TEST LEVEL THREE TESTING OF THE RETROFIT RAIL FOR LLANO TRUSS BRIDGE

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Contract No. IAC 88-4DDIA003 (P2004303)
Report/Test No. 409680-1

Sponsored by
Texas Department of Transportation

November 2004
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Report Number 409680-1
Contract Number 88-4DDIA003
Project Title: Test Level 3 Crash Testing of a Truss Rail Retrofit

Performed for the
Texas Department of Transportation

November 2004

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135
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CHAPTER 1. INTRODUCTION

A retrofit railing for the Roy B. Inks Bridge which carries State Highway 16 over the Llano River in Llano, Texas, was developed under research project 0-4419, “Retrofit Railings for Truss Bridges” (1). The retrofit railing was designed for Test Level Two (TL-2) of National Cooperative Highway Research Program (NCHRP) Report 350 (2). Test 2-11 was performed on a prototype of the retrofit railing and its performance was found acceptable.

Upon completion of project 0-4419, Texas Department of Transportation (TxDOT) engineers selected the retrofit railing for use in upgrading the Inks Bridge. Implementation of the design required that a suitable expansion joint be designed and proven through full-scale crash testing. Also, observation of the performance and behavior of the retrofit railing in test 2-11 indicated that it would be expected to pass requirements of Test Level Three (TL-3) in which case it would be available for use on other truss bridges.

Therefore, an expansion joint was designed and was included in a TL-3 evaluation of the prototype retrofit railing and that work is reported herein.
CHAPTER 2. CRASH TEST PROCEDURES

TEST FACILITY

The test facilities at the Texas Transportation Institute’s Proving Ground consist of a 2000-acre (809-hectare) complex of research and training facilities situated 10 mi (16 km) northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well-suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for construction of the Llano Truss Bridge is along a wide out-of-service apron. The apron consists of an unreinforced jointed concrete pavement in 12.5 ft by 15 ft (3.8 m by 4.6 m) blocks nominally 8 to 12 inches (203-305 mm) deep. The aprons and runways are about 50 years old and the joints have some displacement, but are otherwise flat and level.

TEST ARTICLE

The retrofit bridge railing (shown in Figures 1 through 23) developed and tested in research project 0-4419 consisted of a TS8x4x1/2 (TS203x102x13) tube with a C12x20.7 (C310x31) attached to the traffic side face (see Figures 19, 22, and 23). Internal tubular splices for the TS8x4x1/2 (TS203x102x13) were fabricated from ½-inch (13 mm) thick steel plates, 2 ft-0 inches (0.6 m) in length (see Figure 20). The C12x20.7 (C310x31), which was attached to the traffic side face of the TS8x4x1/2 (TS203x102x13), was spliced at the joint locations (see Figure 21). The rail was blocked out at the post locations using a piece of W8x18 (W200x27), eight inches (203.2 mm) in length (see Figure 18). The height to the top of the bridge rail was 2 ft-8 inches (0.81 m).

To reduce the impact loads into the truss members, crushable steel pipes were used in lieu of rigid steel blocks. At the truss member locations, 5-inch (127 mm) and 6-inch (152 mm) diameter Schedule 40 steel pipe blocks were designed to have a “crush” strength of approximately 8 kips (35.60 kN). In the test installation, steel tubes were used at all truss member locations to represent the truss members (see Figures 18 and 21). Depending on the geometry of the truss member, 5-inch (127 mm) diameter or 6-inch (152 mm) diameter crushable steel pipe tubes, 12 inches (3.6 m) in length were used between the rigid steel tubes used as a surrogate for the truss members and the bridge rail (see Figure 18).

