection. The additional 18 inches (457 mm) in the new 50-inch PCB design is to serve primarily as an integral glare screen to provide an affordable, low maintenance solution for inhibiting headlight glare and driver distraction in work-zones. Although products are currently available that are effective for mitigating headlight glare, these products often require significant maintenance and some pose serious safety concerns (e.g., debris from the glare shield entering opposing traffic lanes).

ODOT desired to keep the shape as close as possible to the New Jersey Shape to take advantage of existing 50-inch PCB molds.

RESEARCH APPROACH

Two analysis methods were used in the study: finite element (F.E.) analysis and full-scale crash testing. Since the early 1990’s finite element analysis has become a fundamental part of the design and analysis of roadside safety hardware. F.E. analysis is capable of dealing with the highly nonlinear behavior associated with nonlinear material properties, large deformations and strain-rate effects which are all inherent in high energy crash events. The finite element software, LS-DYNA, was used in this research. LS-DYNA is a nonlinear, dynamic, explicit finite element code that is very efficient for the analysis of vehicular impact and is used extensively by automotive industries to analyze vehicle crashworthiness. It evolved from DYNA3D, a public domain software developed in the mid to late 1970's by John Hallquist at Lawrence Livermore National Laboratory.

The use of F.E. analysis provides a very cost effective means of critically evaluating the mechanics (stress, strain, energy, etc.) of individual components of the barrier system, as well as the apparent performance of the barrier system as a whole. For example, once a finite element model has been developed, the cost of making simple modifications to the system’s design is very straight forward and many design modifications can be evaluated at minimal cost compared to full-scale testing. The data collection process using F.E. analysis is an easy task compared to the data collection requirements in full-scale tests. Detailed information about performance of critical components can be obtained very easily. When failure occurs, the cause of failure can be identified directly from the analysis and measures can be taken to correct the deficiency.

The advantage of full-scale crash tests is that they are actual physical impact events where there is little ambiguity about the results. The disadvantage is that they are costly and it is seldom feasible to perform very many tests. Another disadvantage of full-scale testing is that it is not feasible to collect detailed data at every critical point in the system, thus when a test fails, a forensic approach is often necessary in order to determine the actual cause of failure. Although full-scale testing is not an efficient means of analysis in the design stages of a system, it is very important for the final verification of system performance and is often required for qualification of roadside safety hardware by the FHWA for use on the National Highway System.

Finite element analysis was the primary analysis tool used in the design and development of the 50-inch PCB. The basic research approach taken in this study was to first ensure that model predictions were reliable; a F.E. model of the existing 32-inch PCB was developed and its efficacy was verified by comparing to a full-scale crash test. A number of design options were identified for the 50-inch PCB that would have a high potential for success in NCHRP Report 350 test level three impact conditions and F.E. analysis was then used to evaluate the various design options. Finally, a full-scale crash test conforming to the requirements of NCHRP Report 350 Test 3-11 was performed at the Transportation Research Center in East Liberty, Ohio to confirm F.E. analysis predictions and to assess the performance of the final design.

The project consisted of the following tasks:

- **Task 1) Model Development and Verification**- Develop F.E. model of existing 32-inch PCB and verify model results by comparing to full-scale crash test
- **Task 2) Preliminary 50-inch PCB Design** - Increase height of barrier to 50-inches and assess performance under NCHRP Report 350 Test 3-11 conditions
- **Task 3) Development of 50-Inch PCB Design Options -** Identify a number of design options that have a high potential for success
- **Task 4) Assessment of Designs -** Determine the best design using F.E. analysis
- **Task 5) Full-Scale Crash Testing -** Conduct full-scale crash test to verify barrier performance for TL-3 conditions

Analysis Criteria

There are two tests required in NCHRP Report 350 for qualifying a longitudinal safety barrier as a TL-3 system: Test 3-10 and Test 3-11. Test 3-10 involves an 1800-lb (820-kg) small car (e.g., Geo Metro) impacting at the critical impact point of the barrier at a speed of 62 mph (100 km/hr) and at an impact angle of 20 degrees. Test 3-11 involves a 4400-lb (2000-kg) pickup truck (e.g., Chevrolet C2500) impacting at the critical impact point of the barrier at a speed of 62 mph (100 km/hr) and at an impact angle of 25 degrees.

The performance of the longitudinal safety barrier is evaluated based on criteria for structural adequacy of the barrier, vehicle stability during and after redirection, and occupant risk factors. In particular, NCHRP Report 350 requires that the guardrail must redirect the vehicle without allowing the vehicle to penetrate behind the system, the vehicle must remain upright during and after redirection, occupant impact with the interior of the vehicle must not exceed velocities more than 39.3 ft/s (12 m/s) and the longitudinal ride-down accelerations of the occupant must not exceed 20 g's.

Data from the accelerometer located at the center of gravity of the vehicle model was collected and input into the Test Risk Assessment Program (TRAP) Version 2.0 to calculate standardized occupant risk factors from the vehicle crash data in accordance with NCHRP Report 350 guidelines and the European Committee for Standardization (CEN).[2] TRAP is a software program that was developed to evaluate actual full-scale crash tests and generate important evaluation parameters like the occupant impact velocities, ride down accelerations, 50 msec average acceleration, etc.

TASK 1 – MODEL DEVELOPMENT AND VERIFICATION

To verify that model predictions were reliable, a F.E. model of the existing 32-inch PCB was developed and its efficacy was verified by comparing to a full-scale crash test. A finite element (FE) model of the ODOT 32-inch PCB was obtained from the National Crash Analysis Center (NCAC) at George Washington University and was used in a F.E. simulation of TRC test No. 011012. Two vehicle models were used in this project: the modified NCAC C2500R and the NCAC C2500D v5-b.

C2500 Vehicle Models

The vehicle type recommended for NCHRP Report 350 Test 3-11 is the 2000P test vehicle (e.g., Chevrolet 2500 and GMC 2500 pickup trucks). A finite element model of the Chevrolet 2500, called the C2500 model, was developed by the NCAC under FHWA sponsorship. The reduced element model, C2500R, was developed to serve as a "bullet" vehicle for computational evaluation of roadside safety hardware. The mass of the vehicle model is 4400 lb (2000 kg) and the center of gravity is at approximately 29 inches (737 mm) above ground. The model provides realistic characterization of the overall dynamics of the vehicle and provides accurate loading to the roadside safety feature. In general, there are two basic aspects that are important in a "bullet" model: accurate mass distribution and realistic global stiffness properties.

Another important aspect that must be considered for models used to evaluate roadside safety hardware is proper modeling of the wheels and suspension components, which can have significant effects on both vehicle and barrier response when the wheels interact with the barrier. The suspension is particularly important for simulating impacts into slope-faced PCB because of the tendency for the vehicle to climb the barrier. Several modifications were made to the suspension system components of the model in an earlier study by researchers at Worcester Polytechnic Institute.[3,4] This version of the model has been used extensively by members of the research team in previous studies for simulating vehicle-to-guardrail impacts and the performance of the model in those analyses was satisfactory.[5,6]

In August 2005, NCAC provided Battelle with their latest version of the C2500D (detailed model) pickup truck model, designated C2500D v5b. The C2500D v5b model is an update to their previous detailed model, C2500D v5. Compared to the C2500R model, the detailed model has much more accurate geometry, connections and mesh refinements. Two important updates to this model that were missing in the previous detailed model are better material characterization and more detailed suspension characterization.

TRC TEST No. 011012

A full-scale crash test was conducted on the ODOT 32-inch PCB at the TRC in East Liberty Ohio on October 12, 2001.[7] The 32-inch PCB consisted of twenty 10-ft PCB sections connected using a simple pin-and-loop connection. The test was conducted based on the crash testing guidelines specified in NCHRP Report 350 for Test 3-11. The test vehicle was a 1997 Ford F-250. The vehicle impacted the barrier at 63.6 mph (102.4 km/hr) at 25 degrees. The initial impact point was 4.9 ft (1.5 m) upstream from the joint between PCB units 6 and 7. The vehicle started to climb the barrier almost immediately upon impact. As the vehicle moved along the barrier the front wheel continued to climb. Just prior to the wheel climbing on top of the barrier, the wheel rim caught on the edge of a PCB segment at one of the barrier joints causing the wheel to be torn away from the vehicle. Subsequently, the vehicle climbed on top of the test barrier and slid along the top of the barrier until it reached the end of the system. The vehicle remained upright, all occupant risk factors were within NCHRP Report 350 criteria, and the test was deemed successfully by the FHWA.

The maximum lateral displacement of the barrier was 5.48 ft (1.67) m and the upstream end of the system displaced longitudinally 1.25 ft (0.38 m). During impact there were large deformations in the joint connections in the impact region, as shown in Figure 1.

Figure 1: Side view of joint at PCB units 7 and 8 after full-scale test illustrating the excessive deformation of the joint.

Finite Element Model

A finite element model of the ODOT 32-inch New Jersey Shape PCB was obtained from the National Crash Analysis Center (NCAC). The PCB model was modified to adjust the spacing between the PCB units. The model obtained from NCAC was modeled with closed gaps between the PCB units. The PCB joints are initially closed to facilitate the pin-and-loop connection process. The PCB units are then separated in the longitudinal direction such that the joint is fully open to complete the installation, which results in a 1.73 inch (44 mm) gap between the units (see Figure 2). This in affect removes all “slack” in the joint.

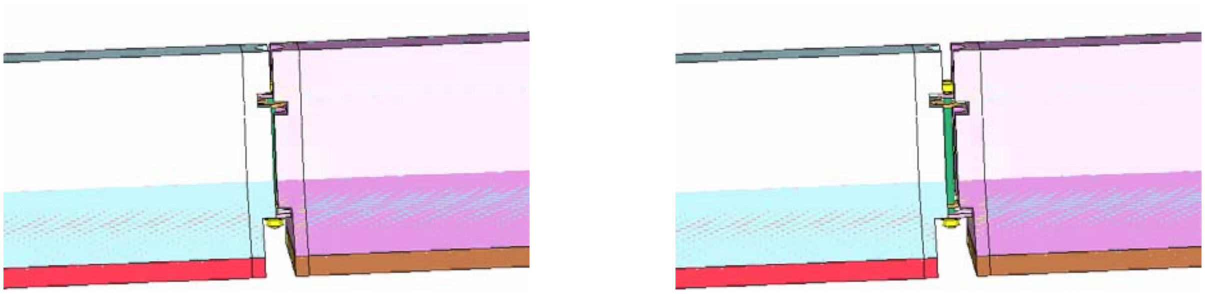


Figure 2: Closed and Open joint of PCB, respectively.

The PCB units were modeled as elastic material with properties of concrete (i.e., Young's Modulus = 2.9 x 10^6 psi (20,000 N/mm^2), Poisson's ratio = 0.28 and density = 2.25 lb-s^2/in^4 (2.4E-9 N-s^2/mm^4), thus concrete damage (e.g., spalling and cracking) was not considered in the analysis. The components of the pin and loop assembly were modeled with properties of steel using an elastic-piecewise linear plasticity model (Material 24 in LS-DYNA) and were connected to the barrier segments using the tied-nodes-to-surface option in LS-DYNA.

Three analyses were conducted and the friction between the PCB units and the ground were modeled using two different methods:

- *Rigidwall* with friction (the rigidwall card applies a constant value of friction)
  - Two analyses were conducted using this method
    - Static = Dynamic Friction = 0.2
    - Static = Dynamic Friction = 0.6
- *Shell Surface Model of Ground* with velocity dependent friction based on the equation:

$$F = fd + (fs-fd)*\exp(-dc*vel)$$

- Applied coefficient of friction, F
- Static coefficient of friction, Fs = 1.0
- Dynamic coefficient friction, Fd = 0.2
- Decay Constant, dc = 0.001(sec/mm)

The values for the coefficients of friction and decay constant, which were used in the shell surface model of the ground, were obtained from the NCAC and were based on results of physical tests. The applied coefficient of friction reduces to 0.2 at a relative velocity of 11.8 mph (19 km/hr) between the shell surface and the barrier segments.

The C2500 vehicle model is significantly different from the Ford F-250 used in the full-scale test; therefore, only a qualitative comparison was made between the test and simulation. The C2500 vehicle model impacted the PCB barrier 4.9 ft (1.5 m) upstream from the joint between PCB units 6 and 7. Upon contact, the vehicle was traveling at 63.4 mph (102 km/hr) at an angle of 25 degrees with respect to the longitudinal direction of the barrier.

Finite Element Simulation (*Rigidwall* with friction Static = Dynamic Friction = 0.2)

The vehicle model (C2500R) started to climb the barrier almost immediately upon impact as the front tire contacted the lower slope of the PCB face, as shown in Figure 3. As the tire of the vehicle slides along and up the barrier face the wheel steers toward the barrier and pushes back into the wheel well. The wheel of the vehicle model remained in tact since failure was not defined in the model, whereas the wheel was torn away in the full-scale test. At 0.180 seconds the front tire of the vehicle was over the top of the barrier. The rear of the vehicle contacts the barrier at approximately 0.340 seconds just upstream of the joint connection of segment 8 and segment 9. The rear tire proceeds to ride up the barrier face and at approximately 0.380 seconds the rear tire of the vehicle overrode the barrier and the vehicle was oriented approximately parallel to the barrier. The vehicle remained airborne over the top of and parallel to the barrier for the remainder of the analysis. The analysis terminated prematurely at 0.690 seconds due to numerical problems related to the contact definitions in the model. The general kinematics and trajectory of the pickup model in the analysis compared very well to those seen in the full-scale test videos. Figure 3 shows sequential views of the analysis from a downstream view point.

The maximum lateral deformation of the barrier was 5.9 ft (1.8 m) (compared with 5.48 ft in the test) and the maximum longitudinal displacement of the upstream end of the barrier was over 1.6 ft (0.5 m) (compared with 1.3 ft in the test). The movement of the end segment depends on the lateral deformation of the barrier in the impact region, thus the higher the lateral deflection the more the end segment will move. When the run terminated, however, the barrier was still in motion, thus the final displacements would have actually been greater than those reported above.

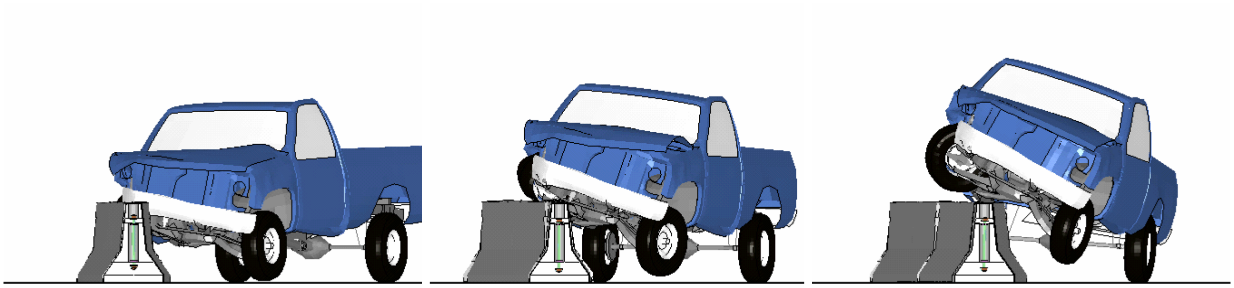
There was considerable deformation in the pin-and-loop joints as the pin-bolts in the impact zone bent during impact. The deformation of the steel pins in the model compare relatively well with those seen in the post-test photos, as shown in Figure 4. Excessive deformation in the joints is undesirable, as it can lead to relative transverse displacement of adjacent barrier segments and create a hazardous "snag" point for the vehicle (e.g., as the vehicle slides along a barrier face and snags on the exposed end of the next PCB segment).

<u>Finite Element Simulation</u> *(Rigidwall* with friction Static = Dynamic Friction = 0.6)

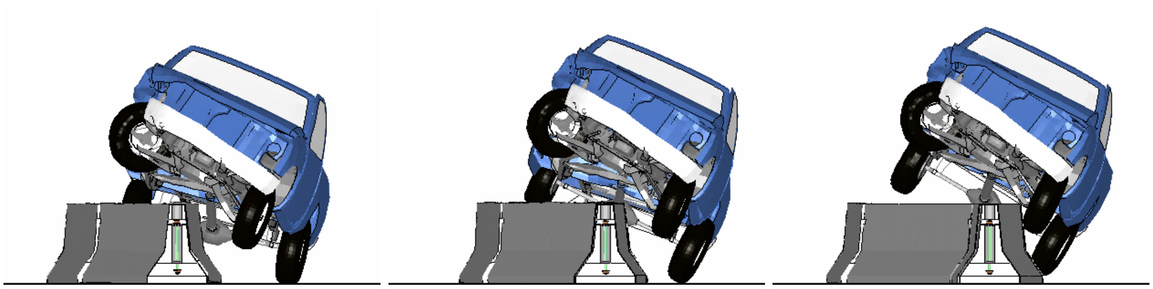
The vehicle kinematics and key events in this analysis were similar to the previous case and will not be repeated. The most notable difference between the two analyses was maximum barrier deflections. In both simulations, as well as in the full-scale test, the maximum deformation of the barrier occurred well after the vehicle had passed by (i.e., after the vehicle impacted and passed various points of the barrier, the barrier segments continued to move laterally due to their momentum). Thus, the analysis results implied that the friction between the PCB segments and the ground did not have a significant influence on the vehicle-to-barrier interaction, but did significantly influence maximum barrier displacements.

Figure 5 shows sequential views of the analysis from a downstream view point. The maximum lateral deformation of the barrier was 3.6 ft (1.1 m) (compared with 5.48 ft in the test) and the maximum longitudinal displacement of the upstream end of the barrier was 0.69 ft (0.21 m) (compared with 1.2 ft in the test).

Time = 0.075 seconds, 0.150 seconds and 0.225 seconds



Time = 0.300 seconds, 0.375 seconds and 0.450 seconds



Time = 0.525 seconds, 0.600 seconds and 0.675 seconds

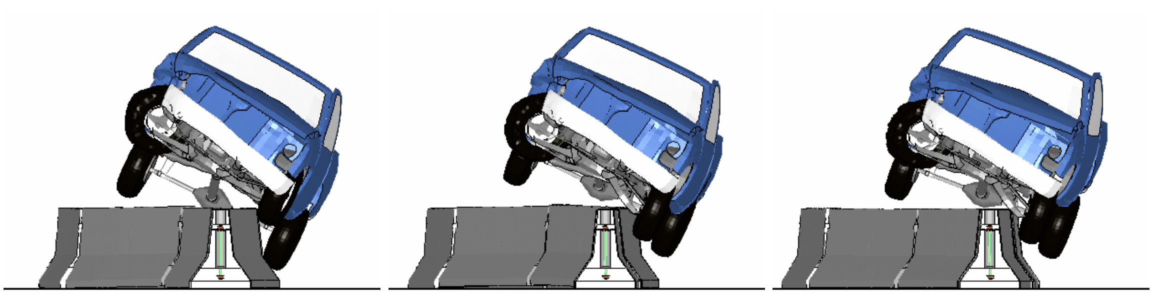


Figure 3: Sequential views of the finite element analysis of the ODOT 32-inch PCB under NCHRP Report 350 Test 3-11 conditions (Friction coefficient = 0.2 = constant).

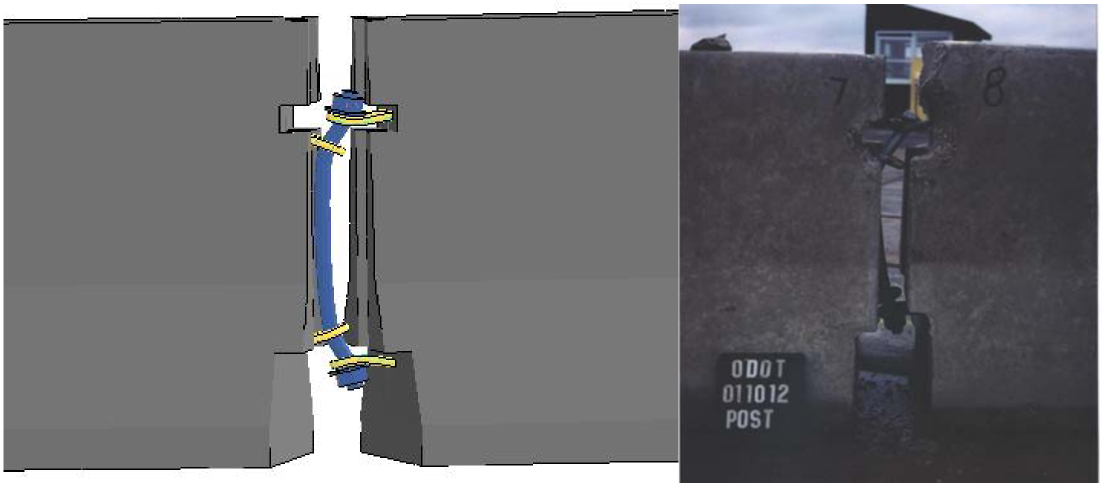
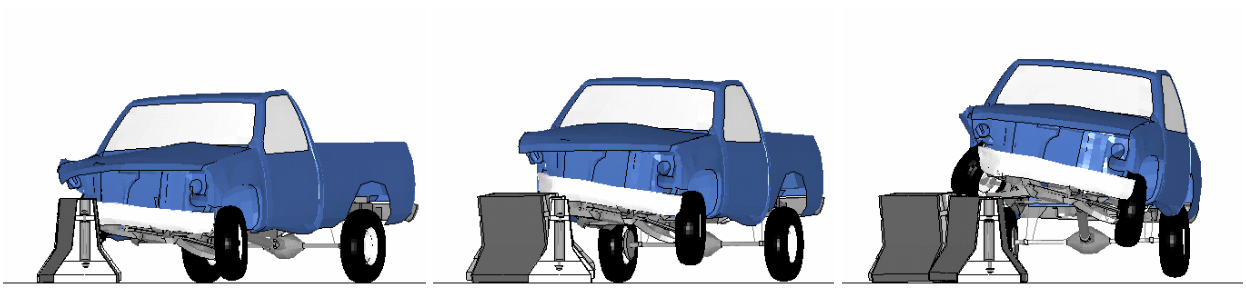


Figure 4: Comparison of pin and loop deformation in F.E. simulation and full-scale test of the 32-inch barrier.

Time = 0.075 seconds, 0.150 seconds and 0.225 seconds



Time = 0.300 seconds, 0.375 seconds and 0.450 seconds

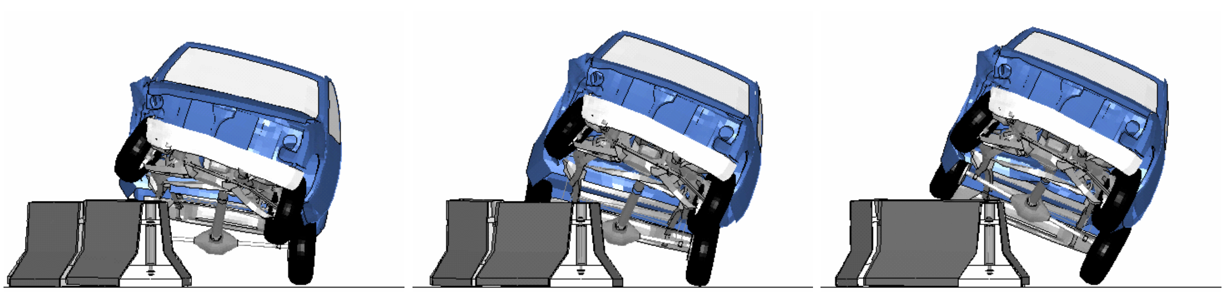
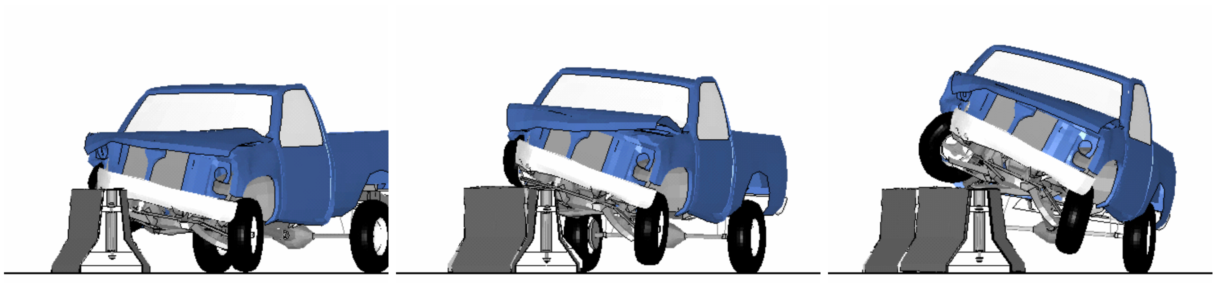


Figure 5: Sequential views of the finite element analysis of the ODOT 32-inch PCB under NCHRP Report 350 Test 3-11 conditions (Friction coefficient = 0.6 = constant).

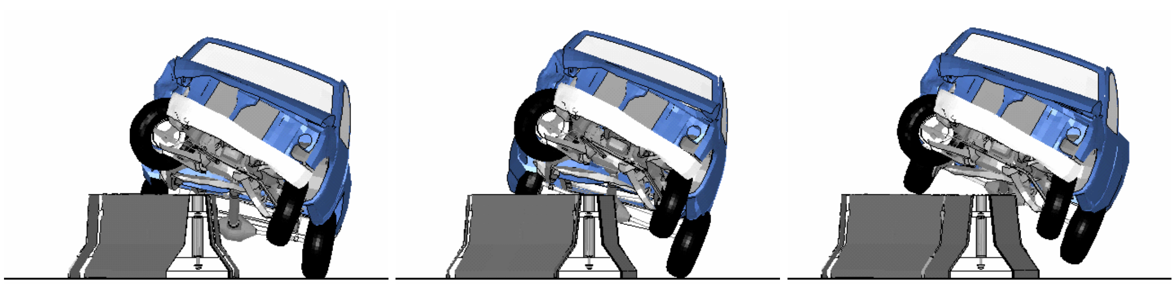
<u>Finite Element Simulation</u> (*Shell Surface ground model* with velocity dependent friction; Static friction = 1.0, Dynamic Friction = 0.6 and decay constant = 0.0254 sec/in)

Again, the vehicle kinematics and key events in this analysis were similar to the previous cases and will not be repeated and the most notable difference was maximum barrier deflections. Figure 6 shows sequential views of the analysis from a downstream view point. The maximum lateral deformation of the barrier was 5.15 ft (1.57 m) (compared with 5.48 ft in the test) and the maximum longitudinal displacement of the upstream end of the barrier was 0.92 ft (0.28 m) (compared with 1.25 ft in the test).

Time = 0.080 seconds, 0.160 seconds and 0.240 seconds



Time = 0.320 seconds, 0.400 seconds and 0.480 seconds



Time = 0.560 seconds, 0.640 seconds and 0.690 seconds

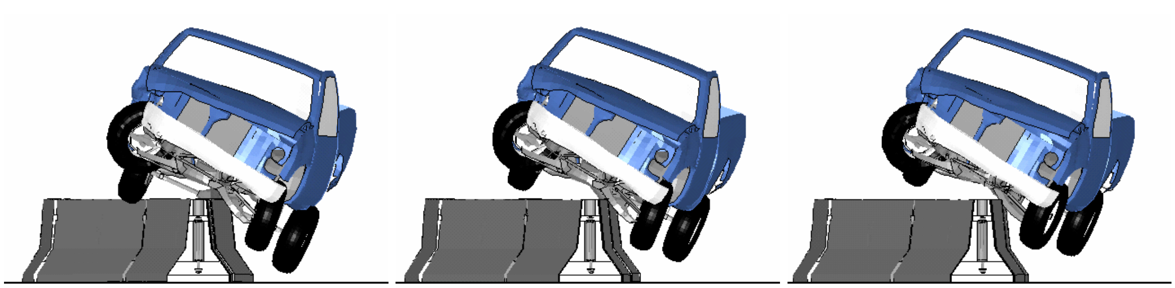


Figure 6: Sequential views of the finite element analysis of the ODOT 32-inch PCB under NCHRP Report 350 Test 3-11 conditions (Static friction = 1.0, Dynamic Friction = 0.6 and decay constant = 0.0254 sec/in).

Summary of Analysis Results

Table 1 shows a comparison of maximum lateral displacement and maximum upstream end displacement for the three analysis cases and the full-scale test. Figure 7 shows a comparison of the F.E.A. results and the full-scale test at approximately 0.5 seconds.

Table 1: Comparison of maximum barrier displacements.

	Friction Coefficient		Maximum Deflection	Maximum End Disp.
	Static	Dynamic		
TRC Test	unknown	unknown	5.48 ft (1.67 m)	1.25 ft (0.38 m)
Analysis 1	0.2	0.2	5.9 ft (1.8 m)*	1.67 ft (0.51 m)*
Analysis 2	0.6	0.6	3.6 ft (1.1 m)	0.69 ft (0.21 m)
Analysis 3	1.0	0.2	5.15 ft (1.57 m)	0.92 ft (0.28 m)

*** In Analysis 1 the barrier had not yet reached maximum deflection**

The results of analysis case 3, which involved a velocity dependent coefficient of friction, yielded results most comparable to the full-scale test. Additional "tuning" of the friction parameters could have been done to achieve better agreement between the test and the simulation; however, the friction values are likely site specific and may vary significantly from site to site. Thus, the values used in analysis case 3 were considered adequate to represent typical friction behavior and these values were used in the subsequent analyses of the 50-inch barrier system.

Figure 7: "Snapshot" of the simulation and test from a downstream viewpoint at approximately 0.52 seconds after the time of impact.

