

# Full-Scale Vehicle Crash Tests on Guardrail-Bridgerail Transition Designs with Special Post Spacing

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Full-scale 4,500-pound vehicle impact tests at 60 mph and 25 degrees were conducted on four new guardrail-bridgerail "transition" designs for use in Nebraska in which the first wood post from the bridge end was left out. The post was left out to represent a common field problem in which a concrete footing prevents installing the post. To compensate for the missing post, a stronger beam member and heavier wood posts were used in addition to a 4:1 tapered end on the concrete bridgerail. The tapered end was used to (1) reduce the unsupported span length and (2) provide a smooth guardrail deflection curve during vehicle redirection. All of the transition designs were identical except for the transition beam member. The designs consisted of two heavy 10 inch x 10 inch posts followed by four heavy 8 inch x 8 inch posts. The remaining posts were standard 6 inch x 8 inch posts. Over a guardrail length of 18 feet 9 inches, the posts were spaced 3 feet 1½ inches on centers, whereas, over the remaining length, a standard post spacing of 6 feet 3 inches was used. The posts were installed in a "native" silty clay (type CL) soil. In terms of the evaluation guidelines in National Cooperative Highway Research Project (NCHRP) 230, the overall performance of the transition designs was as follows: single thrie beam transition—unsatisfactory, double thrie beam transition—satisfactory, tubular thrie beam transition—satisfactory, double W-beam transition—unsatisfactory.

## PROBLEM STATEMENT

The majority of the bridgerail designs in current use are rigid traffic barriers, whereas the guardrail designs on the approaches to the bridge structure are semi-rigid traffic barriers. In restraining and redirecting a large 4,500-pound automobile at 60 mph and 25 degrees, rigid and semi-rigid traffic barriers will typically undergo deflections of 0 to 6 inches and 30 inches, respectively. To provide structural stiffness compatibility between the semi-rigid guardrail and the rigid bridgerail, a guardrail consisting of reduced post spacings and larger size posts is used adjacent to the bridgerail end. A current American Association of State Highway and Transportation Offi-

cials (AASHTO) T1 (1) transition section requires that the first six wood posts back from the bridgerail end be installed on a reduced spacing of 3 feet 1½ inches, and the first three wood posts be larger, 10 inch x 10 inch posts.

Many of the bridge structures in Nebraska were constructed with concrete footings that extend back from the end of the bridgerail. The footing has created a field problem in that the first required 10 inch x 10 inch wood post located 3 feet 1½ inches from the bridgerail end connection cannot be installed in the ground. To compensate for the first post left out or installed further back, the Nebraska Department of Roads (NDR) has designed four new transition sections consisting of longer 6-foot posts and stronger guardrail beam members. Cross-section drawings of the four new beam transition sections are shown in Figure 1.

## RESEARCH STUDY OBJECTIVE

The primary objective of this study was to evaluate the performance characteristics of the four new guardrail-bridgerail transition designs by conducting full-scale vehicle crash tests. In all tests, the first 10 inch x 10 inch-wood post located 3 feet 1½ inches back from the bridgerail end connection was left out.

## DESIGN AND CONSTRUCTION OF TEST ARTICLE

### Simulated Bridge Deck and Railing

The simulated concrete bridge railing and deck were designed by the NDR Bridge Division. Design details of the bridge railing and deck are shown in Figure 2, and photographs of the bridge railing are shown in Figure 4. The bridge railing and deck were constructed by a private contractor who was qualified to bid on NDR bridge contracts. The open bridge railing is a recent design currently in use in Nebraska to help keep the roadway clear of blowing and drifting snow and to facilitate snow removal operations. The cantilevered 4:1 tapered end section was a totally new design feature that was recommended by C. F. McDevitt of the FHWA as a method to (1) provide a smooth guardrail deflection curve in redirecting the test vehicle and (2) reduce the effective unsupported span length to help compensate for the first wood post (post No. 1) that was left out.

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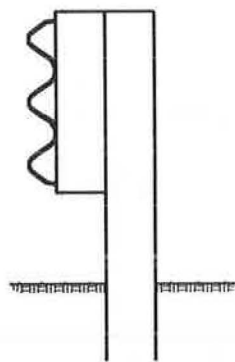


FIGURE 1a

SINGLE THRIE BEAM

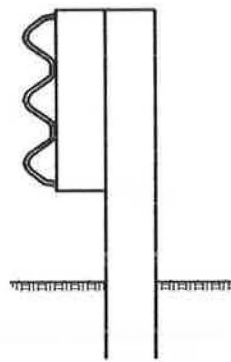


FIGURE 1b

DOUBLE THRIE BEAM

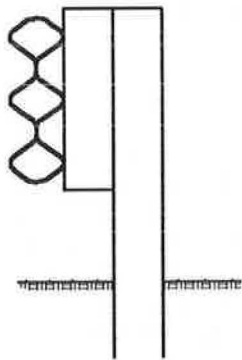


FIGURE 1c

TUBULAR THRIE BEAM

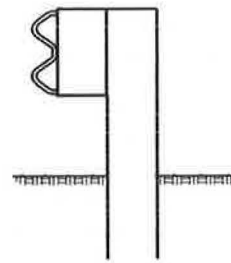


FIGURE 1d

DOUBLE W-BEAM

**FIGURE 1 Transition designs.**

The concrete bridge railing and deck were designed to carry dynamic impact loads computed by the FHWA computer model, named BARRIER VII (2). The average 10 msec design impact loads were 120 kips lateral and 50 kips longitudinal. The lateral impact load is on the order of 12 times higher than the design load of 10 kips specified in the AASHTO Standard Specifications for Highway Bridges (3).

The concrete bridge railing, including the cantilevered 4:1 tapered end section, was 21.5 feet. The solid wall portion of the railing was 32 inches high, whereas the beam portion was 29 inches high. The vertical opening between the deck and railing was 17 inches. The two concrete posts were located approximately 8 feet on centers and were set back 2 inches from the traffic face of the railing to minimize vehicle snagging. The 1½-inch diameter bolt hole pattern in the railing wall was designed to accommodate the end shoes of both the Thrie Beam and the standard W-Beam guardrail sections. The ¾-inch recessed area adjacent to the 4:1 tapered end section was designed to accommodate the added width of the tubular thrie beam guardrail. On the other hand, a ¾-inch-wide wood filler block was cut to fill the recessed area and to extend along the length of the tapered end section to accommodate the other non-tubular guardrail designs. The railing was reinforced with No. 7 and smaller size rebar (Grade 60) to carry the vehicle impact loads.

### Approach Guardrail

Design details of the thrie beam approach guardrail system are shown in Figure 3 and photographs of the approach guardrail system are shown in Figure 4. The overall length of the guardrail installation was 56 feet 3 inches. A 6-foot-wide strip of the concrete roadway slab was sawcut and removed to install the guardrail in native soil. The guardrail was installed at a 25 degree angle relative to the center line of the roadway.

The 12 gauge thrie beam guardrail transition section adjacent to the end of the concrete bridge railing was 12 feet 6 inches long. A 12 gauge 6 foot 3 inches Adapter section was used to transition from the thrie beam section to the upstream standard 12 gauge W-Beam section. The thrie beam was mounted 31 inches high, whereas the standard W-Beam was mounted 27 inches high. The upstream end of the W-Beam guardrail was anchored into an 18 inch (diameter) by 6 feet (deep) reinforced concrete shaft.

The first wood guardrail post (post No. 2) was installed 7 feet 7½ inches from the center line of the bolt hole pattern in the concrete bridge end. The unsupported span length from the 4:1 tapered concrete bridge end to the center of post no. 2 was 4 feet 7 inches. The post spacings between post No. 2 and post No. 6 were 3 feet 1½ inches on centers, whereas, the post spacings of the remaining posts were 6 feet 3 inches on centers. The posts were all 6 feet long. The size of the first 2 posts were 10 inches x 10 inches; the size of the next 4 posts were 8 inches x 8 inches, and the size of the remaining posts were 6 inches x 8 inches. The rail blockouts were all 6 inches x 8 inches.

### Soil

The guardrail wood posts were installed in a "native" silty clay topsoil. The soil was not in conformance with either the strong soil (S-1) or the weak soil (S-2) defined in NCHRP 230 (4). The decision to deviate from the recommended testing procedures in NCHRP 230 was made by NDR engineers because of the desire to evaluate the guardrail-bridgerail transition designs under typical soil conditions encountered in most of Nebraska. The properties of the native soil were

1. Unified Classification (ASTM D-2487), CL;
2. Liquid Limit (LL), 31;
3. Plastic Limit (PL), 20;
4. Plasticity Index (LL-PL), 11;
5. Optimum Moisture Content, 17.6%; and
6. Unconfined Shear Strength, 1,900 psf.

The wood posts were placed in 18- to 20-inch diameter holes. The backfill soil around the posts was compacted by hand in 6-inch layers to a density of approximately 92 percent. The field density of the soil was measured by a Troxler Nuclear Density Meter.

