TECHNICAL REPORT DOCUMENTATION PAGE


## PREFACE

The study reported herein was sponsored by the Federal Highway Administration, 23 States, and the District of Columbia. It was managed by a panel of representatives from those agencies. The panel, as a group, selected existing designs and identified new designs of railing/transitions to be studied and evaluated. Participating agencies and their representatives are listed below.

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[^0]rounding should be made to comply with Section 4 of ASTM E380.

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## CHAPTER 1: INTRODUCTION

Objectives of the study were to develop safer bridge rail and transition designs and to improve design guidelines.

At the beginning of the study, the 13th edition (1983) of AASHTO's Standard Specifications for Highway Bridges and NCHRP Report 230 were the current documents governing design and testing of bridge railings and transitions. ${ }^{(1,2)}$ FHWA was in the process of developing enhanced guidelines for designing and testing bridge railings. That effort was completed in 1989 and resulted in Guide Specifications for Bridge Railings (1989). ${ }^{(3)}$ Two additional research studies related to this subject were performed during this time period. They were an NCHRP study to revise testing procedures and requirements in NCHRP Report 230 (NCHRP Project 22-7) and a study to evaluate the warrants portion of the 1989 guide specifications (NCHRP Project 22-8). ${ }^{(2,4,5)}$

Also, during this time, NCHRP Study 12-33 to develop Load and Resistance Factor Design (LRFD) bridge design specifications and commentary was performed. ${ }^{(6)}$

In this collective work, many sets of requirements for designing, testing, test procedures, test vehicles, and performance (or service) levels were proposed and considered. As a result, not all testing in the study reported herein was performed to a unique set of test conditions. However, all railing designs were eventually tested to conditions recommended in the 1989 guide specifications. ${ }^{(3)}$

At the beginning of the study, drawings of bridge railing systems being used by all States were collected by FHWA. More than 160 railing designs (although some were quite similar) were identified. These designs plus others proposed by research agencies and private industry were reviewed to obtain background information for use in this study.

Various degrees of analysis and evaluation of many designs were performed by the panel and the researchers. A total of 11 ratings and 2 transitions were analyzed/designed, tested, and evaluated in detail. This resulted in a collection of proven railing/transition designs which meet requirements of the 1989 guide specifications. ${ }^{(3)}$

## CHAPTER 2. PERFORMANCE LEVELS AND DESIGN REQUIREMENTS

The 1989 guide specifications sets forth three performance levels for bridge railings. ${ }^{(3)}$ Those performance levels along with their respective crash test conditions and evaluation criteria are given in table G2.7.1.3A of that publication which is reproduced in table 1. The 1989 guide specifications was developed over a period of time prior to 1989. ${ }^{(3)}$ During its development, many proposed performance levels, defined in terms of test conditions, were considered. The February 1987 draft of the guide specification included the following proposed test conditions:

| Performance Level One (PL1) | $5,400 \mathrm{lb}\|45 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg}$ |
| :---: | :---: |
|  | ( 2452 kg \| $72.4 \mathrm{~km} / \mathrm{h} \mid 20 \mathrm{deg}$ ) |
| Performance Level Two (PL2) | $5,400 \mathrm{lb}\|65 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg}$ |
|  | ( 2452 kg \| $104.6 \mathrm{~km} / \mathrm{h} \mid 20 \mathrm{deg}$ ) |
| Performance Level Three (PL3) | $40,000 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg}$ |
|  | (18 $160 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}$ ) |
| Performance Level Four (PL4) | $80,000 \mathrm{lb}\|55 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg}$ |
|  | ( $36320 \mathrm{~kg}\|88.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}$ ) |

The $5,400-\mathrm{lb}(2452-\mathrm{kg})$ vehicle was a pickup truck. The $40,000-\mathrm{lb}$ ( $18160-\mathrm{kg}$ ) vehicle was an intercity bus and the $80,000-\mathrm{lb}(36320-\mathrm{kg})$ vehicle was a tractor with van type trailer.

In January 1988, proposed testing requirements were changed to those shown in the final version of the 1989 guide specifications (table 1). ${ }^{(3)}$ Design forces for performance levels of the 1989 guide specifications are discussed below. ${ }^{(3)}$

For PL1, the test with a $5,400-\mathrm{lb}$ ( $2452-\mathrm{kg}$ ) pickup truck traveling at $45 \mathrm{mi} / \mathrm{h}$ ( 72 $\mathrm{km} / \mathrm{h}$ ) with an impact angle of 20 degrees is used to evaluate the strength and height of a railing. For these test conditions, the short duration ( .050 s ) collision force imposed on a rigid bridge railing is about $30 \mathrm{kips}(133 \mathrm{kN}$ ). The required minimum height of the resultant of resisting force provided by the railing to prevent the vehicle rolling over the railing is at or somewhat below the center-of-gravity of the test vehicle. Height to the center-of-gravity of a typical empty pickup is at about 26 in ( 660 mm ) and the empty weight is about $4,600 \mathrm{lb}$ ( 2088 kg ). Onboard instrumentation used in tests increases the weight, and ballast (fixed to the vehicle) is typically used to adjust the test inertia weight to $5,400 \mathrm{lb}(2452-\mathrm{kg})$. The ballast is positioned to provide a center-of-gravity of the total mass at 27 in ( 690 mm ) above the ground. The recommended design force of $30 \mathrm{kips}(133 \mathrm{kN}$ ) used for PL1 railings is a uniformly distributed line force 42 -in ( $1.07-\mathrm{m}$ ) long located at least 24 in ( 610 mm ) above the roadway surface.

For PL2, the test with an $18,000-\mathrm{lb}(8172-\mathrm{kg})$ single unit truck traveling at $50 \mathrm{mi} / \mathrm{h}$ ( $80 \mathrm{~km} / \mathrm{h}$ ) with an impact angle of 15 degrees is used to evaluate the strength and height of a railing. For these test conditions, the short duration ( .050 s ) collision force imposed on a rigid bridge railing is about $56 \mathrm{kips}(249 \mathrm{kN}$ ). The required minimum height of the resultant

Table 2. Bridge railing performance levels and crash test criteria. (Exerpt from 1989 AASHTO Guide Specifications for Bridge Railings) ${ }^{(3)}$


Notes:

1. Except as noted, all full-scale tests shall be conducted and reported in accordance with the requirements in NCHRP Report No. 230. In addition, the maximum loads that can be transmitted from the bridge railing to the bridge deck are to be determined from static force measurements or ultimate strength analysis and reported.
2. Permissible tolerances on the test speeds and angles are as follows:

$$
\begin{array}{ccc}
\text { Speed } & -1.0 \mathrm{mph} & +2.5 \mathrm{mph} \\
\text { Angle } & -1.0 \mathrm{deg} . & +2.5 \mathrm{deg} .
\end{array}
$$

Tests that indicate acceptable railing performance but that exceed the allowable upper tolerances will be accepted.
3. Criteria for evaluating bridge railing crash test results are as follows:
a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.
b. 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.
c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.
d. The vehicle shall remain upright during and after collision.
e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle or, in the case of a combination vehicle, the rear of the tractor or trailer does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.
f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, $\mu$ :

| $\mu$ |  |
| :---: | :---: |
| $0-0.25$ <br> $0.26-0.35$ | Assessment |
| $>0.35$ | Fair |
| Marginal |  |
| where $\mu=\left(\cos \theta-V_{p} / V\right) / \sin \theta$ |  |

Table 2. Bridge railing performance levels and crash test criteria. (Exerpt from 1989 AASHTO Guide Specifications for Bridge Railings) ${ }^{(3)}$ (continued)
g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and $2.0-\mathrm{ft}$. longitudinal and $1.0-\mathrm{ft}$. lateral diplacements, shall be less than:

| Occupant Impact Velocity-fps |  |
| :---: | :---: |
| Longitudinal | Lateral |
| 30 | 25 |

and the vehicle highest $10-\mathrm{ms}$ average accelerations subsequent to the instant of hypothetical passenger impact should be less than:

| Occupant Ridedown Acceleration-g's |  |
| :---: | :---: |
| Longitudinal | Lateral |
| 15 | 15 |

h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft . plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than $20-\mathrm{ft}$. from the line of the traffic face of the railing. The brakes shall not be applied until the vehicle has traveled at least 100 -ft. plus the length of the test vehicle from the point of initial impact.
4. Values $A$ and $R$ are estimated values describing the test vehicle and its loading. Values of $A$ and $R$ are described in the figure below and calculated as follows:

5. Test articles that do not meet the desirable evaluation criteria shall have their performance evaluated by a designated authority that will decide whether the test article is likely to meet its intended use requirements.

$$
\begin{aligned}
& 1 \mathrm{mi}=1.61 \mathrm{~km} \\
& 1 \mathrm{kip}=4.45 \mathrm{kN} \\
& 1 \mathrm{in}=25.4 \mathrm{~mm}
\end{aligned}
$$

of resisting force provided by the railing to prevent the vehicle from rolling over the railing is at or somewhat below the center-of-gravity of the test vehicle. The 1989 guide specifications requires that the center-of-gravity of an $18,000-\mathrm{lb}(8172-\mathrm{kg})$ test vehicle is at 49 in (1.24 m). (3) A typical vehicle meeting the dimensional specifications weighs about $14,000 \mathrm{lb}(6356 \mathrm{~kg})$ empty. Ballast is used to adjust the total weight and location of the center-of-gravity. The recommended design force of $56 \mathrm{kips}(249 \mathrm{kN}$ ) for PL2 railings is a uniformly distributed line force 42 in ( 1.07 m ) long located at least 29 in ( 740 mm ) above the roadway surface.

For PL3, the test with a $50,000-\mathrm{lb}(22700-\mathrm{kg})$ tractor-trailer traveling at $50 \mathrm{mi} / \mathrm{h}$ ( 80 $\mathrm{km} / \mathrm{h}$ ) with an impact angle of 15 degrees is used to evaluate the strength and height of a railing. For these test conditions, the short duration ( .050 s ) collision force imposed on a rigid bridge railing is about $124 \mathrm{kips}(552 \mathrm{kN})$. The required minimum height of the resultant of resisting force provided by the railing to prevent the vehicle from rolling over the railing is at or somewhat below the center-of-gravity of the test vehicle. The recommended design force of $124 \mathrm{kips}(552 \mathrm{kN})$ for PL3 railings is a uniformly distributed line force 96 in ( 2.44 m ) long located at least 38 in to 40 in ( 970 mm to 1.02 m ) above the roadway surface.

Much of the information used to establish recommended values of design force was developed in two earlier FHWA research studies. ${ }^{(10,11)}$ In those studies, a rigid flat-faced vertical wall was instrumented with load cells to measure transverse forces during collisions under various impact conditions. The collision forces recommended in the paragraphs above for design of railings are based on highest $0.050-\mathrm{s}$ averages of measured forces. It is recommended that no factor of safety (i.e., load factor $=1.0$ ) be used with the values of force in ultimate strength analyses of railings for specified test conditions.

In addition to providing adequate strength, a railing system must provide suitable geometrics for interaction with the vehicle. Adequate height must be provided to prevent the vehicle from rolling over the railing. Sufficient frontal area must be provided to adequately engage the vehicle and provide a smooth redirection without too much snagging and longitudinal deceleration.

For solid-faced concrete parapet type railings, these geometric features are obviously suitable. However, the shape and roughness of the face will influence performance.

For beam and post type railing systems (usually metal railings but some concrete railings), the frontal area provided must be sufficiently large to prevent the rail elements from "cutting" into the vehicle too far and allowing the vehicle to snag too much on the posts. Too much snagging on posts will impose excessive decelerations on the vehicle and will cause excessive deformation of the vehicle. However, a small amount of longitudinal deceleration of the vehicle will generally serve to reduce the exit angle of the vehicle.

General relationships that provide some guidance in establishing suitable geometrics are presented in figures 1 and 2.


Figure 1. Relationship between vertical clear opening between rail elements and post setback distance to prevent excessive snagging of vehicle on posts.


Figure 2. Relationship between the ratio of rail contact area and post setback distance to prevent excessive snagging of vehicle on posts.

If open spaces between rail elements become larger, then post setback distance needs to be increased to prevent the vehicle from snagging on the posts. However, the relationship is also influenced by the amount of frontal area provided by the rail elements. Individual vertical clear openings between rail elements should be less than 10 to 12 in ( 250 to 300 mm ) to prevent excessive snagging of vehicles on posts.

## CHAPTER 3. ANALYSIS/DESIGN PROCEDURES

Design forces for the respective performance levels are presented in chapter 2. These forces with a load factor (or factor of safety) of 1.0 are recommended for use in ultimate strength (failure mode) analysis techniques to design bridge railings. Complete detailed analyses of each bridge railing design are presented in the respective appendixes.

## CONCRETE PARAPETS

A yieldline analysis procedure was used for concrete parapet bridge railings and is summarized here. ${ }^{(7)}$

The expected yieldline failure pattern for a concrete parapet is shown in figure 3. Such a failure pattern would be expected for a concentrated load or a uniformly distributed line load applied transverse to the parapet at or near the top of the parapet.

Ultimate strength of the parapet and dimensions of the yieldline pattern are functions of magnitudes of the various bending moment strengths. $M_{w}$ is the moment capacity ( $\mathrm{ft}-$ $\mathrm{kips} / \mathrm{ft}$ ) of the parapet for bending about a vertical axis. $M_{b}$ is additional moment (in addition to $M_{w}$ ) capacity ( ft -kips) that is provided along the top edge of the parapet. $M_{c}$ is the cantilever moment ( $\mathrm{ft}-\mathrm{kips} / \mathrm{ft}$ ) at the base of the parapet. An increase in the beam moment, $M_{b}$, or the wall moment, $M_{w}$, serves to increase the length, $L$, of the yieldline pattern and, for a given ultimate load, would serve to decrease the magnitude of the cantilever moment that must be resisted by the bridge deck.

The parapet should be analyzed/designed assuming that the deck has adequate strength to support the parapet and force the failure pattern to stay within the parapet. Once this has been accomplished, values for $L, M_{c}$, and $w l$ will be known. At a vertical section through the deck along the traffic face reinforcement of the parapet, the load $w l$ can be assumed distributed over length equal to $L$. This force becomes an inplane tensile force in the deck. The deck can then be analyzed/designed to determine its adequacy for resisting the inplane force and $M_{c}$.

## BEAM AND POST RAILINGS

A plastic hinge failure mechanism analysis technique for bridge railings was used for metal beam and post systems. ${ }^{(7)}$ Typical failure mechanisms for such railing systems are shown in figure 4. Equations for computing ultimate load capacities for various lengths of failure mechanism are:


$$
\begin{aligned}
L & =\frac{l}{2}+\sqrt{\left(\frac{l}{2}\right)^{2}+8 H\left(\frac{M_{b}+M_{w} H}{M_{c}}\right)} \\
(w l)_{u l t} & =\frac{8 M_{b}}{L-\frac{l}{2}}+\frac{8 M_{w} H}{L-\frac{l}{2}}+\frac{M_{c} L^{2}}{H\left(L-\frac{l}{2}\right)}
\end{aligned}
$$

Figure 3. Yieldline failure mechanism for concrete parapet.


Figure 4. Possible failure mechanisms in beam-and-post railing systems. Longer mechanisms would be similar.

Odd number of spans

$$
\begin{equation*}
R=\frac{16 M_{p}+(N-1)(N+1) P_{p} L}{2 N L-L_{t}} \tag{1}
\end{equation*}
$$

Even number of spans

$$
\begin{equation*}
R=\frac{16 M_{p}+N^{2} P_{p} L}{2 N L-L_{t}} \tag{2}
\end{equation*}
$$

where:
$\mathbf{R}=$ total ultimate resistance of railing (kips).
$\mathrm{M}_{\mathrm{p}}=$ total plastic moment capacity of all rail elements (in-kips).
$\mathrm{N}=$ number of railing spans involved in failure mechanism.
$\mathbf{P}_{\mathrm{p}}=$ ultimate transverse load resistance of a single post (kips).
$\mathrm{L}=$ post spacing ( ft ).
$\mathrm{L}_{\mathrm{l}}=$ length over which transverse load is distributed (ft).
It is noted that several requirements must be met for a plastic failure mechanism to occur.

1. Elastic buckling of the individual members must not occur.
2. The materials must be sufficiently ductile to form plastic hinges and allow sufficient rotation at those hinges to form a complete mechanism.
3. Connections must be adequately detailed.
4. Member cross sections must be sufficiently compact to maintain their shape without local buckling in the region of a plastic hinge.

## CHAPTER 4. RALLING DESIGNS

## PERFORMANCE LEVEL ONE DESIGNS

Three performance level one designs were evaluated in this study. They were:

1. Oregon Side-Mounted Railing.
2. BR27D on Sidewalk.
3. BR27D on Deck.

## Oregon Side-Mounted Railing

A drawing for this railing design is shown in figure 5. A strength analysis along with more detailed drawings are presented in appendix A.

The original design for this railing was proposed by Oregon DOT. It has been used on small bridges on low volume rural roads and is typically mounted on prestressed deck planks. The W6x15 posts are mounted on the side face of exterior planks and a single thickness of 10 -gauge thrie-beam is mounted to the post without a blockout. Height to the top of the rail element is 27 in ( 690 mm ).

## BR27D on Sidewalk

This railing design concept was selected by the project panel to meet a need for a railing for urban areas. Many States are currently using railing designs that are somewhat similar to BR27D in that they consist of a concrete parapet with an open metal railing on top.

BR27D was tested to PL1 both with and without the curb and sidewalk. A somewhat similar design, BR27C, was tested to PL2 both with and without the curb and sidewalk.

In the analysis and design of BR27D with curb and sidewalk, information on the influence of the curb on vehicle trajectory was needed. Some information on this subject for $3,500-\mathrm{lb}$ ( $1589-\mathrm{kg}$ ) automobiles was found in the 1977 barrier guide. ${ }^{(8)}$ No data specifically for vehicles used in tests on BR27D were available. The expected influence of the 8 -in (200$\mathrm{mm})$ curb on the trajectory of a Honda Civic, a pickup truck, and an $18,000-\mathrm{lb}(8172-\mathrm{kg})$ truck was estimated from available data. A design force of 30 kips at 35 in ( 890 mm ) above the top surface of the sidewalk was selected for design of BR27D. A cross section of this railing design is shown in figure 6.

## BR27D on Deck

Design of this railing was identical to BR27D on sidewalk. It was mounted on the deck without a curb and sidewalk. A cross section of the prototype test railing is shown in figure 7.


[^1]Figure 5. Details of Oregon side-mounted bridge railing.


Figure 6. Cross section of BR27D bridge railing on sidewalk.

$1 \mathrm{in}=25.4 \mathrm{~mm}$
$1 \mathrm{ft}=0.305 \mathrm{~m}$

Figure 7. Cross section of BR27D bridge railing on deck.

## PERFORMANCE LEVEL TWO DESIGNS

Seven performance level two designs were evaluated in this study. They were:

1. Illinois 2399-1 Railing.
2. 32 -in ( $813-\mathrm{mm}$ ) Concrete Parapet.
3. 32 -in ( $813-\mathrm{mm}$ ) New Jersey Safety Shape.
4. 32 -in ( $813-\mathrm{mm}$ ) F-shape.
5. BR27C on Sidewalk.
6. BR27C on Deck.
7. Illinois Side-Mounted Railing.

## Illinois 2399-1 Railing

The Illinois 2399-1 railing design is a modification of the original Illinois design (designated 2399). It was offered for use as a retrofit railing on structures which have a narrow safety walk. A cross section of the prototype test railing is shown in figure 8. The railing would be appropriate for use on new construction where it would be mounted on top of a similar curb. If no curb were present, the opening below the bottom rail element would be too large and the bending moment in the post would be increased.