It should again be noted that in the full-scale test and the F.E. analysis simulations the maximum deformation of the barrier occurs well after the vehicle passed by (i.e., after the vehicle impacts and passes various points of the barrier, the barrier segments continue to move laterally due to their momentum). Thus, a better "gauge" for discerning accuracy of the model would be to compare deformations of the barrier at specific times while the vehicle is in contact with the barrier. The behavior of the vehicle during impact and redirection are greatly influenced by the position of the barrier and the kinematics of the vehicle at every point in time while the vehicle is in contact with the barrier. This information is readily available from the data generated in the computer analyses, unfortunately, it is not easily measured in full-scale tests.

TASK 2 – PRELIMINARY 50-INCH PCB DESIGN

One of the primary concerns of the FHWA regarding the height extension of the ODOT PCB from 32 inches (0.813 m) to 50 inches (1.27 m) was the possibility of the vehicle snagging in the joints and causing excessive decelerations and unstable vehicle behavior. This theory was based on the fact that as the vehicle pushes on one segment of the barrier it causes a relative lateral shift at the joint of the adjacent PCBs. This is somewhat apparent in Figure 6. As seen in both the analysis and the test, the rotation was more pronounced at the top of the barrier and was the cause of the wheel snagging in the joint and ultimately being torn away from the vehicle in the test. The concern with increasing the height of the barrier was that the relative displacement between the adjacent PCB's may increase as well, thereby creating a higher potential for snagging. This is better illustrated in Figure 8 and Figure 9.

The 32-inch PCB was converted to a 50-inch PCB by simply extending the top by 18 inches (457 mm), such that from 32 inches (0.813 m) to 50 inches (1.27 m) the sides of the barrier are vertical. The pin and loop positions were not altered from the original configuration. Test 3-11 was simulated on the modified barrier and the resulting barrier deflections are shown in Figure 9, which clearly emphasize the problem. A simple solution to this problem was to modify the pin and loop connection such that relative motion between barrier segments was minimized.

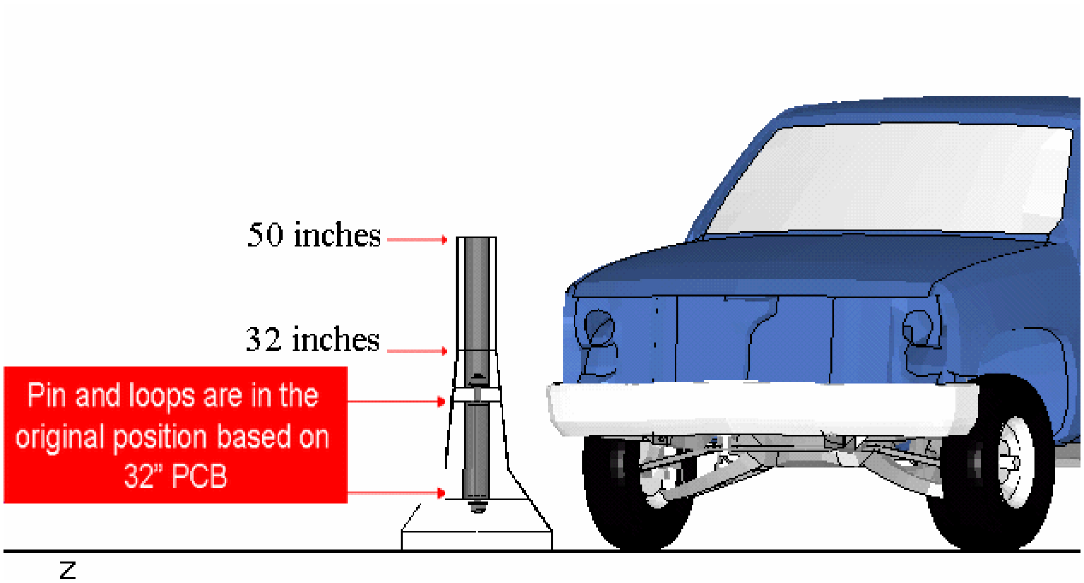


Figure 8: Simple extension of the 32-inch barrier to 50 inches.

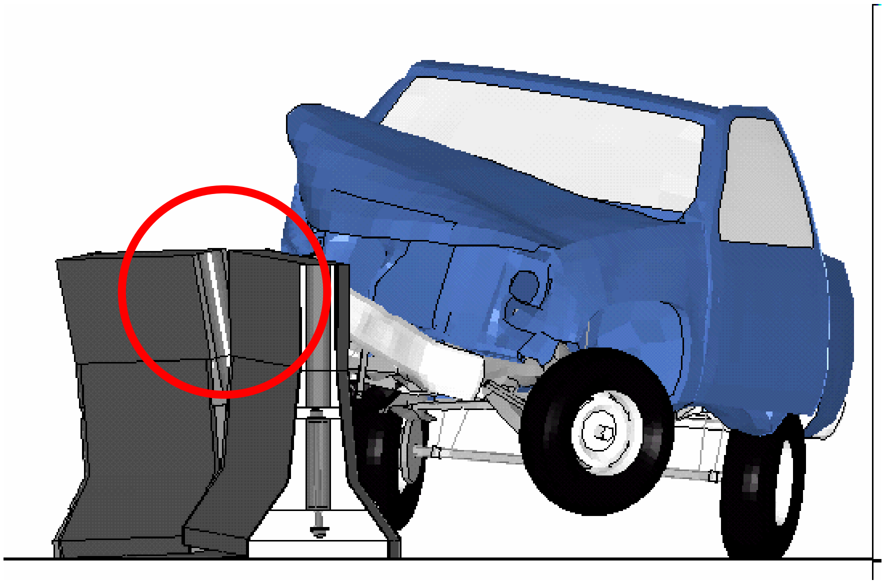


Figure 9: Excessive lateral displacement between adjacent units during impact.

TASK 3 - DESIGN OPTIONS

The proposed 50-inch PCB retains many of the geometric dimensions of the 32-inch PCB. Figure 10 shows geometric dimensions of the 50-inch barrier compared with the ODOT 32-inch PCB. The only differences in the two barriers are the height and the slope of the barriers' face between the first slope break point at 13 inches (330 mm) from the ground and the top of the barrier (i.e., the 50-inch barrier is essentially a 50 inch tall New Jersey barrier with a 3 degrees steeper face).

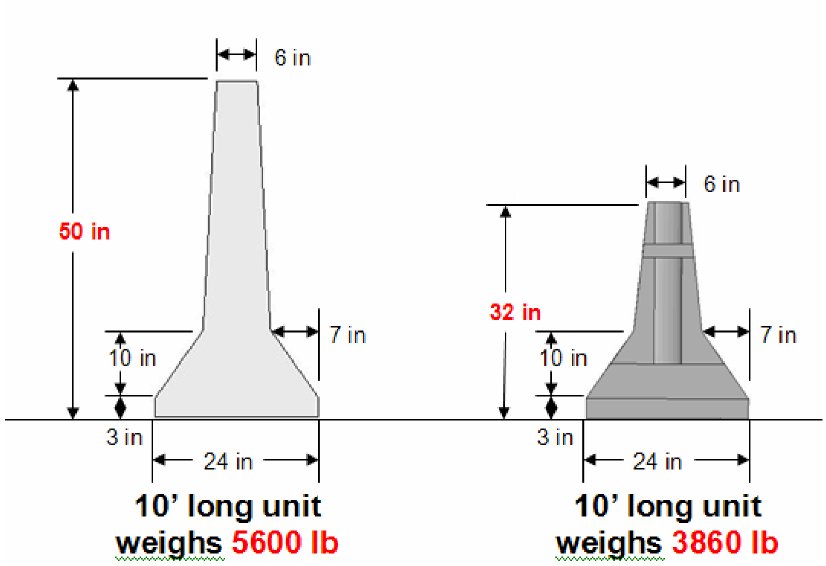


Figure 10: Drawing of Model 1 50-inch PCB and ODOT 32-inch PCB comparing dimensions.

An important aspect of a PCB is the connection of the PCB segments. The proposed 50-inch barrier design uses a simple pin and loop connection with a single pin passing through three or four set of loops at each PCB segment end, as shown in Figure 11. The loop sets are equally spaced along the height of the PCB ends. The top most loop is positioned approximately 5.5 inches (140 mm) from the top of the barrier and the bottom most loop is positioned at 5.5 inches from the bottom of the barrier.

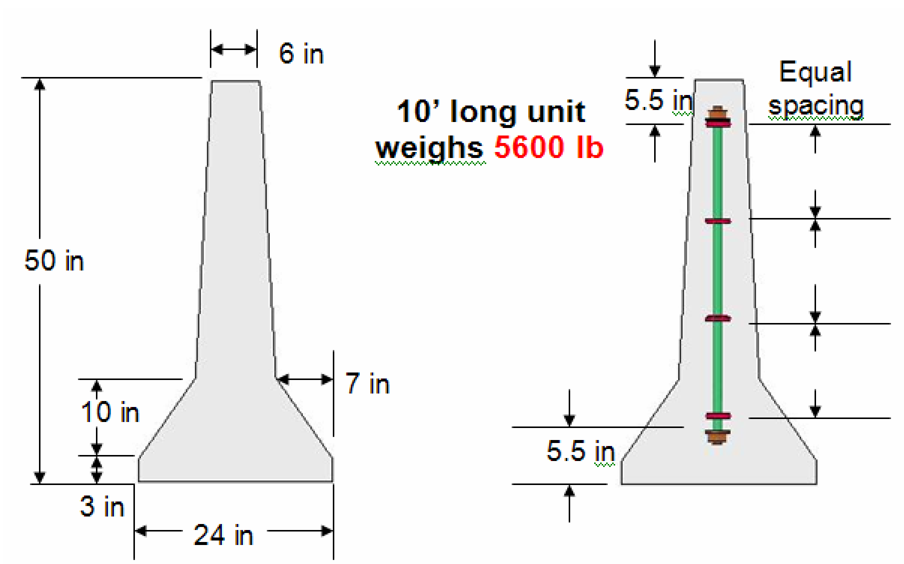


Figure 11: Schematic drawing showing the dimensions of the 50-inch PCB with Pin-and-loop connections.

Another important consideration is the arrangement of the loops with adjacent PCBs. Figure 12 shows four possible scenarios. The first is an anti-symmetrical arrangement where the loops on the left PCB segment are located 1.5 inch (38 mm) below the loops on the right PCB segment. The second is a symmetrical arrangement of the loops. The third is an arrangement which puts the pin in double shear and minimizes the bending deformation of the pins during loading. The fourth is a combination of a double-shear arrangement of the loops at the top and bottom and an anti-symmetrical arrangement of the middle loops.

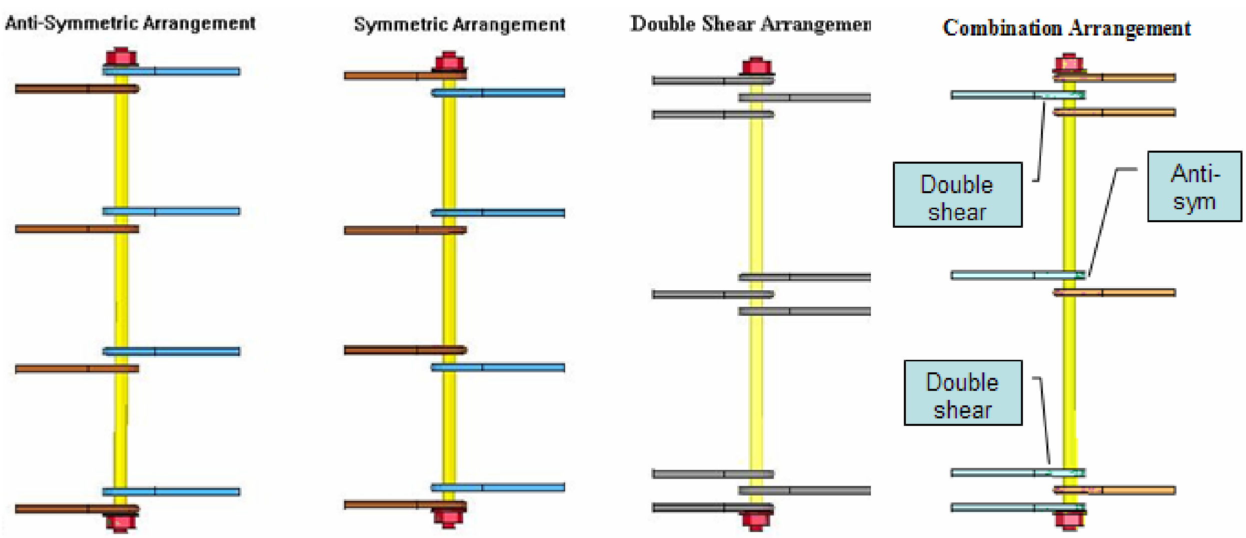


Figure 12: Anti-symmetrical, symmetrical, double shear, and combination double shear/anti-symmetrical pin and loop arrangements, respectively.

The arrangement of the loops is an important consideration since it is desired to achieve as strong a connection as feasibly possible. Figure 13 shows the results of a finite element analysis in which the loops were pulled longitudinally at a constant displacement rate. Figure 14 shows a comparison of force vs. displacement from the analysis results. It is apparent in Figure 13 that the symmetrical arrangement results in a much more flexible connection that will lead to excessive joint opening and relative displacement between adjacent barrier segments and will increase the potential for vehicle “snag” at the barrier joints. Both the anti-symmetric and the double shear arrangements result in relatively strong connections where the dominate load on the pin is shear. It should be noted, however, that for the anti-symmetrical case the right segment can move vertically upward relative to the left segment and situations may exist for which this would be undesirable.

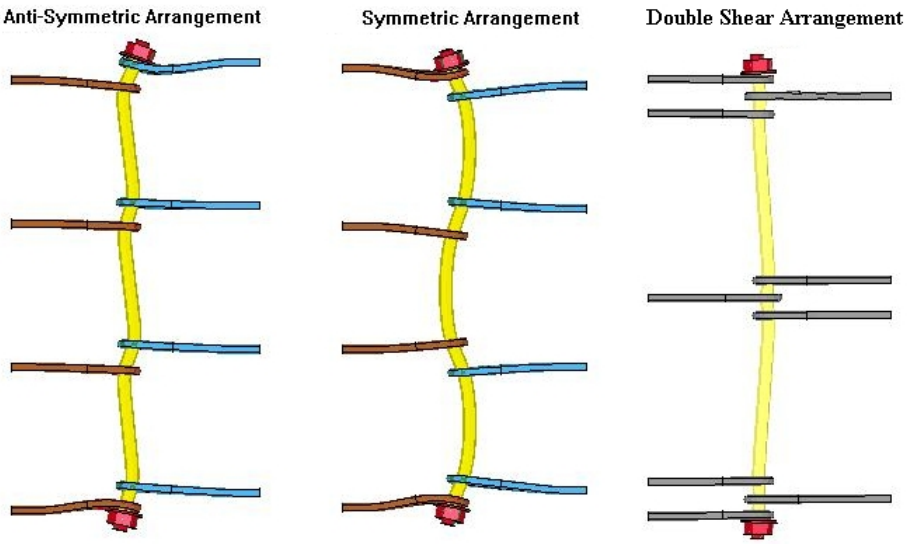


Figure 13: Typical deformation of a pin and loop assembly for symmetrical, anti-symmetrical and double shear loop arrangements.

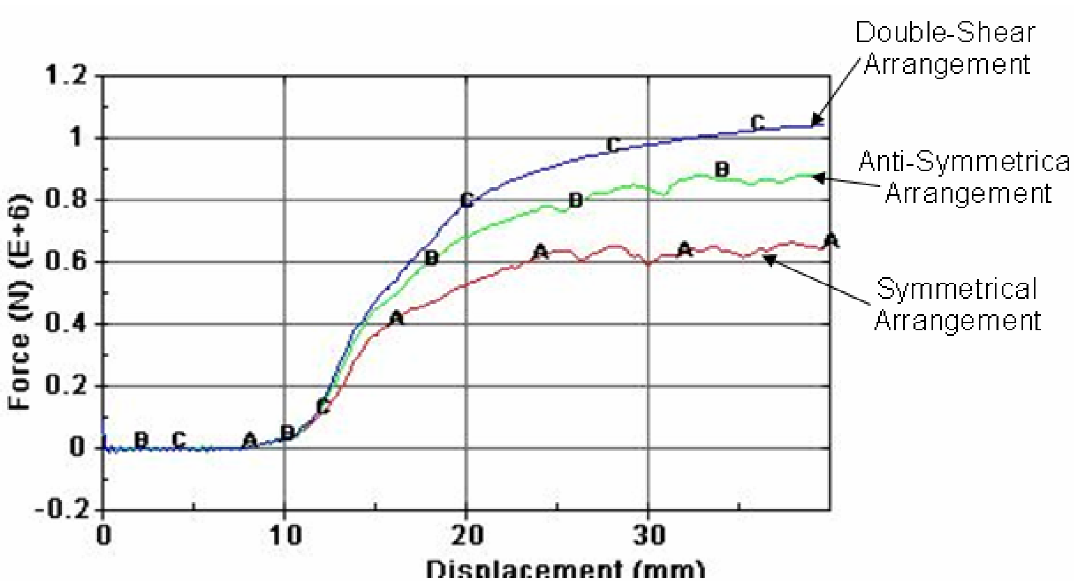
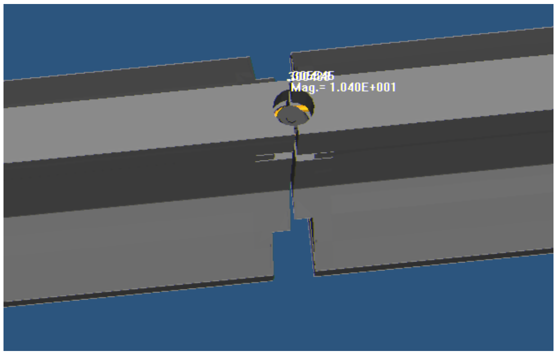


Figure 14: Force vs displacement for anti-symmetrical, symmetrical and double shear arrangement of pin-loops.

Another important consideration in a PCB design is the geometry of the ends of the barrier segments and the spacing of the segments. In general, the closer the spacing between segments the less the joint can rotate without interference, which theoretically would result in less lateral deflection of the barrier system. In the ODOT 32-inch PCB design the geometry of segment ends allows the PCB segments to be positioned very close together, as shown in Figure 15. Unfortunately, the geometry results in a relatively small cross-sectional area of concrete along the upper portion of the PCB units at the joints. As the segments are pushed back during impact, the joint rotates and concrete spalls off when the two PCB segments press together, effectively opening up the joint further. In the full-scale test, the lateral deflection of the barrier was 5.48 ft (1.67 m) which is typical of similar barriers with greater spacing between PCB segments.



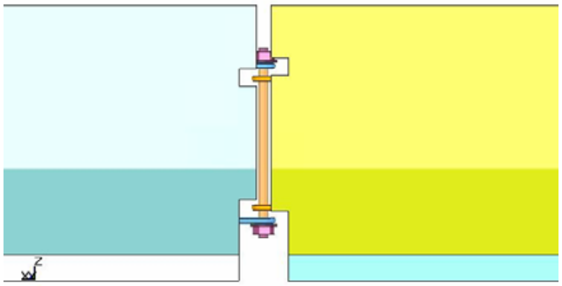


Figure 15: **Top** and side views of ODOT 32-inch PCB illustrating PCB segment end details.

The ends of the PCB segments for the 50-inch barrier design were modeled as a flat surface and the spacing between PCB segments was set to 3.15 inch (80 mm) to facilitate the connection process of the PCB units. The PCB units were modeled with linear elastic material properties in the impact region (i.e., barrier segments 5-10), and thus do not account for spalling concrete. The PCB units, up- and down-stream from the impact region, were model with rigid material properties. The pin and loop assembly were modeled with properties of steel using an elastic - piecewise linear plasticity model (Material 24 in LS-DYNA).

TASK 4 – ASSESSMENT OF DESIGNS

Finite element analyses of the 50-inch PCB were conducted to evaluate the performance of the system under NCHRP Report 350 Test 3-11 conditions. Two pin-and-loop connections were investigated: 1) Double shear pin-and-loop arrangement and 2) Combination pin-and-loop arrangement (see Task 3 for definition of terms). Additionally, two PCB segment lengths were analyzed: 10-ft (3.05-m) long segment and 12-ft (3.66-m) long segments. The 10-ft PCB segments lengths were analyzed because PCB's with 10-ft long segments have historically performed less successfully than the same PCB with longer segments (e.g., 12 and 20 ft long). Thus, successful performance with the shorter segments would imply a high probability of success with the longer PCB segments. Further, the shorter PCB segments are lighter making them easier to handle and install. Conversations with PCB manufactures, however, indicated that they prefer longer PCB units because of the decreased labor cost for manufacturing the PCB's as well as the decreased cost of installing the system (i.e., reduced number of connections over a given length of the barrier system). The equipment used for installing PCB's are very capable of handling 12-ft long segments and longer.

The simulation study matrix for Task 5 is shown in Table 2.

Table 2: Simulation study matrix.

	PCB Unit Length	**Connection Type**	**Vehicle Model**
Case 1	10-ft (3.05 m)	Double shear	C2500R
Case 2	10-ft (3.05 m)	Combination	C2500R
Case 3	10-ft (3.05 m)	Combination	C2500D v5-b
Case 4	12-ft (3.66 m)	Combination	C2500R
Case 5	12-ft (3.66 m)	Combination	C2500D v5-b

Case 1 (10-ft PCB units, double shear pin-and-loop, C2500R vehicle model)

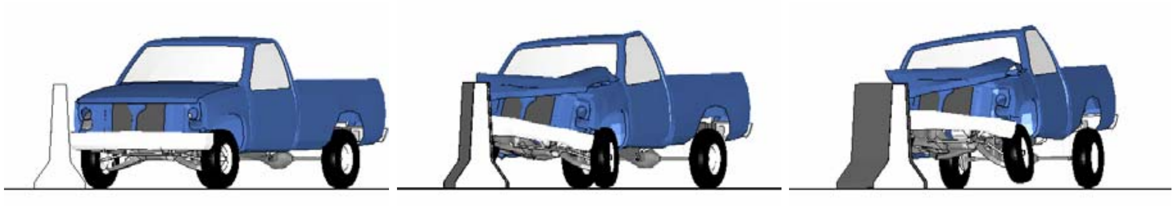
The C2500R vehicle model impacted the PCB barrier 3.9 ft (1.2 m) upstream from the joint between PCB units 7 and 8. Upon contact, the vehicle was traveling at 63.4 mph (102 km/hr) at an angle of 25 degrees with respect to the longitudinal direction of the barrier.

The vehicle started to climb the barrier when the front tire contacted the lower slope of the PCB face, as shown in Figure 16. At approximately 0.06 seconds the wheel of the vehicle pass the joint between PCB segments 7 and 8. At 0.150 seconds the front wheel of the vehicle passes by the joint between segments 8 and 9. The vehicle was parallel with the barrier at 0.200 seconds. At 0.500 seconds the vehicle exited the system in a very stable manner at a velocity of 45.4 mph (73 km/hr) at an angle of 13 degrees.

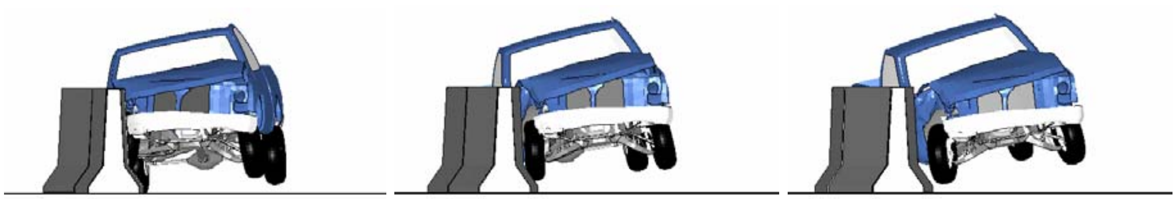
The overall kinematics and trajectory of the vehicle were very much improved compared to the vehicle's behavior in Test 3-11 of the ODOT 32-inch PCB, as shown in Figure 17. The maximum roll angle of the vehicle was 18.1 degrees and the maximum pitch angle was 7.5 degrees. The vertical trajectory of the vehicle was significantly less in the analysis of the 50-inch PCB compared to the vehicle's vertical trajectory in the 32-inch barrier test.

Deformations of the pin and loop connections were negligible as shown in Figure 18 and the integrity of the joint was maintained throughout the impact event. The maximum lateral deflection of the barrier was 3.18 ft (0.97 m) and the longitudinal movement of the up-stream end PCB unit was 0.31 ft (0.095 m).

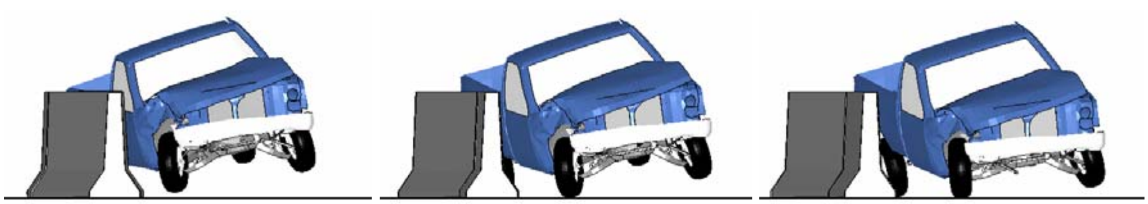
Time = 0.000 seconds, 0.060 seconds and 0.120 seconds



Time = 0.180 seconds, 0.240 seconds and 0.300 seconds



Time = 0.360 seconds, 0.420 seconds and 0.480 seconds



Time = 0.540 seconds and 0.700 seconds

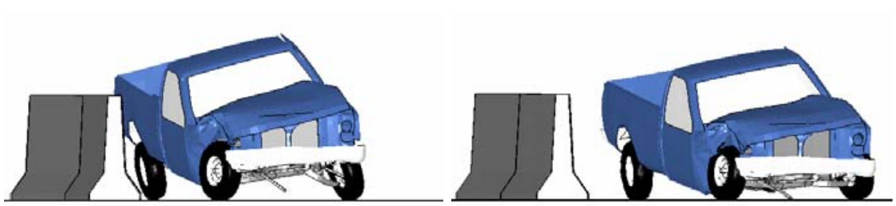


Figure 16: Sequential views of the finite element analysis of the 50-inch PCB under NCHRP Report 350 Test 3-11 conditions – Case 1.

Figure 17: Snapshot illustrating vehicle trajectory in Test 3-11 of ODOT 32-inch PCB (TRC Test No. 011012).

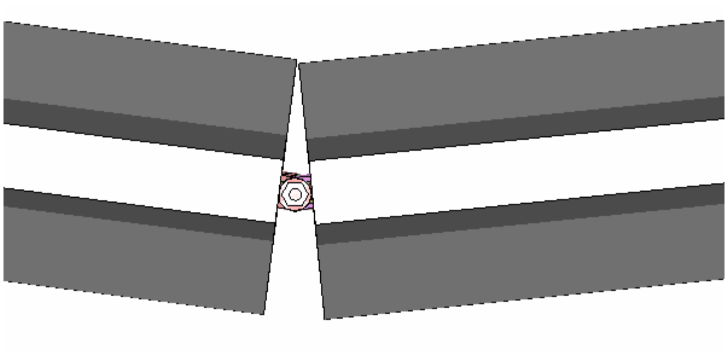


Figure 18: Negligible deformation in pin-and-loop connections.

Occupant Risk Values

The acceleration time-histories of the vehicle during the event are shown in Figure 19 and the angular displacement-time histories are shown in Figure 20. Data from the accelerometer located at the center of gravity of the vehicle were collected and input into the Test Risk Assessment Program (TRAP) Version 2.0 to determine occupant risk factors. The data as provided directly from TRAP is presented in Figure 21.

In the longitudinal direction, the occupant impact velocity was 21.0 ft/s (6.4 m/s) at 0.0897 seconds, the highest 0.010-second occupant ridedown acceleration was -6.0 g from 0.0956 and 0.1056 seconds, and the maximum 0.050-second average acceleration was -9.4 g between 0.0 and 0.0500 seconds.

In the lateral direction, the occupant impact velocity was 22.3 ft/s (6.8 m/s) at 0.0897 seconds, the highest 0.010-second occupant ridedown acceleration was -17.4 g from 0.3007 and 0.3107seconds, and the maximum 0.050-second average acceleration was -9.5 g between 0.0148 - 0.0648 seconds.

The acceleration spike at time = 0.300 seconds in the y-acceleration plot in Figure 19 coincides with when the side of the vehicle impacts against the barrier. Otherwise, the accelerations are relatively moderate. The maximum lateral deformation of the barrier was 3.18 ft (0.97 m).