After the TL-2 testing performed under research project 0-4419, design and testing of a TL-3 crashworthy rail expansion splice to be used at all expansion joints was performed under the project reported herein. Modifications were made to the existing joint between posts 4 and 5 in the previously described test installation to accommodate thermal expansion and contraction in the rail elements. After review of the existing bridge details and consultation with TxDOT personnel, thermal contraction in the rail elements can result in as much as 2 inches (51 mm) of open distance between rail elements. Maximum expansion in the rail was estimated to be 1.5 inches (38 mm) (the open distance between the rail elements at...
Figure 1. Overall Layout of the Llano Truss Bridge Installation.
Figure 2. Layout of the Foundation for Llano Truss Bridge Installation.
Figure 3. Rebar Details of the Foundation for Llano Truss Bridge Installation.
Figure 4. Cross Section of Post 2.
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Figure 23. Details of TS 4x8x1/2 Bridge Rail.
70 degrees Fahrenheit minus the expansion in the rail due to a 40-degree Fahrenheit temperature increase). Expansion details were developed to accommodate expansion and contraction in the rail members. These details are provided in Figures 24 through 28. Finger joints were machine cut in the exterior C12x20.7 (C310x31) rail member to permit the expansion and contraction, and provide a surface that minimizes vehicular snagging from the crash loads. Steel splice plates were added on top and bottom corners of the C12x20.7 (C310x31) members to minimize vehicular snagging on these corners caused by deformation from the crash loads. The rail elements were slotted on one side of the connection (left side) to accommodate the 3/4-inch (19 mm) diameter connecting bolts with 3/4-inch (19 mm) diameter standard pipe sleeves. These sleeves were fabricated 1/8-inch (3 mm) longer than the connecting parts to minimize friction between the connecting parts during expansion and contracting movement in the rail members. Two inches (51 mm) of space at the splice between the ends of the connecting TS4x8x1/2 (TS203x102x13) was not provided since this joint was not considered problematic. However, for field applications, equivalent expansion and contraction should be provided in this rail element similar to the exterior C12x20.7 (C310x31) rail members. For additional information, please refer to the drawings shown in Figures 1 through 28. Photographs of the completed installation are shown in Figure 29.

CRASH TEST CONDITIONS

Two tests are required to evaluate longitudinal barriers, such as the Llano Truss Bridge Rail to Test Level Three (TL-3) NCHRP Report 350.

**NCHRP Report 350 test designation 3-10**: An 820-kg (1806-lb) passenger car impacting the bridge rail at the critical impact point (CIP) along the length of need at a nominal speed and angle of 100 km/h and 20 degrees, respectively. The test is intended to evaluate occupant risk and post-impact trajectory.

**NCHRP Report 350 test designation 3-11**: A 2000-kg (4404-lb) pickup truck impacting the bridge rail at the CIP along the length of need at a nominal speed and angle of 100 km/h and 25 degrees, respectively. The test is intended to evaluate strength of the section in containing and redirecting the 2000 kg (4404 lb) vehicle.

The test reported herein corresponds to *NCHRP Report 350* test designation 3-11. This test was performed to evaluate the ability of the bridge rail in safely containing and redirecting the pickup truck, and to evaluate behavior of the expansion joint in the rail member. Information and tables contained in the guidelines of *NCHRP Report 350* were used to select the CIP for this test. The target impact point for this test was 4.6 ft (1.4 m) upstream of the center expansion joint, or approximately 6.3 ft (1.9 m) upstream of post 5 (see Figure 30).

All crash test, data analysis, and evaluation and reporting procedures followed under this project were in accordance with guidelines presented in *NCHRP Report 350*. Appendix A presents brief descriptions of these procedures.
Figure 24. Retrofit Railing – Expansion Joint Details (Universal Ends).
Figure 25. Retrofit Railing – Expansion Joint Details (Traffic Side View).
Figure 26. Retrofit Railing – Splice Plate Detail.
Figure 27. Retrofit Railing – Sleeve for Rail Bolts.
3/4” DIA BOLT
INSIDE 3/4” DIA.
STANDARD PIPE
I.D.:=0.824”
WALL THK. = 0.113”

PLAN
1 1/16”

ELEVATION
13/16”

DETAIL 3~3/4” DIA.
SLEEVE FOR 3/4”
DIA. SPlice PLATE
BOLTS (4 REQ’D.)

Figure 28. Retrofit Railing – Sleeve for Splice Bolt.
Figure 29. Llano Truss Bridge Installation before Test No. 409680-1.
EVALUATION CRITERIA

The crash test performed was evaluated in accordance with *NCHRP Report 350*. As stated in *NCHRP Report 350*, “Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision.” Accordingly, researchers used the safety evaluation criteria from Table 5.1 of *NCHRP Report 350* to evaluate the crash test reported herein.
CHAPTER 3. CRASH TEST RESULTS

TEST NO. 409680-1 (NCHRP REPORT 350 TEST DESIGNATION 3-11)

Test Vehicle

A 2000 Chevrolet pickup truck, shown in Figures 31 and 32, was used for the crash test. Test inertia weight of the vehicle was 4586 lb (2082 kg), and its gross static weight was 4586 lb (2082 kg). The height to the lower edge of the vehicle bumper was 16.3 inches (415 mm), and it was 25.0 inches (635 mm) to the upper edge of the bumper. Figure 38 in Appendix B gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Soil and Weather Conditions

The test was performed on the morning of September 29, 2004. Weather conditions at the time of testing were as follows: Wind speed: 0 mi/h (0 km/h); Wind direction: 335 degrees with respect to the vehicle (vehicle was traveling in a northeasterly direction); Temperature: 77°F (25°C), Relative humidity: 55 percent.