## 32-in (813-mm) Concrete Parapet

A vertical faced concrete parapet railing was proposed by South Dakota. A cross section of the prototype design is shown in figure 9. The flat vertical face serves to smoothly redirect a vehicle with good stability in roll and pitch; however, under low-severity impact conditions, damage to the vehicle may be greater than that for a New Jersey safety shape or F-shape concrete parapet. The thickened section along the top edge of the parapet provides beam strength and enhances the longitudinal distribution of forces in the parapet and deck.

## 32-in (813-mm) New Jersey Safety Shape

The safety shape has been tested extensively, especially as a median barrier. Virtually all States include a safety shape in their standards both as a median barrier and as a bridge railing. It was selected for testing in this study with a pickup truck and $18,000-\mathrm{lb}$ ( $8172-\mathrm{kg}$ ) single unit truck to determine compliance with the 1989 guide specifications. ${ }^{(3)}$

The amount of steel used in the safety shape has varied significantly. Details of the prototype safety shape tested in this study are shown in figure 10 . It was designed to resist forces for performance level two.


Figure 8. Cross section of Illinois 2399-1 bridge railing.


Figure 9. Cross section of $32-\mathrm{in}(813-\mathrm{mm})$ concrete parapet.


Figure 10. Cross section of 32 -in ( $813-\mathrm{mm}$ ) New Jersey safety shape.

## 32-in (813-mm) F-Shape

The F-shape is similar in cross section to the New Jersey Safety Shape except the geometry of lower portion of the traffic face is different. The modified lower face is intended to provide improved stability for small automobiles.

A cross section of the F-shape is shown in figure 11. It was designed to resist collision forces for performance level two.

## BR27C on Sidewalk

A cross section of this railing design is shown in figure 12. It was designed to meet performance level one but was tested to performance level two. Detailed design calculations are presented in appendix $G$.

After tests were performed on this railing, two modifications of details were made for the deck-mounted version. The rail-to-post connection bolt was changed from $1 / 2$ to $3 / 4$ in ( 13 to 19 mm ) diameter and an anchorage assembly was added at the end of the anchor bolts. These modifications are recommended for both versions of the design.

## BR27C on Deck

A cross section of this railing design is shown in figure 13. It is basically the same as the sidewalk mounted version but differs in two details. The rail-to-post connection bolt was changed from $1 / 2$ to $3 / 4$ in ( 13 mm to 19 mm ) diameter and an anchorage assembly was installed at the bottom end of the anchor bolts. These details are also recommend for the sidewalk mounted version.

## Illinois Side-Mounted Railing

A cross section of this railing is shown in figure 14. The railing is composed of two A500 grade B steel tubular rails mounted on AASHTO M183 wide-flange steel posts. The W6x25 posts are mounted on the side of a prestressed concrete slab and are $4 \mathrm{ft} 1-1 / 4 \mathrm{in}$ $(1.25 \mathrm{~m})$ long, spaced at $6 \mathrm{ft} 3 \mathrm{in}(1.9 \mathrm{~m})$. The top rail is an 8 -in by 4 -in by $5 / 16$-in (203mm by $102-\mathrm{mm}$ by $8-\mathrm{mm}$ ) tubular rail, and the bottom rail is a 6 -in by 4 -in by $1 / 4$-in ( $152-$ mm by $102-\mathrm{mm}$ by $6-\mathrm{mm}$ ) tubular rail. This railing system has a height of 32 in ( $813-\mathrm{mm}$ ) above the bituminous surface. The center of the top rail is 28 in ( 710 mm ) above the surface.


Figure 11. Cross section of 32 -in $(813-\mathrm{mm})$ F-shape bridge railing.

$1 \mathrm{in}=25.4 \mathrm{~mm}$
$1 \mathrm{ft}=0.305 \mathrm{~m}$

Figure 12. Cross section of BR27C bridge railing on sidewalk.


Figure 13. Cross section of BR27C bridge railing on deck.

$1 \mathrm{in}=25.4 \mathrm{~mm}$
$1 \mathrm{ft}=0.305 \mathrm{~m}$

Figure 14. Cross section of Illinois side-mounted bridge railing.

## PERFORMANCE LEVEL THREE DESIGNS

Two performance level three designs were evaluated in this study. They were:

1. 42 -in ( $1.07-\mathrm{m}$ ) Concrete Parapet.
2. 42 -in ( $1.07-\mathrm{m}$ ) F-shape.

## 42-in (1.07-m) Concrete Parapet

A cross section of this railing is shown in figure 15. The thickened section at the top edge of the parapet serves to strengthen the parapet and enhance longitudinal distribution of forces within the parapet and the deck. The deck extension on the field side of the parapet was considered necessary to provide adequate anchorage of the reinforcement in the top of the deck.

## 42-in (1.07-m) F-Shape

A cross section of the prototype $42-\mathrm{in}(1.07-\mathrm{m})$ F-shape is shown in figure 16 . The slope at the bottom traffic face of the parapet serves to minimize vehicle damage (for automobiles) at low angles of impact by causing the tire to ride up on the parapet and redirect itself back to the pavement. The thickened section at the top acts as a continuous beam and enhances longitudinal distribution of forces in the parapet and deck. It also influences the appearance of the field side face of the parapet. The deck extension beyond the field side face of the parapet was deemed necessary to provide adequate anchorage of the top reinforcement in the deck.


Figure 15. Cross section of 42 -in ( $1.07-\mathrm{m}$ ) concrete parapet.


Figure 16. Cross section of $42-$ in $(1.07 \mathrm{~m})$ F-shape.

## CHAPTER 5. TRANSITION DESIGNS

Two transition designs were developed and tested in this study. One was a performance level one transition. The original design came from Oregon and it is intended for use with the Oregon side-mounted bridge railing. The other is a $32-\mathrm{in}(813-\mathrm{mm})$ high thrie-beam transition for performance level two. It was tested on the $32-\mathrm{in}(813-\mathrm{mm}$ ) concrete parapet bridge railing but it is also intended for use with other performance level two bridge railings where it can be suitably attached to the bridge railing.

## PERFORMANCE LEVEL ONE DESIGN

## Oregon Thrie-Beam Transition

Drawings for the Oregon thrie-beam transition are shown in figure 17. The bridge rail element is a 10 -gauge thrie-beam which terminates at the end of the bridge. A 12 -gauge W-beam connects at this point and continues straight through the transition. An additional 10 -gauge thrie-beam element is connected behind the W -beam at the end of the bridge and extends straight for $6 \mathrm{ft}-3 \mathrm{in}(1.9 \mathrm{~m})$, then curves to the field side on an $111 / 2 \mathrm{ft}(3.5-\mathrm{m})$ radius for a distance of $6 \mathrm{ft}-3$ in $(1.9 \mathrm{~m})$. Timber posts 8 in by 8 in by $6-\mathrm{ft}-0$ in ( 203 mm by by 203 mm by 1.8 m ) and blockouts spaced at $3 \mathrm{ft}-11 / 2 \mathrm{in}(1.0 \mathrm{~m})$ are used in the transition.

Because transition rails are flexible and most bridge rails are either rigid or semirigid, guardrail-to-bridge rail transitions must be designed to prevent impacting vehicles from deflecting the guardrail sufficiently to allow vehicle snagging on the end of the rigid bridge railing. Curving the thrie-beam away from the traffic face creates an area that provides smooth transition from lower stiffness of the W-beam guardrail to higher stiffness of the thrie-beam bridge rail. Consequently, an impacting vehicle is prevented from snagging along the transition and sustaining high levels of damage or injury. In addition, curving the thriebeam prevents the vehicle from snagging on the end of the thrie-beam itself.

## PERFORMANCE LEVEL TWO DESIGN

## 32-in ( $813-\mathrm{mm}$ ) Thrie-Beam Transition

Drawings for the $32-\mathrm{in}(813-\mathrm{mm})$ thrie-beam transition are presented in figure 18 . The prototype transition was installed on the $32-\mathrm{in}(813-\mathrm{mm})$ concrete parapet for testing. A terminal connector was used at the transition-to-parapet connection. In the first two tests (automobile and pickup truck), a standard AASHTO terminal connector was used. ${ }^{(9)}$ The terminal connector was lapped on the traffic face with the two layers of thrie-beam being sandwiched between the terminal connector and the parapet. In a connection such as this


[^2]Figure 17. Details of Oregon thrie-beam transition.


SECTION A-A


Figure 17. Details of Oregon thrie-beam transition. (continued)


$$
\begin{aligned}
& 1 \mathrm{in}=25.4 \mathrm{~mm} \\
& 1 \mathrm{ft}=0.305 \mathrm{~m}
\end{aligned}
$$

Figure 18. Cross section of 32 -in ( $813-\mathrm{mm}$ ) thrie-beam transition.
with three layers of rail element, splice bolts cannot be inserted in the holes unless the holes in at least one layer of material are enlarged.

For the repeat of the pickup truck test (test 7069-21) and the $18,000-\mathrm{lb}(8172-\mathrm{kg})$ truck test (test 7069-29), a modified terminal connector was used. In test 21, the connector thickness was 12 gauge; and in test 29 , it was 10 gauge. It has slanted, slotted holes to facilitate assembly of the splice as shown in figure 19. It was sandwiched between the two layers of thrie-beam rail element.


[^3]Figure 19. Modified terminal connector.

## CHAPTER 6. SUMMARY OF CRASH TEST RESULTS

A total of 37 full-scale crash tests were performed on the railing and transition designs evaluated in this study. Results of these tests are summarized in this chapter and details of the tests are given in appendixes A through L.

## PERFORMANCE LEVEL ONE RAILINGS

Performance level one railings evaluated in this study were: Oregon side-mounted thrie-beam railing and bridge railing BR27D mounted both on a sidewalk and on the deck. Tests performed on these railings are listed in table 2. In all tests, the performance obtained is judged acceptable.

The Oregon side-mounted railing is a rather uncomplicated design that uses mostly standard hardware items. It has adequate strength and height for performance level one and, under the more severe impact, exhibits plastic deformation that serves to limit accelerations imposed on the vehicle. Plastic deformation was confined to metal railing components and no damage was caused to the deck.

A transition for this railing has been tested and evaluated and results are presented near the end of this chapter.

Railing design BR27D was tested to performance level one under two situations. First, it was tested when mounted on a $5-\mathrm{ft}(1.5-\mathrm{m})$ wide sidewalk with an 8 -in ( 203 mm ) high curb at the face of the sidewalk. It was also tested when mounted flush on the deck. Acceptable results were obtained in both series of tests. For the most part, the railing functioned as a "rigid" railing with only a small amount of permanent deformation in the metal railing in the more severe tests.

Table 2. Summary of full-scale crash tests performed on performance level one railings.

| RAILING DESIGN | $\begin{aligned} & \text { TEST } \\ & \text { NO. } \end{aligned}$ | TEST <br> DATE | ACTUAL CONDITIONS | DESIGN CONDITIONS | COMMENTS |
| :---: | :---: | :---: | :---: | :---: | :---: |
| OREGON SIDEMOUNTED | 7069-17 | 5/10/89 | $1,970 \mathrm{lb}\|52.2 \mathrm{mi} / \mathrm{h}\| 19.7 \mathrm{deg}$ ( $894 \mathrm{~kg}\|84.0 \mathrm{~km} / \mathrm{h}\| 19.7 \mathrm{deg}$ ) | $\begin{gathered} 1,800 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (817 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \\ \hline \end{gathered}$ | Acceptable |
|  | 7069-18 | 5/12/89 | $\begin{gathered} 5,737 \mathrm{lb}\|46.1 \mathrm{mi} / \mathrm{h}\| 20.9 \mathrm{deg} \\ 2605 \mathrm{~kg}\|74.2 \mathrm{~km} / \mathrm{h}\| 20.9 \mathrm{deg}) \end{gathered}$ | $5,400 \mathrm{lb} / 45 \mathrm{mi} / \mathrm{h} / 20 \mathrm{deg}$ $2452 \mathrm{~kg}\|72.4 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}$ | Acceptable |
| $\begin{gathered} \text { BR27D } \\ \text { ON SIDEWALK } \end{gathered}$ | 7069-22 | 3/24/92 | $1,967 \mathrm{lb}\|51.7 \mathrm{mi} / \mathrm{h}\| 20.8 \mathrm{deg}$ ( $893 \mathrm{~kg}\|83.2 \mathrm{~km} / \mathrm{h}\| 20.8 \mathrm{deg}$ ) | $\begin{gathered} 1,800 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (817 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \\ \hline \end{gathered}$ | Acceptable |
|  | 7069-23 | 3/26/92 | $\begin{gathered} 5,565 \mathrm{lb}\|45.3 \mathrm{mi} / \mathrm{h}\| 20.2 \mathrm{deg} \\ (2527 \mathrm{~kg}\|72.9 \mathrm{~km} / \mathrm{h}\| 20.2 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 5,400 \mathrm{lb}\|45 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (2452 \mathrm{~kg}\|72.4 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Acceptable |
| $\begin{aligned} & \text { BR27D } \\ & \text { ON DECK } \end{aligned}$ | 7069-30 | 5/19/92 | $1,970 \mathrm{lb}\|51.2 \mathrm{mi} / \mathrm{h}\| 20.5 \mathrm{deg}$ ( $894 \mathrm{~kg}\|82.4 \mathrm{~km} / \mathrm{h}\| 20.5 \mathrm{deg}$ ) | $\begin{gathered} 1,800 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ 817 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \\ \hline \end{gathered}$ | Acceptable |
|  | 7069-31 | 5/21/92 | $\begin{gathered} 5,400 \mathrm{lb}\|45.6 \mathrm{mi} / \mathrm{h}\| 18.8 \mathrm{deg} \\ (2527 \mathrm{~kg}\|73.4 \mathrm{~km} / \mathrm{h}\| 18.8 \mathrm{deg}) \\ \hline \end{gathered}$ | $\begin{gathered} 5,400 \mathrm{lb}\|45 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ 2452 \mathrm{~kg}\|72.4 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \\ \hline \end{gathered}$ | Acceptable |

# Oregon Side-Mounted Railing 

Test number 7069-17

| Vehicle: | 1980 Honda Civic |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,970 \mathrm{lb}(894 \mathrm{~kg})$ |
| Impact Speed: | $52.2 \mathrm{mi} / \mathrm{h}(84.0 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 19.7 deg |

The vehicle impacted the bridge railing approximately $20.6 \mathrm{ft}(6.3 \mathrm{~m})$ from the upstream end. It began to redirect at 0.042 s after impact. By 0.175 s the vehicle was traveling parallel to the bridge railing at a speed of $44.0 \mathrm{mi} / \mathrm{h}(70.8 \mathrm{~km} / \mathrm{hr})$. Shortly thereafter, the rear of the vehicle impacted the bridge railing. The vehicle lost contact with the bridge railing at 0.261 s traveling at $42.7 \mathrm{mi} / \mathrm{h}(68.7 \mathrm{~km} / \mathrm{h})$ and 7.1 degrees. It was in contact with the railing for $9.3 \mathrm{ft}(2.8 \mathrm{~m})$. The brakes were applied $82 \mathrm{ft}(2.5 \mathrm{~m})$ from impact and the vehicle yawed clockwise. The vehicle subsequently came to rest $172 \mathrm{ft}(5.2$ $\mathrm{m})$ downstream and $30 \mathrm{ft}(9 \mathrm{~m})$ to the field side of the point of impact.

The railing received moderated damage (figure 20). Maximum lateral deflection was 0.5 in ( 13 mm ) at the top of post 5 . At post 4 , the top anchor bolts connecting the post to the bridge deck showed structural distress. One bolt was pulled from the anchor insert in the concrete. Post 5 was bent outward about $0.5 \mathrm{in}(13 \mathrm{~mm})$ at the top and the top anchor bolts showed structural distress. One of the bolts in this post was also pulled from the anchor insert.

After-test examination of anchor bolts in all the posts show that the bolts had been cut off during construction and, in some, only three or four threads were engaged in the anchor insert. The plans called for a minimum of $7 / 8 \mathrm{in}(22 \mathrm{~mm})$ thread engagement. Evidently, concrete had flowed into the anchors during fabrication of the prestressed deck slabs and the anchor bolts had been cut off to prevent them from bottoming out. This was not detected during the construction inspection process. Prior to the next test, concrete was removed from all anchor inserts and new full-length anchor bolts were installed.

The vehicle sustained damage to the right side (figure 21). Maximum crush at the right front corner at bumper height was 9.0 in ( 229 mm ). The strut and constant velocity joint on the impact side were damaged. The right front wheel was canted inward at the bottom and pushed back into the fender well. The right side window was broken out by the dummy's head. Also, damage was done to the front bumper, hood, grill, radiator and fan, right front quarter panel, and right door.

The railing contained the vehicle with minimal lateral movement of the bridge railing. There was no intrusion into the occupant compartment and no deformation of the compartment. The vehicle remained upright and relatively stable during the collision. The bridge railing smoothly redirected the vehicle and the effective coefficient of friction was


Figure 20. Damage to railing system in test 7069-17.


Figure 21. Vehicle and railing for test 7069-17.
considered fair. The occupant risk factors were within the limits recommended in the 1989 AASHTO guide specifications. ${ }^{(3)}$ The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 22 and table 3.



Impact Speed. . . . $52.2 \mathrm{mi} / \mathrm{h}(84.0 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . . 19.7 deg
Speed at Paraliei . $44.0 \mathrm{mi} / \mathrm{h}(70.8 \mathrm{~km} / \mathrm{h})$
Exit Speed . . . . $42.7 \mathrm{mi} / \mathrm{h}(68.7 \mathrm{~km} / \mathrm{h})$
Exit Trajectory . . 7.1 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . . -5.2 g
Lateral . . . . . 8.4 g
Occupant Impact Velocity
Longitudinal. . . $18.8 \mathrm{ft} / \mathrm{s}(5.7 \mathrm{~m} / \mathrm{s})$
Lateral . . . . $18.9 \mathrm{ft} / \mathrm{s}(5.8 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal. . . -1.8 g
Lateral . . . . . 4.5 g
Figure 22. Summary of results for test 7069-17.

Table 3. Evaluation of crash test no. 7069-17.
\{Oregon Side-Mounted Bridge Railing [1,800 lb ( 817 kg ) $|52.2 \mathrm{mi} / \mathrm{h}(84.0 \mathrm{~km} / \mathrm{h})| 19.7$ degrees]\}
$\qquad$
TEST RESULTS

PASS/FAIL*
A. Must contain vehicle
Vehicle was contained Pass
B. Debris shall not penetrate

No debris penetrated passenger Pass passenger compartment compartment
C. Passenger compartment must have

Acceptable deformation Pass essentially no deformation
D. Vehicle must remain upright

Vehicle did remain upright Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  |
| :--- | :--- |
| $\frac{\text { Assessment }}{\text { Good }}$ |  |
| $>.26 .-.35$ | Fair |
| $>.35$ | Marginal |

$\frac{\mu}{.29} \quad \frac{\text { Assessment }}{\text { Fair }}$ Pass
G. Shall be less than

| Occupant Impact | Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $18.8(5.7)$ | $18.9(5.8)$ |

$\frac{\text { Occupant Ridedown Accelerations - } \mathrm{g}^{\prime} \mathrm{s}}{\text { Longitudinal }}$

| Occupant Ridedown | Accelerations - $g^{\prime} \mathrm{s}$ |  |
| :---: | :---: | :---: |
| Longitudinal | Lateral | Pass |
| -1.8 | 4.5 |  |$\quad$

Exit angle was 7.1 degrees Pass
H. Exit angle shall be less than 12 degrees

* $A, B, C, D$ and $G$ are required. $E, F$, and $H$ are desired. (See table 1)

Test Number 7069-18

| Vehicle: | 1982 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,400 \mathrm{lb}(2452 \mathrm{~kg})$ |
| Gross Static Weight: | $5,737 \mathrm{lb}(2605 \mathrm{~kg})$ |
| Impact Speed: | $46.1 \mathrm{mi} / \mathrm{h}(74.2 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.9 deg |

The vehicle impacted the bridge railing approximately $41.3 \mathrm{ft}(12.6 \mathrm{~m})$ from the upstream end. It began to redirect at 0.054 s . By 0.234 s the vehicle was traveling parallel to the railing at a speed of $38.2 \mathrm{mi} / \mathrm{h}(61.5 \mathrm{~m})$, and at approximately the same time the rear of the vehicle impacted the railing. The vehicle lost contact with the bridge railing at 0.458 s traveling at $35.9 \mathrm{mi} / \mathrm{h}(57.8 \mathrm{~km} / \mathrm{h})$ and 10.9 degrees. It was in contact with the railing for $16.3 \mathrm{ft}(5.0 \mathrm{~m})$. The brakes were applied $38 \mathrm{ft}(11.6 \mathrm{~m})$ from impact and the vehicle yawed clockwise. The vehicle subsequently came to rest $150 \mathrm{ft}(46 \mathrm{~m})$ down and $10 \mathrm{ft}(3 \mathrm{~m})$ to the field side of the point of impact.