### TEST RESULTS

A summary and sequential photographs of the full-scale vehicle crash test on the Tubular Thrie Beam Transition are presented in Figure 5. Due to technical problems with the tow

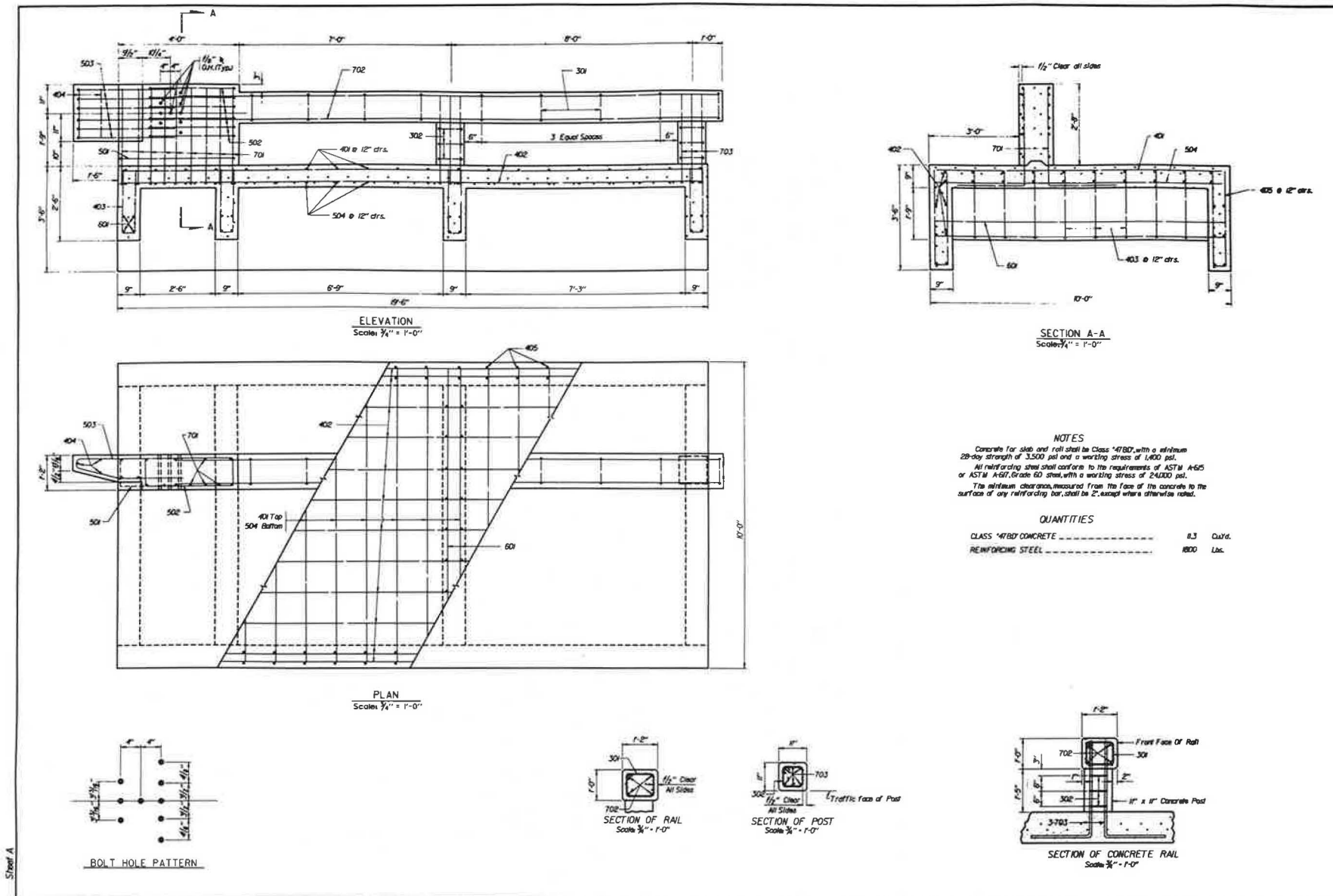


FIGURE 2 Design details of simulated bridge deck and railing.

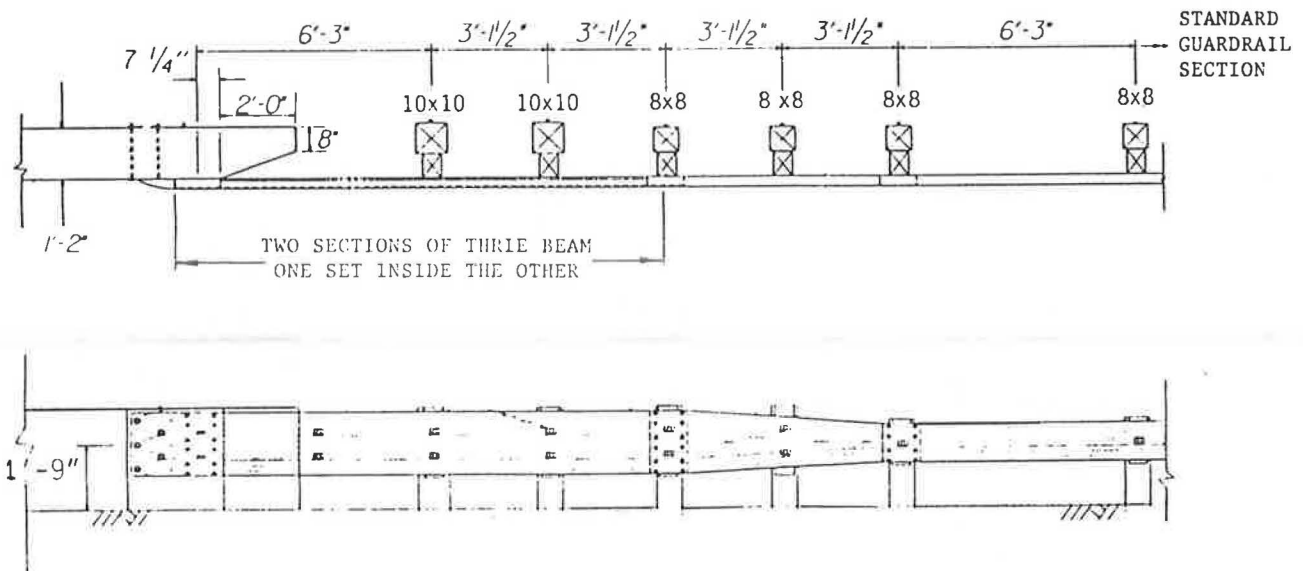


FIGURE 3 Design details of approach guardrail.

vehicle, the impact speed was 13 mph below the recommended target speed (60 mph) in NCHRP 230. The point of impact was between post Nos. 2 and 3. At 76 msec after impact, the vehicle reached its greatest depth of crushing into the guardrail. At 194 msec, the vehicle's "lateral" velocity component was zero as the vehicle became parallel to an extended center line of the traffic barrier. Somewhere between 76 and 194 msec, an occupant would have moved laterally 12 inches and struck the side of the vehicle.

Photographs of the guardrail damage are shown in Figure 6. The Tubular Thrie Beam was fabricated by a local steel manufacturer by shop welding two thrie beams back-to-back (see Figure 1c). The end shoe was welded on the outside of the tubular thrie beam. As evident, the damage to the guardrail was very minor with a maximum guardrail permanent set of only 2½ inches. Due to a technical problem with the overhead camera, the maximum guardrail dynamic deflection was not measured. Assuming a typical impact factor of 1.5, an estimate of the maximum dynamic deflection would be 4 inches.

As can be seen in Figure 6, the vehicle tire marks were relatively straight after exit from the barrier. The vehicle exit angle was 15 deg, and the vehicle travelled 270 feet before it came to a stop without braking. The tire scuff marks were caused by the deformed inward alignment of the two front wheels. The vehicle rebound distance was 72 feet.

The damage to the vehicle was moderate and repairable. The left front door was not sprung open under the lateral side impact loading of the dummy. The left front corner was crushed 15 inches and the right front corner was deformed outward 3 inches. The left rear corner was crushed 4 inches. The vehicle damage was assigned a NSC (5) TAD rating of LFQ-3. Based on the findings in NCHRP 86 (6), the damage rating indicates that injuries will occur in 18 percent of the vehicles damaged to this extent.

The vehicle impact speed was 47 mph and the exit speed was 38 mph. The change-in-speed of 9 mph was well below the 15 mph limit recommended in NCHRP 230 (4).

The results of test No. 1 were used to determine "equiv-

alent" impact conditions presented in table 1 by equating lateral kinetic energy. At an impact angle of about 20 degrees, the same guardrail damage shown in Figure 6 would have occurred under an impact speed of 60 mph. The equation to determine equivalent speeds is presented in Table 1.

In a similar manner, the results of test No. 1 were used to estimate that a dynamic deflection of 6 to 7 inches would have occurred in a 60 mph impact. This estimate is based on the assumption that the guardrail deflection is directly proportional to the vehicle lateral kinetic energy.