Test Description

The 4586 lb (2082 kg) pickup truck, traveling at an impact speed of 63.1 mi/h (101.5 km/h), impacted the Llano Truss Bridge Rail 6.3 ft (1.91 m) upstream of the center of post 5 at an impact angle of 24.8 degrees. Shortly after contact, the front bumper and front of the vehicle began to deform. At 0.020 s after impact, the left front tire snagged on the rail, and at 0.034 s, the tire blew out. The hood and left front quarter panel snagged on the vertical support at 0.053 s, and the vehicle began to redirect at 0.058 s. As the pickup truck continued forward, the quarter panel continued to peel back as it remained snagged on the vertical support, and at 0.177 s, the rear of the pickup truck contacted the rail. At 0.186 s, the pickup truck became parallel with the rail and was traveling at a speed of 51.4 mi/h (82.7 km/h). The tailgate on the pickup truck separated from the vehicle at 0.244 s. At 0.402 s, the vehicle lost contact with the rail and was traveling at an exit speed of 51.2 mi/h (82.4 km/h) and an exit angle of 10.8 degrees. Brakes on the vehicle were applied at 1.5 s after impact, and the vehicle came to rest 233.0 ft (71.0 m) downstream of impact and 39.5 ft (12.0 m) forward of the traffic face of the rail. Figures 39 and 40 in Appendix C show sequential photographs of the test period.
Figure 31. Vehicle/Installation Geometrics for Test No. 409680-1.
Figure 32. Vehicle before Test No. 409680-1.
Damage to Test Installation

Figures 33 and 34 show damage to the prototype railing. The weld in the rail splice on the upper railing fractured laterally across the top between posts 4 and 5. Marks from contact with the pickup truck were on post 5 at 29.5 inches (750 mm) above the top railing. The curb spalled at posts 4 and 5. Concrete broke out around the anchor bolts in the curb at posts 3, 4, and 6, and was cracked at post 7. Maximum dynamic deflection of the railing was 3.5 inches (90 mm) at 54.1 inches (1375 mm) upstream of post 5. Length of contact of the pickup truck with the railing was 11.5 ft (3.5 m).

Vehicle Damage

As shown in Figure 35, damage to the vehicle was mostly to the left front quarter. Structural damage included deformed left frame rail, deformed floor pan, deformed left A-pillar, and the left upper ball joint was pulled out of the socket. The hood was deformed up and back and the quarter panel was peeled back to the cab. The windshield sustained stress cracks, and the left door was deformed open 4.7 inches (120 mm) at the top. The outer rims of both left wheel rims broke at the weld to the inner rims, and the outer rim and wheel separated from the inner rim. Other damage included deformed front bumper, grill, and left rear exterior bed. Maximum exterior crush to the vehicle was 23.6 inches (600 mm) in the side plane at the left front corner of the bumper. Maximum occupant compartment deformation was 2.1 inches (53 mm) in the lateral area across the front of the cab at the kickpanel. Photographs of the interior of the vehicle are shown in Figure 36. Tables 2 and 3 in Appendix B document exterior vehicle crush and occupant compartment deformation.