The railing received moderate damage (figure 23). At post 8 the upper deck bolts connecting the post to the bridge deck were bent and the post was bent back $1.5 \mathrm{in}(38 \mathrm{~mm})$ at the bridge deck surface. Post 9 was bent 2.5 in ( 64 mm ), the upper deck bolt on the right side was bent, and the upper deck bolt on the left side pulled through the outer flange. Post 10 was slightly twisted. Maximum lateral deflection was 13.0 in ( 330 mm ) at the top of the thrie-beam between posts 8 and 9 .

The vehicle sustained damage to the right side as shown in figure 24. Maximum crush at the right front corner at bumper height was 6.5 in ( 165 mm ). The right front tire deflated, and the rim was bent. The right side window was broken out by the dummy's head. Also, damage was done to the front bumper, hood, grill, right front and rear quarter panels, and right door.

The railing contained the vehicle with minimal lateral movement of the bridge railing. There was no intrusion into the occupant compartment and no deformation of the compartment. The vehicle remained upright and relatively stable during the collision. The railing smoothly redirected the vehicle and the effective coefficient of friction was considered fair. The occupant risk factors were within the limits recommended in the 1989 AASHTO guide specifications. ${ }^{(3)}$ The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 25 and table 4.


Figure 23. Damage to railing in test 7069-18.


Figure 24. Damage to vehicle in test 7069-18.


Figure 25. Summary of results for test 7069-18.

Table 4. Evaluation of crash test no. 7069-18.
\{Oregon Side-Mounted Bridge Railing [5,400 $1 \mathrm{~b}(2452 \mathrm{~kg})|46.1 \mathrm{mi} / \mathrm{h}(74.2 \mathrm{~km} / \mathrm{h})| 20.9$ degrees $]\}$
$\qquad$
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

TEST RESULTS

## Vehicle was contained

PASS/FAIL*

No debris penetrated passenger
Pass compartment
Acceptable deformation

Pass

Vehicle did remain upright Pass
Vehicle was smoothly redirected Pass

| $\frac{\mu}{0-.25}$ |  |
| :--- | :--- |
| $=26-.35$ |  |
| $>.35$ | Fair |
| $>$ | Marginal |

$\frac{\mu}{.29} \quad \frac{\text { Assessment }}{\text { Fair }}$
Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :--- | :---: |
| Longitudinal |  |
| $30(9.2)$ |  |
| Lateral |  |
| Occupant Ridedown Accelerations |  |
| Longitudinal |  |
| 15 |  |


| Occupant Impact Velocity - $\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ | Pass |
| :---: | :---: |
| Longitudinal Lateral |  |
| 17.1 (5.2) 11.7 (3.6) |  |
| Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathbf{s}$ | Pass |
| Longitudinal Lateral |  |
| -3.6 8.8 |  |

H. Exit angle shall be less than 12 degrees

Exit angle was 10.9 degrees
Pass

* $A, B, C$, and $D$ are required. $E, F, G$ and $H$ are desired. (See table l)


## BR27D on Sidewalk

Test Number 7069-22

| Vehicle: | 1983 Honda Civic |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,967 \mathrm{lb}(893 \mathrm{~kg})$ |
| Impact Speed: | $51.7 \mathrm{mi} / \mathrm{h}(83.2 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.8 deg |

Upon impact with the curb, the left front tire folded under the vehicle, and at 0.109 s after impact the left rear wheel impacted the curb. As the left rear wheel climbed the curb, the right front wheel lost contact with the roadway. At 0.217 s the right front wheel contacted the curb and the left side of the vehicle was airborne. When the right front wheel reached the top the curb, the vehicle was totally airborne and remained as such as it impacted the concrete parapet at 0.261 s . The vehicle impacted the parapet at post 5 traveling at a speed of $46.6 \mathrm{mi} / \mathrm{h}(75.0 \mathrm{~km} / \mathrm{h})$ and at an angle of 13.4 degrees. As the vehicle continued forward, the bumper protruded between the upper and lower metal railing elements. At 0.332 s the vehicle began to redirect. The right rear wheel struck the curb at 0.414 s as the vehicle was still airborne. By 0.510 s the vehicle was traveling parallel to the bridge railing at a speed of $41.0 \mathrm{mi} / \mathrm{h}(66.0 \mathrm{~km} / \mathrm{h})$, and at the same time the rear of the vehicle impacted the parapet. The vehicle lost contact with the parapet at 0.610 s traveling at $40.8 \mathrm{mi} / \mathrm{h}(65.6$ $\mathrm{km} / \mathrm{h}$ ) and 6.1 degrees. The vehicle contacted the roadway again as it reached posts 7 and 8 and the brakes were applied. The vehicle left the installation and subsequently came to rest $165 \mathrm{ft}(50 \mathrm{~m})$ from the point of impact.

As can be seen in figure 26 , the bridge railing system received minimal damage. There was no measurable permanent deformation to the railing elements and only cosmetic damage to the concrete parapet. There were tire marks on the concrete parapet and on the face of the lower metal railing element in the area of impact, and also on the lower part of post 6. The vehicle was in contact with the bridge railing for $11.5 \mathrm{ft}(3.5 \mathrm{~m})$. Length of contact with the concrete parapet was $7.0 \mathrm{ft}(2.1 \mathrm{~m})$.

The vehicle sustained damage to the left side as shown in figure 26. Maximum crush at the left front corner at bumper height was 6.0 in ( 152 mm ). The left front strut was damaged and the left front wheel was canted inward at the bottom and pushed back reducing the wheelbase on the driver side by 2 in ( 51 mm ). Also, damage was done to the front bumper, hood, left headlight, left front quarter panel, left rear quarter panel, left front and rear tires and rims, and right front tire.

The railing contained the vehicle with no lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing


Figure 26. Vehicle and railing for test 7069-22.
smoothly redirected the vehicle. The effective coefficient of friction was considered marginal. The occupant impact velocities and the occupant ridedown accelerations were within the limits. Vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 27 and table 5.

0.000 s

$ज$

0.161 s


Impact Speed. . . . $51.7 \mathrm{mi} / \mathrm{h}(83.2 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . . 20.8 deg
Speed at Parallel . $41.0 \mathrm{mi} / \mathrm{h}(66.0 \mathrm{~km} / \mathrm{h})$
Exit Speed . . . . $40.8 \mathrm{mi} / \mathrm{h}(65.6 \mathrm{~km} / \mathrm{h})$
Exit Trajectory . . 6.1 deg
Vehicle Accelerations
(Max. 0.050-sec Avg) at true c.g.
Longitudinal. . . -4.4 g
Lateral . . . . . -6.8 g
Occupant Impact Velocity at true c.g.
Longitudinal. . . $12.2 \mathrm{ft} / \mathrm{s}(3.7 \mathrm{~m} / \mathrm{s})$
Lateral .. . . . $6.3 \mathrm{ft} / \mathrm{s}(1.9 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudina1. . . -4.7 g
Lateral . . . . .-13.3 g

Figure 27. Summary of results for test 7069-22.

Table 5. Evaluation of crash test no. 7069-22.
\{BR27D bridge railing on sidewalk [1,800 $1 \mathrm{~b}(817 \mathrm{~kg})|51.7 \mathrm{mi} / \mathrm{h}(83.2 \mathrm{~km} / \mathrm{h})| 20.8$ degrees $]\}$
$\qquad$
CRITERIA
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

TEST RESULTS
PASS/FAIL*
Vehicle was contained Pass
No debris penetrated passenger Pass compartment

No deformation
Pass

Vehicle did remain upright Pass
Vehicle was smoothly redirected


Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal |  |
| $30(9.2)$ | Lateral |
| $25(7.6)$ |  |


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Langitudinal | Lateral |
| $12.2(3.7)$ | $6.3(1.9)$ |$\quad$ Pass

$\frac{\text { Occupant Ridedown Accelerations }-\mathrm{g}^{\prime} \mathrm{s}}{\text { Longitudinal }} \frac{\text { Lateral }}{15}$
$\frac{\text { Occupant Ridedown Accelerations - g's }}{\text { Longitudinal }} \quad$ Pass
$\begin{array}{ll}-4.7 & -13.3\end{array}$
Exit angle was 6.1 degrees
H. Exit angle shall be less than 12 degrees

* A, B, C, D and G are required. E, F, and H are desired. (See table l)

| Vehicle: | 1984 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,400 \mathrm{lb}(2452 \mathrm{~kg})$ |
| Gross Static Weight: | $5,565 \mathrm{lb}(2527 \mathrm{~kg})$ |
| Impact Speed: | $45.3 \mathrm{mi} / \mathrm{h}(72.9 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.2 deg |

At 0.171 s after impact the right front wheel contacted the curb and the left side of the vehicle was airborne. The vehicle impacted the concrete parapet at 0.218 s . The vehicle impacted the parapet $3 \mathrm{ft}(0.9 \mathrm{~m})$ from post 5 (between posts 4 and 5$)$ traveling at a speed of $43.8 \mathrm{mi} / \mathrm{h}(70.5 \mathrm{~km} / \mathrm{h})$ and at an angle of 19.7 degrees. As the vehicle continued forward, the bumper protruded between the lower metal railing element and the concrete parapet. At 0.295 s the vehicle began to redirect. By 0.487 s the vehicle was traveling parallel to the bridge railing at a speed of $40.3 \mathrm{mi} / \mathrm{h}(64.8 \mathrm{~km} / \mathrm{h})$, and at 0.501 s the rear of the vehicle impacted the parapet. The vehicle lost contact with the concrete parapet at 0.587 s traveling at $37.2 \mathrm{mi} / \mathrm{h}(59.9 \mathrm{~km} / \mathrm{h})$ and 5.3 degrees. It was in contact with the railing for $12.8 \mathrm{ft}(3.9$ $\mathrm{m})$. The brakes were applied as the vehicle left the installation. The vehicle yawed counterclockwise and subsequently came to rest $113 \mathrm{ft}(34 \mathrm{~m})$ from the point of impact resting against another barrier downstream of the bridge railing installation.

The bridge railing received minimal damage (figure 28 ). The maximum permanent deformation to the railing element was $0.5 \mathrm{in}(13 \mathrm{~mm})$ between posts 5 and 6 . Posts 5 and 6 were also pushed rearward approximately $3 / 16$ in ( 05 mm ). There was only cosmetic damage to the concrete parapet. There were tire marks on the concrete parapet, on the face of the lower metal railing element in the area of impact, and also on the lower part of posts 5 and 6.

The vehicle sustained damage to the left side as shown in figure 28. Maximum crush at the left front corner at bumper height was $12.5 \mathrm{in}(318 \mathrm{~mm})$ and the right side was deformed outward 5.0 in ( 127 mm ). Also, damage was done to the front bumper, hood, grill, radiator and fan, left front quarter panel, left door, left rear quarter panel, left front and rear tires and rims, rear bumper, and right front quarter panel and right door.

The railing contained the vehicle with minimal lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 29 and table 6.


Figure 28. Vehicle and railing for test 7069-23.


Test No. . . . . . . . . $7069-23$
Date . . . . . . . . . . 03/26/92
Test Installation $\ldots$ BR27D Bridge Railing
Installation Length $\quad . \quad 100 \mathrm{ft}(30 \mathrm{~m})$

Test Vehicle

Impact Speed. . . . $45.3 \mathrm{mi} / \mathrm{h}(72.9 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . . 20.2 deg
Speed at Parallel . $40.3 \mathrm{mi} / \mathrm{h}(64.8 \mathrm{~km} / \mathrm{h})$
Exit Speed . . . . $37.2 \mathrm{mi} / \mathrm{h}(59.9 \mathrm{~km} / \mathrm{h}$ )
Exit Trajectory . . 5.3 deg
Vehicle Accelerations
(Max. 0.050-sec Avg) at true c.g.
Longitudinal. . . -3.7 g
Lateral . . . . -7.8 g
Occupant Impact Velocity at true c.g.
Longitudinal. . . $13.2 \mathrm{ft} / \mathrm{s}(4.0 \mathrm{~m} / \mathrm{s})$
Lateral . . . . $14.0 \mathrm{ft} / \mathrm{s}(4.3 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal. . . -2.3 g
Lateral . . . . . 10.6 g

Figure 29. Summary of results for test 7069-23.

Table 6. Evaluation of crash test no. 7069-23.
\{BR27D bridge railing on sidewalk [5, 400 $\mathrm{lb}(2452 \mathrm{~kg})|45.3 \mathrm{mi} / \mathrm{h}(72.9 \mathrm{~km} / \mathrm{h})| 20.2$ degrees $]\}$
CRITERIA
TEST RESULTS PASS/FAIL*
A. Must contain vehicle
Vehicle was contained Pass
B. Debris shall not penetrate

No debris penetrated passenger Pass compartment
C. Passenger compartment must have No deformation
D. Vehicle must remain upright

Vehicle did remain upright
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
F. Effective coefficient of friction

G. Shall be less than

| Occupant Impact |  |
| :---: | :---: |
| Longitudinal ocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| $30(9.2)$ | Lateral |
| $25(7.6)$ |  |


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |  |
| :---: | :---: | :---: |
| Longitudinal | Lateral |  |
| $13.2(4.0)$ | $14.0(4.3)$ |  |

$\begin{array}{cc}\text { Occupant Ridedown Accelerations - } \mathrm{g}^{\prime} \mathrm{s} \\ \text { Longitudinal } & \text { Lateral } \\ -2.3 & -10.6\end{array}$
Pass
Occupant Ridedown Accelerations - $g^{\prime} s$
Longitudinal Lateral
15
15
H. Exit angle shall be less than 12

Exit angle was 5.3 degreesrees degreesrees

* $A, B, C$, and $D$ are required. $E, F, G$, and $H$ are desired. (See table 1)


## BR27D on Deck

Test Number 7069-30

| Vehicle: | 1983 Honda Civic |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,970 \mathrm{lb}(894 \mathrm{~kg})$ |
| Impact Speed: | $51.2 \mathrm{mi} / \mathrm{h}(82.4 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.5 deg |

Shortly after impact ( 0.036 s ) the vehicle began to redirect and at 0.093 s the right front corner of the vehicle began to shift outward. At approximately 0.095 s after impact the dummy impacted the driver side door and shattered the door glass. The right front tire lost contact with the roadway at 0.108 s . By 0.164 s the vehicle was traveling parallel to the bridge railing at a speed of $43.6 \mathrm{mi} / \mathrm{h}(70.2 \mathrm{~km} / \mathrm{h})$, and at 0.178 s the rear of the vehicle impacted the parapet. The right rear tire lost contact with the roadway at 0.196 s . The vehicle lost contact with the bridge railing at 0.319 s traveling at $43.0 \mathrm{mi} / \mathrm{h}(69.2 \mathrm{~km} / \mathrm{h})$ and 6.8 degrees. It was in contact with the railing for $8.0 \mathrm{ft}(2.4 \mathrm{~m})$. The right front tire of the vehicle contacted the roadway again at 0.476 s and the right rear at 0.0557 s . The brakes were applied as the vehicle exited the test site. The vehicle subsequently came to rest 150 ft $(46 \mathrm{~m})$ down from and $70 \mathrm{ft}(21 \mathrm{~m})$ toward the traffic side of the point of impact.

The bridge railing received minimal damage (figure 30 ). There was no measurable permanent deformation to the railing elements and only cosmetic damage to the concrete parapet. There were tire marks on the concrete parapet and on the face of the lower metal railing element in the area of impact.

Maximum crush of the vehicle at the left front corner at bumper height was 7.0 in ( 178 mm ) (figure 30). The left front strut was damaged and the left front wheel was canted inward at the bottom and pushed back reducing the wheelbase on the driver side by 2.25 in ( 57 mm ). Also, damage was done to the right front quarter panel, front bumper, hood, left headlight, left front quarter panel, left door and glass, left rear quarter panel, rear bumper, and left front and rear tires and rims.

The railing contained the vehicle with no lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 31 and table 7.


Figure 30. Vehicle and railing for test 7069-30.


Table 7. Evaluation of crash test no. 7069-30.
\{BR27D bridge railing on deck [1,800 $1 \mathrm{~b}(817 \mathrm{~kg})|51.2 \mathrm{mi} / \mathrm{h}(82.4 \mathrm{~km} / \mathrm{h})| 20.5$ degrees $]\}$
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle

Vehicle was contained Pass
B. Debris shall not penetrate

No debris penetrated passenger passenger compartment
C. Passenger compartment must have compartment

No deformation essentially no deformation

Vehicle did remain upright
Pass
D. Vehicle must remain upright

Vehicle was smoothly redirected
Pass
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  |
| :--- | :--- |
| $.26-.35$ |  |
| $>.35$ | Assessment |
|  |  |
| Fair |  |
| Marginal |  |

$\frac{\mu}{.24} \quad \frac{\text { Assessment }}{\text { Good }}$

Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |


H. Exit angle shall be less than 12 degrees

Exit angle was 6.8 degrees

* $A, B, C, D$ and $G$ are required. $E, F$, and $H$ are desired. (See table 1)


## Test Number 7069-31

| Vehicle: | 1985 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,400 \mathrm{lb}(2452 \mathrm{~kg})$ |
| Gross Static Weight: | $5,566 \mathrm{lb}(2527 \mathrm{~kg})$ |
| Impact Speed: | $45.6 \mathrm{mi} / \mathrm{h}(73.4 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 18.8 deg |

At 0.020 s after impact the left front wheel contacted the concrete parapet, and at 0.029 s the right front corner of the vehicle began to deform outward. The vehicle began to redirect at 0.048 s after impact, and at 0.148 s the dummy impacted the driver side door and shattered the glass. By 0.231 s the vehicle was traveling parallel to the bridge railing at a speed of $40.8 \mathrm{mi} / \mathrm{h}(65.6 \mathrm{~km} / \mathrm{h})$, and shortly thereafter the rear of the vehicle impacted the parapet. The vehicle lost contact with the bridge railing at 0.333 s traveling at $38.0 \mathrm{mi} / \mathrm{h}$ $(61.1 \mathrm{~km} / \mathrm{h})$ and 6.2 degrees. It was in contact with the railing for $11.7 \mathrm{ft}(3.6 \mathrm{~m})$. The brakes were applied 2.3 s after impact. The vehicle yawed counterclockwise due to the deflated left front tire and subsequently came to rest $225 \mathrm{ft}(69 \mathrm{~m})$ down from and 40 ft (12 $\mathrm{m})$ behind the point of impact.

The bridge railing received minimal damage (figure 32). The maximum permanent deformation to the railing element was $0.5 \mathrm{in}(13 \mathrm{~mm})$ between posts 5 and 6 . There was only cosmetic damage to the concrete parapet. There were tire marks on the concrete parapet, on the face of the lower metal railing element in the area of impact, and also on the lower part of post 6 .