Based on the estimate that the guardrail dynamic deflections would have only been on the order of 6 to 7 inches under a 60 mph impact, NDR decided not to rerun the test because it would most likely be successful. It is interesting to note that the BARRIER VII computer model predicted a dynamic deflection of 9 inches. No attempt was made to fine-tune the computer model in this study.

#### Test No. 2: Single Thrie Beam Transition

A summary and sequential photographs of the full-scale vehicle crash test in the Single Thrie Beam Transition is presented in Figure 7. The point of impact was between posts Nos. 2 and 3. The vehicle impact speed was 60 mph, and the exit speed was 39 mph. During the primary (vehicle front-end) impact stage at 89 msec, the maximum guardrail deflection was 13 inches. At 108 msec, the lateral occupant displacement of 12 inches occurred nearly simultaneously to the time in which the front door sprung open under a dummy side impact loading force of 10 g. It was interesting to observe that the largest guardrail deflection of 14 inches occurred during the secondary (vehicle rear-end) impact stage at 231 msec. Vehicle exit from the barrier occurred at about 280 msec.

Photographs of the guardrail damage are shown in Figure 8. The area where the upstream end anchor was bolted to the W-Beam guardrail buckled inward under the tensile loading of about 48 kips as computed by BARRIER VII. As clearly visible in the photographs, a moderate amount of vehi-

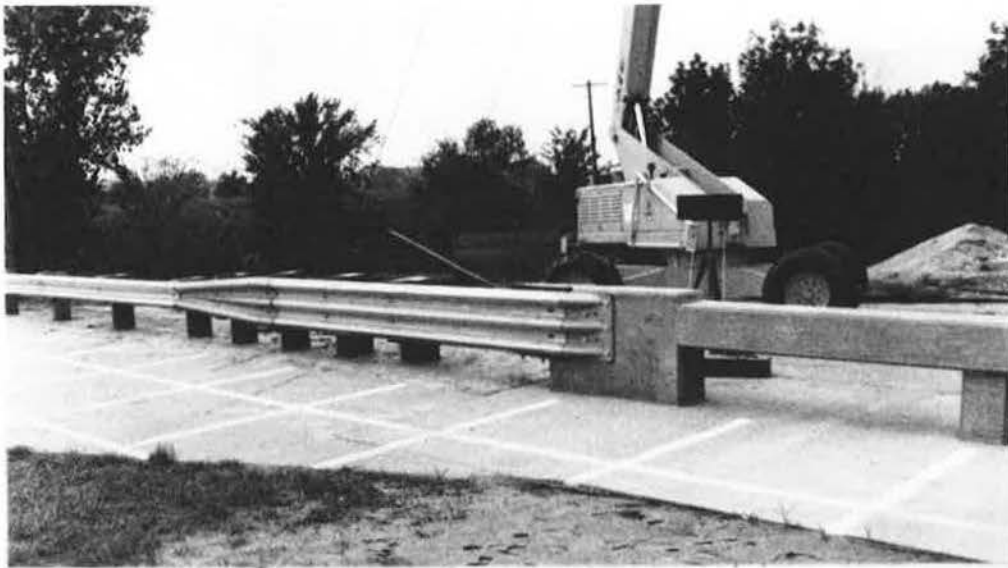


FIGURE 4 Photographs of approach guardrail installation.





Impact



76 msec



194 msec



294 msec

#### TEST VEHICLE

Make . . . . . 1977 Plymouth Fury  
Weight (excluding dummy) . . . . . 4,384 lb.

#### TRAFFIC BARRIER INSTALLATION

Concrete Bridgerail  
Type . . . . . Open Rail/Post; Tapered End  
Length . . . . . 21 ft.-6 in.

Guardrail Members  
Transition  
Type . . . . . Tubular Thrie Beam  
Length . . . . . 12 ft.-6 in.

Adapter  
Length . . . . . 6 ft.-3 in.

Approach  
Type . . . . . Standard W-Beam  
Length . . . . . 37 ft.-6 in.

Guardrail Wood Posts  
Post No. 1 . . . . . Left Out  
Post Nos. 1 and 2 . . . . . 10 x 10 x 72 in.  
Post Nos. 3 thru 6 . . . . . 8 x 8 x 72 in.  
Post Nos. 7 thru 12 . . . . . 6 x 6 x 72 in.

Native Soil  
Type . . . . . Silty-Clay (CL)  
Optimum Moisture . . . . . 18%  
Relative Compaction . . . . . 92%  
Test Conditions . . . . . Dry

#### TEST RESULTS

Vehicle Speed  
Impact . . . . . 47 mph  
Exit . . . . . 38 mph

Vehicle Angle  
Impact . . . . . 25 deg.  
Exit . . . . . 15 deg.

Vehicle Rebound Distance . . . . . 72 ft.

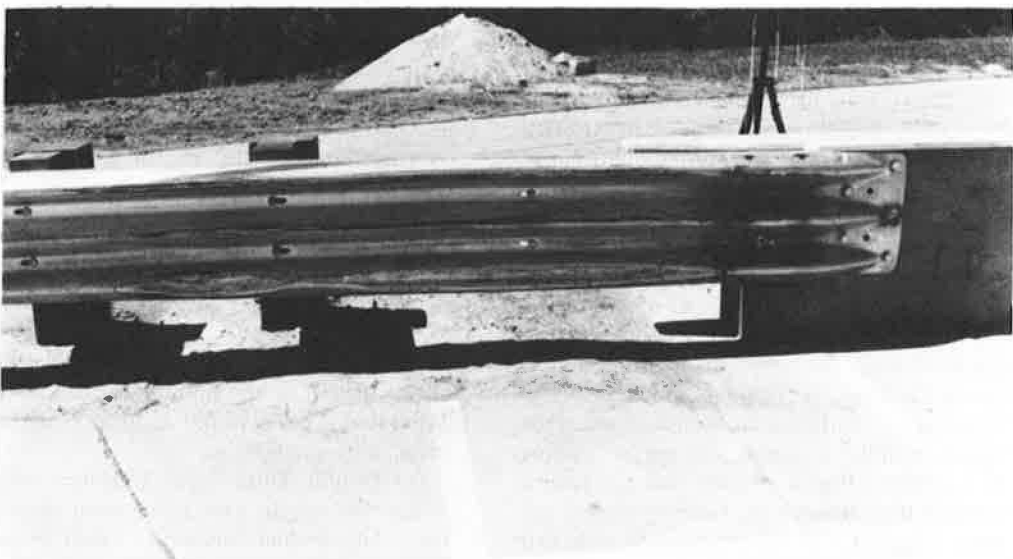
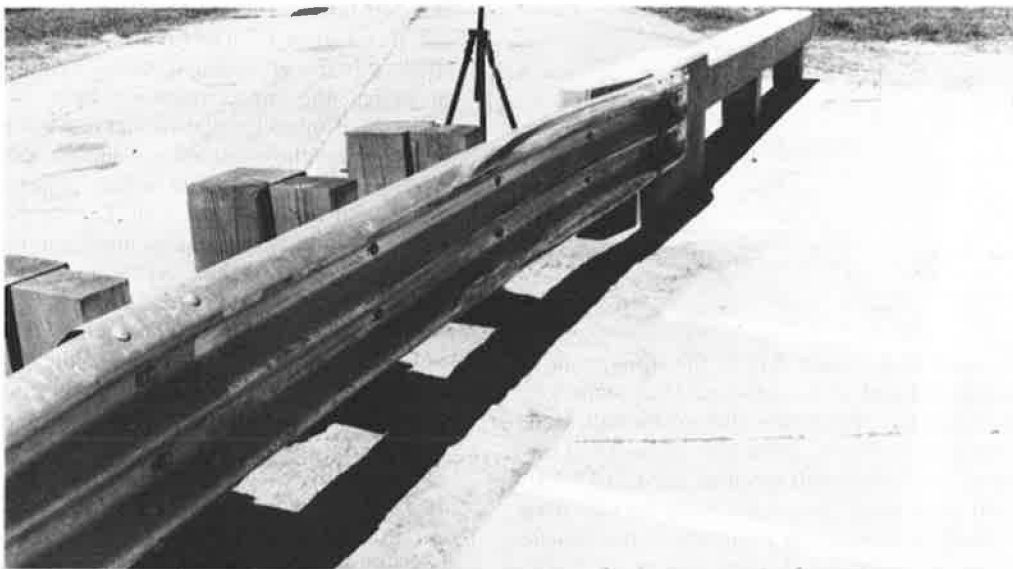
Vehicle Damage . . . . . TAD LFQ-3

Traffic Barrier  
Impact Location . . . . . Bet. Post Nos.2&3  
Max. Dynamic Deflection . . . . . 4 in. (est.)  
Max. Permanent Set . . . . . 2 1/2 in.  
Snagging . . . . . None

Occupant Risk (NCHRP 230)  
Lateral Impact Velocity . . . . . Not Measured  
Ridedown Accelerations . . . . . Not Measured

Occupant Risk (NCHRP 86)  
Injury Accident Prob. . . . . 18%

FIGURE 5 Summary of crash test No. 1.