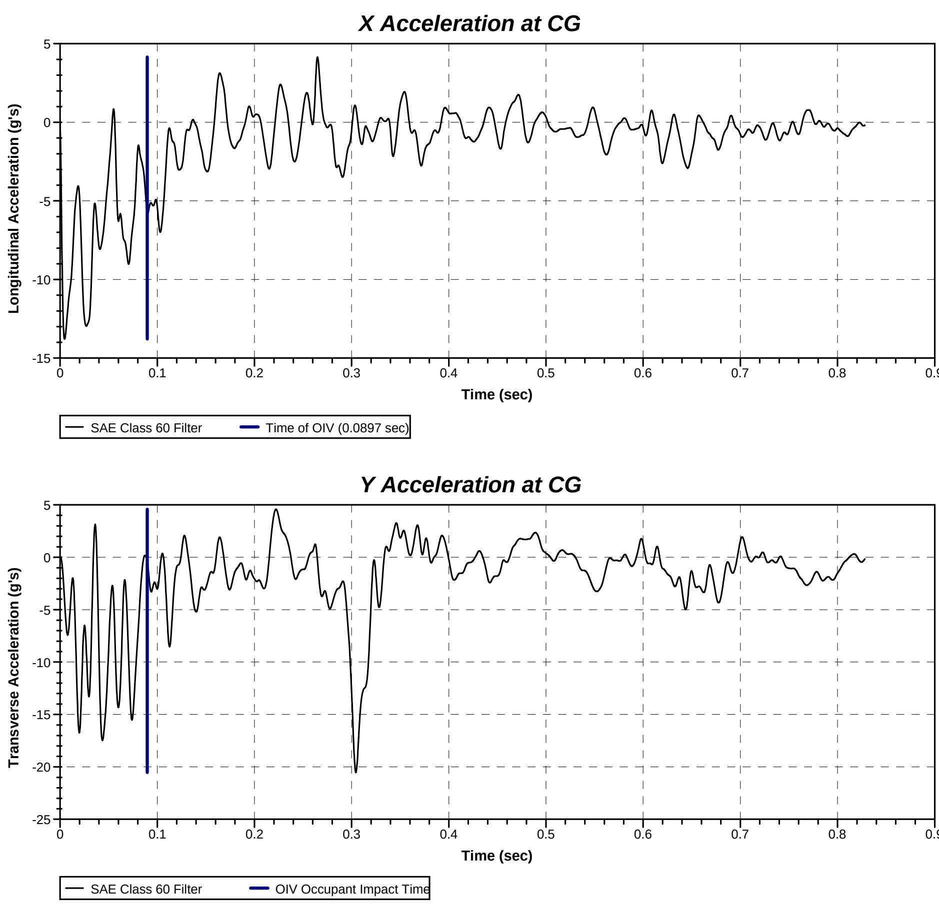


Figure 19: Acceleration-time histories at C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 1.

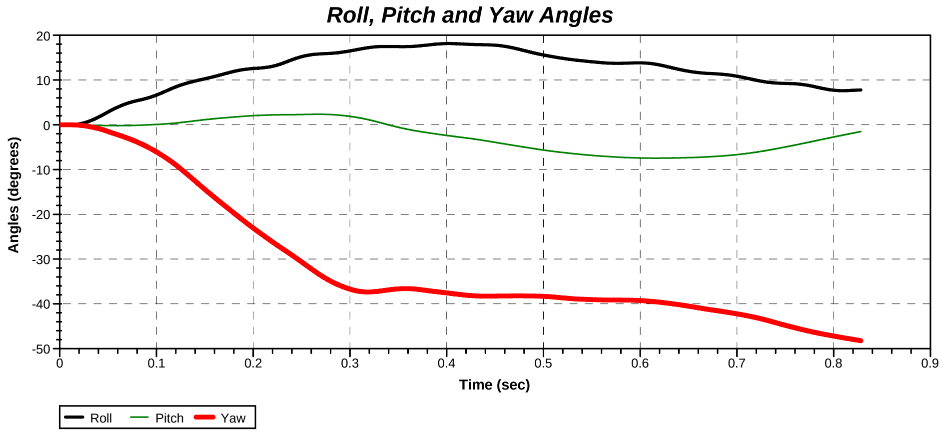


Figure 20: **Angular** displacement-time histories at the C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 1.

Test Summary Report

General Information

Analysis Agency:	Battelle COE
Analysis Number:	2005-02-14
Analysis Date:	02 / 14 / 2005
Analysis Article:	10-ft 50-inch PCB (double shear loops)

Test Vehicle

Description:	C2500R
Test Inertial Mass:	4409 lb (2000 kg)
Gross Static Mass:	4409 lb (2000 kg)

Impact Conditions

Speed: 63.4 mph (102 km/hr)

Angle: 25.0 degrees

Occupant Risk Factors

Impact Velocity	at 0.0897 seconds on right side of interior	
x-direction	21.0 ft/s (6.4 m/s)	
y-direction	22.3 ft/s (6.8 m/s)	
THIV:	28.9 ft/s (8.8 m/s) at 0.0863 seconds on right side of interior	
Ridedown Accelerations (g's)		
x-direction	-6.0	(0.0956 - 0.1056 seconds)
y-direction	-17.4	(0.3007 - 0.3107 seconds)
PHD (g's):	17.4	(0.3007 - 0.3107 seconds)
ASI:	1.20	(0.0151 - 0.0651 seconds)

Max. 50msec Moving Avg. Accelerations (g's)

x-direction	-9.4	(-0.0000 - 0.0500 seconds)
y-direction	-9.5	(0.0148 - 0.0648 seconds)
z-direction	-2.9	(0.0287 - 0.0787 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)

Roll	18.1	(0.4024 seconds)
Pitch	-7.5	(0.6153 seconds)
Yaw	-48.3	(0.8281 seconds)

Figure 21: Summary report of occupant risk values from the analysis using the TRAP software – Case 1.

Case 2 (10-ft PCB units, combination pin-and-loop, C2500R vehicle model)

The C2500R vehicle model impacted the PCB barrier 3.9 ft (1.2 m) upstream from the joint between PCB units 7 and 8. Upon contact, the vehicle was traveling at 63.4 mph (102 km/hr) at an angle of 25 degrees with respect to the longitudinal direction of the barrier.

The vehicle started to climb the barrier when the front tire contacted the lower slope of the PCB face, as shown in Figure 23. At approximately 0.06 seconds the wheel of the vehicle passed by the joint between PCB segments 7 and 8. At 0.200 seconds the front wheel of the vehicle passed by the joint between segments 8 and 9. The vehicle was parallel with the barrier at 0.250 seconds. At 0.550 seconds the vehicle exited the system in a very stable manner at a velocity of 37.9 mph (61 km/hr) at an angle of 14 degrees.

The overall kinematics and trajectory of the vehicle were very stable. The maximum roll angle of the vehicle was 11.0 degrees and the maximum pitch angle was 4.4 degrees. The vertical trajectory of the vehicle was significantly reduced compared to the vehicle's vertical trajectory in the 32-inch barrier test.

Time = 0.000 seconds, 0.060 seconds and 0.120 seconds

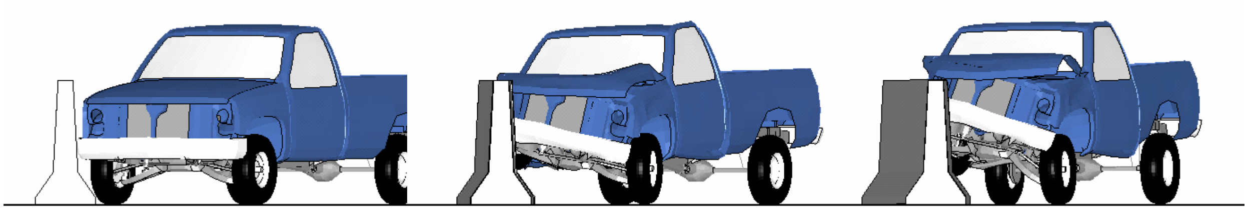
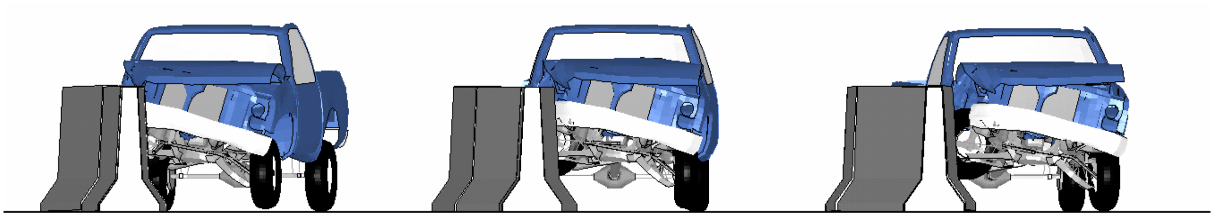
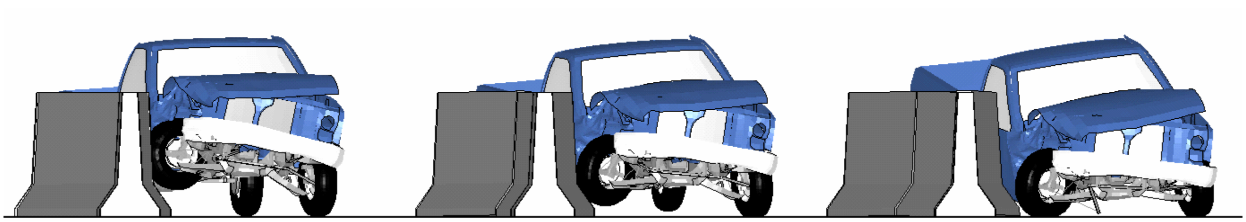


Figure 22: Sequential views of the finite element analysis of the 50-inch PCB under NCHRP Report 350 Test 3-11 conditions – Case 2.

Time = 0.180 seconds, 0.240 seconds and 0.300 seconds



Time = 0.360 seconds, 0.420 seconds and 0.480 seconds



Time = 0.540 seconds

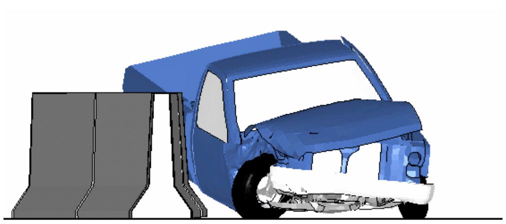


Figure 23: **[continued]** Sequential views of the finite element analysis of the 50-inch PCB under NCHRP Report 350 Test 3-11 conditions – Case 2.

Deformations of the pin and loop connections were negligible and the integrity of the joint was maintained throughout the impact event. The maximum lateral deflection of the barrier was 4.92 ft (1.5 m) and the longitudinal movement of the up-stream end PCB unit was 0.63 ft (0.19 m).

Occupant Risk Values

The acceleration time-histories of the vehicle during the event are shown in Figure 24 and the angular displacement-time histories are shown in Figure 24. Data from the accelerometer located at the center of gravity of the vehicle were collected and input TRAP Version 2.0 to determine occupant risk factors. The data as provided directly from TRAP is presented in Figure 25.

In the longitudinal direction, the occupant impact velocity was 22.0 ft/s (6.7 m/s) at 0.0915 seconds, the highest 0.010-second occupant ridedown acceleration was -9.4 g from 0.0924 and 0.1024 seconds, and the maximum 0.050-second average acceleration was -9.7 g between 0.0 and 0.0500 seconds.

In the lateral direction, the occupant impact velocity was 19.4 ft/s (5.9 m/s) at 0.0915 seconds, the highest 0.010-second occupant ridedown acceleration was -15.1 g from 0.3857 and 0.3957seconds, and the maximum 0.050-second average acceleration was -9.9 g between 0.0169 and 0.0669 seconds.

The maximum ridedown accelerations occur early in the impact event and again at approximately 0.38 seconds when the rear of the vehicle impacts the barrier. The maximum lateral deformation of the barrier was 4.92 ft (1.5 m).

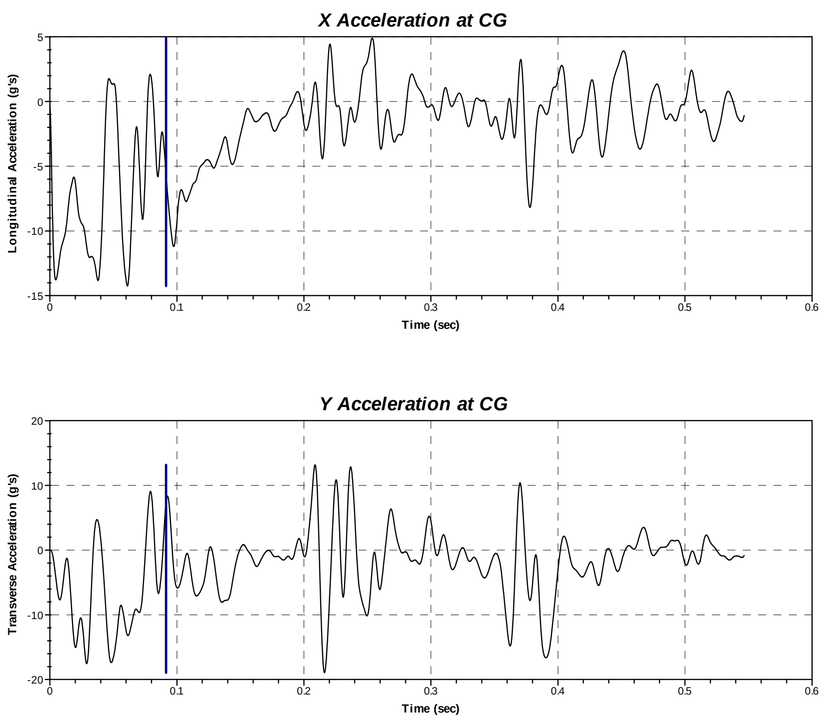


Figure 24: Acceleration-time histories at C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 2.

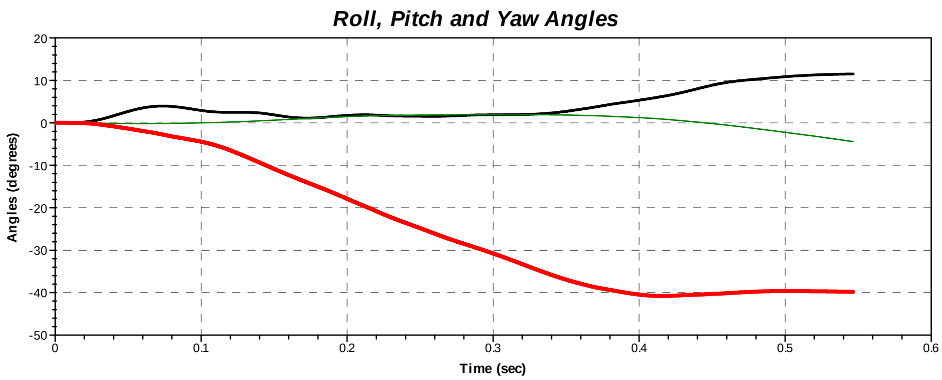


Figure 25: Angular displacement-time histories at the C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 2.

Test Summary Report

General Information			
Analysis Agency:	Battelle COE		
Analysis Number:	2005-03-25		
Analysis Date:	03 / 25 / 2005		
Analysis Article:	10-ft 50-inch PCB (combination pin-and-loops)		
Test Vehicle			
Description:	C2500R		
Test Inertial Mass:	4409 lb (2000 kg)		
Gross Static Mass:	4409 lb (2000 kg)		
Impact Conditions			
Speed:	63.4 mph (102.0 km/hr)		
Angle:	25.0 degrees		
Occupant Risk Factors			
Impact Velocity	at 0.0915 seconds on right side of interior		
x-direction	22 ft/s (6.7 m/s)		
y-direction	19.4 ft/s (5.9 m/s)		
THIV :	28.2 ft/s (8.6 m/s) at 0.0882 seconds on right side of interior		
Ridedown Accelerations (g's)			
x-direction	-9.4	(0.0924 - 0.1024 seconds)	
y-direction	-15.1	(0.3857 - 0.3957 seconds)	
PHD (g's):	15.1	(0.3857 - 0.3957 seconds)	
ASI:	1.29	(0.0167 - 0.0667 seconds)	
Max. 50msec Moving Avg. Accelerations (g's)			
x-direction	-9.7	(-0.0063 - 0.0437 seconds)	
y-direction	-9.9	(0.0169 - 0.0669 seconds)	
z-direction	-2.4	(0.0234 - 0.0734 seconds)	
Max Roll, Pitch, and Yaw Angles (degrees)			
Roll	11.5	(0.5466 seconds)	
Pitch	-4.4	(0.5466 seconds)	
Yaw	-40.8	(0.4151 seconds)	

Figure 26: Summary report of occupant risk values from the analysis using the TRAP software – Case 2.

Case 3 (10-ft PCB units, combination pin-and-loop, C2500D v5-b vehicle model)

The C2500D v5-b vehicle model impacted the PCB barrier 3.9 ft (1.2 m) upstream from the joint between PCB units 7 and 8. Upon contact, the vehicle was traveling at 63.4 mph (102 km/hr) at an angle of 25 degrees with respect to the longitudinal direction of the barrier.

At approximately 0.05 seconds the tie-rod on the impact-side wheel failed and the wheel pushed back into the wheel well (see Figure 26). At approximately 0.09 seconds the wheel passed by the joint between PCB segments 7 and 8. At 0.210 seconds the front wheel of the vehicle passed by the joint between segments 8 and 9. The vehicle was parallel with the barrier at 0.250 seconds. At 0.550 seconds the vehicle exited the system in a very stable manner at a velocity of 39.5 mph (62.5 km/hr) at an angle of 13.7 degrees.

The overall kinematics and trajectory of the vehicle were very stable. The maximum roll angle of the vehicle was -14.2 degrees and the maximum pitch angle was -5.4 degrees.

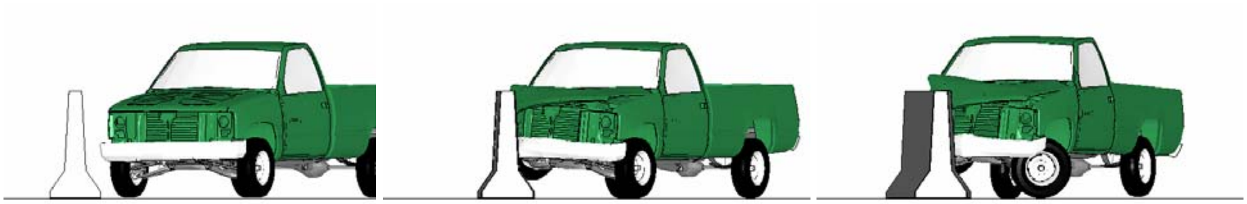
Deformations of the pin and loop connections were negligible and the integrity of the joint was maintained throughout the impact event. The maximum lateral deflection of the barrier was 4.66 ft (1.42 m) and the longitudinal movement of the up-stream end PCB unit was 0.58 ft (0.178 m).

Occupant Risk Values

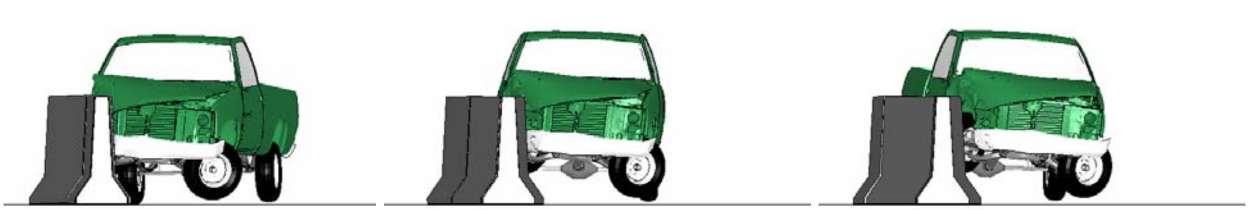
The acceleration time-histories of the vehicle during the event are shown in Figure 28 and the angular displacement-time histories are shown in Figure 29. Data from the accelerometer located at the center of gravity of the vehicle were collected and input into TRAP Version 2.0 to determine occupant risk factors. The data as provided directly from TRAP is presented in Figure 30.

In the longitudinal direction, the occupant impact velocity was 22.0 ft/s (6.7 m/s) at 0.1164 seconds, the highest 0.010-second occupant ridedown acceleration was -12.8 g from 0.3869 and 0.3969 seconds, and the maximum 0.050-second average acceleration was -10.5 g between 0.0530 and 0.1030 seconds.

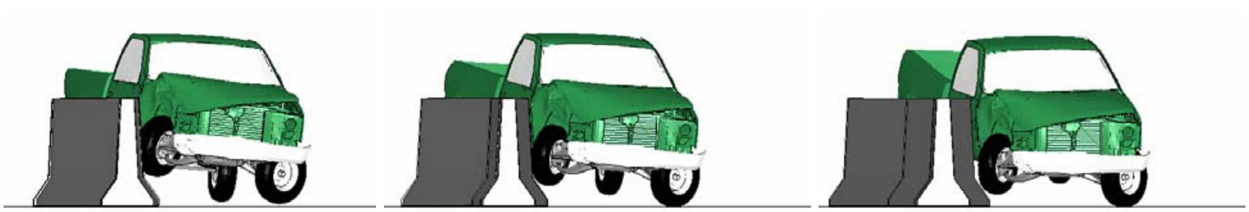
Time = 0.000 seconds, 0.060 seconds and 0.120 seconds



Time = 0.180 seconds, 0.240 seconds and 0.300 seconds



Time = 0.360 seconds, 0.420 seconds and 0.480 seconds



Time = 0.530 seconds

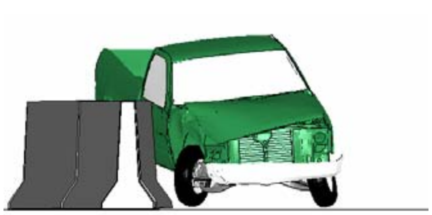


Figure 27: Sequential views of the finite element analysis of the 50-inch PCB under NCHRP Report 350 Test 3-11 conditions – Case 3.

In the lateral direction, the occupant impact velocity was 20.3 ft/s (6.2 m/s) at 0.1164 seconds, the highest 0.010-second occupant ridedown acceleration was -12.2 g from 0.3771 and 0.3871 seconds, and the maximum 0.050-second average acceleration was -9.2 g between 0.0460 and 0.0960 seconds.

The maximum ridedown accelerations occur early in the impact event and again at approximately 0.38 seconds when the rear of the vehicle impacts the barrier. The maximum lateral deformation of the barrier was 4.6 ft (1.42 m).

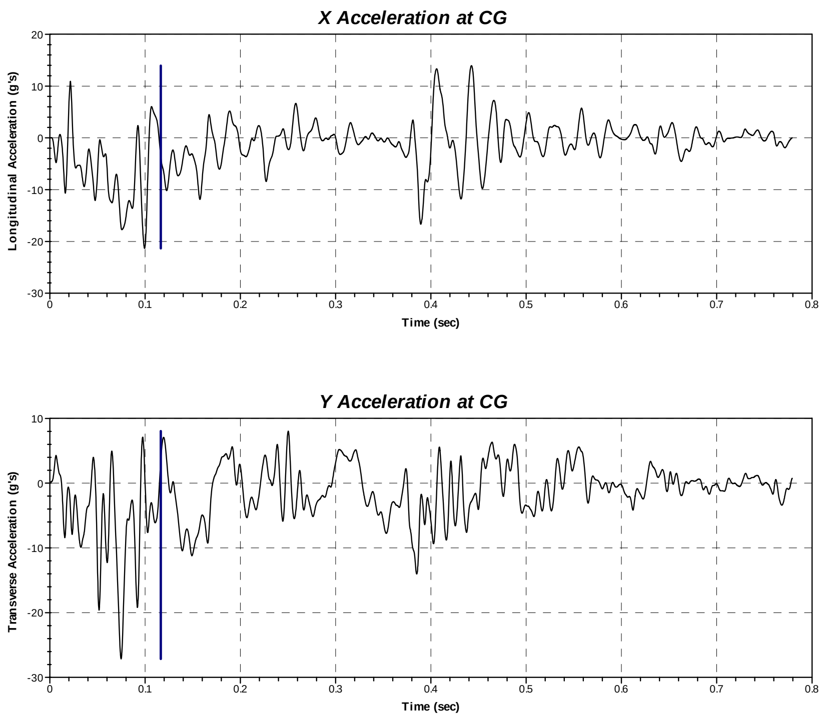


Figure 28: Acceleration-time histories at C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 3.

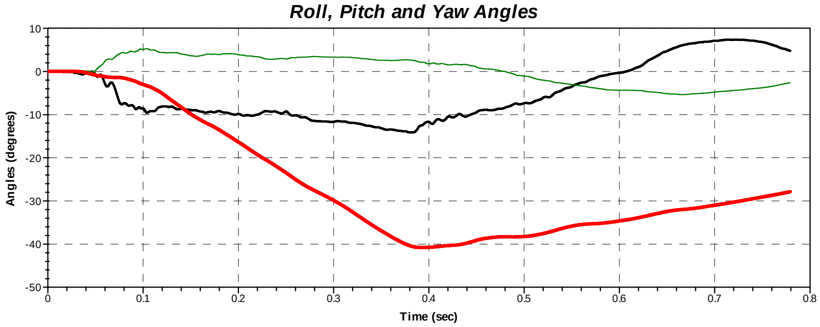


Figure 29: Angular displacement-time histories at the C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 3.

Test Summary Report

General Information

Analysis Agency:	Battelle COE
Analysis Number:	2005-08-02
Analysis Date:	08 / 02 / 2005
Analysis Article:	10-ft 50-inch PCB (combination loops)

Test Vehicle

Description:	C2500D v5b
Test Inertial Mass:	4409 lb (2000 kg)
Gross Static Mass:	4409 lb (2000 kg)

Impact Conditions

Speed: 63.4 mph (102 km/hr)
Angle: 25.0 degrees

Occupant Risk Factors

Impact Velocity	at 0.1164 seconds on right side of interior	
x-direction	22.0 ft/s (6.7 m/s)	
y-direction	20.3 ft/s (6.2 m/s)	

THIV : 28.9 ft/s (8.8 m/s) at 0.1137 seconds on right side of interior

Ridedown Accelerations (g's)		
x-direction	-12.8	(0.3869 - 0.3969 seconds)
y-direction	-12.2	(0.3771 - 0.3871 seconds)
PHD (g's):	18.5	(0.3838 - 0.3938 seconds)
ASI:	1.59	(0.0464 - 0.0964 seconds)

Max. 50msec Moving Avg. Accelerations (g's)

x-direction	-10.5	(0.0530 - 0.1030 seconds)
y-direction	-9.2	(0.0460 - 0.0960 seconds)
z-direction	-9.6	(0.0464 - 0.0964 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)

Roll	-14.2	(0.3835 seconds)
Pitch	-5.4	(0.6648 seconds)
Yaw	-40.8	(0.3941 seconds)

Figure 30: Summary report of occupant risk values from the analysis using the TRAP software – Case 3.

Case 4 (12-ft PCB units, combination pin-and-loop, C2500R vehicle model)

The C2500R vehicle model impacted the PCB barrier 3.9 ft (1.2 m) upstream from the joint between PCB units 7 and 8. Upon contact, the vehicle was traveling at 63.4 mph (102 km/hr) at an angle of 25 degrees with respect to the longitudinal direction of the barrier.

The vehicle started to climb the barrier when the front tire contacted the lower slope of the PCB face, as shown in Figure 31. At approximately 0.04 seconds the wheel of the vehicle passed by the joint between PCB segments 7 and 8. At 0.22 seconds the front wheel of the vehicle passed by the joint between segments 8 and 9. The vehicle was parallel with the barrier at 0.25 seconds. At 0.57 seconds the vehicle exited the system in a very stable manner at a velocity of 36.7 mph (59 km/hr) at an angle of 14 degrees.

The overall kinematics and trajectory of the vehicle were very stable. The maximum roll angle of the vehicle was 14.7 degrees and the maximum pitch angle was -12.4 degrees.

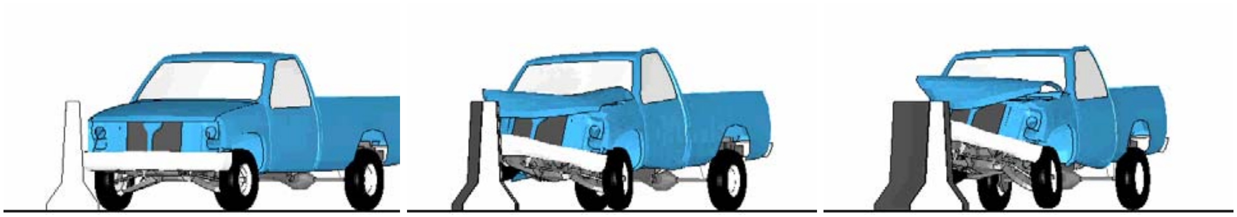
Deformations of the pin and loop connections were negligible and the integrity of the joint was maintained throughout the impact event. The maximum lateral deflection of the barrier was 4.27 ft (1.3 m) and the longitudinal movement of the up-stream end PCB unit was 0.512 ft (0.16 m).

Occupant Risk Values

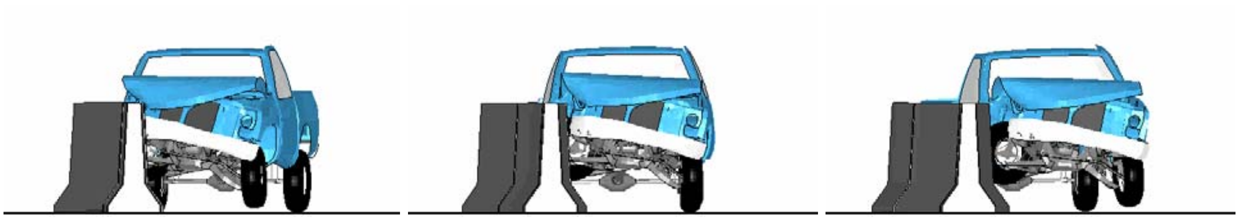
The acceleration time-histories of the vehicle during the event are shown in Figure 32 and the angular displacement-time histories are shown in Figure 33. Data from the accelerometer located at the center of gravity of the vehicle were collected and input into the TRAP Version 2.0 to determine occupant risk factors. The data as provided directly from TRAP is presented in Figure 33.

In the longitudinal direction, the occupant impact velocity was 22.0 ft/s (6.7 m/s) at 0.0937 seconds, the highest 0.010-second occupant ridedown acceleration was -8.0 g between 0.1235 and 0.1335 seconds, and the maximum 0.050-second average acceleration was -9.3 g between 0.000 and 0.0500 seconds.