Maximum crush of the vehicle at the left front corner at bumper height was 6.5 in $(165 \mathrm{~mm})$, and the right side was deformed outward $4.0 \mathrm{in}(102 \mathrm{~mm})$ (figure 32). Also, damage was done to the front bumper, hood, grill, left front quarter panel, left door, left rear quarter panel, left front and rear tires and rims, rear bumper, and right front quarter panel and right door.

The railing contained the vehicle with minimal lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 33 and table 8.


Figure 32. Vehicle and railing for test 7069-31.


$1 \mathrm{in}=25.4 \mathrm{~mm}$

Figure 33. Summary of results for test 7069-31.

Table 8. Evaluation of crash test no. 7069-31.
\{BR27D bridge railing on deck [5, 400 $1 \mathrm{~b}(2452 \mathrm{~kg})|45.6 \mathrm{mi} / \mathrm{h}(73.4 \mathrm{~km} / \mathrm{h})| 18.8$ degrees $]$ \}

CRITERIA
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

| TEST RESULTS | PASS/FAIL |
| :--- | :---: |
| Vehicle was contained | Pass |
| No debris penetrated passenger <br> compartment | Pass |
| No deformation | Pass |

Vehicle did remain upright Pass
Vehicle was smoothly redirected Pass


Assessment Good
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |

Occupant Ridedown Accelerations - $q^{\prime} s$
Longitudinal Lateral
15
15
H. Exit angle shall be less than 12 degrees

| Occupant Impact | city - $\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |
| :---: | :---: |
| Longitudinal | Lateral |
| 11.7 (3.6) | 12.3 (3.7) |
| Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$ |  |
| Longitudinal | Lateral |
| 2.2 | -8.2 |

Exit angle was 6.2 degrees Pass

* $A, B, C$, and $D$ are required. $E, F, G$, and $H$ are desired. (See table 1)


## PERFORMANCE LEVEL TWO RAILINGS

Seven railing designs were tested to performance level two as shown in table 9. Acceptable performance was obtained in all tests.

The original Illinois 2399 railing design was proposed as a retrofit railing. The modified prototype (Illinois 2399-1) was tested on a cantilevered slab that simulated situations where it would be used as a retrofit, but it is deemed suitable for new construction if adequate bridge deck strength is provided.

Posts used in the test installation were somewhat larger than needed based on strength calculations and the railing functioned as a "rigid" system in tests. In test 7069-1 with the small automobile, there was no damage to the railing. There was a small amount of permanent deformation of the metal railing in the test with a pickup (7069-2). In the test with an $18,000-\mathrm{lb}(8172-\mathrm{kg})$ truck, moderate damage occurred to the railing. Bolts connecting the lower rail element to the posts were sheared at five consecutive posts in the impact area; however, the rail element remained reasonably well in place. At one post the upper rail element mounting bolt was sheared. Results of the tests show that acceptable performance was obtained.

The $32-\mathrm{in}$ ( $813-\mathrm{mm}$ ) concrete parapet is a simple, effective railing system that meets performance level two requirements. It showed no structural distress in the tests performed. One could argue that when compared to the New Jersey or F-shape, the vertical-faced parapet imposes slightly higher accelerations and slightly more damage but provides slightly more stability to the vehicle.

The 32 -in ( $813-\mathrm{mm}$ ) New Jersey safety shape has been subjected to extensive fullscale crash testing with various vehicles in many other research studies and is used extensively throughout the Nation. It was included in this study for testing with a $5,400-\mathrm{lb}$ ( $2452-\mathrm{kg}$ ) pickup and an $18,000-\mathrm{lb}$ ( $8172-\mathrm{kg}$ ) single unit truck under conditions meeting performance level two of the 1989 guide specifications. ${ }^{(3)}$ Acceptable performance was obtained in both tests.

The 32 -in ( $813-\mathrm{mm}$ ) F-shape was subjected to tests for performance level two as shown in table 10. The $18,000-\mathrm{lb}(8172-\mathrm{kg})$ truck test was repeated twice because the speed was too slow in the first two attempts. This was caused by two unrelated equipment malfunctions.

The railing functioned acceptably in all tests, and it is recommended as a suitable alternative to the $32-\mathrm{in}(813-\mathrm{mm})$ vertical faced concrete parapet and the 32 -in ( $813-\mathrm{mm}$ ) New Jersey safety shape.

Two versions of railing BR27C were tested to performance level two requirements. The first version was mounted on an $8-\mathrm{in}(200-\mathrm{mm})$ high $5-\mathrm{ft}(1.5-\mathrm{m})$ wide sidewalk and the second was mounted on the deck. Both versions performed acceptably.

Railing BR27C on sidewalk was tested first and two details of the design were changed for BR27C on deck. The rail-to-post connection bolts were changed from $1 / 2$ in (13 mm ) diameter to $3 / 4$ in ( 19 mm ) diameter and an anchorage assembly was added at the end of the anchor bolts. These modifications are recommended for both versions of the railing.

The Illinois side-mounted railing consists of two tubular rail elements mounted on steel wide flange posts. The posts are mounted on the side face of prestressed slab planks with anchor bolts screwed into inserts cast in the planks. Blockouts are used between the posts and planks to provide additional useable bridge width.

The railing was subjected to tests for performance level two and performed acceptably in all tests.

Some difficulty was encountered in installation of the anchor bolts. All hardware was galvanized and galling of the anchor bolt threads occurred. It was necessary to chase the threads to obtain suitable engagement of the anchor bolts in the inserts.

Table 9. Summary of full-scale crash tests performed on performance level two railings.

| RAILING DESIGN | $\begin{aligned} & \hline \text { TEST } \\ & \text { NO. } \end{aligned}$ | $\begin{aligned} & \text { TEST } \\ & \text { DATE } \end{aligned}$ | ACTUAL CONDITIONS | DESIGN CONDITIONS | COMMENTS |
| :---: | :---: | :---: | :---: | :---: | :---: |
| ILLINOIS 2399-1 | 7069-1 | 7/14/87 | $1,795 \mathrm{lb}\|58.7 \mathrm{mi} / \mathrm{h}\| 20.0 \mathrm{deg}$ <br> ( $815 \mathrm{~kg}\|94.4 \mathrm{~km} / \mathrm{h}\| 20.0 \mathrm{deg}$ ) | $\begin{gathered} 1,800 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (817 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| \mid 20 \mathrm{deg}) \end{gathered}$ | Marginal |
|  | 7069-2 | 7/24/87 | $\begin{gathered} 5,450 \mathrm{lb}\|63.6 \mathrm{mi} / \mathrm{h}\| 19.2 \mathrm{deg} \\ (2474 \mathrm{~kg}\|102.3 \mathrm{~km} / \mathrm{h}\| 19.2 \mathrm{deg}) \end{gathered}$ | $5,400 \mathrm{lb}\|65 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg}$ ( $2452 \mathrm{~kg}\|104.6 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}$ ) | Acceptable |
|  | 7069-15 | 9/13/88 | $\begin{gathered} 18,000 \mathrm{lb}\|50.8 \mathrm{mi} / \mathrm{h}\| 15.1 \mathrm{deg} \\ (8172 \mathrm{~kg}\|81.7 \mathrm{~km} / \mathrm{h}\| 15.1 \mathrm{deg}) \end{gathered}$ | $18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg}$ <br> ( $8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}$ ) | Acceptable |
| 32-in (813-mm) <br> PARAPET | 7069-5 | 9/24/87 | $1,800 \mathrm{lb}\|60.5 \mathrm{mi} / \mathrm{h}\| 21.0 \mathrm{deg}$ $(817 \mathrm{~kg}\|97.3 \mathrm{~km} / \mathrm{h}\| 21.0 \mathrm{deg})$ | $\begin{gathered} 1,800 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (817 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Marginal |
|  | 7069-6 | 10/8/87 | $\begin{gathered} 5,420 \mathrm{lb}\|59.7 \mathrm{mi} / \mathrm{h}\| 20.2 \mathrm{deg} \\ (2461 \mathrm{~kg}\|96.1 \mathrm{~km} / \mathrm{h}\| 20.2 \mathrm{deg}) \\ \hline \end{gathered}$ | $5,400 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg}$ $(2452 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg})$ | Acceptable |
|  | 7069-16 | 10/13/88 | $\begin{gathered} 18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 14.0 \mathrm{deg} \\ (8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 14.0 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg} \\ (8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}) \end{gathered}$ | Acceptable |
| $\begin{gathered} \text { 32-in (813-mm) } \\ \text { N.J. } \\ \text { SAFETY SHAPE } \end{gathered}$ | 7069-12 | 6/22/88 | $18,000 \mathrm{lb}\|51.6 \mathrm{mi} / \mathrm{h}\| 15.5 \mathrm{deg}$ $(8172 \mathrm{~kg}\|83.0 \mathrm{~km} / \mathrm{h}\| 15.5 \mathrm{deg})$ | $\begin{gathered} 18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg} \\ (8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}) \end{gathered}$ | Acceptable |
|  | 7069-14 | 8/11/88 | $\begin{gathered} 5,390 \mathrm{lb}\|57.7 \mathrm{mi} / \mathrm{h}\| 20.6 \mathrm{deg} \\ (2447 \mathrm{~kg}\|92.8 \mathrm{~km} / \mathrm{h}\| 20.6 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 5,400 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (2452 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Acceptable |
| $\begin{gathered} \text { 32-in (813-mm) } \\ \text { F-SHAPE } \end{gathered}$ | 7069-3 | 7/28/87 | $\begin{aligned} & 1,800 \mathrm{lb}\|60.1 \mathrm{mi} / \mathrm{h}\| 21.4 \mathrm{deg} \\ & (817 \mathrm{~kg}\|96.7 \mathrm{~km} / \mathrm{h}\| 21.4 \mathrm{deg}) \end{aligned}$ | $\begin{aligned} & 1,800 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ & (817\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \\ & \hline \end{aligned}$ | Acceptable |
|  | 7069-4 | 7/30/87 | $\begin{gathered} 5,440 \mathrm{lb}\|65.4 \mathrm{mi} / \mathrm{h}\| 20.4 \mathrm{deg} \\ (2470 \mathrm{~kg}\|105.2 \mathrm{~km} / \mathrm{h}\| 20.4 \mathrm{deg}) \end{gathered}$ | $5,400 \mathrm{lb}\|65 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg}$ ( $2,452 \mathrm{~kg}\|104.6 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}$ ) | Acceptable |
|  | 7069-8 | 1/28/88 | $\begin{gathered} 18,050 \mathrm{lb}\|46.7 \mathrm{mi} / \mathrm{h}\| 15.0 \mathrm{deg} \\ (8195 \mathrm{~kg}\|75.1 \mathrm{~km} / \mathrm{h}\| 15.0 \mathrm{deg}) \end{gathered}$ | $18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg}$ <br> ( $8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}$ ) | Speed low |
|  | 7069-9 | 2/23/88 | $18,050 \mathrm{lb}\|47.3 \mathrm{mi} / \mathrm{h}\| 15.3 \mathrm{deg}$ <br> ( $8195 \mathrm{~kg}\|76.1 \mathrm{~km} / \mathrm{h}\| 15.3 \mathrm{deg}$ ) | $18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg}$ <br> ( $8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}$ ) | Speed low |
|  | 7069-11 | 3/30/88 | $\begin{gathered} 18,000 \mathrm{lb}\|52.1 \mathrm{mi} / \mathrm{h}\| 14.8 \mathrm{deg} \\ (8172 \mathrm{~kg}\|83.8 \mathrm{~km} / \mathrm{h}\| 14.8 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Acceptable |

Table 9. Summary of full-scale crash tests performed on performance level two railings (continued).

| RAILING DESIGN | $\begin{aligned} & \hline \hline \text { TEST } \\ & \text { NO. } \end{aligned}$ | $\begin{aligned} & \text { TEST } \\ & \text { DATE } \end{aligned}$ | ACTUAL CONDITIONS | DESIGN CONDITIONS | COMMENTS |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{gathered} \text { BR27C } \\ \text { ON SIDEWALK } \end{gathered}$ | 7069-24 | 3/31/92 | $1,800 \mathrm{lb}\|61.7 \mathrm{mi} / \mathrm{h}\| 18.7 \mathrm{deg}$ $(817 \mathrm{~kg}\|99.3 \mathrm{~km} / \mathrm{h}\| 18.7 \mathrm{deg})$ | $\begin{gathered} 1,800 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (817 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Acceptable |
|  | 7069-25 | 4/2/92 | $5,400 \mathrm{lb}\|62.6 \mathrm{mi} / \mathrm{h}\| 19.4 \mathrm{deg}$ $(2452 \mathrm{~kg}\|100.7 \mathrm{~km} / \mathrm{h}\| 19.4 \mathrm{deg})$ | $5,400 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg}$ ( $2452 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}$ ) | Acceptable |
|  | 7069-26 | 4/8/92 | $\begin{gathered} 18,000 \mathrm{lb}\|51.0 \mathrm{mi} / \mathrm{h}\| 13.7 \mathrm{deg} \\ (8172 \mathrm{~kg}\|82.0 \mathrm{~km} / \mathrm{h}\| 13.7 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg} \\ (8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}) \end{gathered}$ | Acceptable |
| $\begin{gathered} \text { BR27C } \\ \text { ON DECK } \end{gathered}$ | 7069-32 | 7/14/92 | $1,800 \mathrm{lb}\|60.3 \mathrm{mi} / \mathrm{h}\| 19.8 \mathrm{deg}$ $(817 \mathrm{~kg}\|97.0 \mathrm{~km} / \mathrm{h}\| 19.8 \mathrm{deg})$ | $\begin{gathered} 1,800 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (817 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Acceptable |
|  | 7069-33 | 7/16/92 | $\begin{gathered} 5,400 \mathrm{lb}\|55.3 \mathrm{mi} / \mathrm{h}\| 19.6 \mathrm{deg} \\ (2452 \mathrm{~kg}\|89.0 \mathrm{~km} / \mathrm{h}\| 19.6 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 5,400 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (2452 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Acceptable |
|  | 7069-34 | 8/12/92 | $\begin{gathered} 18,000 \mathrm{lb}\|52.5 \mathrm{mi} / \mathrm{h}\| 12.8 \mathrm{deg} \\ (8172 \mathrm{~kg}\|84.5 \mathrm{~km} / \mathrm{h}\| 12.8 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg} \\ (8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}) \end{gathered}$ | Acceptable |
| ILLINOIS SIDE MOUNT | 7069-35 | 3/23/93 | $\begin{gathered} 1,800 \mathrm{lb}\|59.9 \mathrm{mi} / \mathrm{h}\| 20.1 \mathrm{deg} \\ (817 \mathrm{~kg}\|96.4 \mathrm{~km} / \mathrm{h}\| 20.1 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 1,800 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (817 \mathrm{~kg})\|6.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Acceptable |
|  | 7069-36 | 3/25/93 | $\begin{gathered} 5,400 \mathrm{lb}\|60.4 \mathrm{mi} / \mathrm{h}\| 20.4 \mathrm{deg} \\ (2452 \mathrm{~kg}\|97.2 \mathrm{~km} / \mathrm{h}\| 20.4 \mathrm{deg}) \end{gathered}$ | $5,400 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg}$ $(2452 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg})$ | Acceptable |
|  | 7069-37 | 4/30/93 | $\begin{gathered} 18,000 \mathrm{lb}\|51.4 \mathrm{mi} / \mathrm{h}\| 14.7 \mathrm{deg} \\ (8172 \mathrm{~kg}\|82.7 \mathrm{~km} / \mathrm{h}\| 14.7 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 18,000 \mathrm{lb} \mid 50 \mathrm{mi} / \mathrm{h} / 15 \mathrm{deg} \\ (8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}) \end{gathered}$ | Acceptable |

## Illinois 2399-1 Railing

## Test Number 7069-1

| Vehicle: | 1980 Honda |
| :--- | :--- |
| Test Inertia Weight: | $1,795 \mathrm{lb}(815 \mathrm{~kg})$ |
| Gross Static Weight: | $1,961 \mathrm{lb}(890 \mathrm{~kg})$ |
| Impact Speed: | $58.7 \mathrm{mi} / \mathrm{h}(94.4 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.0 deg |

The vehicle impacted the barrier midway between posts 6 and 7. At approximately 0.020 s after impact the right front tire contacted the curb, and by 0.030 s the vehicle began to redirect. As the tire and rim rode against the curb, the tire aired-out. The frame around the windshield began to deform and at about 0.070 s the windshield broke. At 0.151 s the vehicle was traveling parallel with the railing and at 0.168 s the rear of the vehicle impacted the railing. The vehicle lost contact with the railing at 0.226 s after impact. It was in contact with the lower rail element for $9.7 \mathrm{ft}(2.9 \mathrm{~m})$. As the vehicle exited the railing, the brakes were applied and the vehicle yawed slightly in clockwise rotation. The vehicle subsequently came to rest $225 \mathrm{ft}(69 \mathrm{~m})$ downstream and $21 \mathrm{ft}(6 \mathrm{~m})$ toward the field side of the point of impact.

The railing received very little damage (figure 34). There were tire marks on the face of the railings and the curb and minor chips on the edge of the curb. There was no measurable movement or deformation in the railing.

The vehicle sustained extensive damage to the right front (figure 34). Maximum crush at the right front corner at bumper height was 8.0 in ( 203 mm ). The right front tire was deflated, the rim was bent, and the suspension was damaged. The front bumper was disconnected on the left side but still attached on the right side. The passenger door was bent and jammed and the right rear quarter panel was bent and scraped. The hood was bent and shifted to the left. The windshield frame was bent and the windshield was broken and partially out. The roof of the vehicle was twisted.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was minimal intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Due to the slightly high lateral occupant impact velocity of $25.1 \mathrm{ft} / \mathrm{s}(7.7 \mathrm{~m} / \mathrm{s})$, performance of the railing in this test is considered marginally acceptable (as indicated in figure 35 and table 10).


Figure 34. Vehicle and railing for test 7069-1.

Impact Speed. . . $58.7 \mathrm{mi} / \mathrm{h}(94.4 \mathrm{~km} / \mathrm{h})$
Impact Speed. . . $58.7 \mathrm{mi} / \mathrm{h}(94.4 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . 20.0 deg
Impact Angle. . . 20.0 deg
Exit Speed. . . . $48.5 \mathrm{mi} / \mathrm{h}(78.0 \mathrm{~km} / \mathrm{h})$
Exit Speed. . . . $48.5 \mathrm{mi} / \mathrm{h}(78.0 \mathrm{~km} / \mathrm{h})$
Exit Angle. . . . 5.2 deg
Exit Angle. . . . 5.2 deg
Vehicle Accelerations
Vehicle Accelerations
(Max. 0.050-sec Avg)
(Max. 0.050-sec Avg)
Longitudinal. . -6.4 g
Longitudinal. . -6.4 g
Lateral . . . . 14.2 g
Lateral . . . . 14.2 g
Occupant Impact Velocity
Occupant Impact Velocity
Longitudinal. . $16.9 \mathrm{ft} / \mathrm{s}(5.2 \mathrm{~m} / \mathrm{s})$
Longitudinal. . $16.9 \mathrm{ft} / \mathrm{s}(5.2 \mathrm{~m} / \mathrm{s})$
Lateral .. . . $25.1 \mathrm{ft} / \mathrm{s}(7.7 \mathrm{~m} / \mathrm{s})$
Lateral .. . . $25.1 \mathrm{ft} / \mathrm{s}(7.7 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Occupant Ridedown Accelerations
Longitudinal. . -1.4 g
Longitudinal. . -1.4 g
Lateral . . . . 8.5 g
Lateral . . . . 8.5 g
$1 \mathrm{in}=25.4 \mathrm{~mm}$
Figure 35. Summary of results for test 7069-1.