Occupant Risk Factors

Data from the triaxial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. Only the occupant impact velocity and ridedown accelerations in the longitudinal axis are required from these data for evaluation of criterion L in NCHRP Report 350. In the longitudinal direction, occupant impact velocity was 5.3 m/s at 0.094 s, maximum 0.010-s ridedown acceleration was -5.7 g’s from 0.094 to 0.104 s, and the maximum 0.050-s average was -9.2 g’s between 0.038 and 0.088 s. In the lateral direction, the occupant impact velocity was 9.0 m/s at 0.094 s, the highest 0.010-s occupant ridedown acceleration was 9.9 g’s from 0.221 to 0.231 s, and the maximum 0.050-s average was 15.0 g’s between 0.045 and 0.095 s. Figure 37 presents these data and other pertinent information from the test. Figures 41 through 47 in Appendix D present vehicle angular displacements and accelerations versus time traces.
Figure 33. After Impact Trajectory Path for Test No. 409680-1.
Figure 34. Installation after Test No. 409680-1.
Figure 35. Vehicle after Test No. 409680-1.
Figure 36. Interior of Vehicle for Test No. 409680-1.
Texas Transportation Institute
409680-1
09/29/2004
Truss Bridge Retrofit
Llano Truss Bridge Retrofit
70 (21.3 m)
Steel Tube Rail With Steel Posts and Blockouts
Concrete Deck, Dry
Production
2000P
2000 Chevrolet 2500 Pickup
4667 (2119)
4586 (2082)
None
4586 (2082)
63.1 (101.5)
24.8
51.2 (82.4)
10.8
17.4 (5.3)
29.5 (9.0)
22.7 (36.5)
-5.7
9.0
10.3
1.83
-9.2
15.3
-8.0
0.30 (0.09)
0.30 (0.09)
1.37 (0.42)
11FL3
11FLEW3
23.6 (600)
2.1 (53)
-45
-6
51

Figure 37. Summary of Results for NCHRP Report 350 Test 3-11 on the Llano Truss Bridge Retrofit.
CHAPTER 4. SUMMARY AND CONCLUSIONS

ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable NCHRP Report 350 safety evaluation criteria is provided below.

Structural Adequacy

A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.

Result: The retrofit railing for the Llano truss bridge contained and redirected the pickup truck. The pickup truck did not penetrate, underride, or override the installation. Maximum dynamic deflection of the bridge rail was 3.5 inches (90 mm). (PASS)

Occupant Risk

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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

Result: No detached elements, fragments, or other debris was present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 2.1 inches (53 mm) in the kickpanel area. (PASS)

F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.

Result: The pickup truck remained upright during and after the collision period. (PASS)

Vehicle Trajectory

K. After collision, it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.

Result: The pickup truck may intrude into adjacent traffic lanes as it came to rest 233.0 ft (71.0 m) downstream of impact and 39.5 ft (12.0 m) forward of the traffic face of the railing. (FAIL)
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g’s.

Result: Longitudinal occupant impact velocity was 17.4 ft/s (5.3 m/s), and longitudinal ridedown acceleration was -5.7 g’s. (PASS)

M. The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.

Result: Exit angle at loss of contact was 10.8 degrees, which was 44 percent of the impact angle. (PASS)

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled “ACTION: Identifying Acceptable Highway Safety Features,” were used for visual assessment of test results (3). Factors underlined below pertain to the results of the crash test reported herein.

**Passenger Compartment Intrusion**
1. **Windshield Intrusion**
   a. No windshield contact
   b. Windshield contact, no damage
   c. Windshield contact, no intrusion
   d. Device embedded in windshield, no significant intrusion
   e. Complete intrusion into passenger compartment
   f. Partial intrusion into passenger compartment

2. **Body Panel Intrusion**
   yes or no

**Loss of Vehicle Control**
1. Physical loss of control
2. Loss of windshield visibility
3. Perceived threat to other vehicles
4. Debris on pavement

**Physical Threat to Workers or Other Vehicles**
1. Harmful debris that could injure workers or others in the area
2. Harmful debris that could injure occupants in other vehicles
   No debris was present.

**Vehicle and Device Condition**
1. **Vehicle Damage**
   a. None
   b. Minor scrapes, scratches or dents
   c. Significant cosmetic dents
   d. Major dents to grill and body panels
   e. Major structural damage

2. **Windshield Damage**
   a. None
   b. Minor chip or crack (stress only)
   c. Broken, no interference with visibility
   e. Shattered, remained intact but partially dislodged
   f. Large portion removed
d. Broken or shattered, visibility restricted but remained intact