**FIGURE 6** Photographs of test No. 1 guardrail damage.

TABLE 1 EQUIVALENT TEST NO. 1 IMPACT CONDITIONS

Impact Angle (deg)	Equivalent Impact Speed (mph)
15	77
16	72
17	68
18	64
19	61
20	58

Actual Test Speed . . . 47 mph

Actual Test Angle . . . 25 deg

$$\frac{1}{2} \frac{W}{g} (V \sin \theta)^2 = \left[ \frac{1}{2} \frac{W}{g} (V \sin \theta)^2 \right]_{\text{test}}$$

$$V^2 = \frac{(V \sin \theta)^2_{\text{test}}}{\sin^2 \theta}$$

$$V^2 = \frac{394.5}{\sin^2 \theta}$$

cle snagging occurred in the lower half of the thrie beam in the area of the tapered end of the concrete bridgerail. The vehicle change-in-speed of 21 mph was also a clear indication of a moderate amount of snagging as the change-in-speed was greatly in excess of the 15 mph limit specified in NCHRP 230.

The vehicle exit angle was 11 degrees. Due to the high drag forces from the badly damaged left front wheel, the vehicle turned back in toward an extended center line of the traffic barrier after it had travelled 78 feet. The maximum rebound distance of the vehicle center of gravity (CG) was 20 feet.

Due to the snagging, the damage to the vehicle was major and not repairable. The vehicle damage was assigned a NSC TAD rating of LFQ-6½. Based on the findings in NCHRP 86 (6), the damage rating indicates that injuries will occur in 86 percent of the vehicles damaged to this extent.

A summary and sequential photographs of the full-scale vehicle crash test on the Double Thrie Beam Transition is presented in Figure 9. The point of impact was between posts Nos. 2 and 3. The vehicle impact speed was 61 mph, and the exit speed was 47 mph. During the primary (vehicle front-end) impact stage at 86 msec, the maximum guardrail deflection was 9 inches. At 114 msec, the lateral occupant displacement of 12 inches occurred nearly simultaneously to when the front door sprung open under a dummy side impact loading force of 10 g. It was interesting to observe that the largest guardrail deflection of 10 inches occurred during the secondary (vehicle rear-end) impact stage at 194 msec. Vehicle exit from the barrier occurred at about 250 msec.

Photographs of the guardrail damage are shown in Figure

10. The damaged guardrail shows no indication of vehicle snagging. The vehicle change-in-speed of 14 mph was also supportive of the fact that no snagging occurred as the change-in-speed was below the 15 mph limit specified in NCHRP 230. Overall, the guardrail "smoothly" redirected the vehicle. The maximum permanent set in the guardrail was 7½ inches.

The vehicle exit angle was 11 degrees, which is well below the 15 degree limit recommended in NCHRP 230. Due to slight damage of the left front wheel, the vehicle turned slowly back in toward an extended center line of the traffic barrier. The maximum rebound distance of the vehicle CG path was approximately 20 feet.

The vehicle damage was assigned a NSC TAD rating of LFQ-4½. Based on the findings in NCHRP 86 (6), it was predicted that injuries would occur in 41 percent of the vehicles damaged to this extent.

#### Test No. 4: Double Thrie Beam Transition

A summary and sequential photographs of the full-scale vehicle crash test on the Double Thrie Beam Transition is presented in Figure 11. The point of impact was at post No. 4; whereas, in the preceding test (No. 3) on the identical guardrail design, the impact point was between posts Nos. 2 and 3. The decision to run the second test was based on the need to determine the most critical impact location in terms of guardrail performance. The vehicle impact speed was 61 mph, and the exit speed was 48 mph. During the primary (vehicle front-end) impact stage at 90 msec, the maximum guardrail deflection was 16 inches. At 99 msec, the lateral occupant displacement of 12 inches occurred nearly simultaneously to when the front door sprung open under a dummy side impact loading force of 8 g. It was interesting to observe that the largest guardrail deflection of 17 inches occurred during the secondary (vehicle rear-end) impact stage at 201 msec. Vehicle exit from the barrier occurred at about 283 msec.

Photographs of the guardrail damage are shown in Figure 12. The soil was saturated from a heavy, two-day storm preceding the test. NDR decided to test under a saturated soil condition as this condition would be representative of the lowest possible soil shearing strength. The damaged guardrail shows no indication of vehicle snagging. The vehicle change-in-speed of 13 mph also supported the fact that no snagging occurred as the change-in-speed was below the 15 mph limit specified in NCHRP 230. Overall, the guardrail "smoothly" redirected the vehicle. The maximum permanent set in the guardrail was 11 inches.

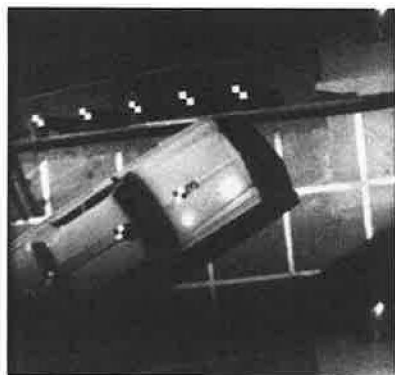
The vehicle exit angle was 15 degrees. Due to slight damage of the left front wheel, the vehicle turned slowly back in toward an extended center line of the traffic barrier. The maximum rebound of the vehicle CG path was approximately 20 feet.

The vehicle damage was assigned a NSC TAD rating of LFQ-4. Based on the findings in NCHRP 86 (6), it was predicted that injuries would occur in 33 percent of the vehicles damaged to this extent.

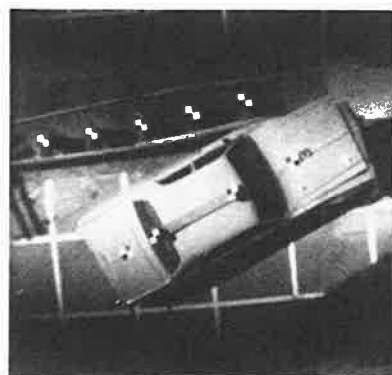
The Double Thrie Beam Transition was similar to an old design that was in wide use several years ago in Nebraska. The old design had smaller (6 x 8 inch) posts spaced on longer (6 foot 3 inch) centers.

A summary and sequential photographs of the full-scale

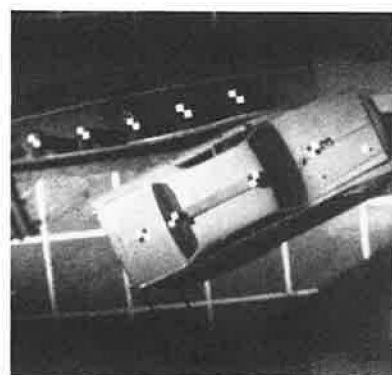




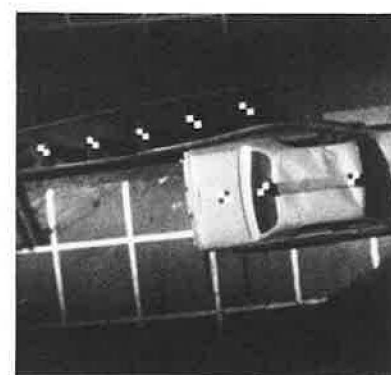
Impact



89 msec



108 msec



185 msec

TEST VEHICLE

Make . . . . . 1977 Plymouth Fury  
Weight (excluding dummy) . . . . . 4,400 lb.

Concrete Bridgerail

Type . . . . . Open Rail/Post; Tapered End  
Length . . . . . 21 ft.-6 in.

Guardrail Members

Transition

Type . . . . . Single Thrie Beam  
Length . . . . . 12 ft.-6 in.

Adapter

Length . . . . . 6 ft.-3 in.

Approach

Type . . . . . Standard W-Beam  
Length . . . . . 37 ft.-6 in.

Guardrail Wood Posts

Post No. 1 . . . . . Left Out  
Post Nos. 1 and 2 . . . . . 10 x 10 x 72 in.  
Post Nos. 3 thru 6 . . . . . 8 x 8 x 72 in.  
Post Nos. 7 thru 12 . . . . . 6 x 6 x 72 in.

Native Soil

Type . . . . . Silty-Clay (CL)  
Optimum Moisture . . . . . 18%  
Relative Compaction . . . . . 92%  
Test Conditions . . . . . Dry

Vehicle Speed

Impact . . . . . 60 mph  
Exit . . . . . 39 mph

Vehicle Angle

Impact . . . . . 25 deg.  
Exit . . . . . 11 deg.

Vehicle Rebound Distance . . . . . 20 ft.

Vehicle Damage . . . . . TAD LFQ-6½

Traffic Barrier

Impact Location . . . . . Bet.Post Nos. 2&3  
Max. Dynamic Deflection . . . . . 14 in.  
Max. Permanent Set . . . . . 10 in.  
Snagging . . . . . Moderate

Occupant Risk (NCHRP 230)

Lateral Impact Velocity . . . . . 21 fps  
Ridedown Accelerations . . . . . 10 g

Occupant Risk (NCHRP 86)

Injury Accident Prob. . . . . 86%

FIGURE 7 Summary of crash test No. 2.