Table 10. Evaluation of crash test no. 7069-1.
\{Illinois 2399-1 Railing [ $1,795 \mathrm{lb}(815 \mathrm{~kg})|58.7 \mathrm{mi} / \mathrm{h}(94.4 \mathrm{~km} / \mathrm{h})| 20.0$ degrees] $\}$
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
TEST RESULTS

| Vehicle was contained | Pass |
| :--- | :---: |
| No debris penetrated passenger <br> compartment | Pass |
| Acceptable deformation | Pass |

C. Passenger compartment must have

Acceptable deformation
D. Vehicle must remain upright

Vehicle did remain upright
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
F. Effective coefficient of friction

| $\mu$ | Assessment |
| :---: | :---: |
| 0-.25 | Good |
| . 26 - . 35 | Fair |
| > . 35 | Marginal |

$\frac{\mu}{.28} \quad \frac{\text { Assessment }}{\text { Fair }}$
Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :--- | :--- |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |


| Occupant Ridedown Accelerations $-g^{\prime} \mathrm{s}$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| 15 | 15 |

H. Exit angle shall be less than 12 degrees

| Occupani Impact Velocity - $\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  | Pass |
| :---: | :---: | :---: |
| Longitudinal | Lateral |  |
| 16.9 (5.2) | 25.1 (7.7) |  |
| Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$ |  | Pass |
| Longitudinal | Lateral |  |
| -1.4 | 8.5 |  |

Exit angle was 5.2 degrees Pass

* $A, B, C, D$ and $G$ are required. $E, F$, and $H$ are desired. (See table 1)


## Test Number 7069-2

| Vehicle: | 1981 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,450 \mathrm{lb}(2474 \mathrm{~kg})$ |
| Gross Static Weight: | $5,797 \mathrm{lb}(2632 \mathrm{~kg})$ |
| Impact Speed: | $63.6 \mathrm{mi} / \mathrm{h}(102.3 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 19.2 deg |

The vehicle impacted the barrier midway between posts 6 and 7. At approximately 0.017 s after impact the right front tire contacted the curb, and by 0.032 s the vehicle began to redirect. As the vehicle continued forward, the wheel rim rubbed the edge of the curb chipping off pieces of concrete. The dummies began to move abruptly to the right at 0.057 s , and at 0.063 s the passenger dummy impacted the right door so hard it knocked the top portion ajar. By 0.069 s the left front tire of the vehicle went airborne. The rear of the vehicle hit the railing at 0.154 s , and at 0.169 s the path of the vehicle $\mathrm{c} . \mathrm{g}$. was parallel with the railing. The vehicle was in contact with the railing for $14.5 \mathrm{ft}(4.4 \mathrm{~m})$ It lost contact with the railing at 0.234 s after impact. As the vehicle exited the railing, it had a yaw angle of 1.0 degree and a trajectory path of 5.8 degrees. The vehicle brakes were applied and the vehicle subsequently came to rest $270 \mathrm{ft}(82 \mathrm{~m})$ downstream from the point of impact.

The railing received moderate damage (figure 36). There were tire marks on the face of the railings and the curb and minor chips on the edge of the curb. The maximum dynamic deflection of the railing was $2.4 \mathrm{in}(61 \mathrm{~mm}$ ) and maximum permanent deformation was $0.5 \mathrm{in}(13 \mathrm{~mm})$. The front of the base plate on post 6 was pulled up slightly and the concrete was chipped around the bolts to the rear of the base plate.

The vehicle sustained extensive damage to the right front corner (figure 36). Maximum crush at the right front corner at bumper height was 5.0 in ( 127 mm ). The right front and right rear wheel rims were bent and the wheel assembly and suspension damaged. The passenger door was bent and jammed and the right rear panel was dented and scraped. The hood was bent and shifted to the left. The windshield frame was bent and the windshield was cracked. The cab of the vehicle was twisted and the frame was bent.

The railing contained and smoothly redirected the vehicle with minimal lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 37 and table 11.


Figure 36. Vehicle and railing for test 7069-2.


Figure 37. Summary of results for test 7069-2.

Table 11. Evaluation of crash test no. 7069-2.
\{Illinois 2399-1 Railing [5,450 $1 \mathrm{~b}(2474 \mathrm{~kg})|63.6 \mathrm{mi} / \mathrm{h}(102.3 \mathrm{~km} / \mathrm{h})| 19.2$ degrees]\}
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
TEST RESULTS Pass

| Vehicle was contained | Pass |
| :--- | :---: |
| No debris penetrated passenger <br> compartment | Pass |
| Minimal deformation | Pass |

C. Passenger compartment must have

Minimal deformation Pass essentially no deformation

Vehicle did remain upright Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected Pass
F. Effective coefficient of friction

| $\mu$ | Assessment |
| :---: | :---: |
| 0-. 25 | Good |
| . 26 - . 35 | Fair |
| > . 35 | Marginal |

Assessment
Good

Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $8.5(2.6)$ | $24.6(7.5)$ |


| Occupant Ridedown Accelerations $-\mathrm{g}^{\prime} \mathrm{s}$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| 15 | 15 |

$\frac{\text { Occupant Ridedown Accelerations - } g^{\prime} s}{\text { Longitudinal }}$

15
15
H. Exit angle shall be less than 12 degrees

* $A, B, C$, and $D$ are required. $E, F, G$, and $H$ are desired. (See table 1)

| Vehicle: | 1980 Ford Single-Unit Truck |
| :--- | :--- |
| Test Inertia Weight: | $18,000 \mathrm{lb}(8172 \mathrm{~kg})$ |
| Empty Weight: | $12,320 \mathrm{lb}(5593 \mathrm{~kg})$ |
| Impact Speed: | $50.8 \mathrm{mi} / \mathrm{h}(81.7 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 15.1 deg |

The vehicle impacted the railing approximately $26 \mathrm{ft}(8 \mathrm{~m})$ from the end between posts 4 and 5 . Shortly after impact, the right front tire made contact with the lower railing element and began to ride up the curb. As the vehicle continued its forward motion into the railing, the right front tire pushed the lower railing element down. By 0.071 s after impact the cab began to shift to the left, and at approximately 0.109 s the vehicle began to redirect. At 0.149 s the right front tire made contact with post 6 , and by 0.276 s the vehicle was airborne. The rear of the vehicle contacted the railing at approximately 0.310 s and began to move parallel to the bridge railing at 0.320 s traveling at $47.5 \mathrm{mi} / \mathrm{h}(76.4 \mathrm{~km} / \mathrm{h})$. The vehicle continued along the top of the railing, and at 0.447 s the lower edge of the box made contact with the top edge of post 8 and began to tear the box as the vehicle continued down the railing still airborne. The vehicle made contact with the ground at about 1.129 s and lost contact with the railing at 1.392 s . Total length of contact with the bridge railing was 74 ft ( 22.5 m ). After the vehicle left the railing, the brakes were applied but the left side of the vehicle made contact with another barrier. The vehicle came to rest $132 \mathrm{ft}(40 \mathrm{~m})$ from the point of impact.

Damage to the railing was moderate (figure 38). The bolts connecting the lower railing element to the post were sheared on posts 3 through 7 . At post 5 the bolt on the upper railing element was sheared and the face of the element itself was gouged. The flange on post 6 was bent and the concrete curb was cracked at posts 6 through 9 . The top of post 8 was bent where it made contact with the box. During the test the lower railing element was pushed down. After the test, the maximum vertical movement was $3 \mathrm{in}(76 \mathrm{~mm})$ at post 5.

Damage to the vehicle was extensive. The steering arm rod, $u$-bolts, spring pins, and front and rear spring mounts were damaged. The frame was bent as well as the rear part of the drive shaft, the rear $u$-joint, the battery box, and the gas tank. The cargo box was torn during the test and, as the vehicle left the railing and rolled to the right, the load shifted and tore open the right side of the box.

The railing contained and smoothly redirected the vehicle with minimal lateral movement of the railing. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes, and the vehicle remained relatively stable during the collision.

Performance of the railing in this test is judged acceptable, as indicated in figure 39 and table 12.


Figure 38. Vehicle and railing for test 7069-15.

$1 \mathrm{in}=25.4 \mathrm{~mm}$
Figure 39. Summary of results for test 7069-15.

Table 12. Evaluation of crash test no. 7069-15.
\{Illinois 2399 Bridge Railing [18,000 1b ( 8172 kg )|50.8 mi/h ( $81.7 \mathrm{~km} / \mathrm{h}$ )|15.1 degrees])
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
$\qquad$
Vehicle was contained Pass
No debris penetrated passenger Pass compartment

Acceptable deformation Pass

Vehicle remained upright Pass
Vehicle was smoothly redirected Pass
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ | $\frac{\text { Assessment }}{\text { Good }}$ |
| :--- | :--- | :--- |
| $.26-.35$ | Fair |
| $>.35$ | Marginal |


$\frac{\text { Assessment }}{\text { Good }}$
Pass
G. Shall be less than

| Occupant Impact |  |
| :---: | :---: |
| Volocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| $30(9.2)$ | Lateral |
| $25(7.6)$ |  |


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $9.8(3.0)$ | $12.4(3.8)$ |$\quad \mathrm{N} / \mathrm{A}$

Occupant Ridedown Accelerations - $g^{\prime} s$ Longitudinal 15 15
H. Exit angle shall be less than 12 degrees

[^4]
## 32-in (813-mm) Parapet

## Test Number 7069-5

| Vehicle: | 1981 Honda |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,965 \mathrm{lb}(892 \mathrm{~kg})$ |
| Impact Speed: | $60.5 \mathrm{mi} / \mathrm{h}(97.3 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 21.0 deg |

The vehicle impacted the parapet at midlength. At approximately 0.023 s after impact, the right front tire impacted the parapet and began to redirect after 0.062 s . The rear of the vehicle hit the parapet at 0.157 s and was parallel to the parapet at 0.162 s . The vehicle lost contact with the parapet at 0.236 s after impact. As the vehicle exited the parapet, it had a yaw angle of 3.5 degrees and trajectory path of 6.2 degrees. The vehicle brakes were then applied, and the vehicle came to rest $167 \mathrm{ft}(51 \mathrm{~m})$ downstream and 26 ft ( 8 m ) toward the field side of the point of impact.

The parapet received cosmetic damage only (figure 40). There were tire marks on the face of the parapet. The vehicle was in contact with the parapet for $10.3 \mathrm{ft}(3.1 \mathrm{~m})$.

The vehicle sustained extensive damage to the right front as shown in figure 40. Maximum crush at the right front corner at bumper height was 5.0 in ( 127 mm ). The right front and right rear wheel rims were bent, and the right front strut was bent. The passenger door was bent and jammed, and the right side was dented and scraped. The hood was bent and shifted to the left. The windshield frame was bent, and the windshield was cracked. The roof of the vehicle was buckled and twisted.

The parapet contained and smoothly redirected the vehicle with no lateral movement of the parapet. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the compartment occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

The lateral occupant impact velocity of $26.0 \mathrm{ft} / \mathrm{s}(7.9 \mathrm{~m} / \mathrm{s})$ is higher than the maximum acceptable value of $25 \mathrm{ft} / \mathrm{s}(7.6 \mathrm{~m} / \mathrm{s})$. However, the authors conclude that the performance of this parapet in this test is acceptable on the basis of two arguments. The value obtained is marginally close to being acceptable. The acceptable value was selected as a reasonably achievable value for impact angles of 15 degrees, not the more severe condition of 20 degrees used in this test. See figure 41 and table 13.


Figure 40 . Vehicle and parapet for test 7069-5.

$\underset{\omega}{\infty}$

$1 \mathrm{in}=25.4 \mathrm{~mm}$

| Test No. Date | $\begin{aligned} & 7069-5 \\ & 9 / 24 / 87 \end{aligned}$ |
| :---: | :---: |
| Test Installation | $32-\mathrm{in}$ ( 813 mm ) |
|  | Concrete Parapet |
| Installation Length | 100 ft ( 30 m ) |
| Vehicle | 1981 Honda Civic |
| Vehicle Weight |  |
| Test Inertia | 1,800 $\mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static . | 1,965 lb (892 kg) |
| Vehicle Damage Clas | tion |
| TAD | 01RFQ4 |
| CDC | 01FREK2 \& O1RYEW3 |
| Maximum Vehicle Crus | $5.0 \mathrm{in} \mathrm{( } 127 \mathrm{~mm}$ ) |



Figure 41. Summary of results for test 7069-5.

Table 13. Evaluation of crash test no. 7069-5.
$\{32-\mathrm{in}(813-\mathrm{mm})$ Concrete Parapet Bridge Railing $[1,800 \mathrm{lb}(817 \mathrm{~kg})|60.5 \mathrm{mi} / \mathrm{h}(97.3 \mathrm{~km} / \mathrm{h})| 21.0$ degrees $]\}$
$\qquad$
TEST RESULTS PASS/FAIL*
A. Must contain vehicle
Vehicle was contained Pass
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation

Vehicle was contained Pass
No debris penetrated passenger Pass compartment

Acceptable deformation Pass
D. Vehicle must remain upright

Vehicle remained upright
Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected Pass
F. Effective coefficient of friction

| $\mu$ | Assessment |
| :---: | :---: |
| 0-. 25 | Good |
| . 26 - . 35 | Fair |
| > . 35 | Marginal |

G. Shall be less than


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $20.1(6.1)$ | $26.0(7.9)$ | Fail


| Occupant Ridedown Accelerations $-g^{\prime} \mathrm{s}$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| -1.6 | 9.4 |$\quad$ Pass

H. Exit angle shall be less than 12

Exit angle was 6.2 degrees
Pass

* $A, B, C, D$ and $G$ are required. $E, F$, and $H$ are desired. (See table l)


## Test Number 7069-6

| Vehicle: | 1982 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,420 \mathrm{lb}(2461 \mathrm{~kg})$ |
| Gross Static Weight: | $5,759 \mathrm{lb}(2615 \mathrm{~kg})$ |
| Impact Speed: | $59.7 \mathrm{mi} / \mathrm{h}(96.1 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.2 deg |

The vehicle impacted the parapet at midlength. At approximately 0.021 s after impact, the right front wheel contacted the parapet. The vehicle began to redirect at 0.074 s as the rear end began to slide toward the parapet. The dummies began to move abruptly to the right at 0.080 s , and 0.130 s , the passenger dummy's head shattered the right side window glass. The rear of the vehicle slapped the parapet at 0.192 s , and by 0.209 s , the vehicle was traveling parallel to the parapet. The vehicle lost contact with the parapet at 0.418 s . It was in contact with the parapet for $10.5 \mathrm{ft}(3.2 \mathrm{~m})$. The vehicle exited the parapet with a yaw angle of 5.6 degrees and a vehicle trajectory path of 6.4 degrees. The brakes were applied, and the vehicle came to rest $225 \mathrm{ft}(69 \mathrm{~m})$ downstream and 40 ft ( 12 m ) toward the field side of the point of impact.

The parapet received only cosmetic damage as shown in figure 42 . There were tire marks on the face of the parapet.

The vehicle sustained extensive damage to the right side (figure 42). Maximum crush at the right front corner at bumper height was 9.0 in ( 229 mm ). The right front and right rear wheel rims were bent, and the welds had broken on the right front wheel rim, allowing the outer rim and tire to become completely separated. The wheel assembly and suspension were damaged. The passenger door was bent and jammed, and the window was broken. The right rear panel was dented and scraped. The hood was bent and shifted to the left. The cab of the vehicle was twisted, and the frame was bent.

The parapet contained and smoothly redirected the vehicle with minimal lateral movement of the parapet. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the parapet in this test is judged acceptable, as indicated figure 43 and table 14.


Figure 42. Vehicle and parapet for test 7069-6.

${ }^{\infty}$


[^5]


Figure 43. Summary of results for test 7069-6.

Table 14. Evaluation of crash test no. 7069-6.
$\{32-\mathrm{in}(813-\mathrm{mm})$ Concrete Parapet Bridge Railing [5,420 $\mathrm{lb}(2461 \mathrm{~kg})|59.7 \mathrm{mi} / \mathrm{h}(96.1 \mathrm{~km} / \mathrm{h})| 20.2$ degrees] $\}$
$\qquad$
TEST RESULTS
A. Must contain vehicle

Vehicle was contained Pass
B. Debris shall not penetrate

No debris penetrated passenger passenger compartment
C. Passenger compartment must have compartment

Acceptable deformation Pass essentially no deformation

Vehicle remained upright
Pass
D. Vehicle must remain upright

Vehicle was smoothly redirected Pass
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal |  |
| $30(9.2)$ | Lateral |
| $25(7.6)$ |  |


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $18.6(5.7)$ | $21.1(6.4)$ |$\quad$ Pass

Occupant Ridedown Accelerations - $g^{\prime} s$ Longitudinal Lateral 15
15
Occupant Ridedown Accelerations - $g^{\prime} s \quad$ Pass
Longitudinal Lateral
H. Exit angle shall be less than 12 degrees

Exit angle was 6.4 degrees

* $A, B, C$, and $D$ are required. $E, F, G$, and $H$ are desired. (See table 1)

| Vehicle: | 1982 Ford Single-Unit Truck |
| :--- | :--- |
| Test Inertia Weight: | $18,000 \mathrm{lb}(8172 \mathrm{~kg})$ |
| Empty Weight: | $13,820 \mathrm{lb}(6274 \mathrm{~kg})$ |
| Impact Speed: | $50.0 \mathrm{mi} / \mathrm{h}(80.5 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 14.0 deg |

The vehicle impacted the parapet approximately $20 \mathrm{ft}(6 \mathrm{~m})$ from the end. Shortly after impact, the right front wheel made contact with the parapet and was pushed back and to the left. The vehicle began to redirect at approximately 0.101 s after impact. At 0.263 s , the left side of the vehicle became airborne. The rear of the vehicle impacted the parapet at about 0.305 s and began to travel parallel to the parapet. As the vehicle rode along the parapet, it continued to roll to the right and attained a maximum roll angle of 17.6 degrees at 0.480 s . At about 0.750 s , the vehicle began to right itself. It lost contact with the parapet at 0.963 s , traveling at $34.2 \mathrm{mi} / \mathrm{h}(55.0 \mathrm{~km} / \mathrm{h})$ and 5.0 degrees. It was in contact with the parapet for about $45 \mathrm{ft}(14 \mathrm{~m})$. By 1.101 s , the vehicle was traveling upright; however, it continued to roll to the left and began to yaw clockwise. The vehicle came to rest on its left side $175 \mathrm{ft}(53 \mathrm{~m})$ downstream and $25 \mathrm{ft}(7.6 \mathrm{~m})$ toward the field side of the point of impact.

The parapet received only cosmetic damage (figure 44). There were tire marks on the face of the parapet and along the top for about $30 \mathrm{ft}(9 \mathrm{~m})$. The bed of the vehicle scraped the top of the parapet for another $15 \mathrm{ft}(4.6 \mathrm{~m})$.

The vehicle sustained moderate damage to the right side (figure 44). Maximum crush at the right front corner at bumper height was 10.0 in ( 254 mm ). The front bumper, the hood, and the right front quarter were damaged, and the windshield was cracked. The rear U-bolt on the right front springs was broken, and the springs were dislocated. The fuel tank and straps were also damaged.

The parapet contained and smoothly redirected the vehicle with no lateral movement of the parapet. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the parapet in this test is judged acceptable, as indicated in figure 45 and table 15.


Figure 44. Vehicle and parapet for test 7069-16.



| Test N Date | $\begin{aligned} & 7069-16 \\ & 10 / 13 / 88 \end{aligned}$ |
| :---: | :---: |
| Test Installation | . 32 -in ( $813-\mathrm{mm}$ ) Concrete Parapet |
| Installation Length | 100 ft ( 30.5 cm ) |
| Vehicle | . 1982 Ford 7000 Single-Unit Truck |
| Vehicle Weight |  |
| Empty Weight | 13,820 lb (6 274 kg ) |
| Test Inertia | . 18,000 lb (8 172 kg ) |
| Maximum Vehicle Crush | . 10.0 in ( 254 mm ) |



Figure 45. Summary of results for test 7069-16.