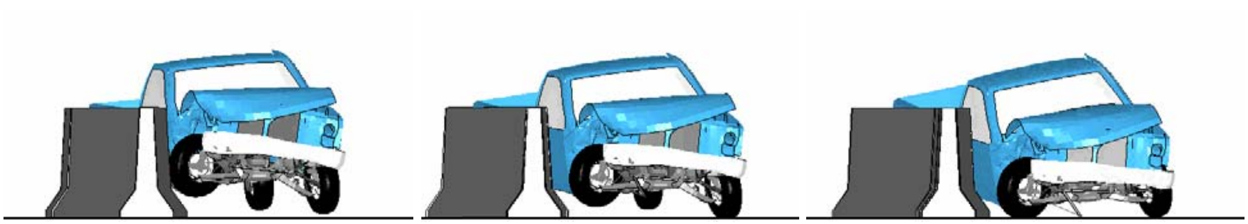
Time = 0.000 seconds, 0.060 seconds and 0.120 seconds



Time = 0.180 seconds, 0.240 seconds and 0.300 seconds



Time = 0.360 seconds, 0.420 seconds and 0.480 seconds



Time = 0.750 seconds and 1.000 seconds

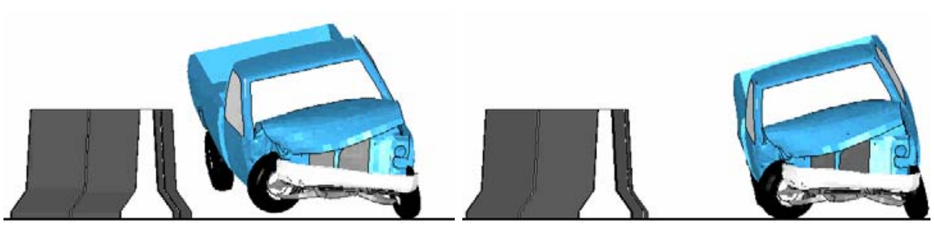
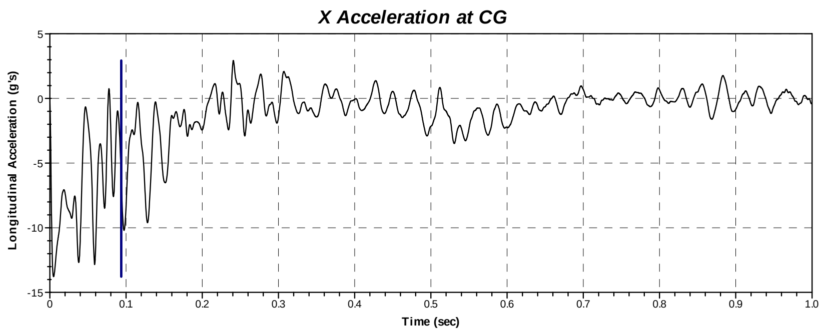


Figure 31: Sequential views of the finite element analysis of the 50-inch PCB under NCHRP Report 350 Test 3-11 conditions – Case 4.

In the lateral direction, the occupant impact velocity was 18.4 ft/s (5.6 m/s) at 0.0937 seconds, the highest 0.010-second occupant ridedown acceleration was -8.9 g from 0.1378 and 0.1478 seconds, and the maximum 0.050-second average acceleration was -9.5 g between 0.0158-0.0658 seconds.

The maximum ridedown accelerations occur early in the impact event and are relatively moderate throughout the remainder of the redirection.



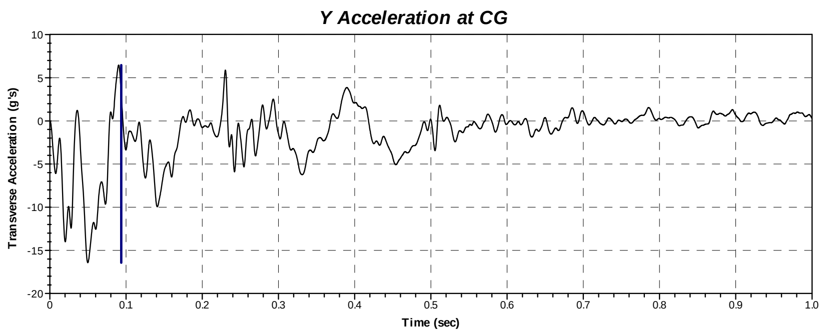


Figure 32: Acceleration-time histories at C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 4.

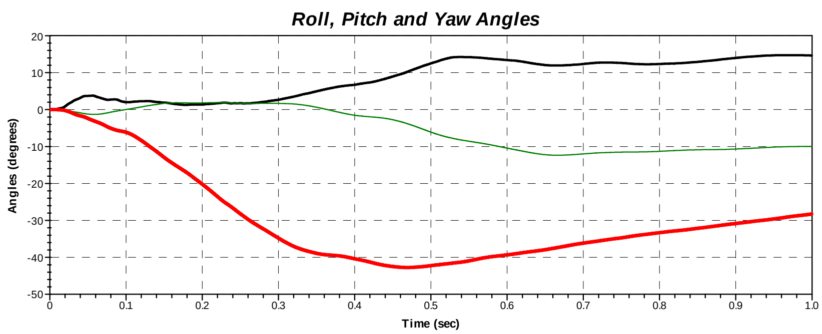


Figure 33: Angular displacement-time histories at the C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 4.

Test Summary Report

General Information

Analysis Agency:	Battelle COE
Analysis Number:	2005-08-10
Analysis Date:	08 / 10 / 2005
Analysis Article:	12-ft 50-inch PCB (Combination pin-and-loop)

Test Vehicle

Description:	C2500R
Test Inertial Mass:	4409 lb (2000 kg)
Gross Static Mass:	4409 lb (2000 kg)

Impact Conditions

Speed: 63.4 mph (100.0 km/hr)
Angle: 25.0 degrees

Occupant Risk Factors

Impact Velocity	at 0.0937 seconds on right side of interior	
x-direction	22.0 ft/s (6.7 m/s)	
y-direction	18.4 ft/s (5.6 m/s)	
THIV:	27.6 ft/s (8.4 m) at 0.0886 seconds on right side of interior	
Ridedown Accelerations (g's)		
x-direction	-8.0	(0.1235 - 0.1335 seconds)
y-direction	-8.9	(0.1378 - 0.1478 seconds)
PHD (g's):	9.5	(0.1391 - 0.1491 seconds)
ASI:	1.23	(0.0164 - 0.0664 seconds)

Max. 50msec Moving Avg. Accelerations (g's)

x-direction	-9.3	(-0.0000 - 0.0500 seconds)
y-direction	-9.5	(0.0158 - 0.0658 seconds)
z-direction	-2.6	(0.0237 - 0.0737 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)

Roll	14.7	(0.9761 seconds)
Pitch	-12.4	(0.6656 seconds)
Yaw	-42.8	(0.4690 seconds)

Figure 33: Summary report of occupant risk values from the analysis using the TRAP software – Case 4.

Case 5 (12-ft PCB units, combination pin-and-loop, C2500D v5-b vehicle model)

The C2500D v5-b vehicle model impacted the PCB barrier 3.9 ft (1.2 m) upstream from the joint between PCB units 7 and 8. Upon contact, the vehicle was traveling at 63.4 mph (102 km/hr) at an angle of 25 degrees with respect to the longitudinal direction of the barrier.

The vehicle started to climb the barrier when the front tire contacted the lower slope of the PCB face, as shown in Figure 34. At approximately 0.06 seconds the wheel of the vehicle passed by the joint between PCB segments 7 and 8. At 0.25 seconds the front wheel of the vehicle passed by the joint between segments 8 and 9. The vehicle was parallel with the barrier at 0.29 seconds. At 0.57 seconds the vehicle exited the system in a very stable manner at a velocity of 39.1 mph (63 km/hr) at an angle of 13 degrees.

The overall kinematics and trajectory of the vehicle were very stable. The maximum roll angle of the vehicle was 15.6 degrees and the maximum pitch angle was -5.7 degrees.

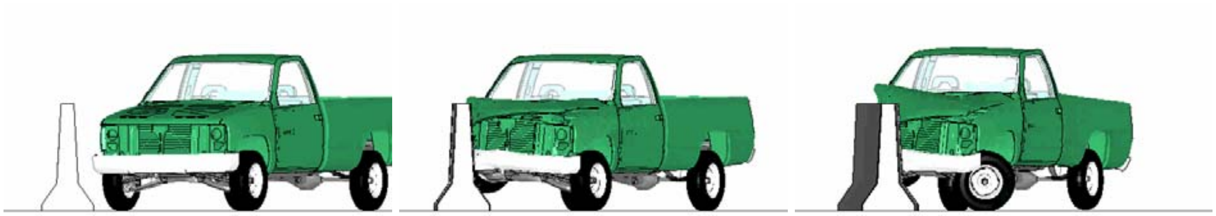
Deformations of the pin and loop connections were negligible and the integrity of the joint was maintained throughout the impact event. The maximum lateral deflection of the barrier was 3.6 ft (1.1 m) and the longitudinal movement of the up-stream end PCB unit was 0.413 ft (0.126 m).

Occupant Risk Values

The acceleration time-histories of the vehicle during the event are shown in Figure 35 and the angular displacement-time histories are shown in Figure 36. Data from the accelerometer located at the center of gravity of the vehicle were collected and input into (TRAP Version 2.0 to determine occupant risk factors. The data as provided directly from TRAP is presented in Figure 37.

In the longitudinal direction, the occupant impact velocity was 24.9 ft/s (7.6 m/s) at 0.1025 seconds, the highest 0.010-second occupant ridedown acceleration was -7.8 g from 0.1424 and 0.1524 seconds, and the maximum 0.050-second average acceleration was -9.4 g between 0.0334 and 0.0834 seconds.

Time = 0.000 seconds, 0.060 seconds and 0.120 seconds



Time = 0.180 seconds, 0.240 seconds and 0.300 seconds

Time = 0.360 seconds, 0.420 seconds and 0.480 seconds

Time = 0.750 seconds and 0.940 seconds

Figure 34: Sequential views of the finite element analysis of the 50-inch PCB under NCHRP Report 350 Test 3-11 conditions – Case 5.

In the lateral direction, the occupant impact velocity was 17.1 ft/s (5.2 m/s) at 0.1025 seconds, the highest 0.010-second occupant ridedown acceleration was -11.3 g from 0.1368 and 0.1468 seconds, and the maximum 0.050-second average acceleration was -10.2 g between 0.0339-0.0839 seconds.

The maximum ridedown accelerations occur early in the impact event and are relatively moderate throughout the remainder of the redirection.

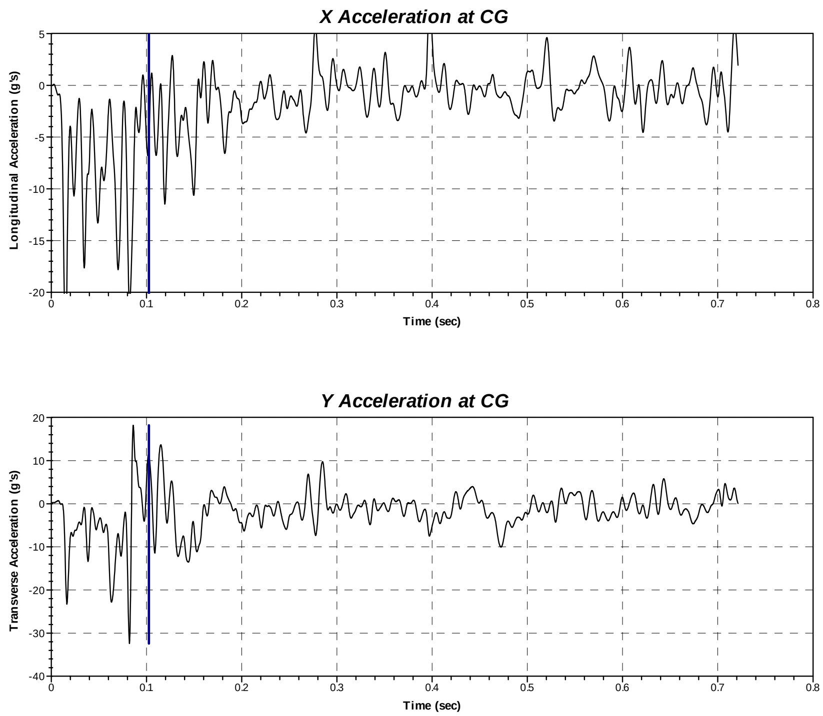


Figure 35: Acceleration-time histories at C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 5.

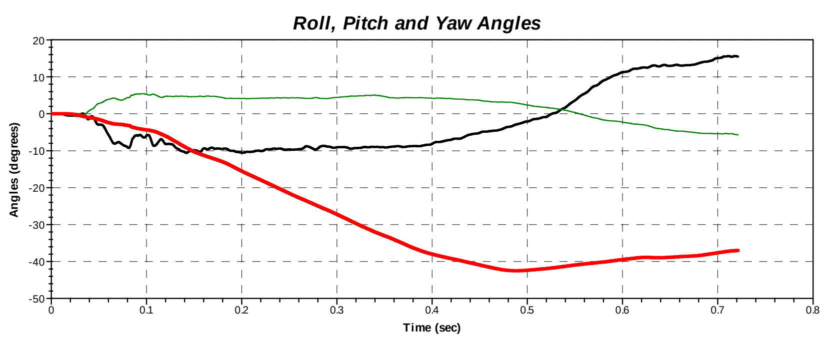


Figure 36: Angular displacement-time histories at the C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model – Case 5.

Test Summary Report

General Information			
Analysis Agency:	Battelle COE		
Analysis Number:	2005-08-11		
Analysis Date:	08 / 11 / 2005		
Analysis Article:	12-ft 50-inch PCB (combination pin-and-loop)		
Test Vehicle			
Description:	C2500D-v5b		
Test Inertial Mass:	4409 lb (2000 kg)		
Gross Static Mass:	4409 lb (2000 kg)		
Impact Conditions			
Speed:	63.4 mph (102 km/hr)		
Angle:	25.0 degrees		
Occupant Risk Factors			
Impact Velocity	at 0.1025 seconds on right side of interior		
x-direction	24.9 ft/s (7.6 m/s)		
y-direction	17.1 ft/s (5.2 m/s)		
THIV :	29.5 ft/s (9.0 m/s) at 0.0992 seconds on right side of interior		
Ridedown Accelerations (g's)			
x-direction	-7.8	(0.1424 - 0.1524 seconds)	
y-direction	-11.3	(0.1368 - 0.1468 seconds)	
PHD (g's):	13.6	(0.1082 - 0.1182 seconds)	
ASI:	1.74	(0.0342 - 0.0842 seconds)	
Max. 50msec Moving Avg. Accelerations (g's)			
x-direction	-9.4	(0.0334 - 0.0853 seconds)	
y-direction	-10.2	(0.0339 - 0.0839 seconds)	
z-direction	-10.9	(0.0343 - 0.0843 seconds)	
Max Roll, Pitch, and Yaw Angles (degrees)			
Roll	15.6	(0.7180 seconds)	
Pitch	-5.7	(0.7213 seconds)	
Yaw	-42.5	(0.4882 seconds)	

Figure 37: Summary report of occupant risk values from the analysis using the TRAP software – Case 5.

TASK 5 – FULL-SCALE CRASH TEST[8]

A full-scale crash test of the ODOT 50-inch PCB was conducted on April 12, 2006 at the Transportation Research Center in East Liberty, Ohio. The 50-inch PCB System consisted of seventeen 12-ft long pre-cast reinforced concrete barriers interlocked with pin-and-loop connectors (refer to Appendix 1). The test and data analysis procedures were performed in accordance with NCHRP Report 350 test 3-11.

Test Article

The test article was a 50-inch high, modified New Jersey shape concrete barrier with each segment being 12-feet long. Since the base width of the PCB system remained a standard 24 inches and the top width remained 6 inches, the extended upper sloped face was about 3 degrees steeper than the upper slope of the ODOT 32-inch tall New Jersey shape PCB.

The system was manufactured by Lindsay Concrete Products Company in Canal Fulton, Ohio. The concrete was specified to have a 28-day break strength of 5000 psi. Reinforcement consisted of five #5 steel bars and two sections of 6 x 6 x W2.9 welded wire fabric. Segments were connected by 1.25-inch diameter x 43-inch long galvanized Grade 5 (high strength) steel bolts passing through 8 loops (4 loops at the ends of each segment). These loops are made from 0.75-inch diameter A36 steel bars bent to an inside radius of 2.25 inches. There are two loops at the top of each segment at one end and a single upper loop at the opposite end. The bottom loops are reversed, with a single loop beneath the upper double loops and vice versa. Each segment also has a single loop, approximately centered between the upper and lower sets of loops.

The barrier system was positioned such that the impacting vehicle struck the longitudinal barrier system at the seventh PCB unit from the upstream end of the system, as shown in Figure 38. The critical impact point for the system was 47.2 inch (1.2 m) upstream of the joint between PCB units #7 and #8.

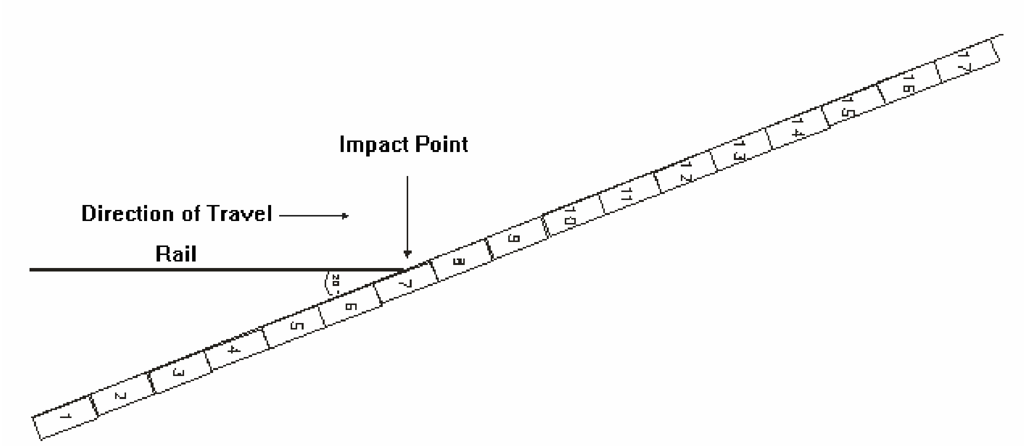


Figure 38: Schematic drawing of the ODOT 50" PCB System for test TRC-060412.

Test Vehicle

A 2003 Chevrolet Silverado 2500 2-door pickup truck was used for this crash test. Test inertia weight was 4498.7 lb (2040.6 kg) and the gross static weight of the vehicle was 4498.7 lb (2040.6 kg). The height to the lower edge of the vehicle bumper at the center of the vehicle was 20.9 inch (531 mm) and it was 27.2 inch (692 mm) to the upper edge of the bumper. The vehicle was directed into the installation using the tow system, and was released to be freewheeling and unrestrained just prior to impact.

Electronic Instrumentation and Data Processing

The test vehicle was instrumented with three angular rate transducers to measure roll, pitch and yaw; a primary and redundant set of triaxial accelerometers near the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels.

The electronic signals from the accelerometers and transducers were collected by means of a self-contained onboard digital data acquisition system at a rate of 10,000 samples per second. The onboard digital data acquisition system was connected by an umbilical cable to the data acquisition room only for pre-test setup and checkout and post-test data downloading.

Each data channel was filtered to SAE J211 OCT88 Channel Class 1000. Immediately preceding each test, all data channels were checked and balanced by the data acquisition system software. The data was downloaded from the onboard digital storage to the data acquisition room by an umbilical cable, which is connected from the test vehicle to the personal computer in the data acquisition room. Following initial verification of the data signal, a fiber optic cable transferred the data to the digital computer for all subsequent digital data processing.

Subsequent digital filtering of the data was performed. As specified in NCHRP 350, the filters conform to the Society of Automotive Engineers Recommended Practice SAE J211 OCT88.

Photographic Instrumentation and Data Processing

Photographic coverage of the test included five (5) high-speed digital cameras: two (2) overhead with fields of view perpendicular to the ground and directly over the impact point, one upstream and one downstream, with fields of view parallel to the impacted side of the array, and one with a field of view perpendicular to the impact point on the non-impacted side of the vehicle. Two (2) real-time panning cameras recorded the test: one upstream with a field of view parallel to the impacted side of the array, and one with a field of view perpendicular to the array from the non-impacted side of the vehicle. The camera positions are illustrated in the schematic drawing of Figure 39 and camera information is provided in Table 3.

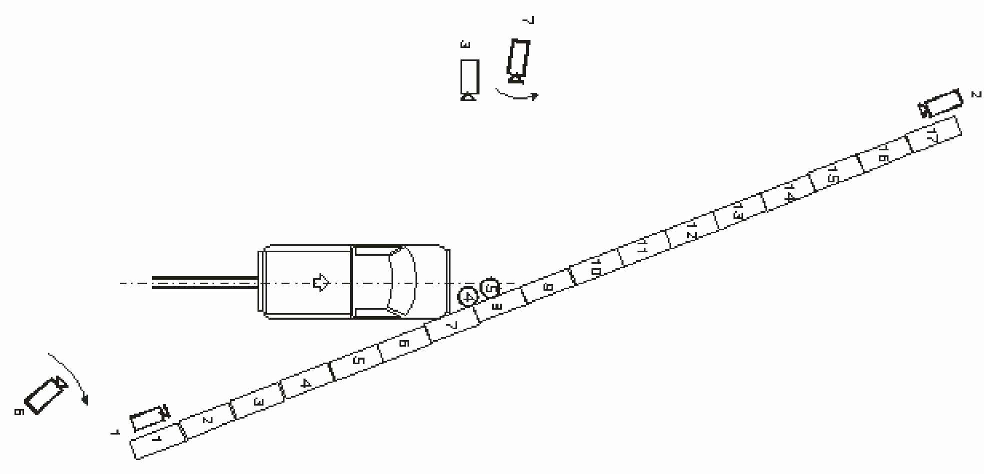


Figure 39: Schematic drawing illustrating camera positions.

Table 3: Photographic Instrumentation Details**.**

Camera Number	**Location**	**Type**	**Lens (mm)**	**Speed (fps)**
1	Upstream barrier (wide angle)	Redlake-LE	12.5	500
2	Downstream barrier (wide angle)	Redlake-LE	50	500
3	Left (wide angle)	Redlake-LE	12.5	500
4	Overhead (wide angle)	Redlake-LE	6.5	500
5	Overhead (tight angle)	Redlake-LE	25	500
6	Upstream panning	Panasonic	Zoom	30
7	Perpendicular panning	Panasonic	Zoom	30

Pressure sensitive tape switches were positioned on the impacting vehicle to indicate the instant of contact with the 50-inch PCB system. The views from these high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement and angular data. One (1) real-time motion picture camera was used to record and document a portion of the barrier array assembly, and the condition of the test vehicle before and after the test. A still camera was used to record and document conditions of the test vehicle and installation before and after the test.

Description of Timing Marks on TRC, Inc. Digital High-Speed Cameras

All TRC Inc. high-speed cameras are equipped with frame and timing displays. When converted to AVI files, this information is displayed in the upper left corner of the picture.

Test Vehicle Propulsion and Guidance

The test vehicle was towed into the test article by towing cables attached to each side of the vehicle's front suspension and connected to the drive cable by a frangible skate assembly. The frangible skate assembly was attached to a monorail providing lateral guidance while towing the vehicle. The test vehicle's steering wheel was unlocked to allow proper tracking of vehicle while attached to the monorail. At a predetermined point prior to impact, the frangible skate assembly struck a block of steel driving the wedge portion of the assembly through the assembly's channels. This action simultaneously released the tension to the drive cable, the vehicle towing cables, and the attachment to the monorail. This method allowed the vehicle to free-roll to the impact point without influence from the propulsion system.

Test Description

The vehicle, traveling at 62.5 mph (100.5 km/h) and 25 degrees relative to the barrier system, impacted the segment labeled number seven at 47.2 inch (1.2 m) upstream from the joint between segments labeled number 7 and number 8 (see figure 40).

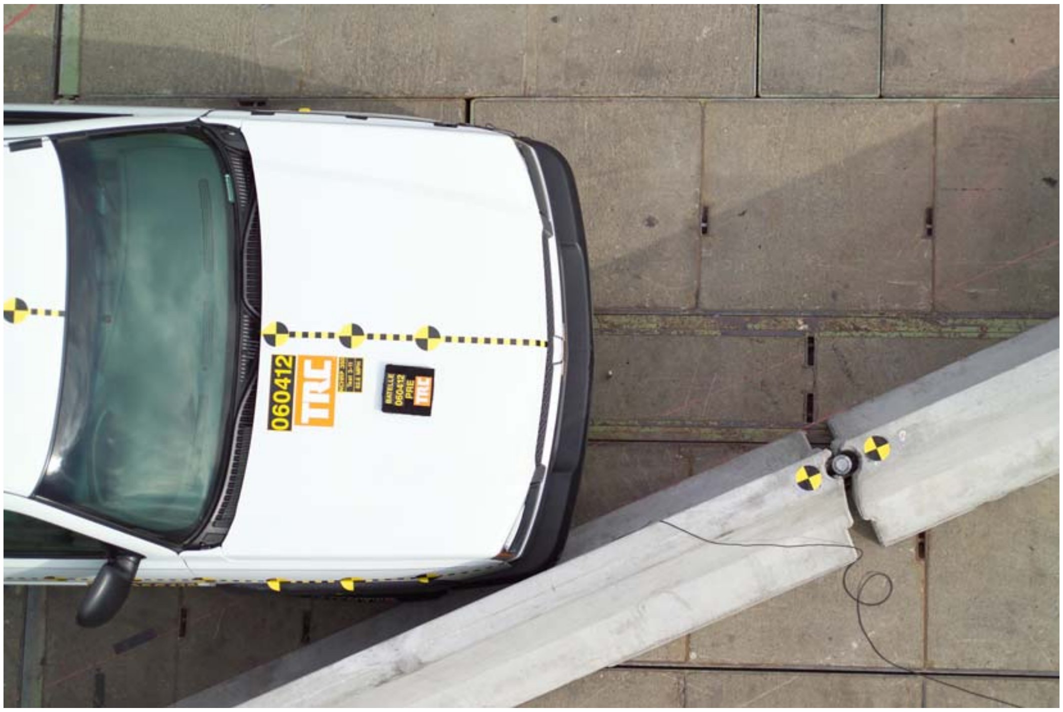
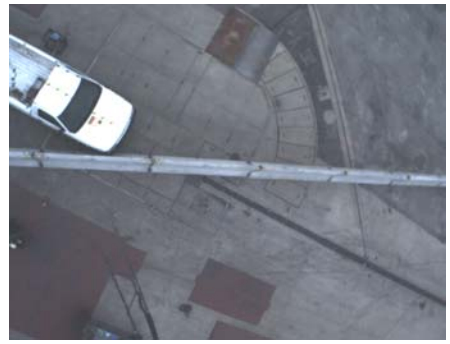


Figure 40: Impacting vehicle/Battelle 50” PCB Array Barrier System geometrics for test 060412.

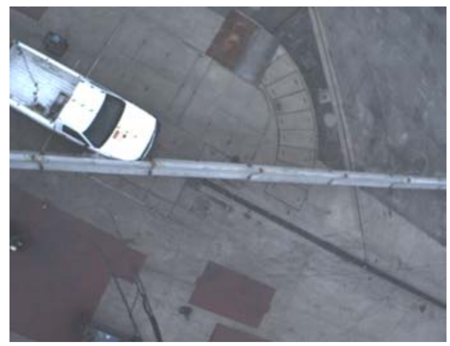
Sequential views of the impact event from a downstream viewpoint and an overhead viewpoint are shown in Figure 41. At approximately 32 milliseconds after initial impact (time = 0.0) the barrier began to displace laterally, away from the vehicle. At approximately 72 milliseconds, as the vehicle encountered barrier segment eight, it began to yaw counter-clockwise away from the barrier. The vehicle continued along barrier segment eight, displacing it laterally and continuing to be redirected. The vehicle’s right side was in contact with the barrier at approximately 304 milliseconds and continued to be redirected as it displaced barrier segments eight, nine, and ten. The vehicle lost contact with the barrier at approximately 578 milliseconds. The vehicle came to rest upright after the impact approximately 165 ft (50.3 m) downstream from the original impact point and 6.89 ft (2.1 m) left of the barrier face.

The overall kinematics and trajectory of the vehicle were very stable. The maximum roll angle of the vehicle was 16.2 degrees and the maximum pitch angle was -10.2 degrees.