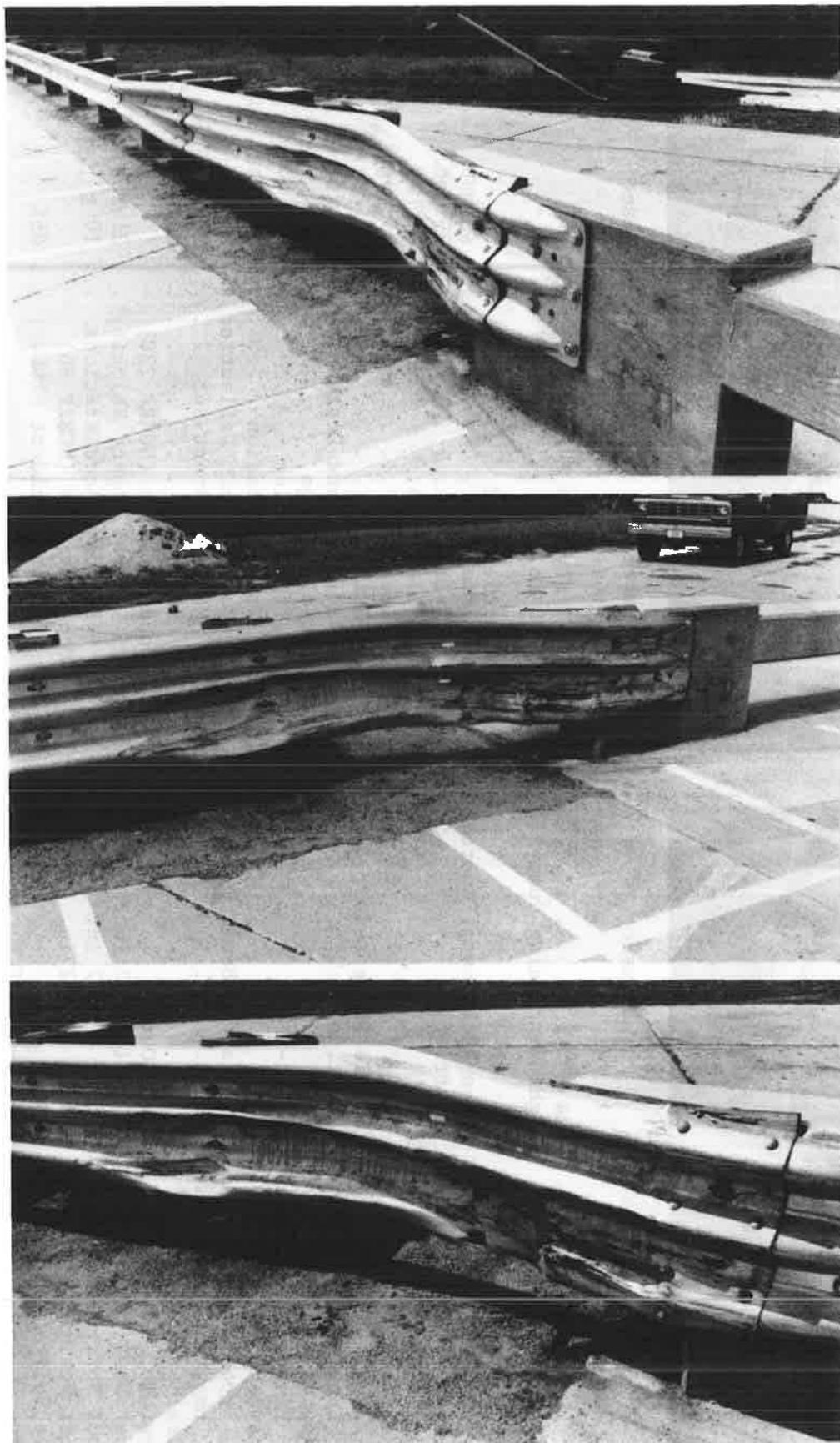
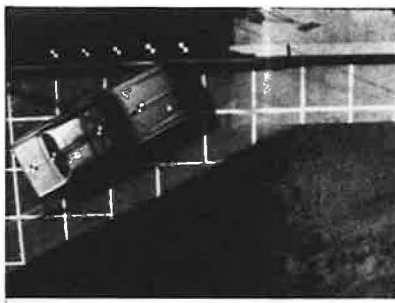
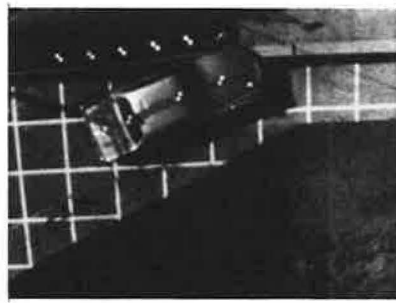


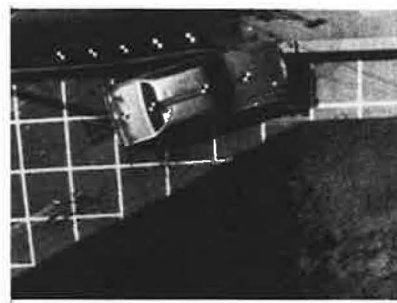
FIGURE 8 Photographs of test No. 2 guardrail damage.



Impact



86 msec



114 msec



166 msec

TEST VEHICLE

Make . . . . . 1977 Plymouth Fury  
Weight (excluding dummy) . . . . . 4,360 lb.

TRAFFIC BARRIER INSTALLATION

Concrete Bridgerail  
Type . . . . . Open Rail/Post; Tapered End  
Length . . . . . 21 ft.-6 in.  
Guardrail Members  
Transition  
Type . . . . . Double Thrie Beam  
Length . . . . . 12 ft.-6 in.  
Adapter  
Length . . . . . 6 ft.-3 in.  
Approach  
Type . . . . . Standard W-Beam  
Length . . . . . 37 ft.-6 in.  
Guardrail Wood Posts  
Post No. 1 . . . . . Left Out  
Post Nos. 1 and 2 . . . . 10 x 10 x 72 in.  
Post Nos. 3 thru 6 . . . . 8 x 8 x 72 in.  
Post Nos. 7 thru 12 . . . . 6 x 6 x 72 in.  
Native Soil  
Type . . . . . Silty-Clay (CL)  
Optimum Moisture . . . . 18%  
Relative Compaction . . . . 92%  
Test Conditions . . . . . Dry

TEST RESULTS

Vehicle Speed  
Impact . . . . . 61 mph  
Exit . . . . . 47 mph  
Vehicle Angle  
Impact . . . . . 25 deg.  
Exit . . . . . 11 deg.  
Vehicle Rebound Distance . . . 20 ft.  
Vehicle Damage . . . . . TAD LFQ-4½  
Traffic Barrier  
Impact Location . . . . . Bet.Post Nos. 2&3  
Max. Dynamic Deflection . . . 10 in.  
Max. Permanent Set . . . . 7½ in.  
Snagging . . . . . None  
Occupant Risk (NCHRP 230)  
Lateral Impact Velocity . . . 19 fps  
Ridedown Accelerations . . . 10 g  
Occupant Risk (NCHRP 86)  
Injury Accident Prob. . . . 41%

FIGURE 9 Summary of crash test No. 3.