Table 15. Evaluation of crash test no. 7069-16.
(32-in ( $813-\mathrm{mm}$ ) Concrete Parapet [18,000 $1 \mathrm{~b}(8172 \mathrm{~kg})|50 \mathrm{mi} / \mathrm{h}(80.5 \mathrm{~km} / \mathrm{h})| 14.0$ degrees $]\}$
$\qquad$
CRITERIA

| TEST RESULTS | PASS/FAIL* |
| :--- | :---: |
| Vehicle was contained | Pass |
| No debris penetrated passenger <br> compartment | Pass |
| Acceptable deformation | Pass |

C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction
$\frac{\mu}{0.41} \quad \frac{\text { Assessment }}{\text { Marginal }}$
Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |

Occupant Ridedown Accelerations $-\mathrm{g}^{\prime} \mathrm{s}$
Longitudinal
15
H. Exit angle shall be less than 12 degrees

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $10.9(3.3)$ | $\mathrm{ll} .8(3.6)$ |$\quad \mathrm{A}$


| Occupant Ridedown Accelerations - $g^{\prime} \mathrm{s}$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| -2.3 | 8.4 |$\quad$ N/A

Exit angle was 5 degrees Pass
*A, B, and C are required. D, E, F, and $H$ are desired. $G$ is not applicable for this test. (See table 1)

## 32-in (813-mm) New Jersey Safety Shape

Test Number 7069-12

| Vehicle: | 1982 GMC Single-Unit Truck |
| :--- | :--- |
| Test Inertia Weight: | $18,000 \mathrm{lb}(8172 \mathrm{~kg})$ |
| Empty Weight: | $10,900 \mathrm{lb}(4949 \mathrm{~kg})$ |
| Impact Speed: | $51.6 \mathrm{mi} / \mathrm{h}(83.0 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 15.5 deg |

 Shortly after impact, the right front wheel began to ride up the face of the safety shape. At 0.093 s , the axle broke on the right side, and the left front tire became airborne. The vehicle began to slowly redirect as the rear end began to slide toward the safety shape. The lower edge of the front bumper reached the top of the safety shape at 0.101 s . At 0.312 s , the left rear wheels became airborne, and the front of the vehicle reached a maximum height of approximately $1 \mathrm{ft}(.03 \mathrm{~m})$ above the safety shape. As the vehicle rode along the top of the safety shape, it continued to roll to the right and reached maximum redirection at 0.324 s at an angle of 8.6 degrees into the safety shape. At about 0.627 s , the front of the vehicle extended over the safety shape by one-half the vehicle's width. By 1.040 s , the vehicle attained a maximum roll angle of 44 degrees to the right and began to right itself. As the vehicle slid off the end of the safety shape, it continued to roll to the left (away from the railing). The vehicle subsequently came to rest on its left side $75 \mathrm{ft} \mathrm{( } 23 \mathrm{~m}$ ) from the end of the safety shape.

The safety shape received only cosmetic damage and some scraping and gouging (figure 46). There were tire marks on the face and top of the safety shape. The top of the safety shape was scraped along the remaining length by the undercarriage of the truck.

The vehicle sustained extensive damage to the right side. Maximum crush at the right front corner at bumper height was 8.0 in ( 203 mm ). The front axle was torn off the vehicle, and the undercarriage damaged. There was damage to the U-bolts, Pittman arm rod, steering arm, brake lines, and leaf spring bolts. The outer right rear wheel rim and tire were damaged. The fuel tank also sustained damage.

The safety shape contained and redirected the vehicle with no lateral movement of the safety shape. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes; however, the vehicle did not remain upright after. collision.

Performance of the safety shape in this test is judged acceptable, as indicated in figure 47 and table 16.


Figure 46. Vehicle and safety shape for test 7069-12.



Impact Speed. . . $51.6 \mathrm{mi} / \mathrm{h}(83.0 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . 15.5 deg
Exit Speed. . . . N/A
Exit Trajectory . 2.0 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . -3.2 g
Lateral .. . . 2.5 g
Occupant Impact Velocity
Longitudinal. . $13.4 \mathrm{ft} / \mathrm{s}(4.1 \mathrm{~m} / \mathrm{s})$
Lateral . . . $10.2 \mathrm{ft} / \mathrm{s}(3.1 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal. . -3.0 g
Lateral . . . . 4.9 g

Figure 47. Summary of results for test 7069-12.

Table 16. Evaluation of crash test no. 7069-12.
$\{32-\mathrm{in}(813-\mathrm{mm})$ New Jersey Safety Shape $[18,000 \mathrm{lb}(2172 \mathrm{~kg})|51.6 \mathrm{mi} / \mathrm{h}(83.0 \mathrm{~km} / \mathrm{h})| 15.5$ degrees $]\}$
$\qquad$
CRITERIA
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction
$\qquad$ PASS/FAIL
Vehicle was contained Pass
No debris penetrated passenger Pass compartment

Acceptable deformation
Pass

Vehicle did not remain upright
Fail
Vehicle was smoothly redirected
Pass
$\frac{\mu}{N / A}$
Assessment
$N / A$
G. Shall be less than
$\frac{\text { Occupant Impact Velocity }-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})}{\text { Longitudinal }} \frac{\text { Lateral }}{30(9.2)}$

| Occupant Ridedown | Accelerations $-\mathrm{g}^{\prime} \mathrm{s}$ |
| :---: | :---: |
| Lateral |  |
| 15 | 15 |

H. Exit angle shall be less than 12 degrees
$\frac{\text { Occupant Impact Velocity }-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})}{\text { Longitudinal }} \quad \mathrm{N} / \mathrm{A}$ Longitudinal Lateral

Occupant Ridedown Accelerations - $g^{\prime} s \quad N / A$ Longitudinal

Lateral
4.9
about 2 degrees
Pass

* $A, B, C$ are required. $D, E, F$, and $H$ are desired. $G$ is not applicable for this test. (see table 1)

Test Number 7069-14

| Vehicle: | 1981 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,390 \mathrm{lb}(2447 \mathrm{~kg})$ |
| Gross Static Weight: | $5,724 \mathrm{lb}(2599 \mathrm{~kg})$ |
| Impact Speed: | $57.7 \mathrm{mi} / \mathrm{h}(92.8 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.6 deg |

The vehicle impacted the safety shape approximately $11 \mathrm{ft}(3.4 \mathrm{~m})$ from the upstream end. Shortly after impact, the right front wheel began to ride up the face of the safety shape. At 0.060 s , the dummies began to move to the right. The vehicle began to redirect at 0.103 s , and the left front tire became airborne at 0.195 s . By 0.241 s , the vehicle was traveling parallel to the safety shape at a speed of $37.1 \mathrm{mi} / \mathrm{h}$. At 0.356 s , the vehicle became completely airborne, and the front of the vehicle reached a maximum height of approximately 23 in ( 58.9 m ) above the bridge deck. While still airborne, the vehicle lost contact with the safety shape at 0.365 s traveling at $35.8 \mathrm{mi} / \mathrm{h}$ and 0.9 degrees. It was in contact with the safety shape for $15 \mathrm{ft}(4.6 \mathrm{~m})$. The vehicle's left front wheel touched ground at 0.532 s after impact. The brakes were then applied, and the vehicle yawed clockwise and came to rest $280 \mathrm{ft}(85 \mathrm{~m})$ from the point of impact.

The safety shape received only cosmetic damage (figure 48). There were tire marks on the face and top of the safety shape.

The vehicle sustained extensive damage to the right side (figure 48). Maximum crush at the right front corner at bumper height was 12.0 in ( 307 mm ). The right front suspension system broke away from the vehicle, and the right rear tire and wheel rim broke at the welded connection points. There was damage to the right ball joints and tie rods, as well as the upper and lower control arms. The left rear tire was deflated.

The safety shape contained and smoothly redirected the vehicle with no lateral movement of the safety shape. There was no intrusion into the occupant compartment and minimal deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and relatively stable during the collision.

Performance of the safety shape in this test is judged acceptable, as indicated in figure 49 and table 17.


Figure 48. Vehicle and safety shape for test 7069-14.




Figure 49. Summary of results for test 7069-14.

Table 17. Evaluation of crash test no. 7069-14.
$\{32-\mathrm{in}(813-\mathrm{mm})$ New Jersey Safety Shape $[5,390 \mathrm{lb}(2447 \mathrm{~kg})|57.7 \mathrm{mi} / \mathrm{h}(92.8 \mathrm{~km} / \mathrm{h})| 20.6$ degrees $]\}$
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle

Vehicle was contained Pass
B. Debris shall not penetrate

No debris penetrated passenger passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright compartment

Acceptable deformation Pass

Vehicle did remain upright Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected Pass
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  |
| :--- | :--- |
| $\frac{\text { Assessment }}{}$ |  |
| $>.26-.35$ | Fair |
| $>.35$ |  |
|  | Marginal |

$\frac{\mu}{0.83} \quad \frac{\text { Assessment }}{\text { Marginal }}$

Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $\mathrm{N} / \mathrm{A}$ | $\mathrm{N} / \mathrm{A}$ |


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $17.8(5.4)$ | $18.7(5.7)$ |$\quad \mathrm{N} / \mathrm{A}$

$\frac{\text { Occupant Ridedown Accelerations }-g^{\prime} s}{\text { Longitudinal }}$
Occupant Ridedown Accelerations - $g^{\prime} s$
Longitudinal Lateral
$-5.1$
9.2
H. Exit angle shall be less than 12
about 0.9 degrees
Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

32-in (813-mm) F-Shape

## Test Number 7069-3

| Vehicle: | 1980 Honda |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,966 \mathrm{lb}(893 \mathrm{~kg})$ |
| Impact Speed: | $60.1 \mathrm{mi} / \mathrm{h}(96.7 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 21.4 deg |

The vehicle impacted the bridge railing at midlength. At approximately 0.025 s after impact the right front tire began to ride up the concrete face of the bridge railing, and by 0.034 s the vehicle began to redirect. As the vehicle continued forward, the right side of the vehicle continued to ride up the face of the bridge railing, and at 0.186 s the left front wheel left the ground. The rear of the vehicle hit the railing at 0.189 s , and at 0.271 s the vehicle was parallel with the railing. The vehicle was in contact with the railing for $10.3 \mathrm{ft}(3.1 \mathrm{~m})$. It lost contact with the railing at 0.276 s after impact. As the vehicle exited the railing, it had a yaw angle of 0.9 degree and a trajectory path of 6.2 degrees. The vehicle brakes were applied and the vehicle subsequently came to rest $209 \mathrm{ft}(64 \mathrm{~m})$ downstream and $27 \mathrm{ft}(8 \mathrm{~m})$ toward the field side of the point of impact.

The railing received cosmetic damage only (figure 50). There were tire marks on the face of the bridge railing indicating the vehicle rose a maximum height of about 27 in ( 610 mm ).

The vehicle sustained extensive damage to the right front corner (figure 50). Maximum crush at the right front corner at bumper height was 9.0 in ( 229 mm ). The right front and right rear wheel rims were bent and the wheel assembly and suspension damaged. The passenger door was bent and jammed and the right side was dented and scraped. The hood was bent and shifted to the left. The windshield frame was bent and the windshield was cracked. The roof of the vehicle was buckled and twisted.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the compartment occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the railing in this test is judge acceptable, as indicated in figure 51 and table 18.


Figure 50. Vehicle and F-shape for test 7069-3.


Table 18. Evaluation of crash test no. 7069-3.
\{32-in ( $813-\mathrm{mm}$ ) F-Shape Bridge Railing [1,800 $1 \mathrm{~b}(817 \mathrm{~kg})|60.1 \mathrm{mi} / \mathrm{h}(96.7 \mathrm{~km} / \mathrm{h})| 21.4$ degrees]\}
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment

| TEST RESULTS |  | PASS/FAIL |
| :--- | :---: | :---: |
| Vehicle was contained | Pass |  |
| No debris penetrated passenger <br> compartment | Pass |  |
| Acceptable deformation | Pass |  |

C. Passenger compartment must have

Acceptable deformation Pass essentially no deformation
D. Vehicle must remain upright

Vehicle remained upright Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
F. Effective coefficient of friction

| $\mu$ | Assessment |
| :---: | :---: |
| 0-. 25 | Good |
| . 26 - . 35 | Fair |
| > . 35 | Marginal |

$\frac{\mu}{.33} \quad \frac{\text { Assessment }}{\text { Fair }}$
Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |


H. Exit angle shall be less than 12 degrees

Exit angle was 6.2 degrees

* $A, B, C, D$ and $G$ are required. $E, F$, and $H$ are desired. (See table 1)

| Vehicle: | 1981 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,440 \mathrm{lb}(2470 \mathrm{~kg})$ |
| Gross Static Weight: | $5,780 \mathrm{lb}(2624 \mathrm{~kg})$ |
| Impact Speed: | $65.4 \mathrm{mi} / \mathrm{h}(105.2 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.4 deg |

The vehicle impacted the bridge railing at midlength. At approximately 0.013 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.019 s the right front tire aired out. The vehicle began to redirect as the rear end began to slide toward the bridge railing. The dummies began to move abruptly to the right at 0.046 s , and at 0.106 s the passenger dummy's head shattered the right side window glass. At 0.139 s the left front wheel left the ground and at 0.141 s the rear of the vehicle slapped the bridge railing and aired out the right rear tire. By 0.154 s the vehicle was totally airborne and remained so as it became parallel with the railing (at 0.179 s ) and exited the railing (at 0.238 s ). The left front wheel touched down at 0.287 s and the right touched down at 0.433 s . The vehicle exited the railing with a yaw angle of 0.4 degrees and a vehicle trajectory path of 7.4 degrees. It was in contact with the railing for $18.0 \mathrm{ft}(5.5 \mathrm{~m})$. The brakes were applied and the vehicle subsequently came to rest $240 \mathrm{ft}(73 \mathrm{~m})$ downstream and $37 \mathrm{ft}(11 \mathrm{~m})$ toward the field side of the point of impact.

The railing received only cosmetic damage (figure 52). There were tire marks on the face of the bridge railing which indicated the vehicle rose a maximum height of 24 in ( 610 mm ) above the ground.

The vehicle sustained extensive damage to the right side (figure 52). Maximum crush at the right front corner at bumper height was 5.0 in ( 127 mm ). The right front and right rear wheel rims were bent and the tires were deflated. The wheel assembly and suspension was damaged. The passenger door was bent and jammed and the window broken out. The right rear panel was dented and scraped. The hood was bent and shifted to the left. The cab of the vehicle was twisted.

The railing contained and smoothly redirected the vehicle with minimal lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 53 and table 19.


Figure 52. Vehicle and F-shape for test 7069-4.

0.099 s

0.201 s
0.308 s



Impact Speed. . . $65.4 \mathrm{mi} / \mathrm{h}(105.2 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . 20.4 deg
Exit Speed. . . . $56.9 \mathrm{mi} / \mathrm{h}(91.6 \mathrm{~km} / \mathrm{h})$
Exit Trajectory . 7.4 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . -4.7 g
Lateral . . . . 13.1 g
Occupant Impact Velocity
Longitudinal. . $12.5 \mathrm{ft} / \mathrm{s}(3.8 \mathrm{~m} / \mathrm{s})$
Lateral .. . . $24.1 \mathrm{ft} / \mathrm{s}(7.3 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal. . -1.2 g
Lateral . . . . 5.9 g

Figure 53. Summary of results for test 7069-4.

Table 19. Evaluation of crash test no. 7069-4.
$\{32-\mathrm{in}(813-\mathrm{mm})$ F-Shape Bridge Railing [5,440 1b (2 470 kg ) $|65.4 \mathrm{mi} / \mathrm{h}(105.2 \mathrm{~km} / \mathrm{h})| 20.4$ degrees $]\}$
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
TEST RESULTS

Pass
Vehicle was contained Pass

No debris penetrated passenger Pass compartment
C. Passenger compartment must have

Minimal deformation
Pass essentially no deformation
D. Vehicle must remain upright

Vehicle did remained upright Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
Pass
F. Effective coefficient of friction

| $\mu$ | Assessment |
| :---: | :---: |
| 0-. 25 | Good |
| . 26 - . 35 | Fair |
| > . 35 | Marginal |

$\frac{\mu}{.31} \quad \frac{\text { Assessment }}{\text { Good }}$
Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |


| Occupant Impact Velocity - $\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s}) \quad$ Pass |  |  |
| :---: | :---: | :---: |
| Longitudinal | Lateral |  |
| 12.5 (3.8) | 24.1 (7.3) |  |
| Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathbf{s}$ Pass |  |  |
| Longitudinal | Lateral |  |

H. Exit angle shall be less than 12 degrees

Exit angle was 7.3 degrees
Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table l)

| Vehicle: | 1982 Ford Single-Unit Truck |
| :--- | :--- |
| Test Inertia Weight: | $18,050 \mathrm{lb}(8195 \mathrm{~kg})$ |
| Empty Weight: | $13,050 \mathrm{lb}(6288 \mathrm{~kg})$ |
| Impact Speed: | $46.7 \mathrm{mi} / \mathrm{h}(75.1 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 15.0 deg |

[NOTE: In test 7069-8, the engine of the test vehicle (which was remotely controlled) stalled, causing the impact speed of the test vehicle to be lower than specified in the crash test requirements ( $46.7 \mathrm{mi} / \mathrm{h}$ vs $50 \mathrm{mi} / \mathrm{h}$ ). The test was repeated ( $7069-9$ ) and again the impact speed was too low ( $47.3 \mathrm{mi} / \mathrm{h}$ vs $50 \mathrm{mi} / \mathrm{h}$ ). In a third test (7069-11), an acceptable impact speed of $52.1 \mathrm{mi} / \mathrm{h}$ was attained.]

The vehicle impacted the bridge railing at midlength. At approximately 0.021 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.163 s the left front tire began to leave the ground. The vehicle began to redirect at 0.184 s as the rear end began to slide toward the bridge railing. At 0.343 s the left rear wheels left the ground, and at approximately 0.448 s the rear of the vehicle slapped the bridge railing. By approximately 0.495 s the vehicle became parallel with the railing and was continuing to roll to the right. As the vehicle continued along the railing, the lower edge of the bed rode along the top of the railing. A maximum roll angle of 34 degrees was achieved at about 1.286 s . The vehicle slid off the end of the bridge railing at about 1.713 s after impact. Total length of contact with the railing was $60 \mathrm{ft}(18 \mathrm{~m})$. The brakes were applied and the vehicle subsequently came to rest $186 \mathrm{ft}(57 \mathrm{~m})$ downstream.

The railing received only cosmetic damage (figure 54). There were tire marks on the face of the bridge railing and along the top. The top of the bridge railing was scraped along the remaining length from the lower edge of the bed of the truck.

The vehicle sustained extensive damage to the right side (figure 54). Maximum crush at the right front corner at bumper height was 6.0 in $(152 \mathrm{~mm})$. The right front wheel rim was bent and the tire damaged. The spring and spring shackle was broken loose from the axle. The steering gear box and steering cylinder was damaged. Also, the fuel tank broke loose from the truck.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and marginally stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 55 and table 20.


Figure 54. Vehicle and F-shape for test 7069-8.

| Test No. Date . | $1 / 28 / 88$ |
| :---: | :---: |
| Test Installation | 32-in (813-mm) |
|  | pe Bridge Railing |
| Installation Length | h . . 100 ft ( 30 m ) |
| Vehicle | 1982 Ford Single-Unit Truck |
| Vehicle Weight |  |
| Empty Weight | 13,050 1b (6 288 |
| Test Inertia | . . 18,050 1b (8 195 kg ) |
| aximum Vehicle Crush | ush . $6.0 \mathrm{in} \mathrm{(152} \mathrm{mm)}$ |


$1 \mathrm{in}=25.4 \mathrm{~mm}$
Figure 55. Summary of results for test 7069-8.