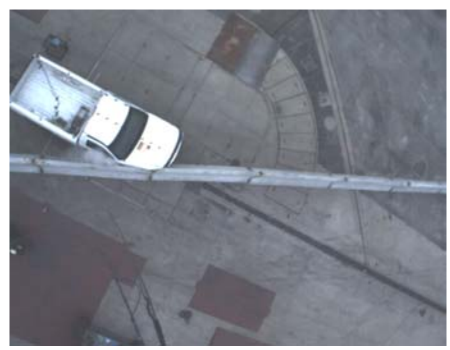
0.000 s



0.030 s



0.060 s



0.140 s

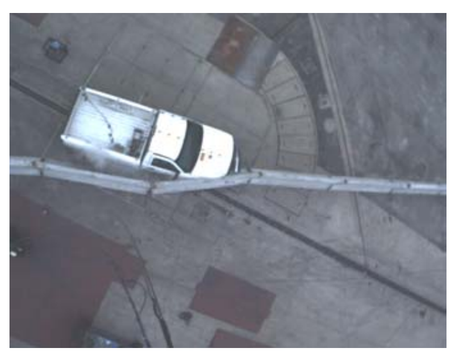
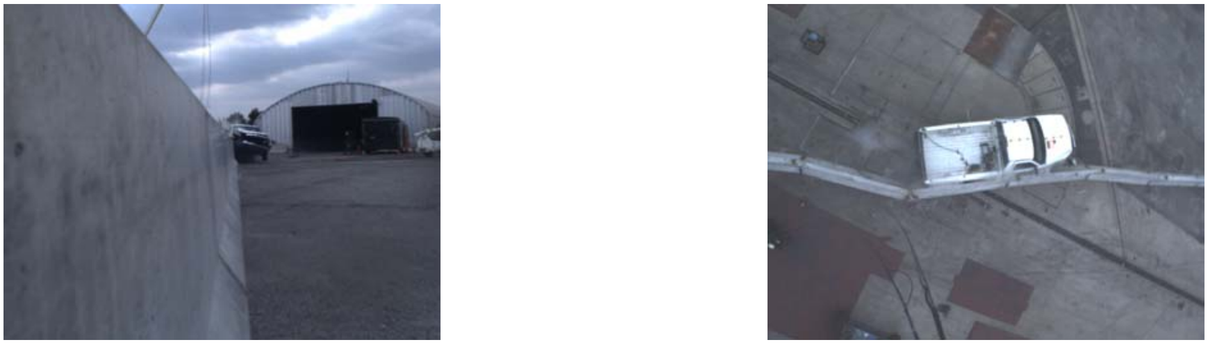


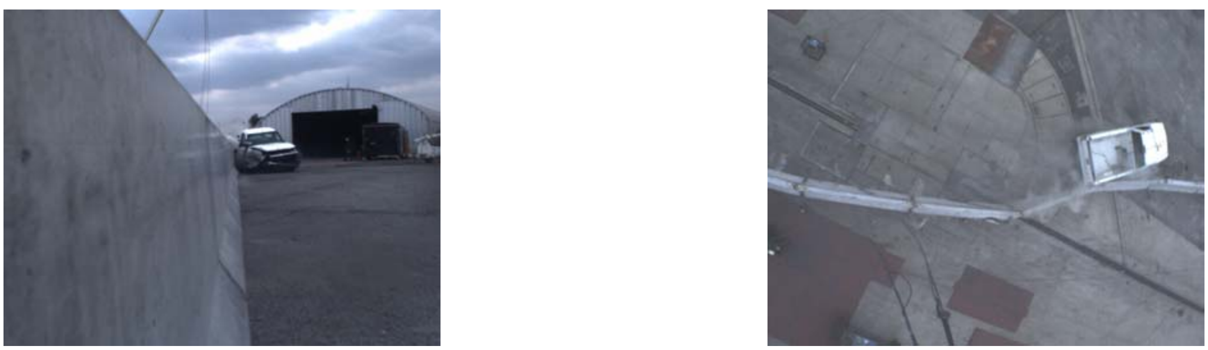
Figure 41: Sequential photographs for test 060412 (overhead and front views).

0.280 s



0.424 s

0.560 s



0.680 s

Figure 41: Sequential photographs for test 060412 (overhead and front views) (continued).

1.400 s

2.000 s

Figure 41: Sequential photographs for test 060412 (overhead and front views) (continued).

Damage to Test Installation

Five (5) of the seventeen sections of 50” PCB system were damaged and/or rearranged in the immediate impact zone. Individual barrier sections, numbers 7, 8, and 9 incurred noticeable damage, with portions of the concrete broken away. The connections of the PCB units sustained minimal damage as there was no noticeable deformation of the pin-and-loop connections, as shown in Figures 42 and 43. The maximum lateral deflection of the barrier was 5.15 ft (1.57 m) and the longitudinal movement of the up-stream end PCB unit was 0.83 ft (0.254 m). The schematic drawing in Figure 44 illustrates the maximum lateral displacements of the PCB segments.

Figure 42: ODOT 50-inch PCB System after test 060412.

Figure 43: Joint connection of the PCB after test 060412 (integrity of the joints were maintained throughout the impact event).

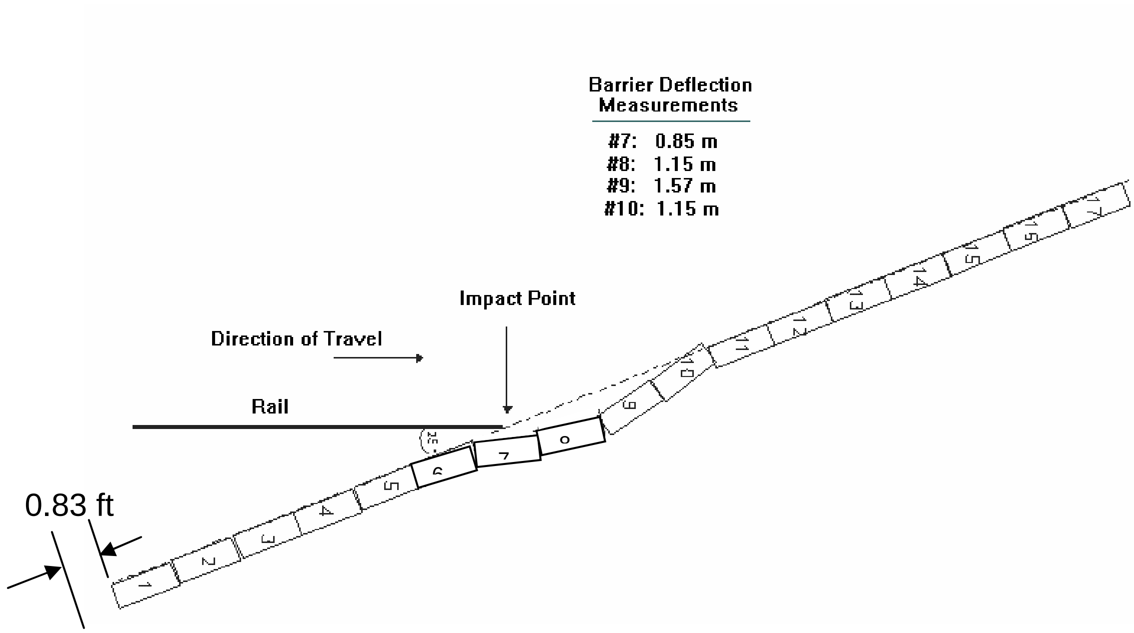


Figure 44: Schematic drawing denoting barrier deflections.

Damage to Test Vehicle

Damage to the vehicle was confined to the front and right front sides as shown in Figure 45. The bumper, hood, right fender, and right front suspension were severely damaged. The left side of the vehicle was only moderately damaged. Maximum exterior crush was not measured. Maximum crush into the occupant compartment was 0.79 inch (20 mm) to the right toeboard to rear interior area.

Figure 45: Impacting vehicle after test 060412.

Occupant Risk Values

The acceleration time-histories of the vehicle during the event are shown in Figure 46 and the angular displacement-time histories are shown in Figure 47. Data from the accelerometer located at the center of gravity of the vehicle were collected and input into TRAP Version 2.0 to determine occupant risk factors. The data as provided directly from TRAP is presented in Figure 48.

In the longitudinal direction, the occupant impact velocity was 14.8 ft/s (4.5 m/s) at 0.1004 seconds, the highest 0.010-second occupant ridedown acceleration was -5.4 g from 0.6351 and 0.6451 seconds, and the maximum 0.050-second average acceleration was -6.8 g between 0.0160 and 0.0660 seconds.

In the lateral direction, the occupant impact velocity was 20.0 ft/s (6.1 m/s) at 0.1004 seconds, the highest 0.010-second occupant ridedown acceleration was -8.6 g from 0.3046 and 0.3146 seconds, and the maximum 0.050-second average acceleration was -9.0 g between 0.0352-0.0852 seconds.

The highest ridedown accelerations occur early in the impact event and at the time when the front of the vehicle contacts the ground after redirection. The accelerations are relatively moderate throughout the remainder of the redirection.

Figure 49 shows a summary of results for test 060412 and Table 4 shows the performance evaluation summary.

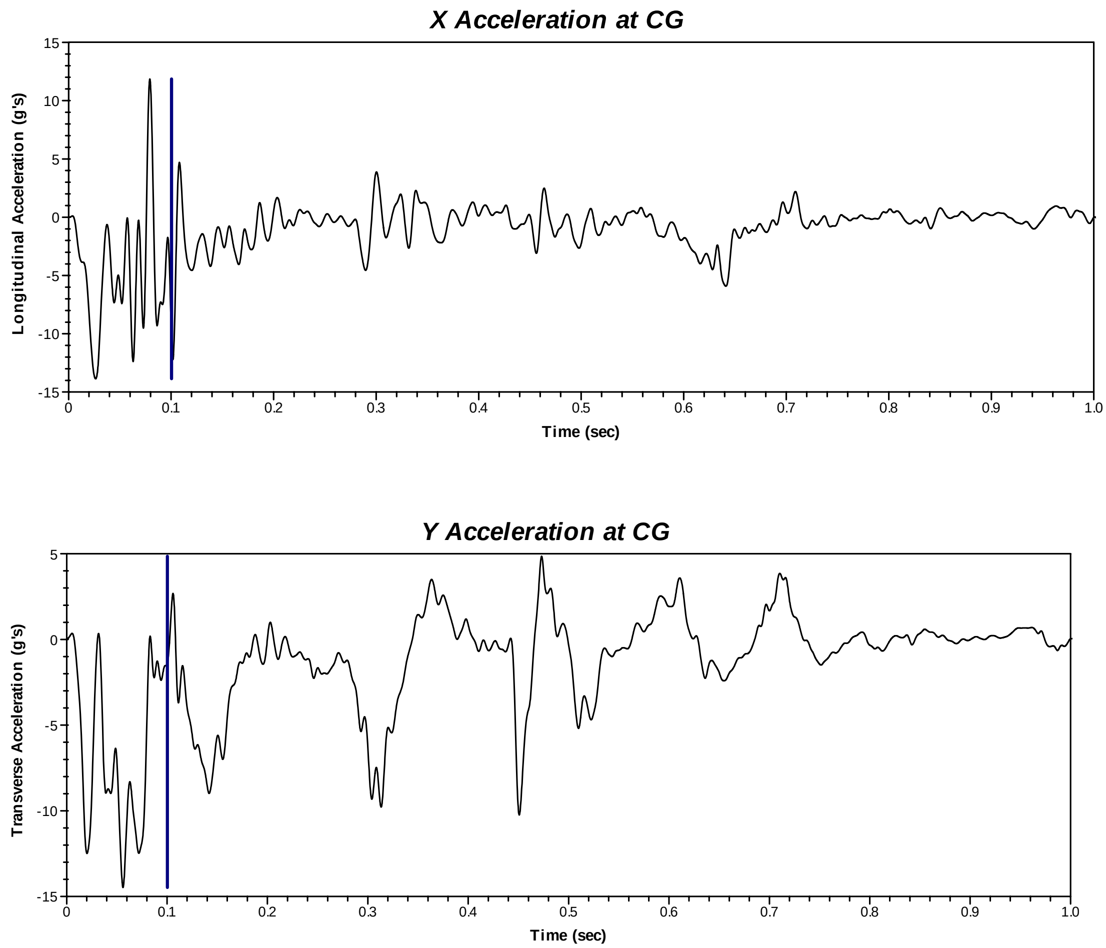


Figure 46: Acceleration-time histories at C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB in test 060412.

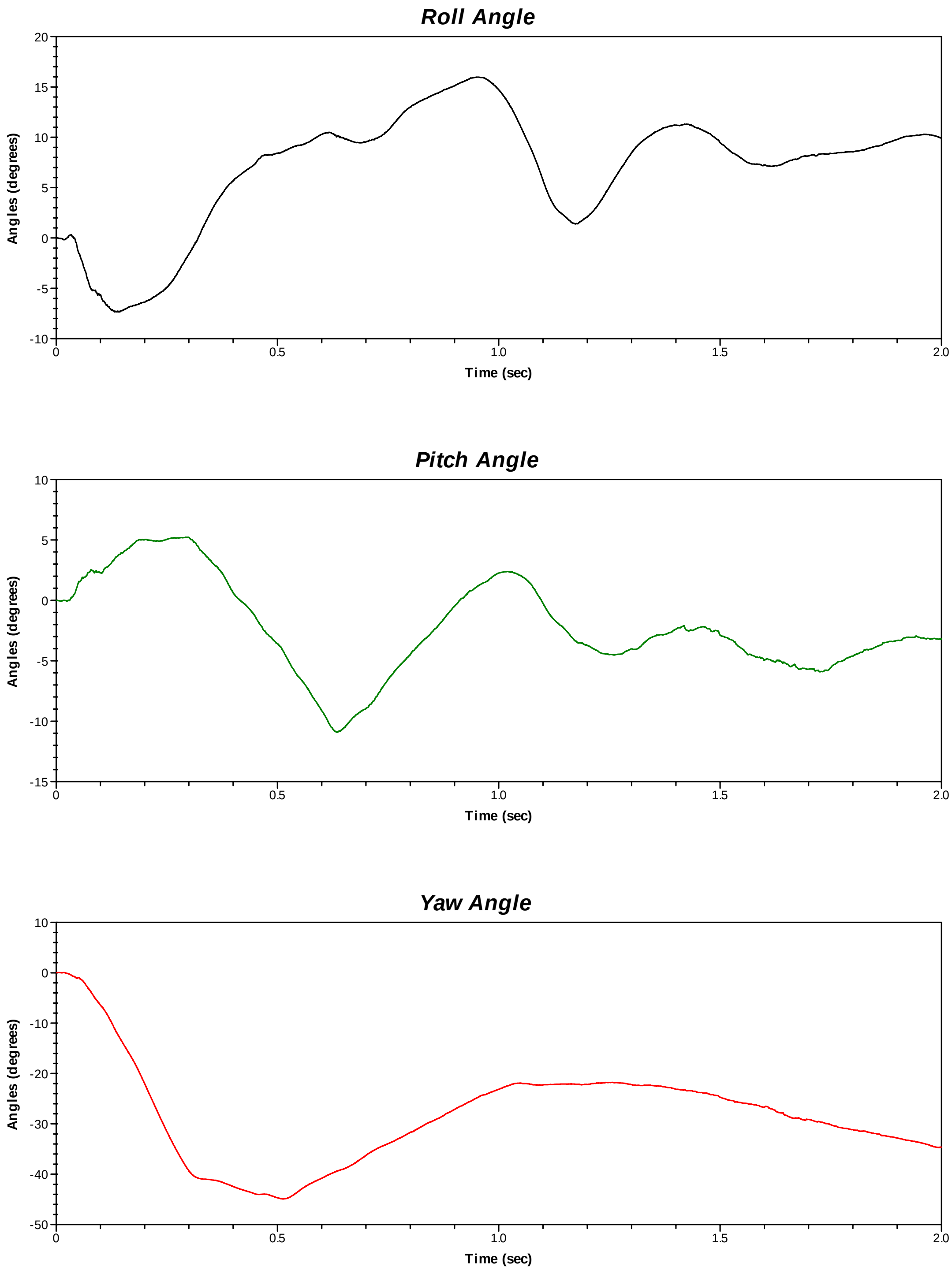


Figure 47: Angular displacement-time histories at the C.G. of pickup truck in local coordinates for the test 3-11 impact analysis of the 50-inch PCB Model in test 060412.

Test Summary Report

General Information

Test Agency:	Transportation Research Center
Test Number:	060412
Analysis Date:	04 / 12 / 2006
Analysis Article:	50-inch PCB / 12-ft sections

Test Vehicle

Description:	Chevrolet Silverado 2500
Test Inertial Mass:	4499 lb (2040.6 kg)
Gross Static Mass:	4499 lb (2040.6 kg)

Impact Conditions

Speed: 62.4 mph (100.5 km/hr)

Angle: 25.0 degrees

Occupant Risk Factors

Impact Velocity	at 0.1003 seconds on right side of interior	
x-direction	14.8 ft/s (4.5 m/s)	
y-direction	20.0 ft/s (6.1 m/s)	
THIV :	23.6 ft/s (7.2 m/s) at 0.0970 seconds on right side of interior	
Ridedown Accelerations (g's)		
x-direction	-5.4	(0.6351 - 0.6451 seconds)
y-direction	-8.6	(0.3046 - 0.3146 seconds)
PHD (g's):	8.9	(0.1352 - 0.1452 seconds)
ASI:	1.10	(0.0173 - 0.0673 seconds)

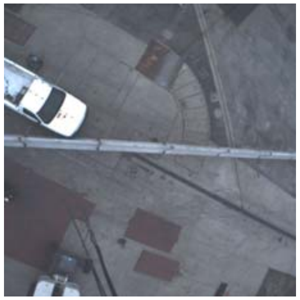
Max. 50msec Moving Avg. Accelerations (g's)

x-direction	-6.8	(0.0160 - 0.0660 seconds)
y-direction	-9.0	(0.0319 - 0.0819 seconds)
z-direction	-4.4	(0.6040 - 0.6540 seconds)

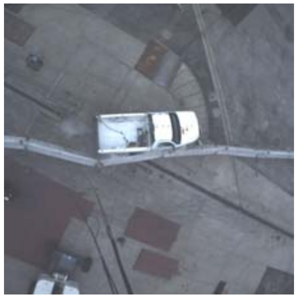
Max Roll, Pitch, and Yaw Angles (degrees)

Roll	16.2	(0.9518 seconds)
Pitch	-10.2	(0.6348 seconds)
Yaw	-45.1	(0.5133 seconds)

Figure 48: Summary report of occupant risk values from the analysis using the TRAP software in test 060412.



0.000 s



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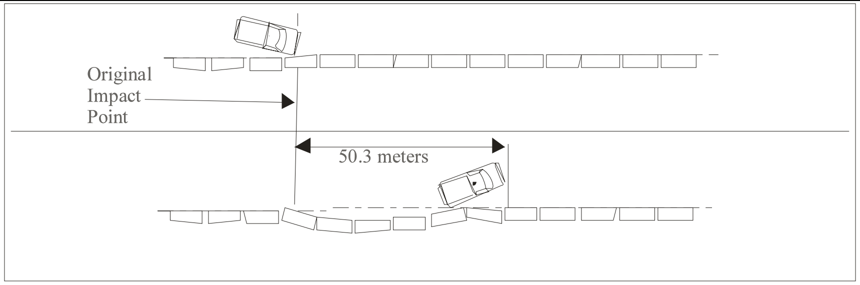
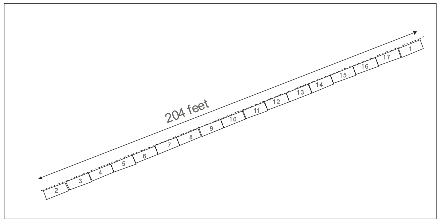
0.480 s

0.800 s





General Information

Test Agency	Transportation Research Center Inc. (TRC Inc.)
Test No.	060412
Date	April 12, 2006
Test Article	
Type	Longitudinal median barrier system
Name or Manufacturer	Battelle Memorial Institute
Size and/or dimension and material of key elements	17-50" x 12' steel reinforced portable concrete barriers
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	2000P
Model	2003 Chevrolet 2500 Pickup truck
Mass (kg)	
Curb	2254.3
Test Inertial	2040.6
Dummy(s)	N/A
Gross Static	2040.6

Impact Conditions	
Speed (km/h)	100.5
Angle (deg)	25.0
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.5
y-direction	6.1
THIV (optional)	N/A
Ridedown Acceleration (g's)	
x-direction	5.4
y-direction	8.6
PHD (optional)	N/A
ASI (optional)	N/A
Max. 0.050 –s Average (g's)	
x-direction	N/A
y-direction	N/A
z-direction	N/A

Test Article Deflections (m)	
Dynamic	~1.6
Permanent	~1.6
Vehicle Damage	
Exterior	
VDS	N/A
CDC	02FZEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	N/A
Max. Occ. Compart. Deformation (mm)	25
Post-Impact Vehicular Behavior	
Maximum Roll Angle (deg)	16.2
Maximum Pitch Angle (deg)	-10.2
Maximum Yaw Angle (deg)	-45.1

Figure 49: Summary of Results for Test 060412

Table 4: Performance Evaluation Summary for Test 060412.

<table>
<tr><th>NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td><u>Structural Adequacy</u>
A. Test article should contain and redirect the vehicle; the vehicle should net penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>The 50-inch PCB system safely redirected the test vehicle. The test vehicle did not penetrate the barrier nor continue into the theoretical work zone area.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>There was minimal deformation to the occupant compartment.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.</td><td>The impacting vehicle remained upright</td><td>Pass</td></tr>
<tr><td>H. Occupant impact velocities:
<table><tr><th colspan="3">Occupant Impact Velocity Limits (ft/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal And Lateral</td><td>29.5</td><td>39.4</td></tr></table></td><td>Longitudinal Velocity
14.7 ft/s (4.5 m/s)

Lateral Velocity
20.0 ft/s (6.1 m/s)</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations:
<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (G's)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal And Lateral</td><td>15</td><td>20</td></tr></table></td><td>Longitudinal Ridedown Acceleration: 5.4 g's

Lateral Ridedown Acceleration: 8.6 g's</td><td>Pass</td></tr>
<tr><td><u>Vehicle Trajectory</u>
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</td><td>The impacting vehicle's final trajectory came to rest 4.6 ft laterally outside the theoretical work zone area. Assuming a 12-foot lane width*, the vehicle would not have intruded into adjacent traffic lanes.</td><td>Pass</td></tr>
</table>

* As referenced in the American Association of State Highway and Transportation Officials (AASHTO) publication "A Policy on the Geometric Design of Highways and Streets, 2001", Chapter 4, Page 315.

Summary of Test 060412

Test 060412, with the 2000P vehicle, met all NCHRP Report 350 evaluation criteria for test designation 3-11. The impacting vehicle did not penetrate the barrier and came to rest 165 ft (50.3 m) longitudinally from the critical impact point and 6.9 ft (2.1 m) laterally outside the theoretical work zone area. The impacting vehicle was brought to a stop through electro/mechanical means. All occupant risk factors were well within the limits specified in NCHRP Report 350.

PROJECT SUMMARY

A 50-inch New Jersey Shape barrier design was developed and finite element analyses were conducted to assess the performance of the barrier under NCHRP Report 350 Test 3-11 impact conditions using the finite element software LS-DYNA.

F.E.A. Model Development

To verify that model predictions were reliable, a F.E. model of the existing 32-inch PCB was developed and the model's efficacy was verified by comparing to a full-scale crash test. A finite element model of the ODOT 32-inch PCB was obtained from the National Crash Analysis Center at George Washington University and was used in a F.E. simulation of TRC test No. 011012. The vehicle model used in the analysis was the best "off the shelf" model available at Battelle.

The analysis demonstrated that the finite element model replicates the principle behavior of the system in a redirectional impact with a 4400-lb (2000 kg) vehicle under NCHRP Report 350 Test 3-11 conditions. The analysis also highlighted the fact that there was a significant amount of deformation in the joint connections during impact that could lead to snagging of the vehicle at the joints. One of the primary concerns of the FHWA regarding the height extension of the ODOT PCB from 32 inches (0.813 m) to 50 inches (1.27 m) was the possibility of the vehicle snagging in the joints and causing excessive decelerations and unstable vehicle behavior. This theory was based on the fact that as the vehicle pushes on one segment of the barrier it causes a relative lateral shift at the joint of the adjacent PCBs. The concern with increasing the height of the barrier was that the relative displacement between the adjacent PCB's may increase as well, thereby creating a higher potential for snagging.

Design and F.E.A. Analysis of 50-inch PCB

The new 50-inch PCB design retains many of the geometric dimensions of a New Jersey shape barrier. The only difference is the slope of the barrier's face between the first slope break point at 13 inches (330 mm) from the ground and the top of the barrier (i.e., the 50-inch barrier is essentially a 50 inch tall New Jersey barrier with a steeper face).

The 50-inch barrier design uses a simple pin and loop connection with a single pin passing through three set of loops at each PCB segment end. The arrangement of the loops was an important consideration since it was desired to achieve as strong a connection as feasibly possible. Several arrangements of the loops were analyzed to determine their affects on the performance of the barrier system (see Figure 50). The analyses showed that the symmetrical arrangement, which is commonly used in PCB designs, resulted in a much more flexible connection that leads to excessive joint opening and relative displacement between adjacent barrier segments and increases the potential for vehicle "snag" at the barrier joints. The arrangement used in the final design of the 50-inch PCB was the "combination arrangement" with a double-shear connection at the top and bottom and an anti-symmetrical connection in the center.

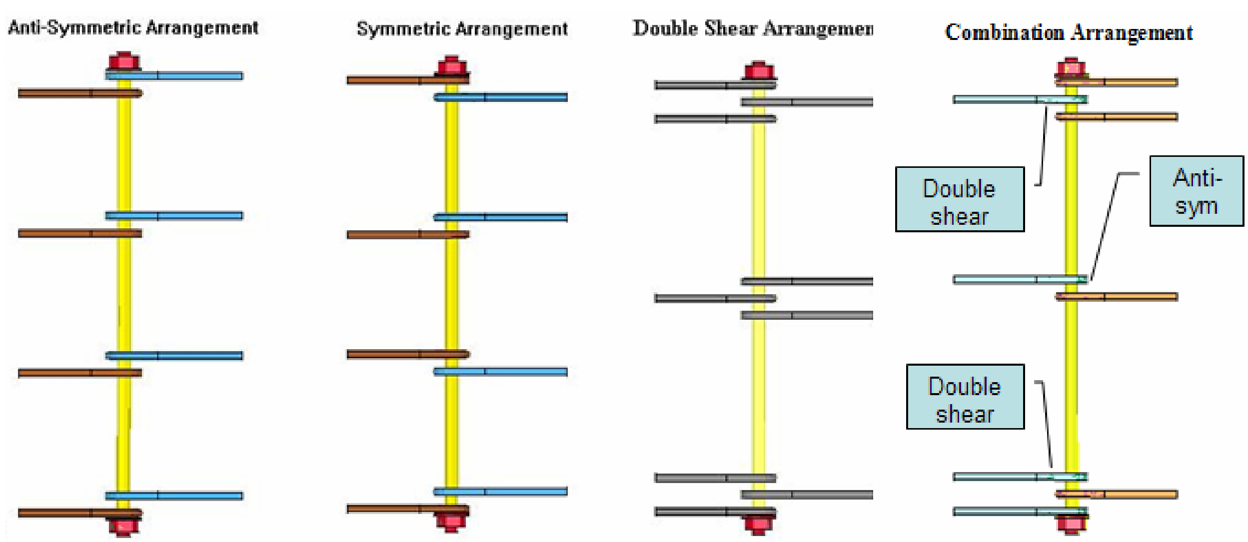


Figure 50: **Anti-symmetrical, symmetrical, double shear, and combination double shear/anti-symmetrical pin and loop arrangements, respectively.**

Analyses were conducted on 10-ft long PCB segments and 12-ft long PCB segments. The simulation study matrix is shown below in Table 5. The analyses indicated that the barrier system with both 10-ft sections and 12-ft sections would perform well and would satisfy all NCHRP Report 350 safety criteria. A drawing of the new 50-inch barrier design is provided in Appendix 1. A summary of occupant risk measures computed from the results of the analyses is presented in Table 6.

Table 5: Simulation study matrix.

	PCB Unit Length	Connection Type	Vehicle Model
Case 1	10-ft (3.048 m)	Double shear	C2500R
Case 2	10-ft (3.048 m)	Combination	C2500R
Case 3	10-ft (3.048 m)	Combination	C2500D v5-b
Case 4	12-ft (3.048 m)	Combination	C2500R
Case 5	12-ft (3.048 m)	Combination	C2500D v5-b

Table 6: Summary of Occupant Risk Factors and Vehicle Maximum Roll and Pitch Angles for the 50-inch PCB with combination pin-and-loop connection arrangement (Cases 2, 3, 4, and 5).

Occupant Risk Measure	Case 2	Case 3	Case 4	Case 5
	10-ft segments, C2500R	**10-ft segments, C2500D v5-b**	**12-ft segments, C2500R**	**12-ft segments, C2500D v5-b**
Long – OIV	22.0 ft/s (6.7 m/s)	22.0 ft/s (6.7 m/s)	22.0 ft/s (6.7 m/s)	24.9 ft/s (7.6 m/s)
Trans – OIV	19.4 ft/s (5.9 m/s)	20.3 ft/s (6.2 m/s)	18.4 ft/s (5.6 m/s)	17.1 ft/s (5.2 m/s)
Long-ride-down acceleration (g)	-9.4	-12.8	-8.0	-9.4
Trans–ride-down acceleration (g)	-15.1	-12.2	-8.9	-10.2
Roll (deg)	11.5	-14.2	14.7	15.6
Pitch (deg)	-4.4	-5.4	-12.4	-5.7

Full-Scale Crash Test

Based on the results from the F.E. analyses, which indicated that the 50-inch PCB system with 12-ft segments would successfully meet all safety requirements of Report 350 for test level 3, a full-scale crash test was conducted on the system at the Transportation Research Center (TRC) in East Liberty, Ohio. The test was performed in accordance with NCHRP Report 350 Test 3-11. The 50-inch PCB system successfully passed all NCHRP Report 350 evaluation criteria for test 3-11. The impacting vehicle did not penetrate the barrier and came to rest 165 ft (50.3 m) longitudinally from the critical impact point and 6.9 ft (2.1 m) laterally outside the theoretical work zone area. All occupant risk factors were within the limits specified in NCHRP Report

350. The occupant impact velocity was 14.8 ft/s (4.5 m/s) and 20.0 ft/s (6.1 m/s) in the longitudinal and lateral directions, respectively. The highest 0.010-second occupant ridedown acceleration was -5.4 g and -8.6 g in the longitudinal and lateral directions, respectively. The connections of the PCB units successfully prevented any opening of the PCB joints during impact (e.g., there was no noticeable deformation of the pin-and-loop connections after the test).