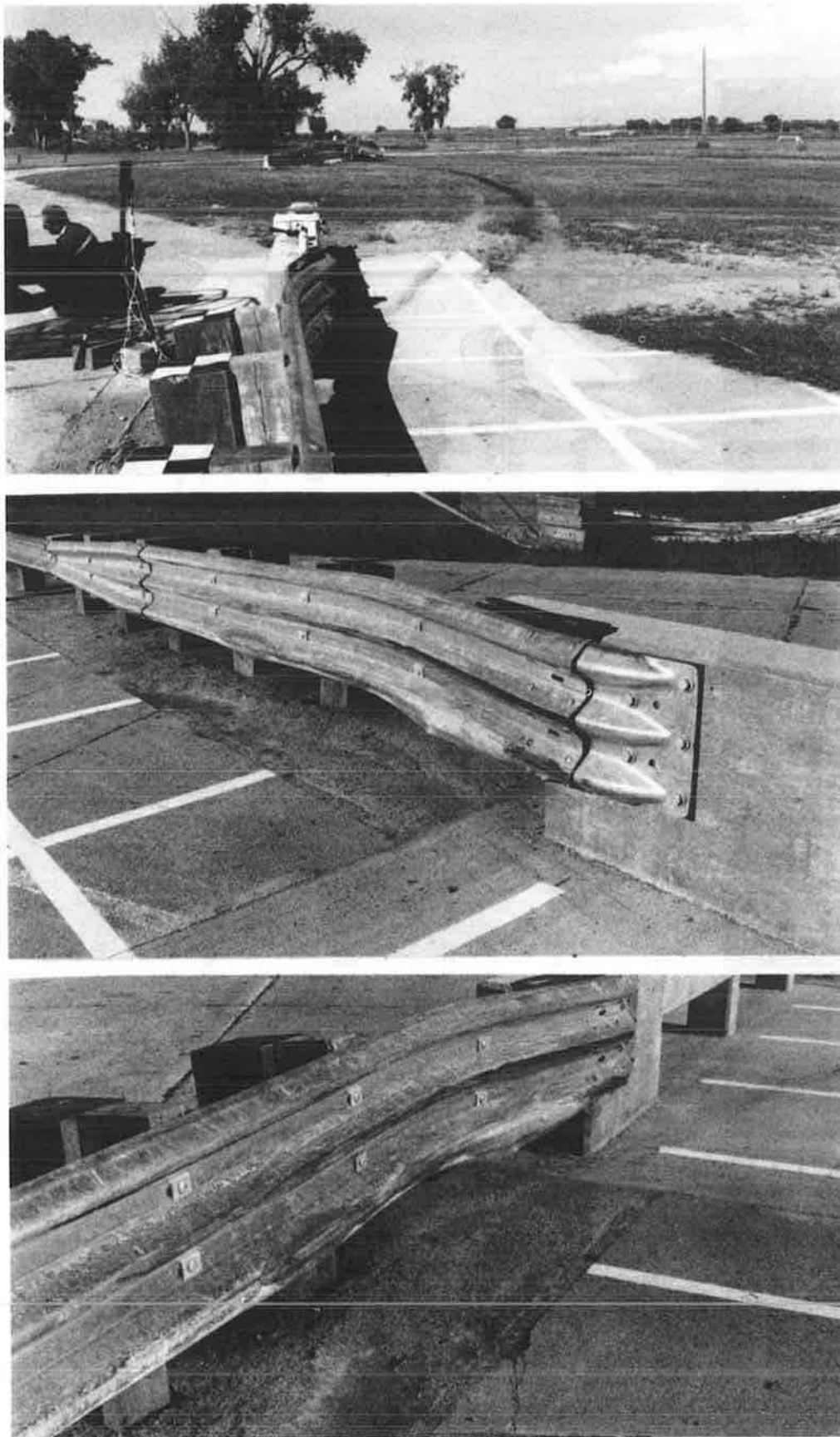


FIGURE 10 Photographs of test No. 3 guardrail damage.



Impact



90 msec



101 msec



155 msec

#### TEST VEHICLE

Make . . . . . 1977 Plymouth Fury  
Weight (excluding dummy) . . . . . 4,320 lb.

#### TRAFFIC BARRIER INSTALLATION

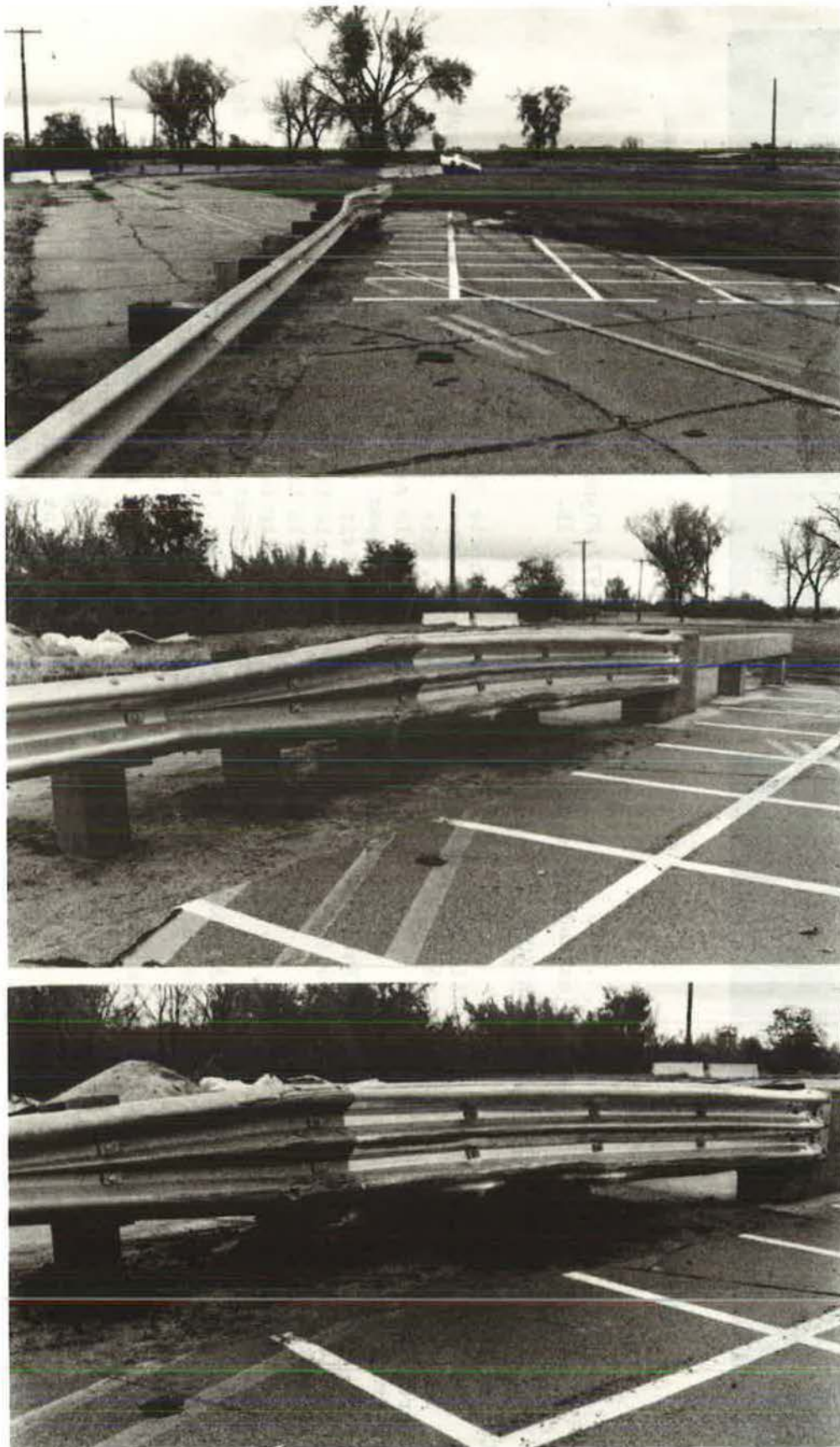
Concrete Bridgerail  
Type . . . . . Open Rail/Post; Tapered End  
Length . . . . . 21 ft.-6 in.  
Guardrail Members  
Transition  
Type . . . . . Double Thrie Beam  
Length . . . . . 12 ft.-6 in.  
Adapter  
Length . . . . . 6 ft.-3 in.  
Approach  
Type . . . . . Standard W-Beam  
Length . . . . . 37 ft.-6 in.  
Guardrail Wood Posts  
Post No. 1 . . . . . Left Out  
Post Nos. 1 and 2 . . . . 10 x 10 x 72 in.  
Post Nos. 3 thru 6 . . . . 8 x 8 x 72 in.  
Post Nos. 7 thru 12 . . . . 6 x 6 x 72 in.  
Native Soil  
Type . . . . . Silty-Clay (CL)  
Optimum Moisture . . . . 18%  
Relative Compaction . . . 92%  
Test Conditions . . . . . Wet

#### TEST RESULTS

Vehicle Speed  
Impact . . . . . 61 mph  
Exit . . . . . 48 mph  
Vehicle Angle  
Impact . . . . . 25 deg.  
Exit . . . . . 15 deg.  
Vehicle Rebound Distance . . . 20 ft.  
Vehicle Damage . . . . . TAD LFQ-4  
Traffic Barrier  
Impact Location . . . . . Post No. 4  
Max. Dynamic Deflection . . . 17 in.  
Max. Permanent Set . . . . 11 in.  
Snagging . . . . . None  
Occupant Risk (NCHRP 230)  
Lateral Impact Velocity . . . 17 fps  
Ridedown Accelerations . . . 8 g  
Occupant Risk (NCHRP 86)  
Injury Accident Prob. . . . . 33%

FIGURE 11 Summary of crash test No. 4.





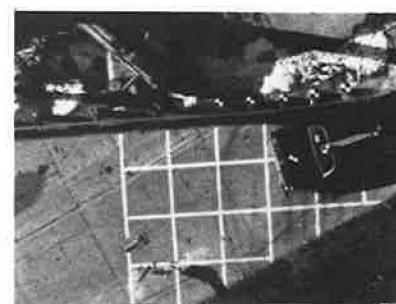
**FIGURE 12** Photographs of test No. 4 guardrail damage.



Impact



75 msec



113 msec



182 msec

#### TEST VEHICLE

Make . . . . . 1977 Plymouth Fury  
Weight (excluding dummy) . . . . . 4,560 lb.

#### TRAFFIC BARRIER INSTALLATION

Concrete Bridgerail  
Type . . . . . Open Rail/Post; Tapered End  
Length . . . . . 21 ft.-6 in.

Guardrail Members  
Transition  
Type . . . . . Double W-Beam  
Length . . . . . 12 ft.-6 in.