g. Completely removed

3. Device Damage

a. None

b. Superficial

c. Substantial, but can be straightened

d. Substantial, replacement parts needed for repair

e. Cannot be repaired

CONCLUSIONS

The retrofit railing for the Llano truss bridge perform acceptably for NCHRP Report 350 test 3-11, as shown in Table 1.
<table>
<thead>
<tr>
<th><strong>NCHRP Report 350 Evaluation Criteria</strong></th>
<th><strong>Test Results</strong></th>
<th><strong>Assessment</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation, although controlled lateral deflection of the test article is acceptable.</td>
<td>The retrofit railing contained and redirected the pickup truck. The pickup truck did not penetrate, underride, or override the installation. Maximum dynamic deflection of the bridge rail was 3.5 inches (90 mm).</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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>No detached elements, fragments, or other debris was present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 2.1 inches (53 mm) in the kickpanel area.</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 pickup truck remained upright during and after the collision period.</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Vehicle Trajectory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K. After collision, it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td>
<td>The pickup truck may intrude into adjacent traffic lanes as it came to rest 233.0 ft (71.0 m) downstream of impact and 39.5 ft (12.0 m) forward of the traffic face of the railing.</td>
<td>Fail*</td>
</tr>
<tr>
<td>L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g’s.</td>
<td>Longitudinal occupant impact velocity was 17.4 ft/s (5.3 m/s), and longitudinal ridedown acceleration was -5.7 g’s.</td>
<td>Pass</td>
</tr>
<tr>
<td>M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.</td>
<td>Exit angle at loss of contact was 10.8 degrees, which was 44 percent of the impact angle.</td>
<td>Pass*</td>
</tr>
</tbody>
</table>

* Criteria K and M are preferable, but not required.
REFERENCES


APPENDIX A. CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented as follows.

**ELECTRONIC INSTRUMENTATION AND DATA PROCESSING**

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a backup biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO® Model 2262CA, piezoresistive accelerometers with a $\pm 100$ g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Angular rate transducers are solid state, gas flow units designed for high-“g” service. Signal conditioners and amplifiers in the test vehicle increase the low-level signals to a $\pm 2.5$ volt maximum level. The signal conditioners also provide the capability of an resistive calibration (R-cal) or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15-channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals from the test vehicle are recorded before the test and immediately afterwards. A crystal-controlled time reference signal is simultaneously recorded with the data. Wooden dowels actuate pressure-sensitive switches on the bumper of the impacting vehicle prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an “event” mark on the data record to establish the instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto separate tracks of a 28-track (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R-cal and pre-zero values at 10,000 samples per second per channel. WinDigit also provides Society of Automotive Engineers (SAE) J211 class 180 phaseless digital filtering and vehicle impact velocity.

All accelerometers are calibrated annually according to the SAE J211 4.6.1 by means of an ENDEVCO® 2901, precision primary vibration standard. This device and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are made any time data is suspect.
The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. WinDigit calculates change in vehicle velocity at the end of a given impulse period. In addition, WinDigit computes maximum average accelerations over 50-ms intervals in each of the three directions. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

Use of a dummy in the 2000 kg pickup truck is optional according to NCHRP Report 350, and there was no dummy used in the test.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field-of-view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field-of-view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2-to-1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or
braking inputs, until the vehicle cleared the immediate area of the test site, at which time the vehicle’s brakes were activated to bring it to a safe and controlled stop.
APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

Date: 9-29-2004        Test No.: 409680-1        VIN No.: 1GCGC24RXJR192254
Year: 2000          Make: Chevrolet       Model: Cheyenne 2500
Tire Inflation Pressure: 50/80 PSI       Odometer: 196643       Tire Size: 245 / 75R16

Describe any damage to the vehicle prior to test:

• Denotes accelerometer location.

NOTES: ____________________________
______________________________
______________________________
Engine Type: V-8
Engine CID: 5.7 L
Transmission Type: Auto
X Manual
Optional Equipment:

______________________________
______________________________
______________________________

Dummy Data:
Type: None
Mass:
Seat Position:

Geometry (mm)

A 1880   E 1310   J 1038   N 1590   R 750
B 810   F 5470   K 635   O 1610   S 900
C 3350   G 1456.2   L 70   P 725   T 1460
D 1820   H __________   M 415   Q 440   U 3360

Mass (kg)  Curb   Test Inertial   Gross Static
M1 1222   1177   ______
M2 897   905   ______
MTotal 2119   2082   ______


Figure 38. Vehicle Properties for Test No. 409680-1.
### Table 2. Exterior Crush Measurements for Test No. 409680-1.

**VEHICLE CRUSH MEASUREMENT SHEET\(^1\)**

<table>
<thead>
<tr>
<th>End Damage</th>
<th>Side Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undeformed end width ________</td>
<td>Bowing: B1 ________ X1 ________</td>
</tr>
<tr>
<td>Corner shift: A1 ________</td>
<td>B2 ________ X2 ________</td>
</tr>
<tr>
<td>A2 ________</td>
<td>Bowing constant</td>
</tr>
</tbody>
</table>
| End shift at frame (CDC) | \[
\frac{X1 + X2}{2} = ________
\]
| (check one) | |
| < 4 inches ________ | |
| ≥ 4 inches ________ | |

Note: Measure C\(_1\) to C\(_6\) from driver to passenger side in front or rear impacts – rear to front in side impacts.