Comparison of F.E.A. Results with Full-Scale Crash Test

Although some differences between the F.E.A. results and test results were expected due to the differences in the F.E. vehicle model and the test vehicle (the finite element model was based on a 1996 Chevrolet C2500 vehicle and the crash test was performed with a 2003 Chevrolet C2500 vehicle), the F.E. analyses predicted the basic phenomenological behavior and crash performance of the system with reasonable accuracy. Figure 51 shows sequential views from TRC test 060412 and the finite element analyses (case 4 and case 5) from a downstream viewpoint. Figures 52 and 53 show sequential views from the test and the finite element analysis from overhead viewpoints (tight angle and wide angle views, respectively). From Figures 51 through 53, a qualitative comparison of the F.E. analyses to the full-scale test shows that the F.E. analyses accurately replicates the overall kinematic behavior of the vehicle as well as the overall deformations of the PCB system.

The acceleration time-histories from the test data and the F.E. analysis (measured at the center of gravity of the vehicle) are shown in Figure 54 and the angular displacement-time histories are compared in Figure 55.

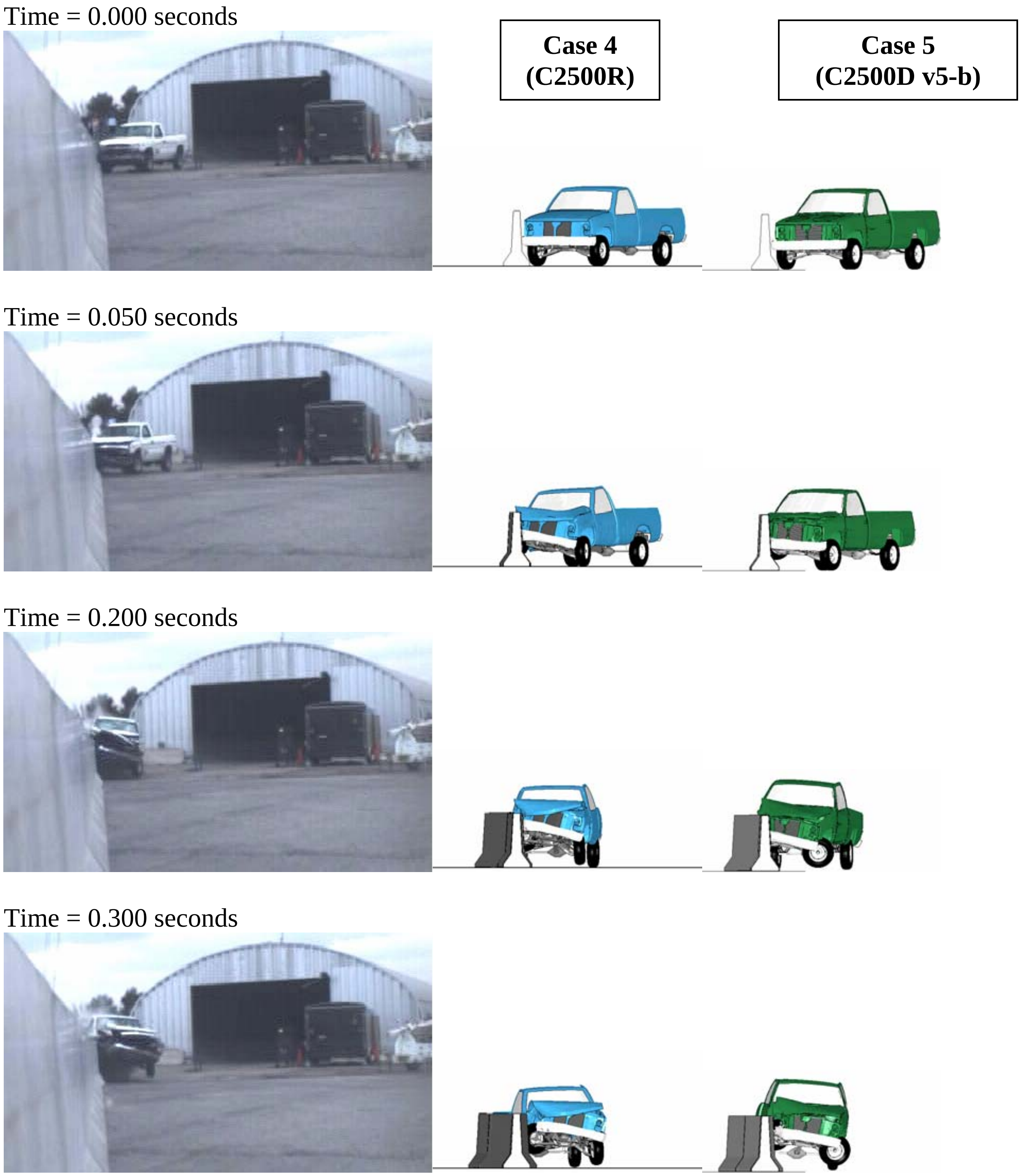
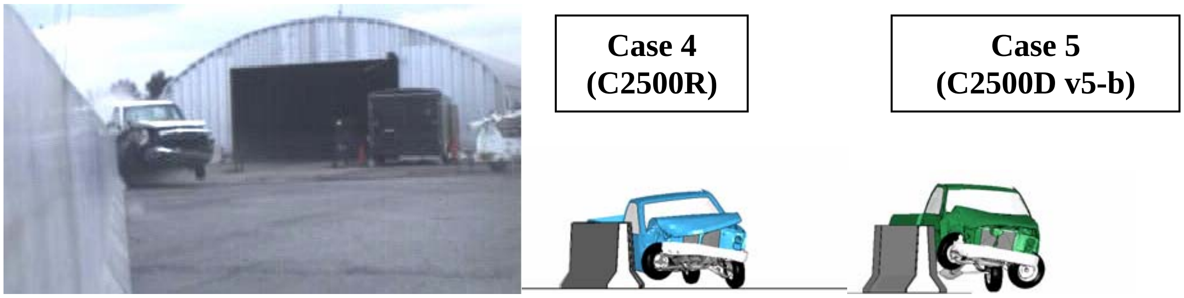


Figure 51: Sequential views from TRC test 060412 and the finite element analyses (case 4 and case 5) from a downstream viewpoint.

Time = 0.400 seconds



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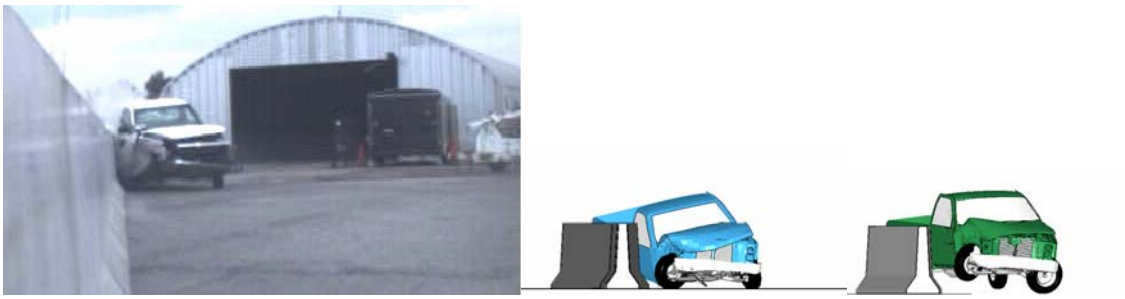

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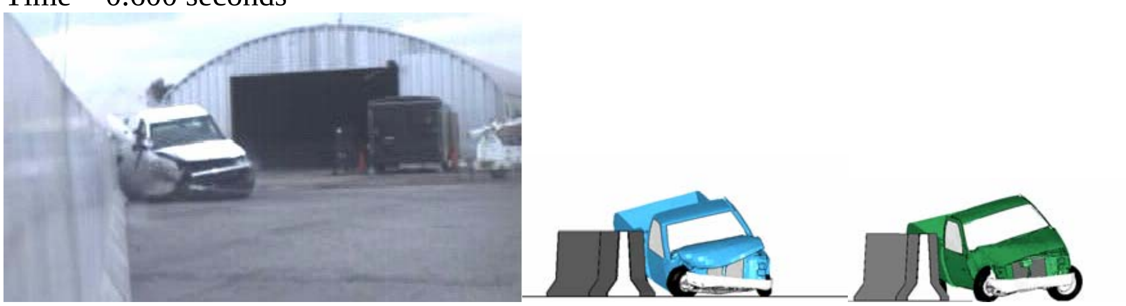

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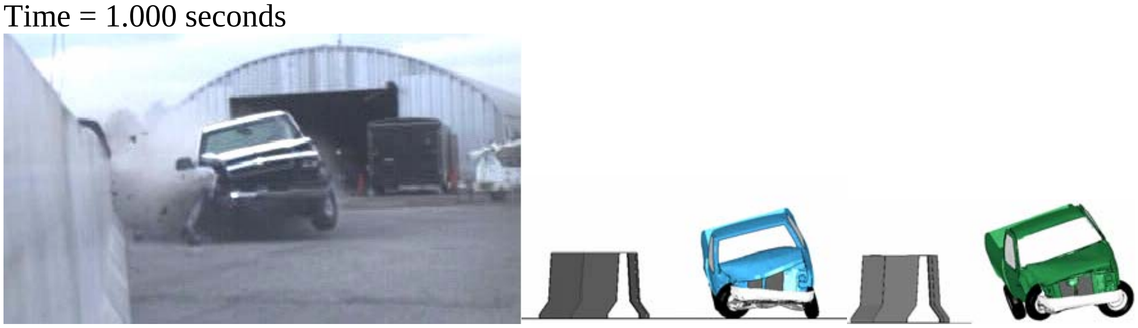
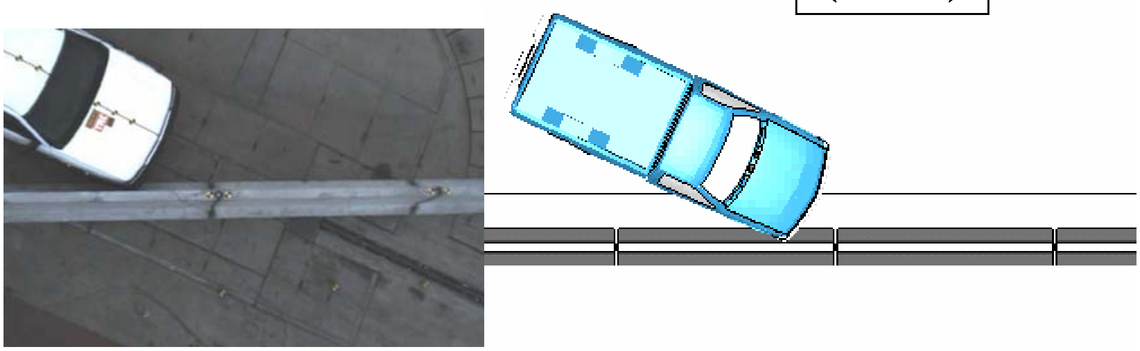


Figure 51: Sequential views from TRC test 060412 and the finite element analyses (case 4 and case 5) from a downstream viewpoint. (continued)

Case 4 (C2500R)

Time = 0.000 seconds



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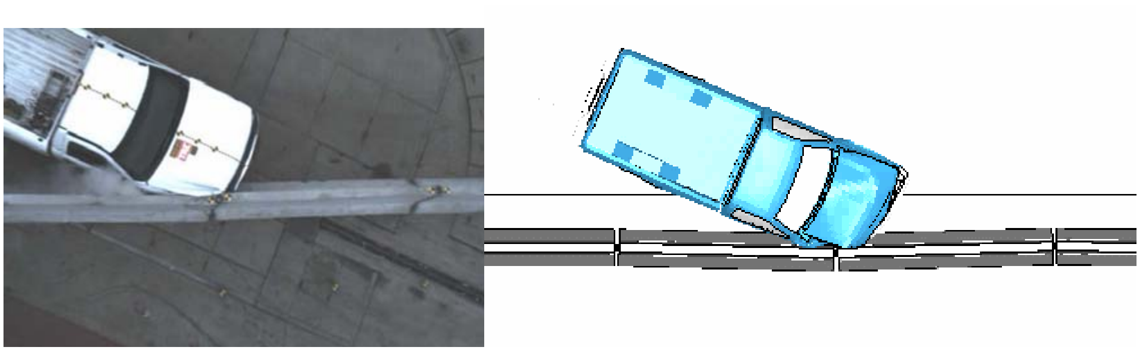

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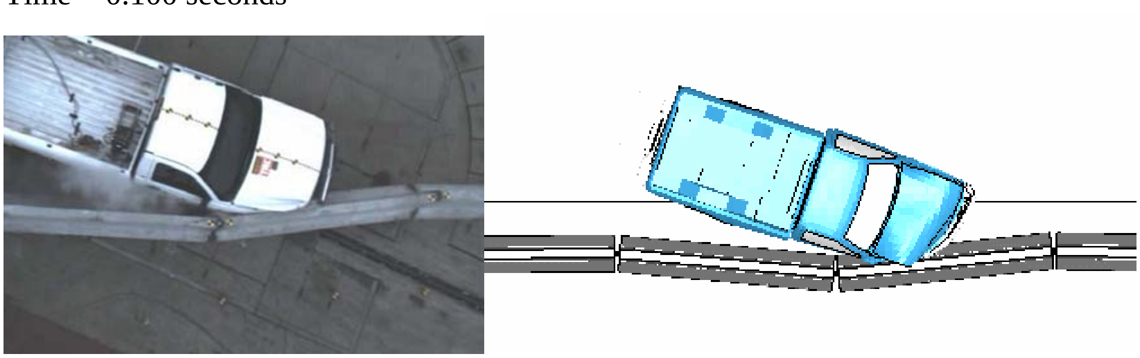


Time = 0.200 seconds

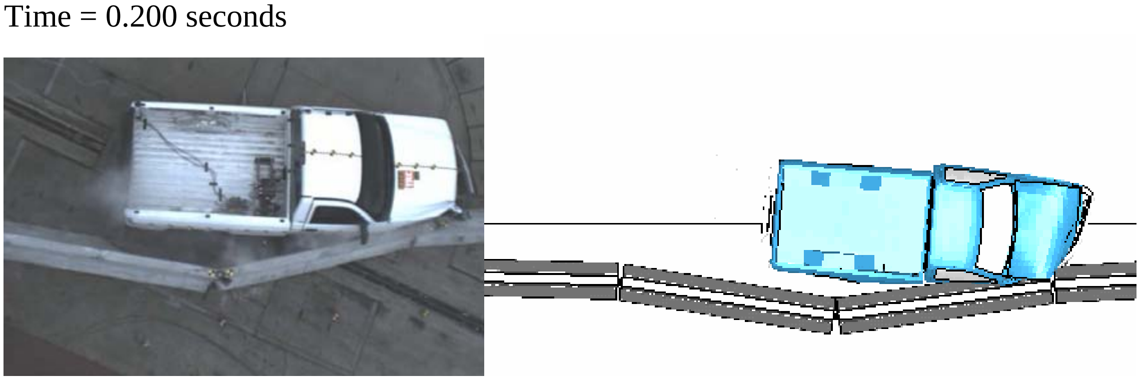
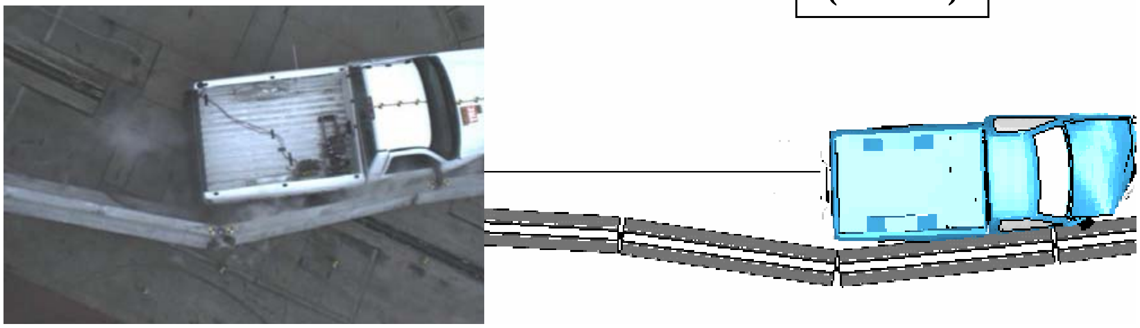


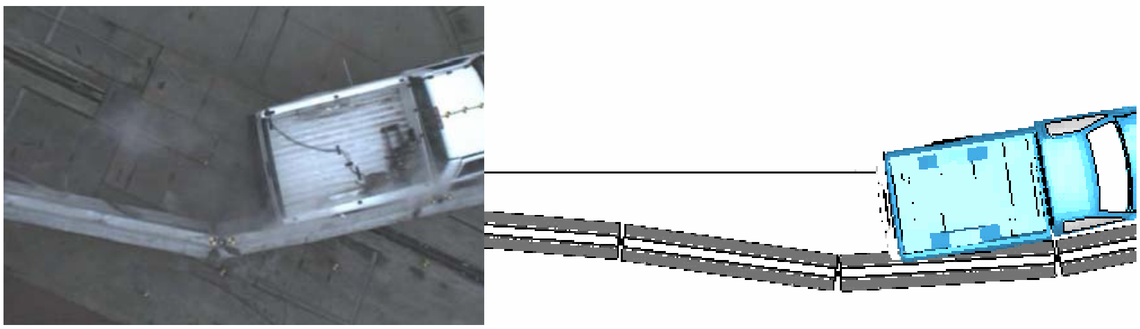
Figure 52: Sequential views of TRC test 060412 and the finite element analysis (case 4) from an overhead viewpoint.

Case 4
(C2500R)

Time = 0.250 seconds



Time = 0.300 seconds



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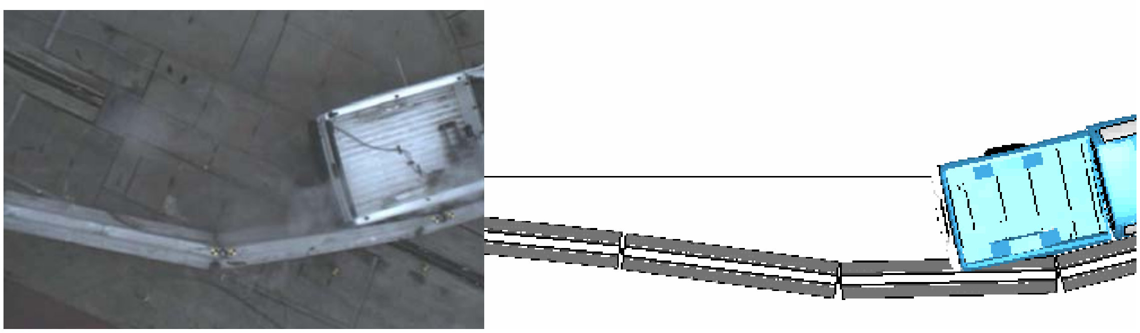
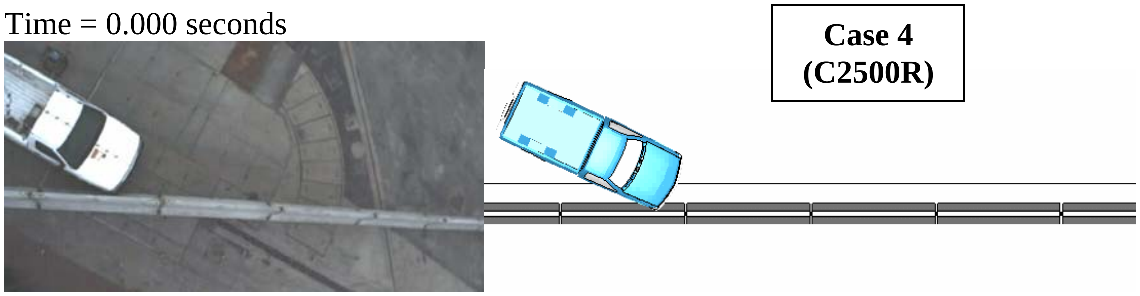
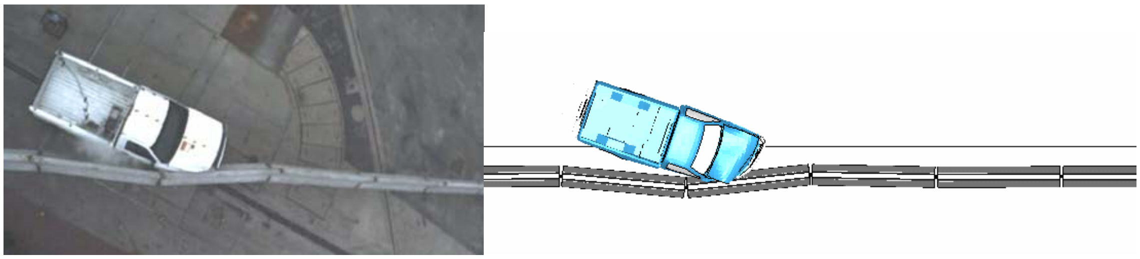


Figure 52: Sequential views of TRC test 060412 and the finite element analysis (case 4) from an overhead viewpoint. (continued)

Time = 0.000 seconds



Time = 0.100 seconds



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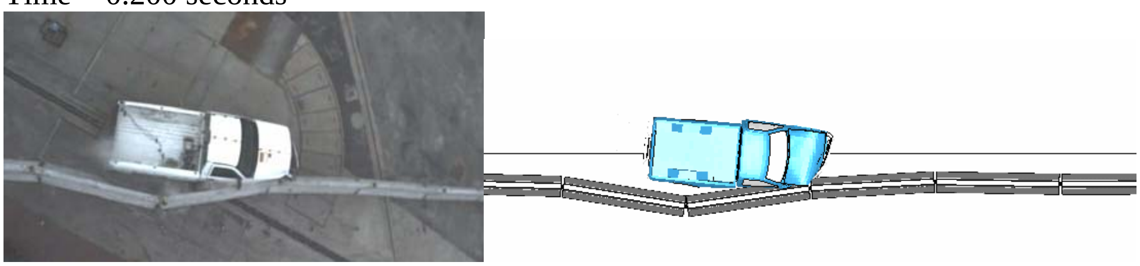
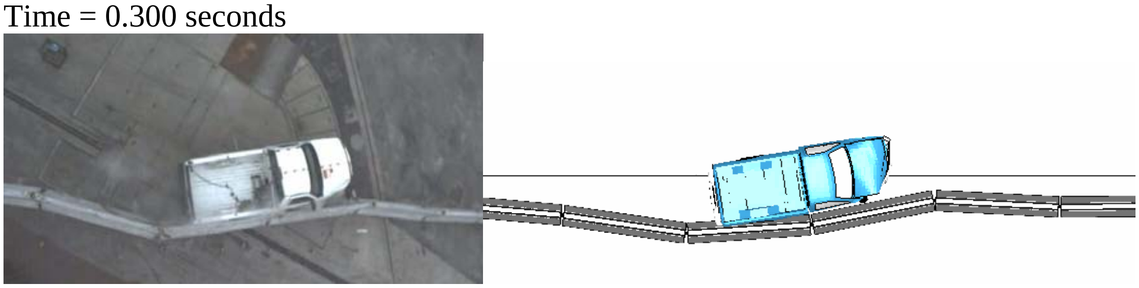


Time = 0.300 seconds



Time = 0.400 seconds

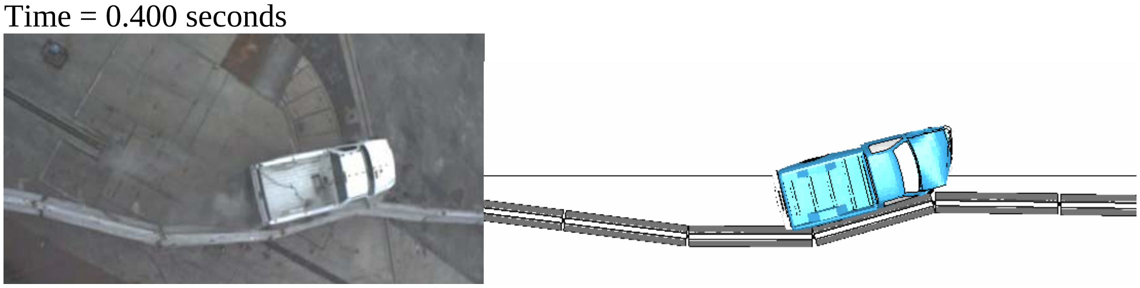
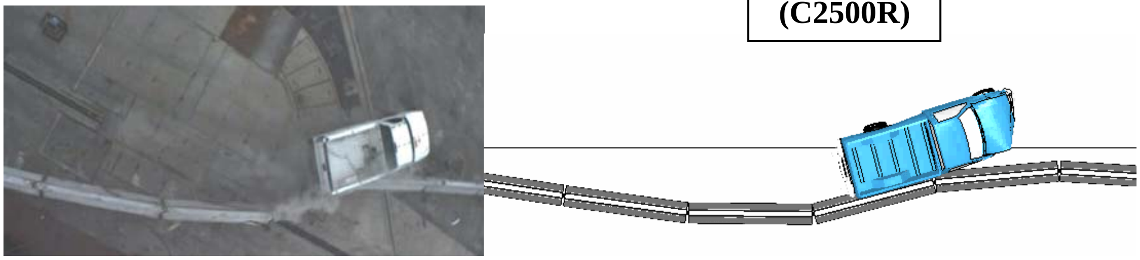


Figure 53: Sequential views of TRC test 060412 and the finite element analysis (case 4) from an overhead viewpoint.

Case 4 (C2500R)

Time = 0.500 seconds



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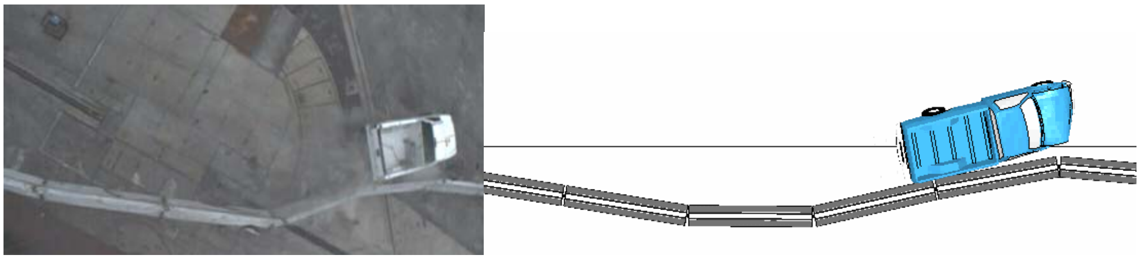

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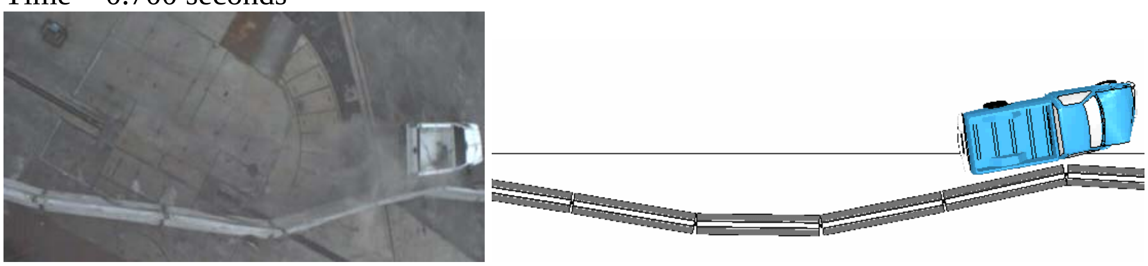

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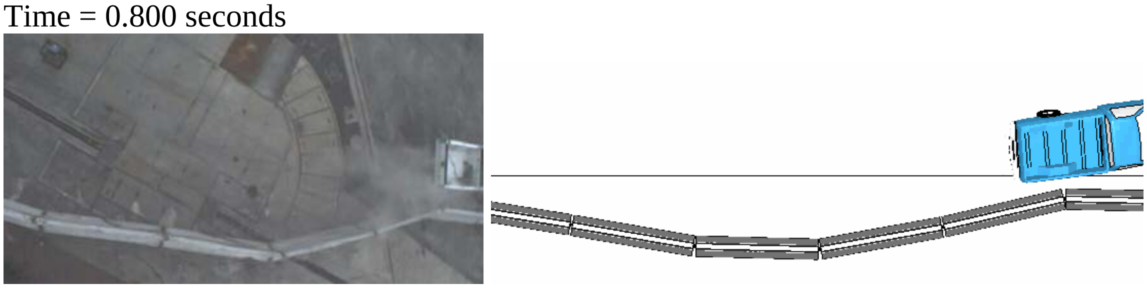

Figure 53: Sequential views of TRC test 060412 and the finite element analysis (case 4) from an overhead viewpoint. (continued)

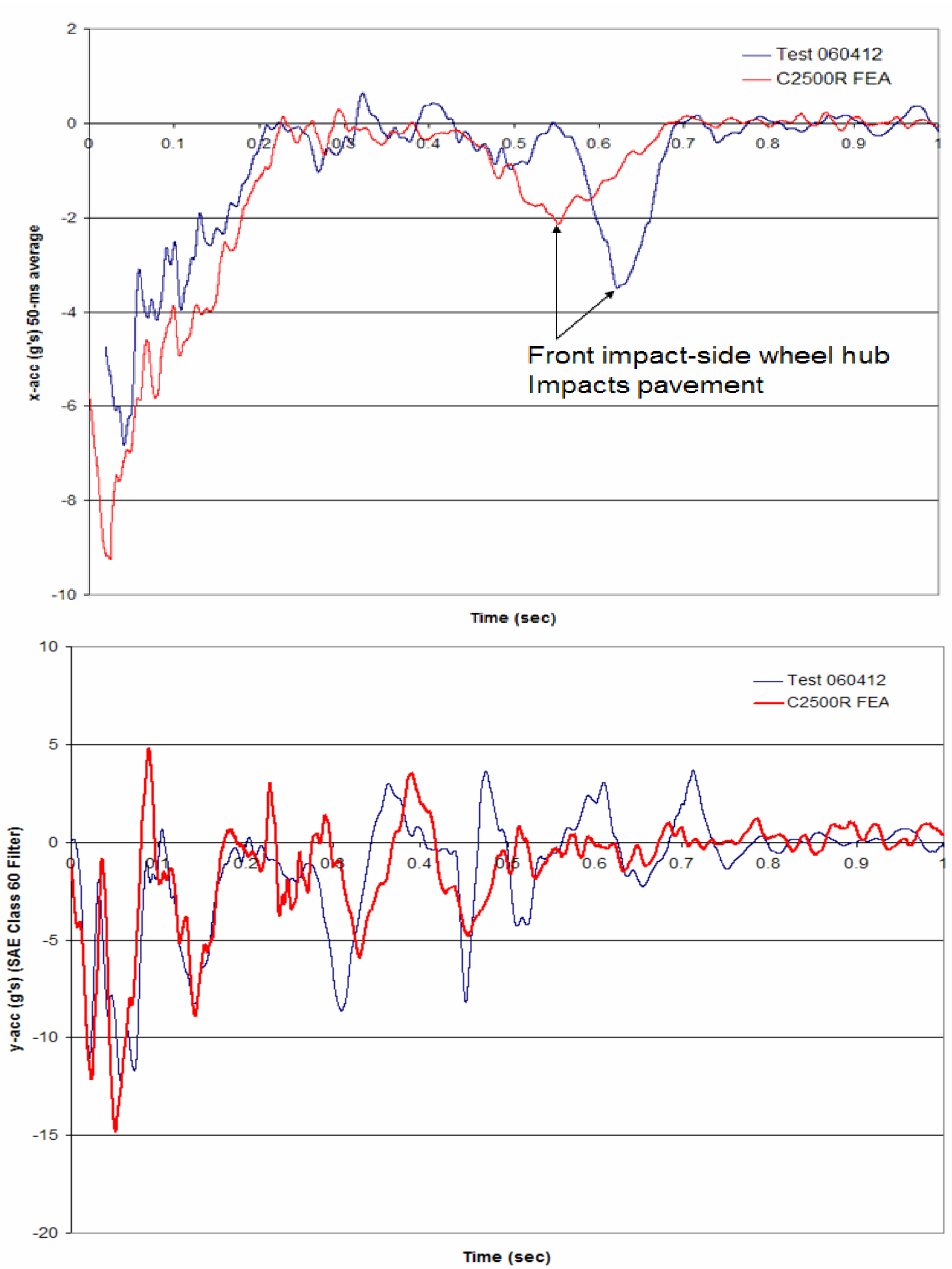

Figure 54: Acceleration time-histories from the test data and the F.E. analysis (measured at the center of gravity of the vehicle) .