Adapter  
Length . . . . . 6 ft.-3 in.

Approach  
Type . . . . . Standard W-Beam  
Length . . . . . 37 ft.-6 in.

Guardrail Wood Posts  
Post No. 1 . . . . . Left Out  
Post Nos. 1 and 2 . . . . . 10 x 10 x 72 in.  
Post Nos. 3 thru 6 . . . . . 8 x 8 x 72 in.  
Post Nos. 7 thru 12 . . . . . 6 x 6 x 72 in.

Native Soil  
Type . . . . . Silty-Clay (CL)  
Optimum Moisture . . . . . 18%  
Relative Compaction . . . . . 92%  
Test Conditions . . . . . Ground Frozen 6 to 8 in.

#### TEST RESULTS

Vehicle Speed  
Impact . . . . . 62 mph  
Exit . . . . . 39 mph

Vehicle Angle  
Impact . . . . . 25 deg.  
Exit . . . . . 9 deg.

Vehicle Rebound Distance . . . . . 20 ft.

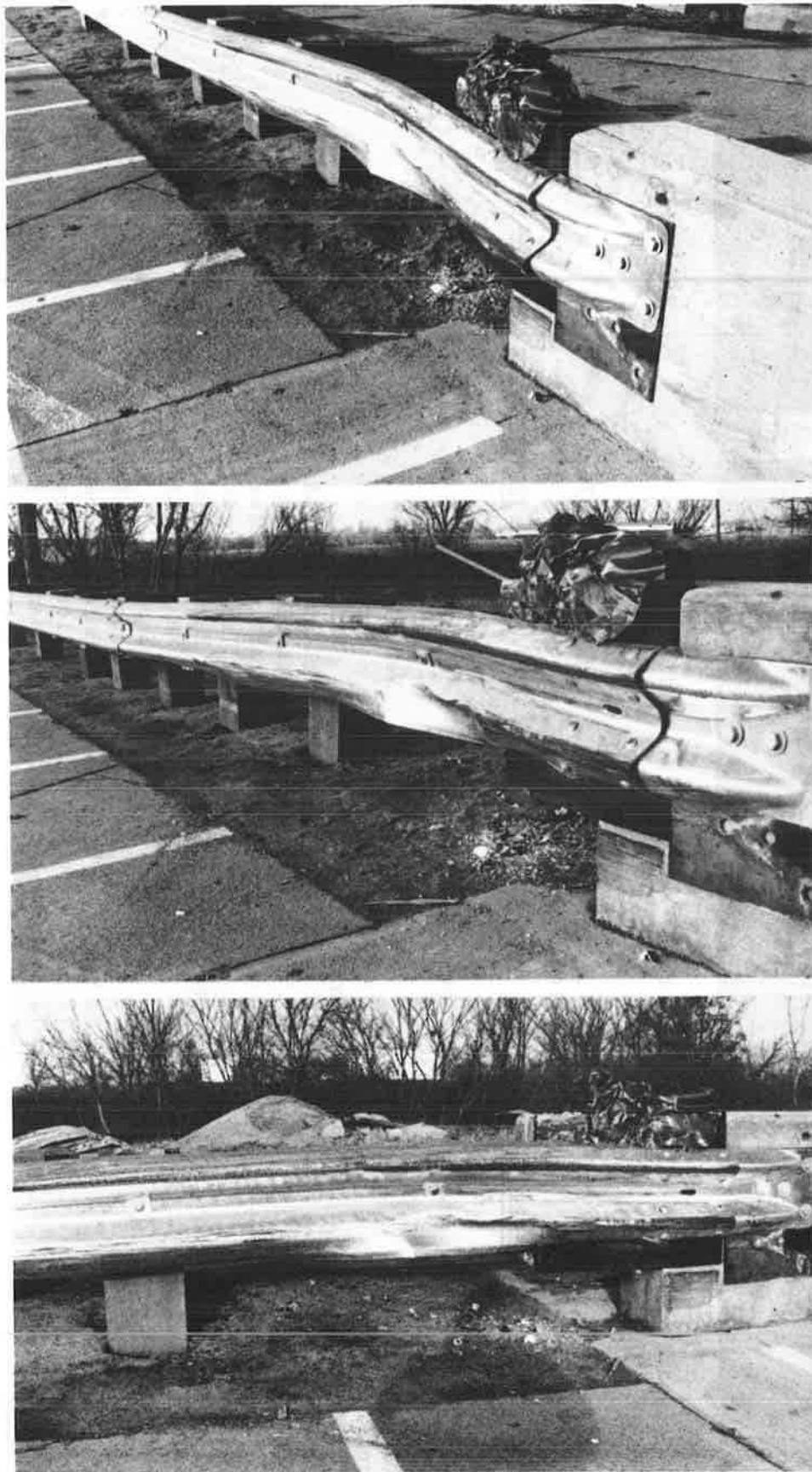
Vehicle Damage . . . . . TAD LFQ-7

Traffic Barrier  
Impact Location . . . . . Bet.Post Nos. 2&3  
Max. Dynamic Deflection . . . . . 10 in.  
Max. Permanent Set . . . . . 6 in.  
Snagging . . . . . Severe

Occupant Risk (NCHRP 230)  
Lateral Impact Velocity . . . . . 24 fps  
Ridedown Accelerations . . . . . 6 g

Occupant Risk (NCHRP 86)  
Injury Accident Prob. . . . . 100%

FIGURE 13 Summary of crash test No. 5.



**FIGURE 14** Photographs of test No. 5 guardrail damage.



vehicle crash test on the Double W-Beam Transition is presented in Figure 13. The point of impact was between posts Nos. 2 and 3. The vehicle impact speed was 62 mph, and the exit speed was 39 mph. During the primary (vehicle front-end) impact stage at 75 msec, the maximum guardrail deflection was 9 inches. At 113 msec, the lateral displacement of an occupant was 12 inches, however, there was no sign of the front door being sprung open under the side impact loading of the dummy as had occurred in three previous tests. The largest guardrail deflection of 10 inches occurred during the secondary (vehicle rear-end) impact stage at 212 msec. Vehicle exit from the barrier occurred at 262 msec.

Photographs of the guardrail damage are shown in Figure 14. The soil was frozen 6 to 8 inches deep. The effect of the frozen soil was readily apparent by comparing the permanent set deflections in test No. 3 with this test. Aside from the fact that the strength of the Double Thrie Beam in test No. 3 was much stronger than the strength of the Double W-Beam, the permanent set deflections of the Double W-Beam were much less. The damaged guardrail in Figure 13 shows severe vehicle snagging. The vehicle change-in-speed of 23 mph also supported the fact that severe snagging occurred as the change-in-speed greatly exceeded the 15 mph limit specified in NCHRP 230. Snagging resulted when the vehicle frame and wheel assembly got under the guardrail and impacted the tapered end of the concrete bridgerail. As shown in Figure 14, sheet metal was torn from the vehicle and wedged between the guardrail and the wood filler block in the recessed area of the bridgerail tapered-end.

The vehicle exit angle was 9 degrees. Due to the badly damaged left front wheel, the vehicle turned slowly back-in toward an extended center line of the traffic barrier. The vehicle was extensively damaged due to the severe snagging. The vehicle damage was assigned a NSC TAD rating of LFQ-7. Based on the findings in NCHRP 86 (6), it was predicted that in vehicles damaged to this extent, injuries would occur in 100 percent of the accidents.

## SUMMARY AND CONCLUSIONS

A comparative summary of the crash test results is presented in Table 2, and the performance of the traffic barrier measured in terms of the NCHRP 230 safety evaluation guidelines (4) is presented in Table 3.

Due to technical problems with the tow vehicle, the impact speeds in test No. 1 were approximately 14 mph below the 60 mph target speed recommended in NCHRP 230. Test No. 1 on the Tubular Thrie Beam transition was not rerun because it was estimated that the dynamic deflection would have only been about 3 inches greater at the higher 60 mph impact speed, and hence, the 60 mph test would have most likely been satisfactory. The estimated deflections were determined on the assumption that the deflection of the guardrail was directly proportional to the lateral kinetic energy of the vehicle.

After impact with the guardrail transition, the vehicle trajectory (CG path) in each of the tests was unsatisfactory in accordance with NCHRP 230 (Item *H*), as each vehicle would have been redirected back into the adjacent lanes of traffic. To compensate for this type of situation, NCHRP 230 (Item 1) specifies that (1) the change-in-speed of the vehicle

should be less than 15 mph, and (2) the exit angle should be less than 15 degrees.

In test No. 2 on the Single Thrie Beam transition, a moderate amount of vehicle snagging occurred in the lower half of the thrie beam adjacent to the tapered end of the concrete bridgerail. As a result, the test was considered to be unsatisfactory because the vehicle change-in-speed of 21 mph was significantly higher than the limit of 15 mph specified in NCHRP 230. Due to vehicle snagging on the Single Thrie Beam transition, NDR decided to run the next test on a Double Thrie Beam transition in favor of the much stronger and costly Tubular Thrie Beam transition that was used earlier in the study.