Table 20. Evaluation of crash test no. 7069-8.
$\{32-i n(813-\mathrm{mm})$ F-shape Bridge Rail [18,050 $1 \mathrm{~b}(8195 \mathrm{~kg})|46.7 \mathrm{mi} / \mathrm{h}(75.1 \mathrm{~km} / \mathrm{h})| 15.0$ degrees $]\}$
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
$\qquad$
Vehicle was contained Pass

No debris penetrated passenger Pass compartment

Acceptable deformation
Pass

Vehicle remained upright Pass
Vehicle was smoothly redirected Pass
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  | Assessment |
| :--- | :--- | :--- |
| $.26--.35$ | Fair |  |
| $>.35$ |  | Marginal |


not redirected into traffic.
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $11.8(3.6)$ | $9.2(2.8)$ |$\quad \mathrm{N} / \mathrm{A}$

Occupant Ridedown Accelerations - $g^{\prime} s$ Longitudinal 15
15
Occupant Ridedown Accelerations - q's
Longitudinal
-3.8
Lateral
6.1
$N / A$
about 5 degrees

* A, B, C, and D are required. E, F, and H are desired. G is not applicable for this test. (See table l)

| Vehicle: | 1982 Ford Single-Unit Truck |
| :--- | :--- |
| Test Inertia Weight: | $18,050 \mathrm{lb}(8195 \mathrm{~kg})$ |
| Empty Weight: | $13,050 \mathrm{lb}(6288 \mathrm{~kg})$ |
| Impact Speed: | $47.3 \mathrm{mi} / \mathrm{h}(76.1 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 15.3 deg |

The vehicle impacted the bridge railing at midlength. At approximately 0.017 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.153 s the left front tire began to leave the ground. The vehicle began to redirect at 0.156 s as the rear end began to slide toward the bridge railing. At 0.292 s the left rear wheels left the ground, and at 0.421 s the rear of the vehicle contacted the bridge railing. By approximately 0.523 s the vehicle became parallel with the railing and was continuing to roll to the right. As the vehicle continued along the railing, the lower edge of the bed rode along the top of the railing. A maximum roll angle of 25 degrees was achieved at about 0.886 s . The vehicle slid off the end of the bridge railing at about 1.326 s after impact. The brakes were applied and the vehicle subsequently came to rest $150 \mathrm{ft}(46 \mathrm{~m})$ downstream.

The railing received only cosmetic damage (figure 56). There were tire marks on the face of the railing and along the top. The top of the bridge railing was scraped along the remaining length from the lower edge of the bed of the truck.

The vehicle sustained extensive damage to the right side (figure 56). Maximum crush at the right front corner at bumper height was 16.0 in ( 406 mm ). The right front wheel rim was bent and the tire damaged. The spring and spring shackle was broken loose from the axle and the axle torn loose on the left side. The steering gear box and steering cylinder was damaged. Also, the fuel tank broke loose from the truck.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There was no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and marginally stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 57 and table 21.


Figure 56. Vehicle and F-shape for test 7069-9.

$1 \mathrm{in}=25.4 \mathrm{~mm}$
Figure 57. Summary of results for test 7069-9.

Table 21. Evaluation of crash test no. 7069-9.

```
in (813-mm) F-shape Bridge Railing [18,050 lb (8 195 kg)|47.3 mi/h (76.1 km/h)|15.3 degrees]}
```


## CRITERIA

A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ | $\frac{\text { Assessment }}{\text { Good }}$ |
| :---: | :---: |
| $.26-.35$ | Fair |
| $>.35$ |  |
|  | Marginal |

TEST RESULTS

TEST
PASS/FAIL
Vehicle was contained Pass
No debris penetrated passenger
Pass
compartment
Acceptable deformation Pass

Vehicle remained upright
Pass
Vehicle was smoothly redirected
Pass

## $\frac{\mu}{09} \quad$ Assessment $\quad$ Pass

G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |

## Occupant Ridedown Accelerations - $g^{\prime} s$ Longitudinal 15 <br> 15

H. Exit angle shall be less than 12 degrees

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $11.7(3.6)$ | $9.9(3.0)$ |$\quad \mathrm{N} / \mathrm{A}$

Occupant Ridedown Accelerations - $g^{\prime} s \quad N / A$

Longitudinal $\quad$ Lateral
-2.7
6.8
about 2 degrees

* $A, B, C, D$ are required. $E, F$, and $H$ are desired. $G$ is not applicable for this test. (See table 1)

| Vehicle: | 1982 Ford Single-Unit Truck |
| :--- | :--- |
| Test Inertia Weight: | $18,000 \mathrm{lb}(8172 \mathrm{~kg})$ |
| Empty Weight: | $13,530 \mathrm{lb}(6145 \mathrm{~kg})$ |
| Impact Speed: | $52.1 \mathrm{mi} / \mathrm{h}(83.8 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 14.8 deg |

The vehicle impacted the bridge railing at midlength. At approximately 0.022 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.132 s the left front tire began to leave the ground. The vehicle began to redirect at 0.144 s as the rear end began to slide toward the bridge railing. At 0.240 s the left rear wheels left the ground, and at 0.350 s the rear of the vehicle slapped the bridge railing. By approximately 0.524 s the vehicle became parallel with the railing and was continuing to roll to the right. As the vehicle continued along the railing, the lower edge of the bed rode along the top of the railing. A maximum roll angle of 31 degrees was achieved at about 0.683 s . The vehicle slid off the end of the bridge railing at approximately 1.346 s after impact. The brakes were applied and the vehicle subsequently came to rest 231 ft ( 70 m ) downstream.

The railing received only cosmetic damage (figure 58). There were tire marks on the face of the bridge railing and along the top. The top of the bridge railing was scraped along the remaining length from the lower edge of the bed of the truck. The vehicle was in contact with the bridge railing for $39 \mathrm{ft}(12 \mathrm{~m})$.

The vehicle sustained extensive damage to the right side as shown in figure 58. Maximum crush at the right front corner at bumper height was 20.0 ( 508 mm ). The front axle was torn loose which caused damage to the springs, shackles, U-bolts, and tie rods. The steering arm and cylinder were damaged and the oil pan was dented. Also, the fuel tank broke loose from the truck.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There was no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and marginally stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 59 and table 22.


Figure 58. Vehicle and F-shape for test 7069-11.


$1 \mathrm{in}=25.4 \mathrm{~mm}$


Impact Speed. . . . $52.1 \mathrm{mi} / \mathrm{h}(83.8 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . . 14.8 deg
Exit Speed . . . . Not Available
Exit Trajectory . . 0 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . . -1.4 g
Lateral . . . . . 3.9 g
Occupant Impact Velocity
Longitudinal. . . $5.7 \mathrm{ft} / \mathrm{s}(1.7 \mathrm{~m} / \mathrm{s})$
Lateral .. . . $8.2 \mathrm{ft} / \mathrm{s}(2.5 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal. . . 1.3 g
Lateral . . . . . 5.4 g

Figure 59. Summary of results for test 7069-11.

Table 22. Evaluation of crash test no. 7069-11.
\{32-in ( $813-\mathrm{mm}$ ) F-Shape Bridge Railing [18,000 1b (8 172 kg ) $|52.1 \mathrm{mi} / \mathrm{h}(83.8 \mathrm{~km} / \mathrm{h})| 14.8$ degrees]\}

## CRITERIA

TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction
Assessment
Good
Fair
Marginal
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |

Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$
Longitudinal
15
Lateral
15
H. Exit angle shall be less than 12 degrees

| TEST RESULTS |  |
| :--- | :---: |$\quad$ PASS/FAIL*

[^6]
## BR27C on Sidewalk

Test Number 7069-24

| Vehicle: | 1982 Honda Civic |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,965 \mathrm{lb}(892 \mathrm{~kg})$ |
| Impact Speed: | $61.7 \mathrm{mi} / \mathrm{h}(99.3 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 18.7 deg |

At approximately 0.025 s after impact, the left front corner of the vehicle began to deform and at 0.185 s the right front tire impacted the curb. The vehicle impacted the concrete parapet at 0.219 s traveling at a speed of $55.5 \mathrm{mi} / \mathrm{h}(89.3 \mathrm{~km} / \mathrm{h})$ and an angle of 18.1 degrees. At 0.267 s the vehicle began to redirect significantly, and at 0.302 s the right rear tire impacted the curb. The vehicle briefly lost contact with the parapet at 0.397 s , became totally airborne, and remained as such as it began to travel parallel with the bridge railing at a speed of $50.9 \mathrm{mi} / \mathrm{h}(81.9 \mathrm{~km} / \mathrm{h})$. The rear of the vehicle contacted the parapet at 0.440 s and then exited the bridge railing at 0.521 s traveling at a speed of $50.3(80.9 \mathrm{~km} / \mathrm{h})$ and an exit angle of 1.0 degrees. The vehicle was in contact with the bridge railing system for $12.25 \mathrm{ft}(3.7 \mathrm{~m})$. As the vehicle exited the bridge railing installation, the brakes were applied. The vehicle yawed clockwise and subsequently came to rest $187 \mathrm{ft}(57 \mathrm{~m})$ down and $50 \mathrm{ft}(15 \mathrm{~m})$ toward the traffic side of the point of impact.

The bridge railing system received minimal damage (figure 60). There was no measurable permanent deformation to the metal railing elements; however, the left corner of the bumper had snagged post 6 (leaving plastic trim). Also, posts 5 and 6 were pulled up such that the washers rotated freely under the nuts on the front side of the railing. There was only cosmetic damage to the concrete parapet, i.e., tire marks on the concrete parapet from post 5 on past post 6 and then again between posts 8 and 9 where the vehicle contacted the parapet the second time.

The vehicle sustained damage to the left side (figure 60). Maximum crush at the left front corner at bumper height was $7.5 \mathrm{in}(191 \mathrm{~mm})$. The left front strut was bent and the left front wheel was pushed back reducing the wheelbase on the driver side by 3 in ( 76 mm ). Also damage was done to the front bumper, hood, left front quarter panel, left rear quarter panel, rear bumper, left front and rear tires and rims, and right front tire.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing system smoothly redirected the vehicle. Although the lateral ridedown acceleration of 17.2 g 's was slightly above the recommended limit, performance was judged acceptable for this category because it was well within the limits of the other three occupant risk factors. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.


Figure 60. Vehicle and railing for test 7069-24.

Performance of the railing in this test is judged acceptable, as indicated in figure 61 and table 23.


$1 \mathrm{in}=25.4 \mathrm{~mm}$

| $\begin{aligned} & \text { Test No. . . . . . . } \\ & \text { Date . . . . . . . . } \end{aligned}$ | $\begin{gathered} . \\ . \\ .03 / 31 / 92-24 \end{gathered}$ |
| :---: | :---: |
| Test Installation | . . BR27C Bridge Railing on sidewalk |
| Installation Length | . 100 ft ( 30 m ) |
| Test Vehicle | 1982 Honda Civic |
| Vehicle Weight |  |
| Test Inertia | . 1,800 lb (817 kg) |
| Gross Static. | . . 1,965 lb (892 kg) |
| Vehicle Damage Classi | fication |
| TAD | . 11LFQ3 |
| CDC | . 11FLEK2 \& 11LFES2 |
| Maximum Vehicle Crush | . 7.5 in ( 191 mm ) |

Impact Speed. . . . $61.7 \mathrm{mi} / \mathrm{h}(99.3 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . . 18.7 deg
Speed at Parallel . $50.9 \mathrm{mi} / \mathrm{h}(81.9 \mathrm{~km} / \mathrm{h})$
Exit Speed . . . . $50.3 \mathrm{mi} / \mathrm{h}(80.9 \mathrm{~km} / \mathrm{h})$
Exit Trajectory . . 1.0 deg
Vehicle Accelerations
(Max. 0.050-sec Avg) at true c.g.
Longitudinal. . . -5.6 g
Lateral . . . . . -9.3 g
Occupant Impact Velocity at true c.g.
Longitudinal. . . $15.3 \mathrm{ft} / \mathrm{s}(4.7 \mathrm{~m} / \mathrm{s})$
Lateral . . . . . $6.5 \mathrm{ft} / \mathrm{s}(2.0 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal. . . -3.8 g
Lateral . . . . .-17.2 g

Figure 61. Summary of results for test 7069-24.

Table 23. Evaluation of crash test no. 7069-24.
\{BR27C bridge railing on sidewalk [1,800 $1 \mathrm{~b}(817 \mathrm{~kg})|61.7 \mathrm{mi} / \mathrm{h}(99.3 \mathrm{~km} / \mathrm{h})| 18.7$ degrees $]\}$
$\qquad$
CRITERIA
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  |
| :--- | :--- |
| $\frac{\text { Assessment }}{\text { Good }}$ |  |
| $>.26-.35$ |  |
| $>.35$ |  |
| Fair Marginal |  |

G. Shall be less than
Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$
Longitudinal
$30(9.2)$
$\frac{\text { Occupant Ridedown Accelerations }-\mathrm{g}^{\prime} \mathrm{s}}{\text { Longitudinal }} \begin{gathered}\text { Lateral } \\ 15\end{gathered}$
H. Exit angle shall be less than 12 degrees

| TEST RESULTS |  | PASS/FAI |
| :--- | :--- | ---: |
| Vehicle was contained | Pass |  |
| No debris penetrated passenger <br> compartment | Pass |  |
| No deformation | Pass |  |

Vehicle did remain upright Pass
Vehicle was smoothly redirected Pass
$\begin{array}{ll}.38 \text { (Impact @ curb) } & \frac{\text { Assessment }}{\text { Marginal }} \\ .11 \text { (Impact @ rail) Good } & \text { Pass }\end{array}$

15.3 (4.7) $\quad 6.5$ (2.0)

| Occupant Ridedown | Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$ |
| :---: | :---: |
| Longitudinal | Lateral |
| -3.8 | -17.2 |

Pass

Exit angle was 1.0 degrees
Pass

* $A, B, C, D$ and $G$ are required. $E, F$, and $H$ are desired. (See table l)

Test Number 7069-25

| Vehicle: | 1984 GMC Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,400 \mathrm{lb}(2452 \mathrm{~kg})$ |
| Gross Static Weight: | $5,568 \mathrm{lb}(2528 \mathrm{~kg})$ |
| Impact Speed: | $62.6 \mathrm{mi} / \mathrm{h}(100.7 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 19.4 deg |

The vehicle impacted the curb approximately $8.8 \mathrm{ft}(2.7 \mathrm{~m})$ downstream from the end. As the left front wheel of the vehicle mounted the curb, the tire was deflated. At approximately 0.064 s after impact, the vehicle began to redirect, and at 0.118 s the left rear tire contacted the curb. The vehicle bumper impacted the concrete parapet (near post 4) at 0.150 s traveling at a speed of $59.8 \mathrm{mi} / \mathrm{h}(96.2 \mathrm{~km} / \mathrm{h})$ and an angle of 17.9 degrees. At 0.167 s the right front wheel contacted the curb and the vehicle impacted the metal railing element. By 0.214 s the vehicle began to redirect significantly, and by 0.329 s the vehicle was traveling parallel with the bridge railing at a speed of $56.7 \mathrm{mi} / \mathrm{h}(91.2 \mathrm{~km} / \mathrm{h})$. The rear of the vehicle contacted the concrete parapet at 0.348 s and then exited the bridge railing at 0.463 s traveling at a speed of $53.5(86.1 \mathrm{~km} / \mathrm{h})$ and an exit angle of 5.4 degrees. The vehicle was in contact with the bridge railing system for a total of $13.0 \mathrm{ft}(4.0 \mathrm{~m})$. As the vehicle exited the bridge railing installation, the brakes were applied. The vehicle yawed counter-clockwise and subsequently came to rest $210 \mathrm{ft}(64 \mathrm{~m})$ down and $6 \mathrm{ft}(2 \mathrm{~m})$ toward the field side of the point of impact.

The railing system received minimal damage (figure 62). There was no measurable permanent deformation to the metal railing elements; however, the left corner of the bumper had snagged post 5 and pulled it up such that the washer rotated freely under the nut on the left front side of the railing. There was only cosmetic damage to the concrete parapet, i.e., tire marks on the concrete parapet from post 4 to post 6 .

The vehicle sustained damage to the left side (figure 62). Maximum crush at the left front corner at bumper height was 12.0 in ( 305 mm ) and the right front corner was deformed outward 7.0 in ( 178 mm ). The left front wheel was pushed back reducing the wheelbase on the driver side by 2.25 in ( 57 mm ). Also, damage was done to the front bumper, hood, grill, the left front quarter panel, left door and glass, left rear quarter panel, rear bumper and tailgate, left front tire and rim, and right front tire. The welds on the left rear rim broke and the tire separated from the rim.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing system smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant risk factors were well within the specified limits. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes.


Figure 62. Vehicle and railing for test 7069-25.

Performance of the railing in this test is judged acceptable, as indicated in figure 63 and table 24.

0.000 s

0.191 s


0.319 s


0.463 s



| Test No. . . . . . . . . 7069-25 |  |
| :---: | :---: |
| Date | 04/02/92 |
| Test Installation . . . BR27C Bridge Railing |  |
|  | on sidewalk |
| Installation Length | 100 ft ( 30 m ) |
| Test Vehicle . . . . . . 1984 GMC Sierra |  |
| Vehicle Weight Pickup |  |
| Test Inertia | 5,400 lb (2 452 kg ) |
| Gross Static $\dot{\text { a }}$ - 5,568 |  |
|  |  |
| TAD | $11 L F Q 4$ \& 11LD4 |
| CDC | 11FLEK2 \& 11LDEW2 |
| Maximum Vehicle Crus | 12.0 in ( 305 mm ) |

Impact Speed. . . . $62.6 \mathrm{mi} / \mathrm{h}(100.7 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . . 19.4 deg
Speed at Paralle1 . $56.7 \mathrm{mi} / \mathrm{h}(91.2 \mathrm{~km} / \mathrm{h})$
Exit Speed . . . . $53.5 \mathrm{mi} / \mathrm{h}(86.1 \mathrm{~km} / \mathrm{h})$
Exit Trajectory . . 5.4 deg
Vehicle Accelerations
(Max. 0.050-sec Avg) at true c.g.
Longitudinal. . . -4.6 g
Lateral . . . . . -9.3 g
Occupant Impact Velocity at true c.g.
Longitudinal. . . $12.9 \mathrm{ft} / \mathrm{s}(3.9 \mathrm{~m} / \mathrm{s})$
Lateral . . . . . $19.9 \mathrm{ft} / \mathrm{s}(6.1 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal. . . -4.4 g
Lateral . . . . .-10.8 g

Figure 63. Summary of results for test 7069-25.