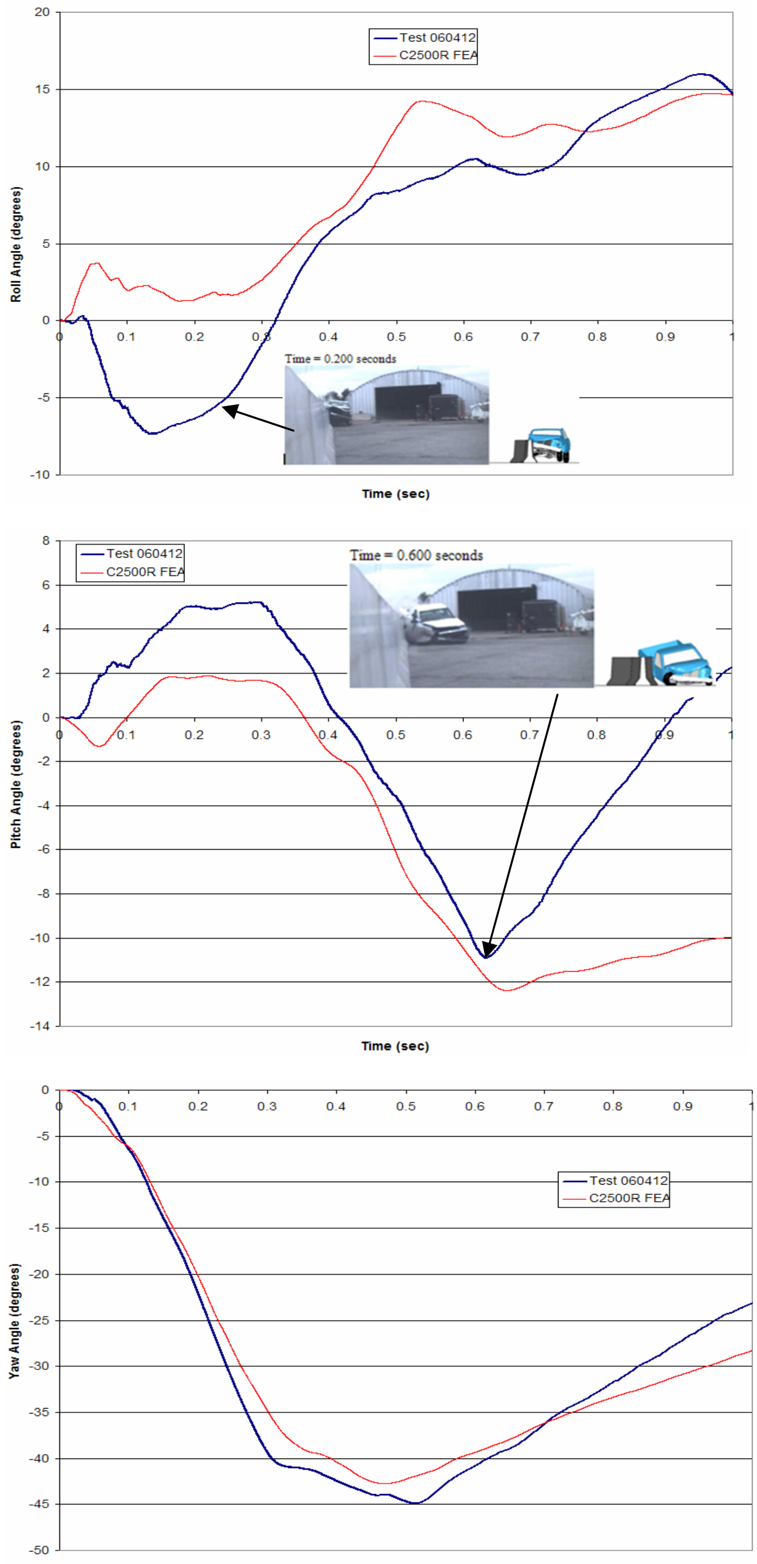

Figure 55: Angular displacement time-histories from the test data and the F.E. analysis (measured at the center of gravity of the vehicle) .

CONCLUSIONS AND RECOMMENDATIONS

The objective of the project was to develop a temporary barrier with an integral glare shield for use in roadway median work-zone areas. Currently-available 32-inch portable concrete barriers require the use of an add-on glare shield attached to the top of the barrier. The add-on glare shields are an extra expense and complicate barrier set-up and handling. An alternative solution was to develop a 50-inch high portable concrete barrier which is tall enough to serve as its own glare-shield. This study resulted in the development of a 50-inch portable concrete barrier that satisfies all safety requirements of NCHRP Report 350 for test level 3.

The 50-inch PCB barrier demonstrated a significant improvement in crash performance over the 32-inch PCB design for NCHRP Report 350 Test 3-11 regarding vehicle trajectory and work-zone safety. The trajectory of the vehicle during impact with the 50-inch PCB was very stable and the height of the barrier successfully prevented most debris as well as any part of the vehicle from penetrating behind the barrier into the work-zone area. In the full-scale test, there were no “flying” debris from the barrier (e.g., no spalling of concrete except on the lower curb part of the barrier) and most of the broken glass and other debris from the vehicle were contained on the traffic side of the barrier.

The results of the analyses indicated that minimizing deformation of the PCB connection joints would significantly reduce the potential for the vehicle snagging at the joints and for the vehicle overriding the barrier. The new barrier system uses a pin-and-loop design to connect adjacent PCB segments. This pin-and-loop design maintains the integrity of the joint connection during impact resulting in negligible deformation of the joint (i.e., there was no deformation of the pin-and-loop connection during impact).

The ODOT 50-inch PCB has been approved by the FHWA as NCHRP Report 350 TL-3 system (Letter B-149) and may be used on the National Highway System at the state’s discretion. The FHWA acceptance letter is included in Appendix 2.

IMPLEMENTATION PLAN

Implementation of the ODOT 50-inch PCB should be efficient and cost effective since the design includes many of the standard materials already used in the current ODOT 32-inch PCB for which materials should be readily available.

An important attribute of the 50-inch barrier is the added safety to both vehicle occupant and work-zone personnel. The trajectory of the vehicle during impact with the 50-inch PCB was very stable and the height of the barrier successfully prevented most debris as well as any part of the vehicle from penetrating behind the barrier into the work-zone area.

Additionally, the 50-inch PCB it is tall enough to serve as its own glare-shield, providing an effective, low maintenance solution for inhibiting headlight glare and driver distraction in work-zones.

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[6] Kennedy, J.C, Jr., C.A. Plaxico and C.R. Miele, "Design, Development and Qualification of a New Guardrail Post," Paper in review, Transportation Research Board, Washington, D.C., 2006.

[7] Dresback, T.L and J.W. Sankey, "NCHRP Report 350 Test 3-11 of the Ohio Department of Transportation New Jersey Shape Portable Concrete Barrier," TRC Test Number 011012, Transportation Research Center Inc., East Liberty, Ohio, October 2001.

[8] Tonneman, M.R. and J.W. Sankey, "NCHRP Report 350 Test 3-11 – 2003 Chevrolet 2500 into Battelle 50-inch PCB Array Longitudinal Median Barrier System," TRC Test Number 060412, Transportation Research Center Inc., East Liberty, Ohio, April 2006.

APPENDIX 1

50-inch PCB Design Drawings

DWG NO G005063-30 | SH 1 | REV A

REVISION HISTORY					
ZONE		REV	DESCRIPTION	DATE	APPROVED
1	D3	A	(1) 144.000 WAS 120.00.	2005-08-25	
1	B2		(2) 48.00 WAS 36.00.		
1	A3		(3) ITEM #5 LENGTH 138.00 WAS 114.00.		
1	A3		(4) HINGE BAR DIAMETER IS: .75, WAS #6		
1	D8		(5) ADDED MATERIAL SPECIFICATIONS TO CONNECTING HARDWARE, HINGE AND REINFORCING BARS.		
2	B5		(6) (144.000) WAS 120.000.		
2	D3		(7) 3X 47.50 WAS 47.50.		
3	B4		(8) 138.000 WAS 114.000.		
3	B7		(9) G005063-21-10 WAS SPLIT IN HALF ALONG THE VERTICAL PLANE AND WAS CONNECTED AT THE TOP BY A RADIAL BEND.		

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS:
   ASME Y14.5M-1994, DIMENSIONS AND TOLERANCES
   ASME Y14.38, ABBREVIATIONS

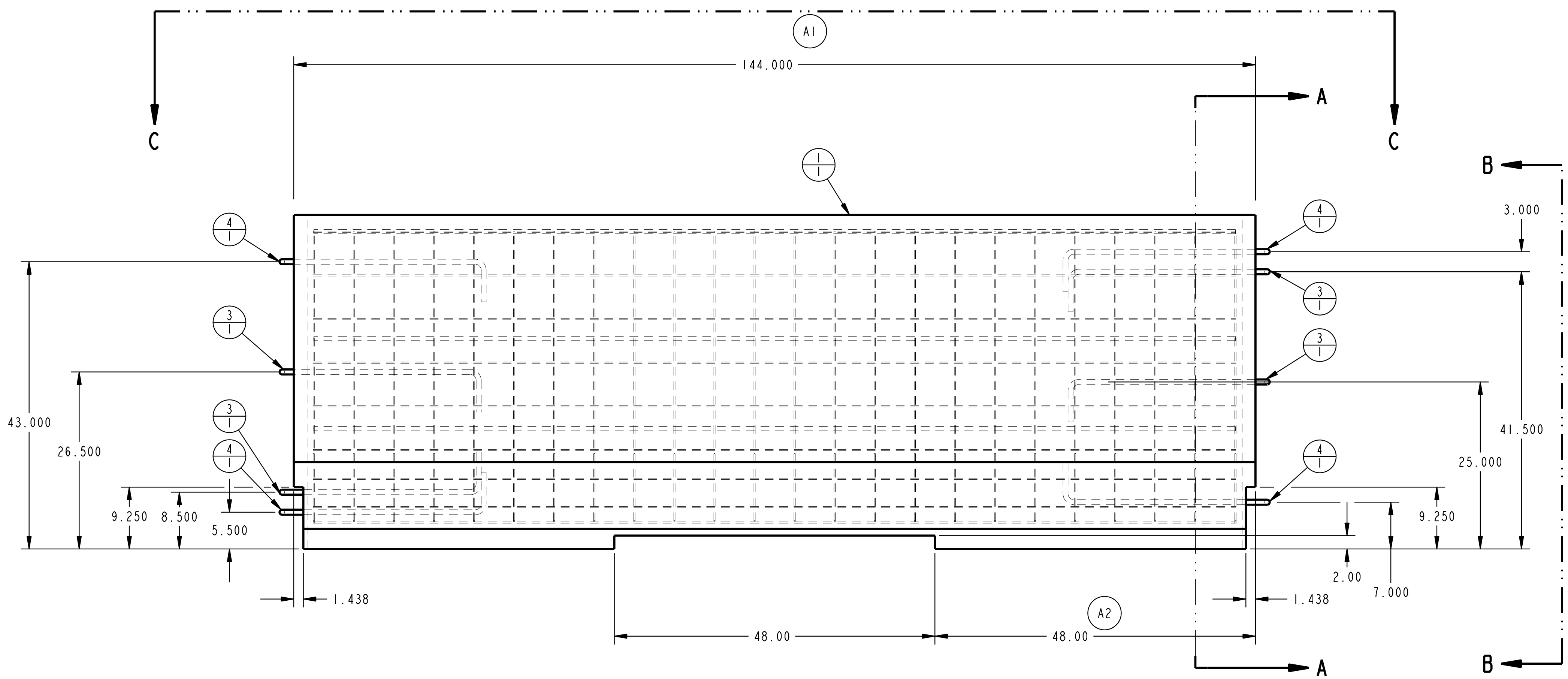
2. BARRIER SPECIFICATIONS, INCLUDING BARS AND CONCRETE, SHALL BE PER CMS 622.

   (A5) HINGE AND REINFORCING BARS:
   THE .75 HINGE MAY BE ASTM A-36. REBARS SHALL MEET
   THE REQUIREMENTS OF CMS 509. BLACK STEEL IS PERMITTED.

   CONNECTING HARDWARE:
   BOLTS, WASHERS AND HEX NUTS SHALL BE GALVANIZED AFTER
   FABRICATION PER CMS 711.02 AND SHALL MEET THE REQUIREMENTS OF CMS 711.09 EXCEPT
   THAT THE ROTATIONAL CAPACITY TEST SPECIFIED IN ASTM A-325 SHALL BE WAIVED.

3. MARKING:
   MARK WITH DAY, MONTH, YEAR OF CAST AND UNIQUE IDENTIFICATION NUMBER IN THE LOCATION SHOWN.
   MARKINGS SHALL BE PERMANENTLY IMPRESSED IN THE BARRIER USING A MINIMUM OF 2 IN HIGH LETTERING.

4. REFLECTORIZATION:
   BARRIER REFLECTORS SHALL BE INSTALLED IN ACCORDANCE WITH TRAFFIC ENGINEERING'S
   STANDARD DRAWING MT-95.82, WHEN SPECIFIED IN THE PLANS.



	QTY REQD -10	FIND NO	PART OR IDENTIFYING NO	CAGE CODE	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION
(A3)	5	5	G005063-19-01		BAR, REINF, STR, #5 X 138.00	2
(A4)	4	4	G005063-14-01		BAR, HINGE, .75 X 87.87	2
	4	3	G005063-13-01		BAR, HINGE, .75 X 86.37	2
(A9)	2	2	G005063-21-10		WWF, 6 X 6 X W2.9 X W2.9	2
	1	1	G005063-11-01		BARRIER, CONCRETE	2

PARTS LIST

G005063-40

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
DECIMAL: .XX ±0.01 .XXX ±0.005
FRACTIONAL: ±1/32 ANGULAR: ±0.5°

THIRD ANGLE PROJECTION

CONTRACT NO

APPROVAL	DATE
DRAWN J. V.	2005-05-25
CHECKED	
ENGINEER	

Battelle
The Business of Innovation
505 King Avenue
Columbus, Ohio 43201-2693
Telephone (614) 424-6424

TITLE

BARRIER, ASSEMBLY

SIZE D | CAGE CODE 79986 | DWG NO G005063-30 | REV A

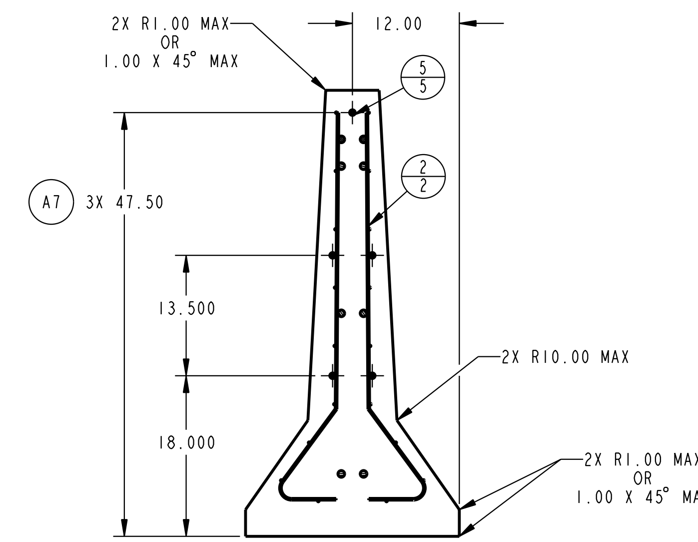
SCALE 1/10 | DO NOT SCALE DRAWING | SHEET 1 OF 3

COMPUTER FILE NAME
DRAWING G005063-30
MODEL ASSEM G005063-30

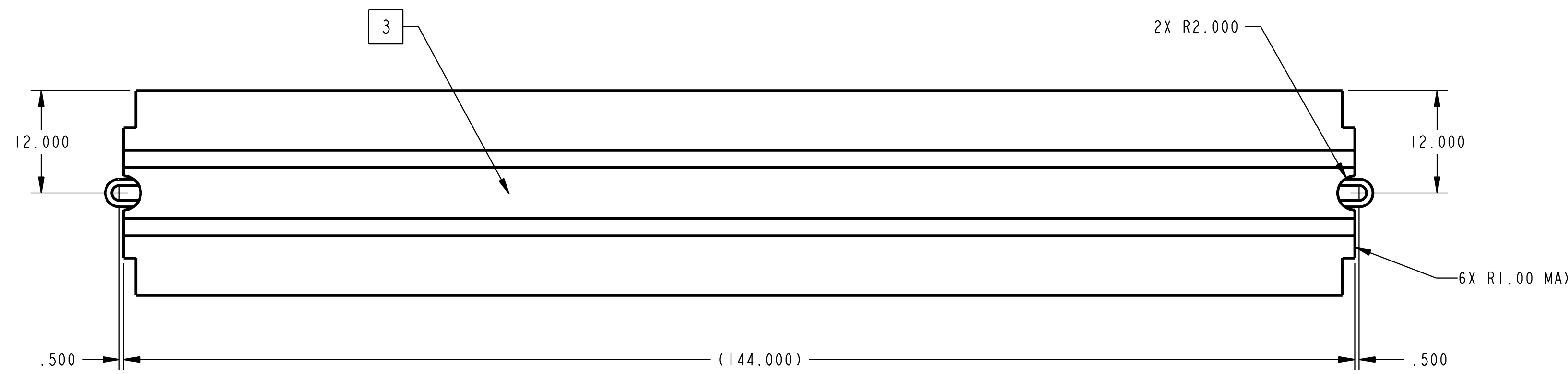
DWG NO	SH	REV
G005063-30	2	A

REVISION HISTORY

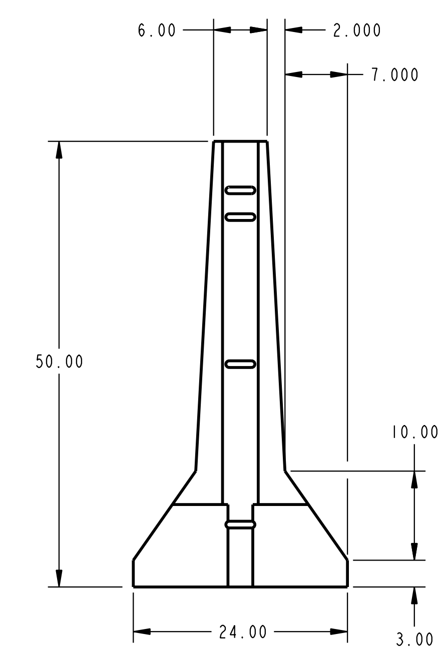
ZONE	REV	DESCRIPTION	DATE	APPROVED



SECTION A-A



VIEW C-C



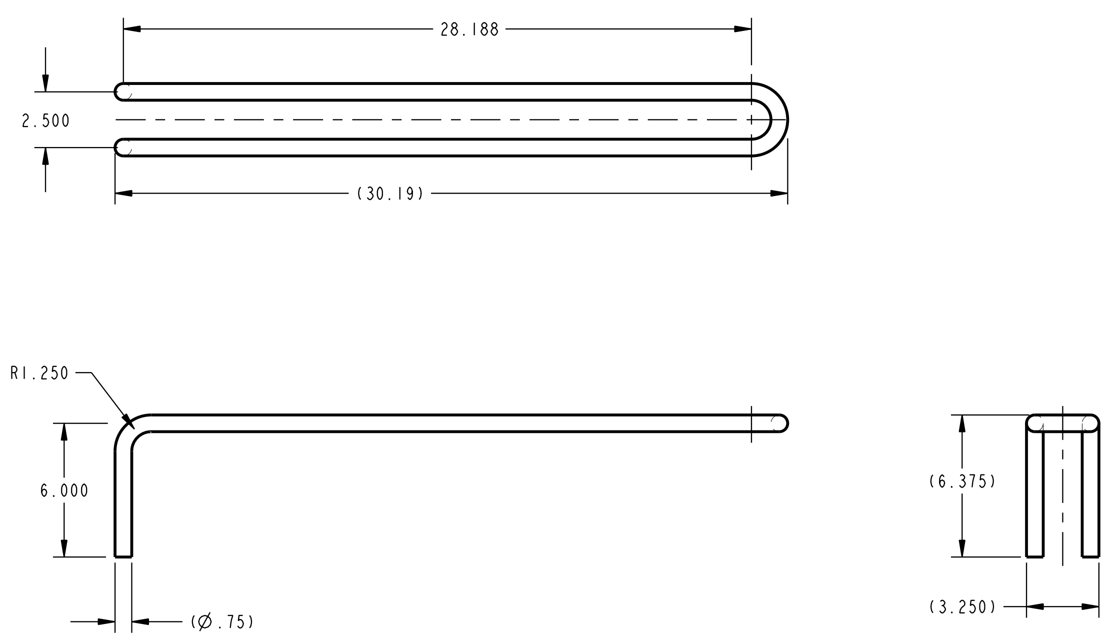
VIEW B-B

SIZE	CAGE CODE	DWG NO	REV
D	79986	G005063-30	A
SCALE 1/10	DO NOT SCALE DRAWING	SHEET 2 OF 3	

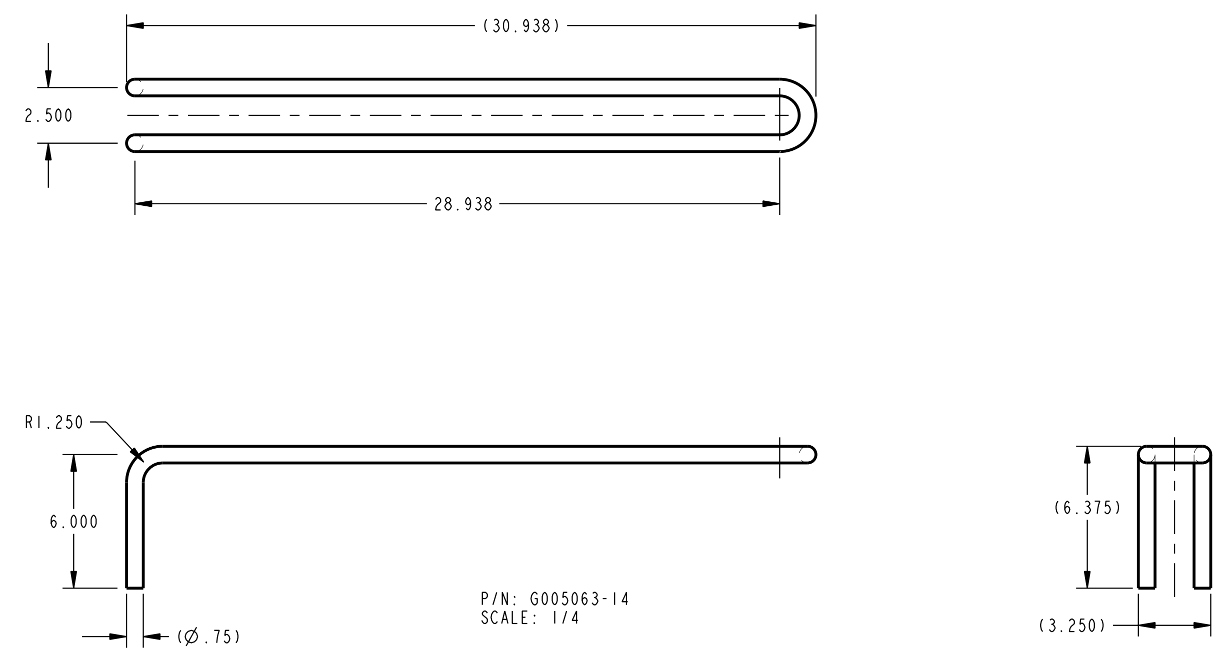
DWG NO	SH	REV
G005063-30	3	A

REVISION HISTORY

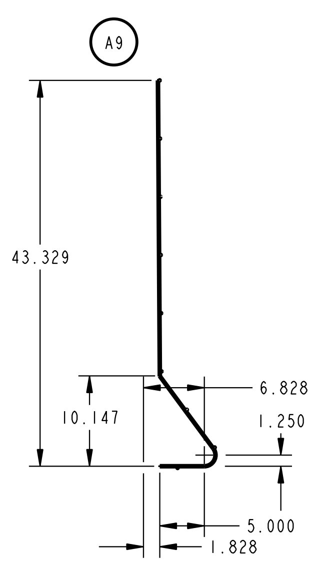
ZONE	REV	DESCRIPTION	DATE	APPROVED

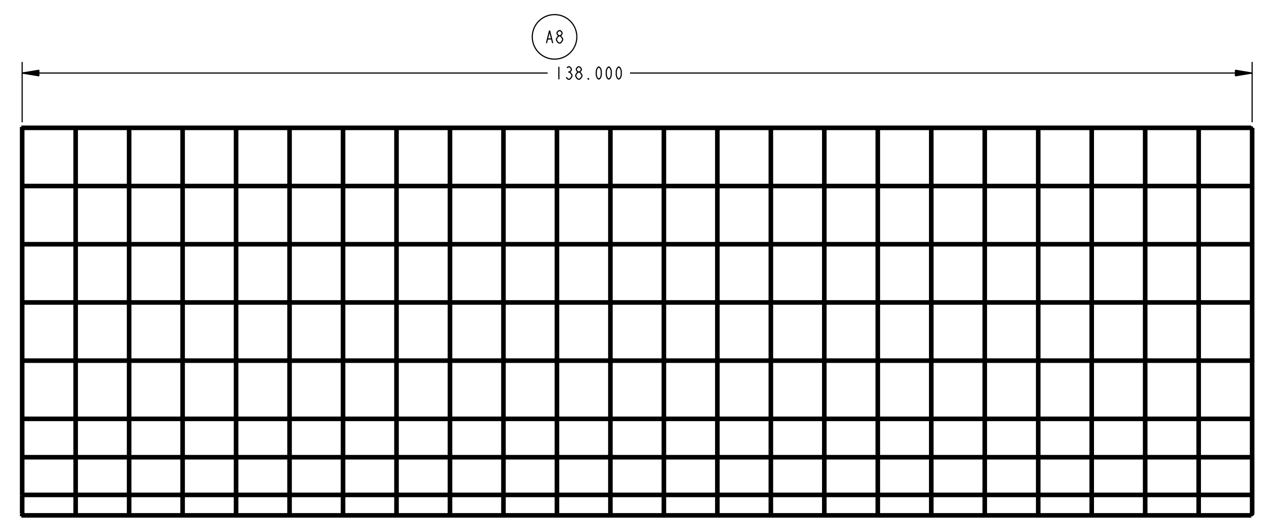


P/N: G005063-13
SCALE: 1/4



P/N: G005063-14
SCALE: 1/4





SIZE	CAGE CODE	DWG NO	REV
D	79986	G005063-30	A
SCALE 1/10	DO NOT SCALE DRAWING	SHEET 3 OF 3	

NOTES:
1. APPLICABLE STANDARDS/SPECIFICATIONS:
ASME Y14.5M-1994, DIMENSIONS AND TOLERANCES
ASME Y14.38, ABBREVIATIONS

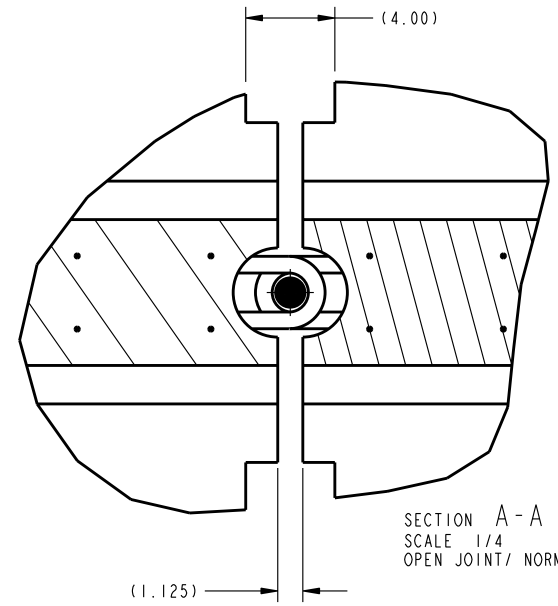
2. BARRIER SPECIFICATIONS, INCLUDING HARWARE, SHALL BE PER CMS 622 AND 711.