Note: Measure C\(_1\) to C\(_6\) from driver to passenger side in front or rear impacts – rear to front in side impacts.

<table>
<thead>
<tr>
<th>C-Measurements</th>
<th>Direct Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width** (CDC)</td>
<td>Max*** Crush</td>
</tr>
<tr>
<td>At front bumper</td>
<td>800</td>
</tr>
<tr>
<td>2</td>
<td>800</td>
</tr>
</tbody>
</table>

\(^1\)Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.
### Table 3. Occupant Compartment Measurements for Test No. 409680-1.

#### TRUCK

**Occupant Compartment Deformation**

<table>
<thead>
<tr>
<th></th>
<th>BEFORE (mm)</th>
<th>AFTER (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>872</td>
<td>848</td>
</tr>
<tr>
<td>A2</td>
<td>945</td>
<td>930</td>
</tr>
<tr>
<td>A3</td>
<td>930</td>
<td>930</td>
</tr>
<tr>
<td>B1</td>
<td>1071</td>
<td>1065</td>
</tr>
<tr>
<td>B2</td>
<td>976</td>
<td>943</td>
</tr>
<tr>
<td>B3</td>
<td>1061</td>
<td>1061</td>
</tr>
<tr>
<td>C1</td>
<td>1370</td>
<td>1346</td>
</tr>
<tr>
<td>C2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>1367</td>
<td>1367</td>
</tr>
<tr>
<td>D1</td>
<td>325</td>
<td>290</td>
</tr>
<tr>
<td>D2</td>
<td>158</td>
<td>155</td>
</tr>
<tr>
<td>D3</td>
<td>309</td>
<td>309</td>
</tr>
<tr>
<td>E1</td>
<td>1585</td>
<td>1593</td>
</tr>
<tr>
<td>E2</td>
<td>1590</td>
<td>1612</td>
</tr>
<tr>
<td>F</td>
<td>1485</td>
<td>1460</td>
</tr>
<tr>
<td>G</td>
<td>1485</td>
<td>1465</td>
</tr>
<tr>
<td>H</td>
<td>1250</td>
<td>1230</td>
</tr>
<tr>
<td>I</td>
<td>1250</td>
<td>1250</td>
</tr>
<tr>
<td>J*</td>
<td>1525</td>
<td>1472</td>
</tr>
</tbody>
</table>

*Lateral area across the cab from driver’s side kickpanel to passenger’s side kickpanel.*
Figure 39. Sequential Photographs for Test No. 409680-1 (Overhead and Frontal Views).
Figure 39. Sequential Photographs for Test No. 409680-1
(Overhead and Frontal Views) (continued).
Figure 40. Sequential Photographs for Test No. 409680-1 (Rear View).
Figure 41. Vehicle Angular Displacements for Test No. 409680-1.
Figure 42. Vehicle Longitudinal Accelerometer Trace for Test No. 409680-1
(Accelerometer Located at Center of Gravity).
Figure 43. Vehicle Lateral Accelerometer Trace for Test No. 409680-1
(Accelerometer Located at Center of Gravity).
Test Number: 409680-1
Test Article: Retrofit Railing for Llano Truss Bridge
Test Vehicle: 2000 Chevrolet 2500 Pickup
Inertial Mass: 2082 kg
Gross Mass: 2082 kg
Impact Speed: 101.5 km/h
Impact Angle: 24.8 degrees

Figure 44. Vehicle Vertical Accelerometer Trace for Test No. 409680-1
(Accelerometer Located at Center of Gravity).
Figure 45. Vehicle Longitudinal Accelerometer Trace for Test No. 409680-1
(Accelerometer Located Over Rear Axle).
**Y Acceleration Over Rear Axle**

Test Number: 409680-1  
Test Article: Retrofit Railing for Llano Truss Bridge  
Test Vehicle: 2000 Chevrolet 2500 Pickup  
Inertial Mass: 2082 kg  
Gross Mass: 2082 kg  
Impact Speed: 101.5 km/h  
Impact Angle: 24.8 degrees

Figure 46. Vehicle Lateral Accelerometer Trace for Test No. 409680-1  
(Accelerometer Located Over Rear Axle).
Figure 47. Vehicle Vertical Accelerometer Trace for Test No. 409680-1
(Accelerometer Located Over Rear Axle).