In test No. 5 on the Double W-Beam transition, an amount of vehicle snagging occurred under the guardrail on the tapered end of the concrete bridgerail. As a result, the test was considered to be unsatisfactory because the vehicle change-in-speed of 23 mph greatly exceeded the limit of 15 mph specified in NCHRP 230. In addition, the integrity of the passenger compartment area in terms of occupant risk (Item *E*) was considered to be marginal as the engine firewall was pushed backward on the side of the driver. The last item of concern was the soil that was frozen to 6 to 8 inches deep. It is predicted that if the soil had not been frozen, the vehicle would have penetrated deeper under the flexible guardrail, and as a result, the vehicle would most likely have abruptly stopped and spun-out on the tapered end of the concrete bridgerail.

From an overall consideration, the Double Thrie Beam transition in test Nos. 3 and 4 was satisfactory in terms of the NCHRP 230 performance categories of structural adequacy (items *A* and *D*), occupant risk (Item *E*), and vehicle trajectory (Item *I*). Two tests were conducted at different points of impact to be certain that the transition design was tested under the most critical condition of impact. Also, in test No. 4 the soil was saturated from a heavy, two-day storm preceding the test. NDR decided to test under a saturated soil condition as this condition would be representative of the lowest possible soil shearing strength.

NCHRP 230 does not specify any evaluation guidelines for conducting tests on a guardrail transition in regard to the "Impact Velocity of a Hypothetical Front Seat Passenger Against the Vehicle Interior." However, data on occupant impact velocity were presented in this study because it was felt that the data provided further insight into the evaluation of the transition designs tested. To supplement the NCHRP 230 data on occupant impact velocity, data on "Injury Accident Probability" contained in NCHRP 86 (6) were also presented in this study. The two sets of data on the tests are presented in Table 2, and a graphic relationship between the two sets of data is presented in Figure 15. An occupant impact velocity of 20 feet per second (fps) is recommended in NCHRP 230 as an "acceptable" design value, whereas, a value of 30 fps is a recommended design "limit." The effects of vehicle snagging are very evident in Figure 15.

In test No. 5, severe snagging on the Double W-Beam transition would result in an injury accident probability of 100 percent; whereas, in test No. 2, moderate snagging on the Single Thrie Beam transition would result in an injury accident probability of 86 percent. In tests Nos. 3 and 4, an impact with the Double Thrie Beam transition in which no snagging occurred would result in an injury accident probability of 35 to 40 percent. Lastly, in test No. 1, at a lower impact speed

TABLE 2 COMPARATIVE SUMMARY OF CRASH TEST RESULTS

TEST NO.	1	2	3	4	5
TRANSITION BEAM DESIGN	Tubular Thrie	Single Thrie	Double Thrie	Double Thrie	Double W-Beam
SOIL (Silty-Clay)	Dry	Dry	Dry	Wet	Frozen <sup>(a)</sup>
VEHICLE WEIGHT (lb)	4,384	4,400	4,360	4,320	4,560
VEHICLE SPEED					
Impact (mph)	47	60	61	61	62
Exit (mph)	38	39	47	48	39
Change (mph)	9	21	14	13	23
VEHICLE ANGLE					
Impact (deg)	25	25	25	25	25
Exit (deg)	15	11	11	15	9
VEHICLE REBOUND DISTANCE (ft)	72	20	20	20	20
VEHICLE DAMAGE (TAD LFQ)	3 moderate	6 1/2 major	4 1/2 moderate	4 moderate	7 extensive
TRAFFIC BARRIER					
Impact Post Location	Bet. 2&3	Bet. 2&3	Bet. 2&3	4	Bet. 2&3
Max. Dynamic deflection	4	14	10	17	10
Max. Permanent Set (in)	2 1/2	10	7 1/2	11	6
Snagging	None	Moderate	None	None	Severe
OCCUPANT RISK (NCHRP 230)					
Lateral Impact Velocity (fps)	12	21	19	17	24
Ridedown Accelerations (g)	-	10	10	8	6
OCCUPANT RISK (NCHRP 86)					
Injury Accident Probability	18	86	41	33	100

Notes: (a) Soil Frozen to Depth to 6 to 8 in.



TABLE 3 PERFORMANCE OF LONGITUDINAL BARRIER, TEST NO. 30, IN TERMS OF NCHRP 230 SAFETY EVALUATION GUIDELINES

Evaluation Factor	Evaluation Criteria	TRANSITION DESIGN <sup>(1)</sup>				
		Tubular Thrie Beam (Test 1)	Single Thrie Beam (Test 2)	Double Thrie Beam (Test 3)	Double Thrie Beam (Test 4)	Double Thrie Beam (Test 5)
Impact Conditions	58 to 60 mph/25 deg	U	S	S	S	S
Structural	A. Test article shall <u>smoothly</u> redirect the vehicle.	S	U	S	S	U
	The vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	S	S	S	S	S
	D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S	S	S	S	S
Occupant Risk	E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	S	S	S	S	S
	Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	S	M	S	S	M
Vehicle Trajectory	H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	U	U	U	U	U
	I. In test where the vehicle is judged to be re-directed into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be elss than 15 mph and the exit angle from the test article should be elss than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	S	U	S	S	U

Notes: (1) S = Satisfactory M = Marginal U = Unsatisfactory

of 47 mph, an impact into either the Single Thrie Beam transition or the Tubular Thrie Beam transition in which no snagging occurred would result in an injury accident probability of about 20 percent.

In summary, the following conclusions were reached in regard to the overall performance of the four new guardrail-bridge-rail transition designs in restraining and smoothly redirecting a large, 4,500-pound automobile under the impact conditions of 60 mph and 25 degrees:

1. Tubular Thrie Beam Transition—Satisfactory,
2. Single Thrie Beam Transition—Unsatisfactory,
3. Double Thrie Beam Transition—Satisfactory,

#### 4. Double W-Beam Transition—Unsatisfactory.

It is to be emphasized that the above conclusions are based on the condition that a new design in the field will be constructed to the exact design details under which the full-scale vehicle crash tests were conducted. In particular, careful attention must be given to ensure that (1) the soil has the properties of a type CL soil, (2) the wood posts are of the proper size and spacing and clear of knots, (3) the 4:1 tapered end is installed to the dimensions tested, and (4) the size and quantity of rebar in the concrete bridge end are adequate to carry a lateral impact load of 120 kips and a longitudinal load of 50 kips.

TEST NO.	TRANSITION BEAM DESIGN	IMPACT SPEED (mph)	VEHICLE SNAGGING LEVEL
1	TUBULAR THRIE	47	NONE
2	SINGLE THRIE	60	MODERATE
3	DOUBLE THRIE	61	NONE
4	DOUBLE THRIE	61	NONE
5	DOUBLE W-BEAM	62	SEVERE

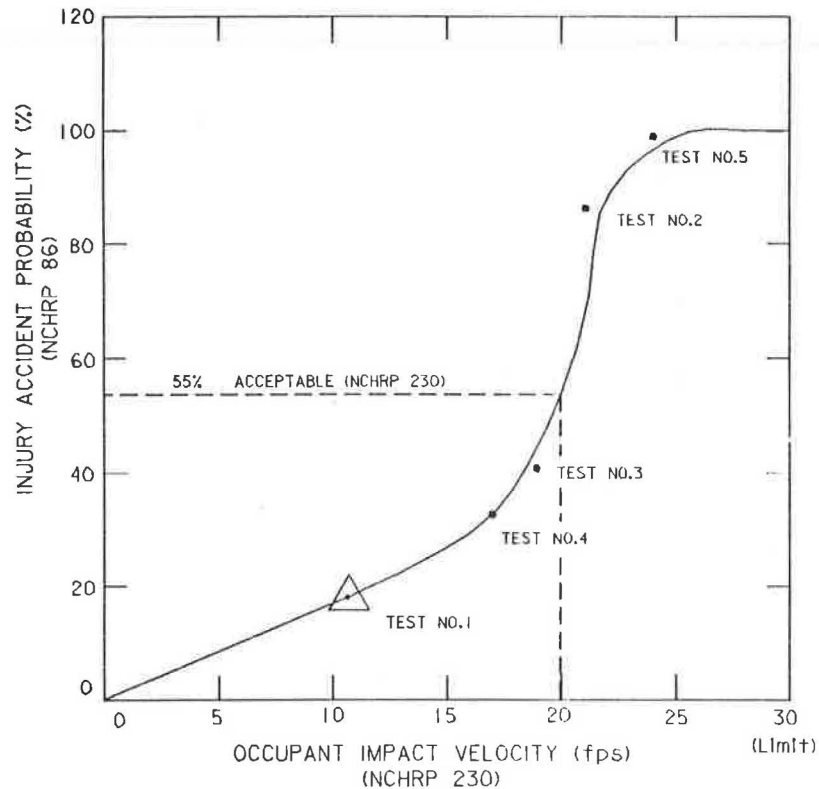


FIGURE 15 Relationship between occupant velocity and injury accident probability.

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