3. INSTALLATION:
INSERT THREADED ROD WHEN JOINT IS CLOSED. FULLY OPEN THE JOINT TO TIGHTEN THE NUT AND NORMAL OPERATION.

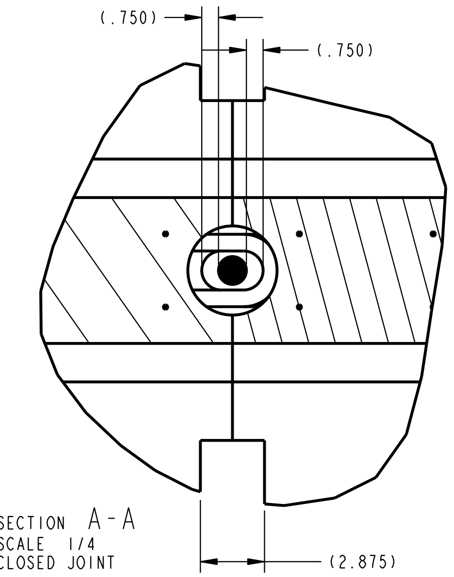
DWG NO	SH	REV
G005063-20	1	-

REVISION HISTORY

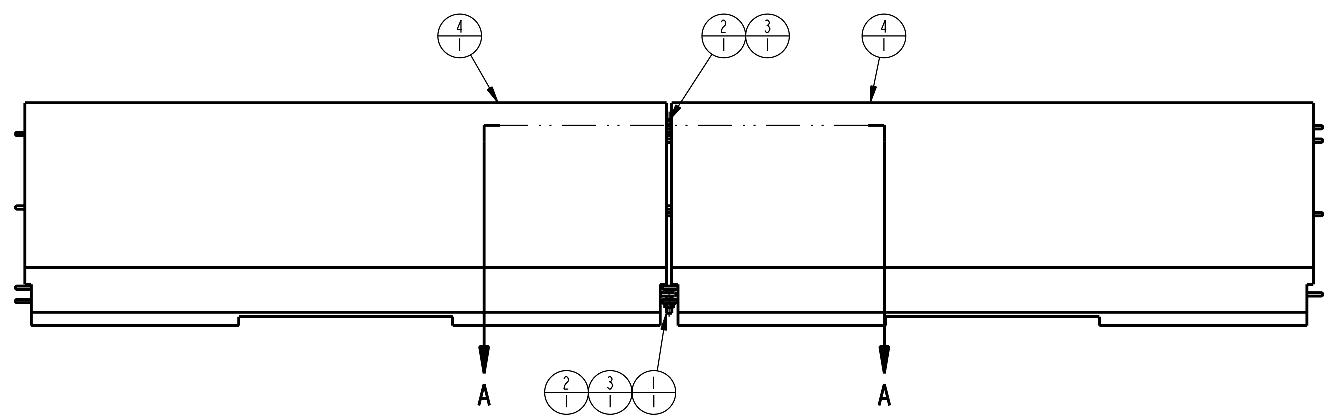
ZONE	REV	DESCRIPTION	DATE	APPROVED

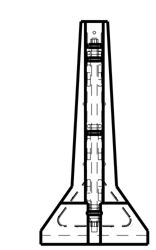


SECTION A-A
SCALE 1/4
OPEN JOINT/ NORMAL OPERATION



SECTION A-A
SCALE 1/4
CLOSED JOINT





QTY REQD -10	FIND NO	PART OR IDENTIFYING NO	CAGE CODE	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION
2	4	G005063-30-10	79986	BARRIER, ASSEMBLY	
2	3	G005063-18-01	79986	WASHER, 1.313 ID, 3.000 OD, .156 THK	STL, GALV
2	2	G005063-17-01	79986	NUT, 1.125-7 UNC	STL, GALV
1	1	G005063-16-01	79986	BOLT, 1.25 DIA X 43 LG GALV GRADE 5	STL, GALV

PARTS LIST

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
DECIMAL: .XX ±0.01 .XXX ±0.005
FRACTIONAL: ±1/32 ANGULAR: ±0.5°

THIRD ANGLE PROJECTION

CONTRACT NO 79986

	APPROVAL	DATE
DRAWN	J. VILLARES	2005-04-13
CHECKED		
ENGINEER		

Battelle
The Business of Innovation
505 King Avenue
Columbus, Ohio 43201-2693
Telephone (614) 424-6424

TITLE
BARRIER SYSTEM, ASSEMBLY

SIZE	CAGE CODE	DWG NO	REV
D	79986	G005063-20	-

SCALE 1/20 DO NOT SCALE DRAWING SHEET 1 OF 1

COMPUTER FILE NAME
DRAWING G005063-20
MODEL ASSEM G005063-20

APPENDIX 2

FHWA Approval Letter B149

U.S. Department
of Transportation
Federal Highway
Administration

May 19, 2006

400 Seventh St., S.W.
Washington, D.C. 20590

In Reply Refer To:
HSA-10/B149

Chuck Plaxico, Ph.D.
Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201-2693

Dear Dr. Plaxico:

In Mr. Michael Halladay's January 8, 2002, letter to the Ohio Department of Transportation's Mr. Larry Sutherland, the Federal Highway Administration (FHWA) agreed that the Ohio Department of Transportation 32-inch high precast New Jersey shape concrete barrier with a standard pin and loop connection met the evaluation criteria for an National Cooperative Highway Research Program (NCHRP) Report 350 test level 3 (TL-3) temporary traffic barrier. In your May 1, 2006, letter to Mr. Richard Powers of my staff, you requested the FHWA's concurrence that a new barrier, a 50-inch high precast safety shape with a unique pin and loop connection, also be accepted as a TL-3 design.

Prior to conducting a full-scale crash test, Battelle developed a new design for the pin and loop connection through a series of finite element analyses that predicted the design would meet all Report 350 evaluation criteria for a TL-3 temporary barrier. The Ohio Department of Transportation's tall barrier is a 50-inch high, modified New Jersey shape concrete barrier with each segment being 12-feet long. Since the base width remained a standard 24 inches and the top width remained 6 inches, the extended upper sloped face was about 3 degrees steeper than the upper slope of a 32-inch tall New Jersey shape. Reinforcement consisted of five #5 steel bars and two sections of 6 x 6 x W2.9 welded wire fabric. Segments were connected by 1.25-inch diameter x 43-inch long galvanized Grade 5 (high strength) steel bolts passing through 8 loops (4 loops at the ends of each segment). These loops are made from 0.75-inch diameter A36 steel bars bent to an inside radius of 2.25 inches. There are two loops at the top of each segment at one end and a single upper loop at the opposite end. The bottom loops are reversed, with a single loop beneath the upper double loops and vice versa. Each segment also has a single loop, approximately centered between the upper and lower sets of loops. This design, shown as Enclosure 1, was successfully tested at the Transportation Research Center in East Liberty, Ohio on April 12, 2006. Total installation length was about 200 feet and the impact point was approximately 80 feet from the upstream end, resulting in a dynamic deflection of 1.9 meters. Equally severe impacts closer to either unanchored end would be expected to result in greater deflections. Enclosure 2 is the test summary sheet. Vehicular pitch and roll were significantly less than typically noted in concrete barrier tests, probably due to the increase in height and the steeper upper slope that minimizes vehicular climb and roll upon contact.

Based on the crash test results, I agree that this 50-inch high New Jersey portable concrete barrier may be considered an NCHRP Report 350 TL-3 design and used on the National Highway System at the State's discretion. The same barrier design in a 20-foot length may also be considered a TL-3 barrier, provided the longitudinal reinforcement is equivalent to that contained in any other 20-ft segment that has been crash tested successfully. California, New York, and Virginia each have such designs. Please note also that the Oregon Department of Transportation successfully tested a 42-inch tall F-shape concrete barrier with a similar double-shear pin connection to NCHRP Report 350 TL-4. It is very likely that the Ohio Department of Transportation 50-inch tall barrier would have similar capacity.

Sincerely yours,

/original signed by/

John R. Baxter, P.E.
Director, Office of Safety Design
Office of Safety

2 Enclosures

DWG NO	SH	REV
G005063-30	1	A

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS:
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   ASME Y14.38, ABBREVIATIONS

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A5 HINGE AND REINFORCING BARS:
THE .75 HINGE MAY BE ASTM A-36. REBARS SHALL MEET THE REQUIREMENTS OF CMS 509. BLACK STEEL IS PERMITTED.

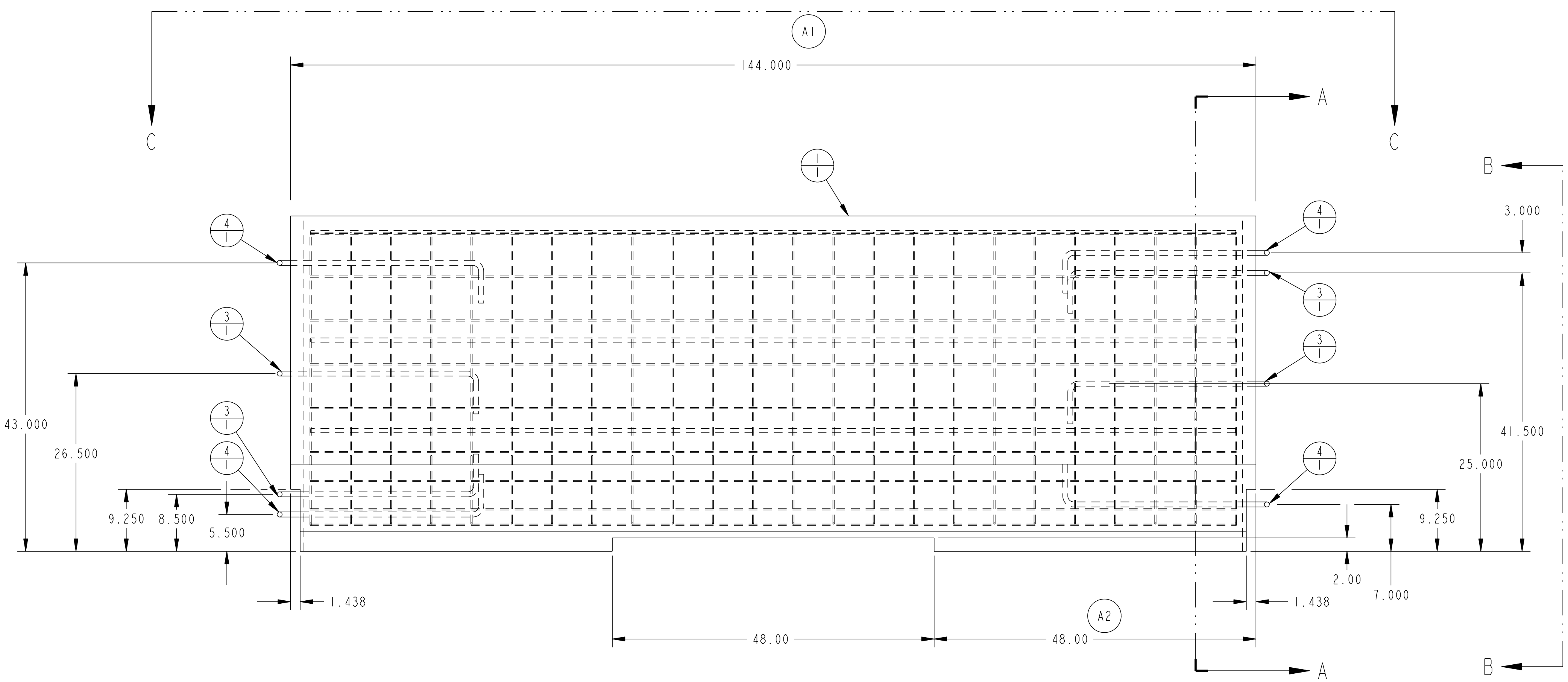
CONNECTING HARDWARE:
BOLTS, WASHERS AND HEX NUTS SHALL BE GALVANIZED AFTER FABRICATION PER CMS 711.02 AND SHALL MEET THE REQUIREMENTS OF CMS 711.09 EXCEPT THAT THE ROTATIONAL CAPACITY TEST SPECIFIED IN ASTM A-325 SHALL BE WAIVED.

3. MARKING:
MARK WITH DAY, MONTH, YEAR OF CAST AND UNIQUE IDENTIFICATION NUMBER IN THE LOCATION SHOWN.
MARKINGS SHALL BE PERMANENTLY IMPRESSED IN THE BARRIER USING A MINIMUM OF 2 IN HIGH LETTERING.

4. REFLECTORIZATION:
BARRIER REFLECTORS SHALL BE INSTALLED IN ACCORDANCE WITH TRAFFIC ENGINEERING'S STANDARD DRAWING MT-95.82, WHEN SPECIFIED IN THE PLANS.

REVISION HISTORY

ZONE		REV	DESCRIPTION	DATE	APPROVED
1	D3	A	(1) 144.000 WAS 120.00.	2005-08-25	
1	B2		(2) 48.00 WAS 36.00.		
1	A3		(3) ITEM #5 LENGTH 138.00 WAS 114.00.		
1	A3		(4) HINGE BAR DIAMETER IS: .75, WAS #6		
1	D8		(5) ADDED MATERIAL SPECIFICATIONS TO CONNECTING HARDWARE, HINGE AND REINFORCING BARS.		
2	B5		(6) (144.000) WAS 120.000.		
2	D3		(7) 3X 47.50 WAS 47.50.		
3	B4		(8) 138.000 WAS 114.000.		
3	B7		(9) G005063-21-10 WAS SPLIT IN HALF ALONG THE VERTICAL PLANE AND WAS CONNECTED AT THE TOP BY A RADIAL BEND.		



	QTY REQD -10	FIND NO	PART OR IDENTIFYING NO	CAGE CODE	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION
A3	5	5	G005063-19-01		BAR, REINF, STR, #5 X 138.00	2
A4	4	4	G005063-14-01		BAR, HINGE, .75 X 87.87	2
	4	3	G005063-13-01		BAR, HINGE, .75 X 86.37	2
A9	2	2	G005063-21-10		WWF, 6 X 6 X W2.9 X W2.9	2
	1	1	G005063-11-01		BARRIER, CONCRETE	2

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
DECIMAL: .XX ±0.25 .XXX ±0.125
FRACTIONAL: ±1/32 ANGULAR: ±0.5°
THIRD ANGLE PROJECTION

CONTRACT NO		
	APPROVAL	DATE
DRAWN	J. V.	2005-05-25
CHECKED		
ENGINEER		

Battelle
The Business of Innovation
505 King Avenue
Columbus, Ohio 43201-2693
Telephone (614) 424-6424

TITLE
BARRIER, ASSEMBLY

SIZE	CAGE CODE	DWG NO	REV
D	79986	G005063-30	A

SCALE 1/10 DO NOT SCALE DRAWING SHEET 1 OF 3

NEXT ASSY	USED ON
G005063-40	

APPLICATION

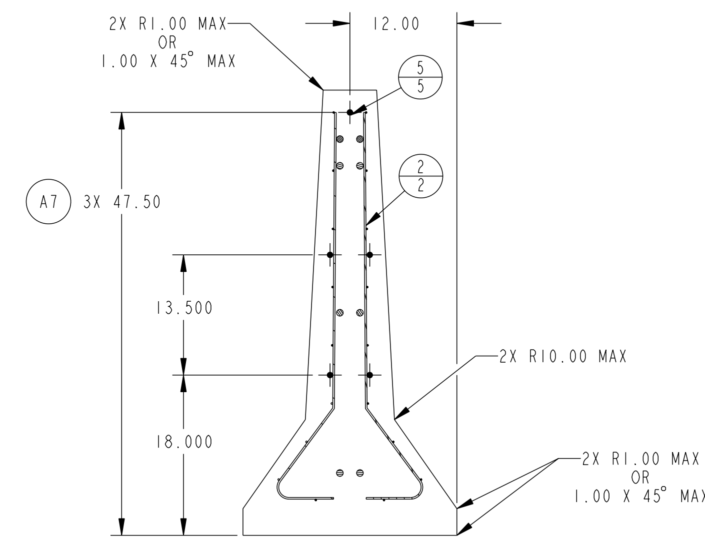
COMPUTER FILE NAME G005063-30
DRAWING ASSEM G005063-30
MODEL

NAME:HARRISS OBJECT:G005063-30_1 DATE:01-Sep-05 09:14:20

DWG NO	SH	REV
G005063-30	2	A

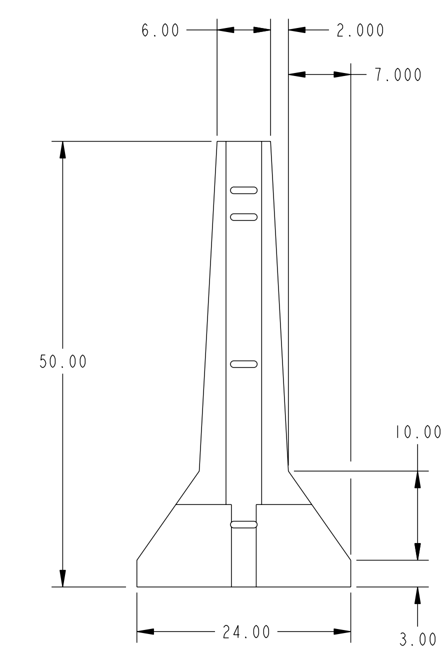
REVISION HISTORY

ZONE	REV	DESCRIPTION	DATE	APPROVED



SECTION A-A

VIEW C-C



VIEW B-B

SIZE	CAGE CODE	DWG NO	REV
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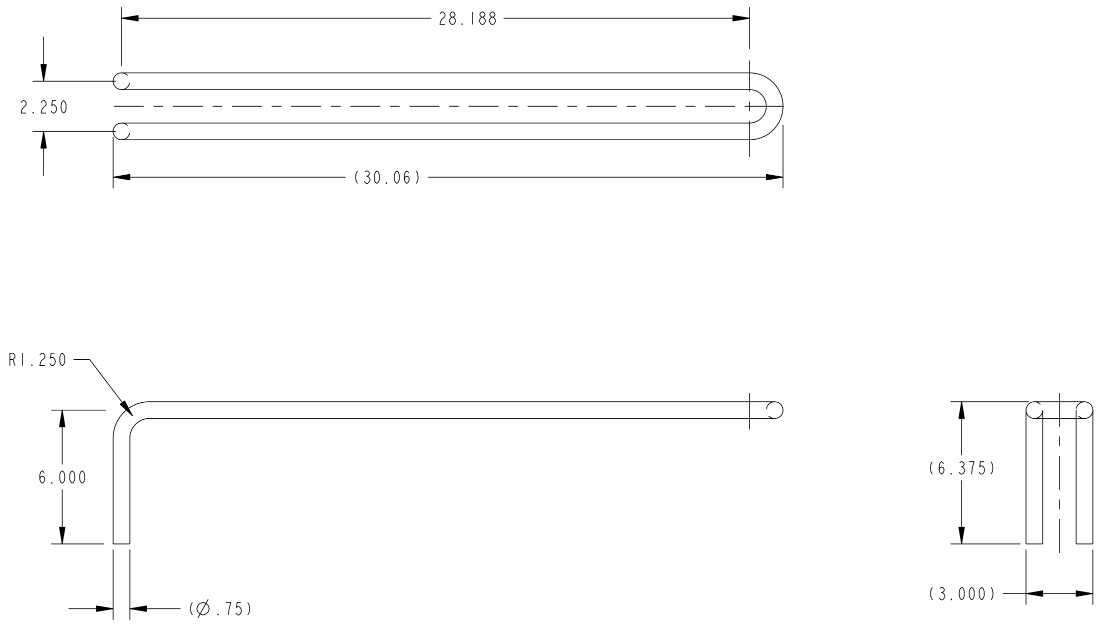
SCALE 1/10	DO NOT SCALE DRAWING	SHEET 2 OF 3	

DWG NO	SH	REV
G005063-30	3	A

REVISION HISTORY

ZONE	REV	DESCRIPTION	DATE	APPROVED



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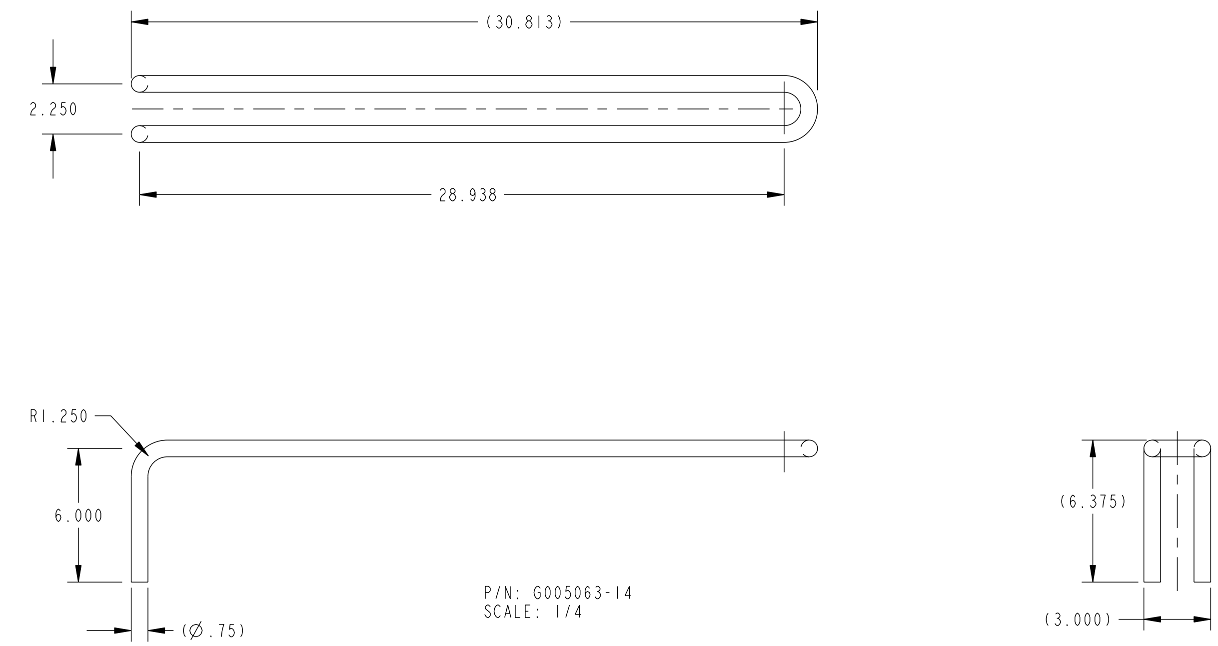

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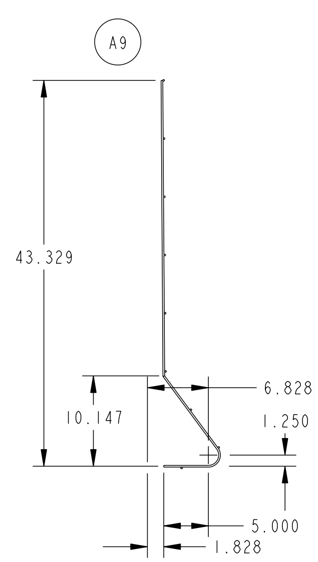
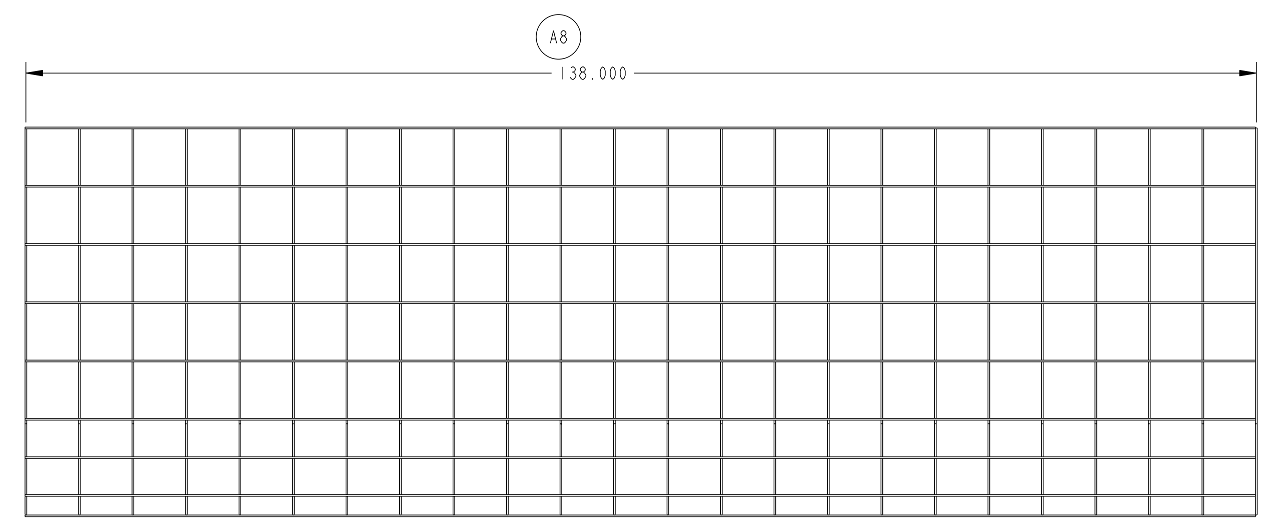
SCALE: 1/4





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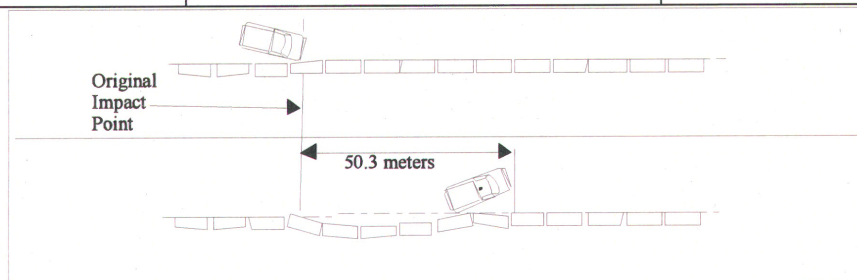
SCALE 1/10	DO NOT SCALE DRAWING	SHEET 3 OF 3	

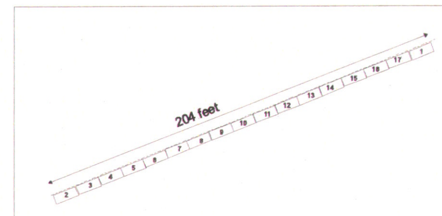
0.000 s

0.260 s

0.480 s

0.800 s





General Information	
Test Agency	Transportation Research Center Inc. (TRC Inc.)
Test No.	060412
Date	April 12, 2006
Test Article	
Type	Longitudinal median barrier system
Name or Manufacturer	Battelle Memorial Institute
Size and/or dimension and material of key elements	17-50" x 12' steel reinforced portable concrete barriers
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	2000P
Model	2003 Chevrolet 2500 Pickup truck
Mass (kg)	
Curb	2254.3
Test Inertial	2040.6
Dummy(s)	N/A
Gross Static	2040.6

Impact Conditions	
Speed (km/h)	100.5
Angle (deg)	25.0
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.5
y-direction	6.1
THIV (optional)	N/A
Ridedown Acceleration (g's)	
x-direction	5.4
y-direction	8.6
PHD (optional)	N/A
ASI (optional)	N/A
Max. 0.050 –s Average (g's)	
x-direction	N/A
y-direction	N/A
z-direction	N/A

Test Article Deflections (m)	
Dynamic	~1.6
Permanent	~1.6
Vehicle Damage	
Exterior	
VDS	N/A
CDC	02FZEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	N/A
Max. Occ. Compart. Deformation (mm)	25
Post-Impact Vehicular Behavior	
Maximum Roll Angle (deg)	16.2
Maximum Pitch Angle (deg)	-10.2
Maximum Yaw Angle (deg)	-45.1

Vehicle Trajectory Post Test	
	The impacting vehicle was redirected by the test article 50.3 meters downstream and 2.1 meters left of the barrier.

Figure 9. Summary of results for test 060412