Table 24. Evaluation of crash test no. 7069-25.
\{BR27C bridge railing on sidewalk [5,400 $1 \mathrm{lb}(2452 \mathrm{~kg})|62.6 \mathrm{mi} / \mathrm{h}(100.7 \mathrm{~km} / \mathrm{h})| 19.4$ degrees $]\}$
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
$\qquad$
Vehicle was contained Pass

No debris penetrated passenger Pass compartment
C. Passenger compartment must have

No deformation Pass essentially no deformation
D. Vehicle must remain upright

Vehicle did remain upright
Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
Pass
F. Effective coefficient of friction

| $\frac{\mu}{11} \frac{\text { Assessment }}{}$ |  |
| :--- | :---: |
| .01 (Impact @ curb) | Good |
| Gass |  |

G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $.25(7.6)$ |

Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$

## Longitudinal Lateral

15
15
H. Exit angle shall be less than 12 degrees


Exit angle was 5.4 degrees Pass

* $A, B, C$, and $D$ are required. $E, F, G$, and $H$ are desired. (See table l)

Test Number 7069-26

| Vehicle: | 1980 Ford Single-Unit Truck |
| :--- | :--- |
| Test Inertia Weight: | $18,000 \mathrm{lb}(8172 \mathrm{~kg})$ |
| Empty Weight: | $10,550 \mathrm{lb}(4790 \mathrm{~kg})$ |
| Impact Speed: | $51.0 \mathrm{mi} / \mathrm{h}(82.0 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 13.7 deg |

At approximately 0.084 s after impact, the vehicle began a slight counter-clockwise yaw, and at 0.220 s the left rear tire contacted the curb of the sidewalk. The vehicle bumper impacted the concrete parapet ( $3 \mathrm{ft}(1 \mathrm{~m}$ ) downstream of post 7) at 0.290 s traveling at a speed of $47.9 \mathrm{mi} / \mathrm{h}(77.1 \mathrm{~km} / \mathrm{h})$ and an angle of 14.4 degrees. At 0.307 s the left front wheel contacted the parapet, and at 0.368 s the right front wheel and part of the hub broke loose from the axle. By 0.431 s the vehicle began to redirect and at 0.502 s the axle contacted the curb. The vehicle was moving parallel with the bridge railing by 0.590 s traveling at a speed of $44.8 \mathrm{mi} / \mathrm{h}(72.1 \mathrm{~km} / \mathrm{h})$. The rear of the vehicle contacted the concrete parapet at 0.607 s and, as the vehicle continued forward, the lower edge of the vehicle's cargo box pulled the metal railing off posts 10 through 14 . The front of the cab dropped off the end of the curb at 1.325 s and, as the vehicle exited the test site, it rode over the dislodged axle and drive shaft. The vehicle was in contact with the bridge railing system for a total of $63 \mathrm{ft}(19 \mathrm{~m})$. The vehicle subsequently came to rest $195 \mathrm{ft}(59 \mathrm{~m})$ from the point of impact.

The railing system received moderate damage (figure 64). There was no measurable permanent deformation to the metal railing elements in the immediate impact area; however the bolts connecting the railing to the posts from 10 through 14 were sheared as a result of vertical load from the cargo box. There was only cosmetic damage to the concrete parapet, i.e., tire marks on the concrete parapet from post midway of posts 7 and 8 to post 11 and then again from posts 13 to 14 .

The vehicle sustained damage to the left side (figure 64). Maximum crush at the left front corner at bumper height was 6.0 in ( 152 mm ). The front axle broke loose and became separated from the vehicle as did the drive shaft. There was damage to the springs and shocks, steering box, front bumper, left front quarter panel, left door, and left front tire and rim. The lower edge of the left side of the cargo box was also damaged.

The railing contained the vehicle with minimal lateral movement of the railing. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing system smoothly redirected the vehicle. The effective coefficient of friction was considered marginal to good. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 65 and table 25.


Figure 64. Vehicle and railing for test 7069-26.

$1 \mathrm{in}=25.4 \mathrm{~mm}$
Figure 65. Summary of results for test 7069-26.

Table 25. Evaluation of crash test no. 7069-26.
\{BR27C bridge railing on sidewalk [18,000 lb (8 172 kg ) $|51.0 \mathrm{mi} / \mathrm{h}(82.0 \mathrm{~km} / \mathrm{h})| 13.7$ degrees]\}
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
$\qquad$
Vehicle was contained
Pass
No debris penetrated passenger Pass compartment

No deformation
Pass
E. Must smoothly redirect the vehicle

Vehicle did remain upright
Pass
Vehicle was smoothly redirected Pass
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  | Assessment  <br> $.26-.35$  <br> $>.35$  <br> Fair  <br> Marginal  |
| :--- | :--- | :--- |

$\frac{\mu}{(\text { Impact @ curb) }}$
.14 (Impact @ rail) $\frac{\text { Assessment }}{\text { Marginal }}$

Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |  |  |
| :---: | :---: | :---: | :---: |
| Longitudinal | Lateral |  |  |
| $30(9.2)$ | $25(7.6)$ |  |  |


H. Exit angle shall be less than 12 degrees

Exit angle was 0 degrees
Pass
*A, $B$, and $C$ are required. $D, E, F$, and $H$ are desired. $G$ is not applicable for this test. (See table 1)

## BR27C on Deck

Test Number 7069-32

| Vehicle: | 1983 Honda Civic |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,970 \mathrm{lb}(894 \mathrm{~kg})$ |
| Impact Speed: | $60.3 \mathrm{mi} / \mathrm{h}(97.0 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 19.8 deg |

At 0.040 s after impact, the front of the vehicle began to deform to the right, and at 0.049 s the vehicle began to redirect. The roof of the vehicle began to deform at 0.084 s after impact. By 0.145 s the vehicle was traveling parallel to the bridge railing at a speed of $53.6 \mathrm{mi} / \mathrm{h}(86.2 \mathrm{~km} / \mathrm{h})$, and at 0.155 s the rear of the vehicle impacted the bridge railing. The vehicle lost contact with the bridge railing at 0.258 s traveling at $50.6 \mathrm{mi} / \mathrm{h}(81.4 \mathrm{~km} / \mathrm{h})$ and 6.6 degrees. The vehicle was in contact with the bridge railing for $9.9 \mathrm{ft}(3.0 \mathrm{~m})$. The brakes on the vehicle were applied at 1.4 s after impact and the vehicle subsequently came to rest $210 \mathrm{ft}(64 \mathrm{~m})$ down from and $120 \mathrm{ft}(37 \mathrm{~m})$ toward the traffic side of the point of impact.

The railing received minimal damage (figure 66). There was no deformation to the metal railing element.

The vehicle sustained damage to the right side (figure 66). Maximum crush at the right front corner at bumper height was $6.5 \mathrm{in}(165 \mathrm{~mm})$, and there was a $1.0-\mathrm{in}(25-\mathrm{mm})$ dent into the occupant compartment at the fire wall. The passenger door was deformed outward approximately 1.3 in ( 33 mm ) and the wheelbase on the right side was reduced 3.0 in ( 76 mm ). An 8 -in by $14-$ in by $7 / 16-\mathrm{in}(203-\mathrm{mm}$ by $356-\mathrm{mm}$ by $11-\mathrm{mm}$ ) deep dent in the roof just over the right rear passenger location. The right front strut and sway bar were damaged and the instrument panel was bent. Also, damage was done to the front bumper, hood, grill, radiator, fan, right front quarter panel, right front rim, right door, right rear quarter panel, and right rear rim.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment although there was a 1 -in $(25-\mathrm{mm})$ dent into the occupant compartment at the fire wall. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was $9.7 \mathrm{mi} / \mathrm{h}(15.6 \mathrm{~km} / \mathrm{h})$. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 67 and table 26 .


Figure 66. Vehicle and railing for test 7069-32.

0.000 s


0.074 s


0.148 s


0.258 s


| Test No. . . . . . . . . $7069-32$Date . . . . . . . |  |
| :---: | :---: |
| Test Installation . . . BR |  |
|  |  |
| Installation Length . . 100 ft (30 m) |  |
| Test Vehicle . . . . . . 1983 Honda Civic |  |
| Vehicle Weight |  |
| Test Inertia . . . . . 1,800 1b (817 kg) |  |
| Gross Static | 1,970 1b (894 kg) |
| Vehicle Damage Classification |  |
| TAD . . . . . . . . . 01 RFQ5 |  |
| CDC | 01FREK3 \& O1RYEW4 |
| Maximum Vehicle Crus | . $6.5 \mathrm{in} \mathrm{(165} \mathrm{mm)}$ |

Impact Speed. . . . $60.3 \mathrm{mi} / \mathrm{h}(97.0 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . . 19.8 deg
Speed at Parallel . $53.6 \mathrm{mi} / \mathrm{h}(86.2 \mathrm{~km} / \mathrm{h})$
Exit Speed . . . . $50.6 \mathrm{mi} / \mathrm{h}(81.4 \mathrm{~km} / \mathrm{h})$
Exit Trajectory . . 6.6 deg
Vehicle Accelerations
(Max. 0.050-sec Avg) at true c.g.
Longitudinal. . . -5.7 g
Lateral . . . . . 12.2 g
Occupant Impact Velocity at true c.g.
Longitudinal. . . $14.5 \mathrm{ft} / \mathrm{s}(4.4 \mathrm{~m} / \mathrm{s})$
Lateral . . . . . $24.6 \mathrm{ft} / \mathrm{s}(7.5 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal . . -1.2 g
Lateral . . . . . 12.7 g

Figure 67. Summary of results for test 7069-32.

Table 26. Evaluation of crash test no. 7069-32.
\{BR27C bridge railing on deck [1,800 $1 \mathrm{~b}(817 \mathrm{~kg})|60.3 \mathrm{mi} / \mathrm{h}(97.0 \mathrm{~km} / \mathrm{h})| 19.8$ degrees $]\}$
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
$\qquad$
Pass
Vehicle was contained Pass

No debris penetrated passenger Pass compartment
C. Passenger compartment must have

Minimal deformation (1 in) Pass essentially no deformation
D. Vehicle must remain upright

Vehicle did remain upright Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
Pass
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  | Assessment |
| :--- | :--- | :--- |
| $.26-.35$ |  | Gair |
| $>.35$ |  | Marginal |

$\frac{\text { Assessment }}{\text { Good }}$
Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |

Occupant Ridedown Accelerations $-\mathrm{g}^{\prime} \mathrm{s}$
Longitudinal
15
H. Exit angle shall be less than 12 degrees
$\begin{array}{cc}\text { Occupant Impact Velocity }-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s}) \\ \text { Longitudinal } & \text { Lateral } \\ 14.5(4.4) & 24.6(7.5)\end{array}$
Pass
$\begin{array}{cc}\text { Occupant Ridedown Accelerations - } g^{\prime} \mathrm{s} \\ \text { Longitudinal } & \text { Latera1 } \\ -1.2 & 12.7\end{array}$
Exit angle was 6.6 degrees

* $A, B, C, D$ and $G$ are required. $E, F$, and $H$ are desired. (See table 1)

Test Number 7069-33

| Vehicle: | 1985 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,400 \mathrm{lb}(2452 \mathrm{~kg})$ |
| Gross Static Weight: | $5,570 \mathrm{lb}(2529 \mathrm{~kg})$ |
| Impact Speed: | $55.3 \mathrm{mi} / \mathrm{h}(89.0 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 19.6 deg |

At 0.022 s after impact the vehicle bumper began to ride up the barrier, and at 0.039 $s$ the vehicle began to redirect. The bumper went between the concrete beam and lower metal railing element at 0.054 s , and at 0.083 the vehicle made contact with post 4 . By 0.195 s the vehicle was traveling parallel to the bridge railing at a speed of $47.9 \mathrm{mi} / \mathrm{h}(77.1$ $\mathrm{km} / \mathrm{h}$ ), and at 0.208 s the rear of the vehicle impacted the bridge railing. The vehicle lost contact with the bridge railing at 0.315 s traveling at $44.8 \mathrm{mi} / \mathrm{h}(72.1 \mathrm{~km} / \mathrm{h})$ and 6.5 degrees. The vehicle was in contact with the bridge railing for $11.0 \mathrm{ft}(3.4 \mathrm{~m})$. The brakes on the vehicle were applied at 1.7 s after impact and the vehicle subsequently came to rest 225 ft (68.6) down from and $5 \mathrm{ft}(2 \mathrm{~m})$ behind the point of impact.

The railing received minimal damage (figure 68). There was 0.5 in ( 13 mm ) deformation to the lower metal railing element and there was a hairline crack in the concrete beam 17.5 in ( 445 mm ) down from post 3 .

The vehicle sustained damage to the right side (figure 68). Maximum crush at the right front corner at bumper height was 9.0 in ( 229 mm ) and there was a $0.5-\mathrm{in}(13-\mathrm{mm})$ dent into the occupant compartment at the fire wall. The wheelbase on the right side was reduced 2.0 in ( 51 mm ). The sway bars were damaged and the frame was bent. Also, damage was done to the front bumper, hood, grill, radiator, fan, right front quarter panel, right front tire and rim, right door, right rear quarter panel, rear bumper, right rear rim, and left front quarter panel.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment although there was a 0.5 in $(13-\mathrm{mm})$ dent into the occupant compartment at the fire wall. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was $10.5 \mathrm{mi} / \mathrm{h}(16.9 \mathrm{~km} / \mathrm{h})$. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 69 and table 27.


Figure 68. Vehicle and railing for test 7069-33.




Impact Speed. . . . $55.3 \mathrm{mi} / \mathrm{h}(89.0 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . . 19.6 deg
Speed at Parallel . $47.9 \mathrm{mi} / \mathrm{h}(77.1 \mathrm{~km} / \mathrm{h})$
Exit Speed . . . . $44.8 \mathrm{mi} / \mathrm{h}(72.1 \mathrm{~km} / \mathrm{h})$
Exit Trajectory . . 6.5 deg
Vehicle Accelerations
(Max. 0.050-sec Avg) at true c.g.
Longitudinal. . . -4.9 g
Lateral . . . . . 9.3 g
Occupant Impact Velocity at true c.g.
Longitudinal. . . $11.6 \mathrm{ft} / \mathrm{s}(3.5 \mathrm{~m} / \mathrm{s})$
Lateral . . . . . $20.1 \mathrm{ft} / \mathrm{s}(6.1 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal . . -2.2 g
Lateral . . . . . 8.1 g
$1 \mathrm{in}=25.4 \mathrm{~mm}$

Figure 69. Summary of results for test 7069-33.

Table 27. Evaluation of crash test no. 7069-33.
\{BR27C bridge railing on deck [5,400 $1 \mathrm{~b}(2452 \mathrm{~kg})|55.3 \mathrm{mi} / \mathrm{h}(89.0 \mathrm{~km} / \mathrm{h})| 19.6$ degrees $]\}$
$\qquad$ TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
TEST RESULTS
Vehicle was contained Pass

No debris penetrated passenger Pass compartment

Minimal deformation of 0.5 in Pass

Vehicle did remain upright Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
F. Effective coefficient of friction
Assessment
Good
Fair
Marginal
$\frac{\mu}{23} \quad$ Assessment Good
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |

$\begin{array}{cc}\text { Occupant Ridedown Accelerations }-\mathrm{g}^{\prime} \mathrm{s} \\ \text { Longitudinal } & \text { Lateral } \\ 15 & 15\end{array}$


Exit angle was 6.5 degrees Pass
H. Exit angle shall be less than 12 degrees

* $A, B, C$, and $D$ are required. $E, F, G$, and $H$ are desired. (See table 1)

Test Number 7069-34
Vehicle:
1981 Ford Single-Unit Truck
Test Inertia Weight: $18,000 \mathrm{lb}(8172 \mathrm{~kg})$
Empty Weight: $\quad 10,490 \mathrm{lb}(4762 \mathrm{~kg})$
Impact Speed: $\quad 52.5 \mathrm{mi} / \mathrm{h}(84.5 \mathrm{~km} / \mathrm{h})$
Impact Angle: $\quad 12.8 \mathrm{deg}$
As the vehicle impacted the bridge railing, the vehicle bumper began to ride up the concrete parapet. At 0.017 s after impact the right front wheel made contact with the concrete parapet, and at 0.072 s a significant clockwise steer input occurred. The bumper went between the concrete parapet and lower metal railing element at 0.094 s , and by 0.118 $s$ the vehicle was traveling parallel to the bridge railing at a speed of $46.8 \mathrm{mi} / \mathrm{h}(75.3 \mathrm{~km} / \mathrm{h})$. At 0.174 the vehicle bumper made contact with post 6 and then contacted post 7 at 0.276 s . The vehicle lost contact with the bridge railing at approximately 0.811 s traveling at 44.6 $\mathrm{mi} / \mathrm{h}(71.8 \mathrm{~km} / \mathrm{h})$ and 3.5 degrees. The brakes on the vehicle were applied at 1.9 s after impact and the vehicle subsequently came to rest 225 ft (68.6) from the point of impact. The vehicle was in contact with the bridge railing for $41.0 \mathrm{ft}(12.5 \mathrm{~m})$.

The railing received minimal damage with most being contained within the area around posts 4,5 , and 6 . Cracking occurred in posts 4 and 5 in the heat affected zone in the posts at the post-to-baseplate connection. The crack occurred at the corners on the traffic side of the tubular steel element (corner of maximum stress) and extended approximately 1 in in both directions. There was a hairline crack in the concrete parapet in line with the rear post bolts at post 4 . There was $1.5 \mathrm{in}(38 \mathrm{~mm})$ deformation to the metal railing element between posts 4 and 5 .

The vehicle sustained damage mostly to the right side (figure 70). Maximum crush at the right front corner at bumper height was 28.0 in ( 711 mm ). The steering arm, front springs and shackles, left front king pin and front axle were damaged and the frame was bent. Also, damage was done to the front bumper, right front quarter panel, right front tire and rim, right door, right rear outside tire and rim, gas tank and box-van.

The railing contained the vehicle with minimal lateral movement of the railing. There was no intrusion of railing components into the occupant compartment. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered marginal. Velocity change of the vehicle during the collision was $9.7 \mathrm{mi} / \mathrm{h}(15.6 \mathrm{~km} / \mathrm{h})$. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 71 and table 28.


Figure 70. Vehicle and railing for test 7069-34.


Figure 71. Summary of results for test 7069-34.

Table 28. Evaluation of crash test no. 7069-34.
\{BR27C bridge railing on deck [18,000 $1 \mathrm{~b}(8172 \mathrm{~kg})|52.5 \mathrm{mi} / \mathrm{h}(84.5 \mathrm{~km} / \mathrm{h})| 12.8$ degrees] $\}$
$\qquad$ TEST RESULTS
A. Must contain vehicle

Vehicle was contained Pass
B. Debris shall not penetrate

No debris penetrated passenger Pass passenger compartment compartment
C. Passenger compartment must have

No deformation Pass essentially no deformation

Vehicle remained upright during test.
D. Vehicle must remain upright

Vehicle was smoothly redirected
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  |
| :--- | :--- |
| $.26-.35$ | Assessment |
| $>.35$ | Fair |
|  |  |
| Marginal |  |

$$
\frac{\mu}{.38} \quad \frac{\text { Assessment }}{\text { Marginal }}
$$

$$
N / A
$$

G. Shall be less than

| Occupant Impact |  |  | Velocity $-\mathrm{ft} / \mathrm{s}$ | $(\mathrm{m} / \mathrm{s})$ |
| :--- | :---: | :---: | :---: | :---: |
| Longitudinal | Lateral |  |  |  |
| $30(9.2)$ | $25(7.6)$ |  |  |  |
|  |  |  |  |  |
| Occupant Ridedown | Accelerations |  |  |  |
| Longitudinal | Lateral |  |  |  |
| 15 | 15 |  |  |  |


| Occupant Impact |  | Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |
| :---: | :---: | :---: |
| Longitudinal | Lateral | N/A |
| $8.2(2.5)$ | $13.1(4.0)$ |  |
|  |  |  |
|  |  |  |

H. Exit angle shall be less than 12 degrees

Exit angle was 3.5 degrees N/A

* $A, B$, and $C$ are required. $D, E, F$, and $H$ are desired. (See table 1)


## Illinois Side-Mounted Railing

Test Number 7069-35

| Vehicle: | 1981 Honda Civic |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,970 \mathrm{lb}(894 \mathrm{~kg})$ |
| Impact Speed: | $59.9 \mathrm{mi} / \mathrm{h}(96.4 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.1 deg |

Upon impact the front bumper was pushed toward the passenger side of the vehicle and the bumper then separated from the vehicle on the passenger side. At 0.044 s after impact the vehicle began to redirect, and at 0.065 s the windshield began to crack at the lower corner on the driver side. The lower edge of the left front tire began to ride down the slope of the asphalt between the lower rail element and deck, and by 0.113 s the tire reached the lowest point under the rail element. By 0.136 s the vehicle was traveling parallel to the bridge railing at a speed of $51.1 \mathrm{mi} / \mathrm{h}(86.2 \mathrm{~km} / \mathrm{h})$, and at 0.148 s the rear of the vehicle impacted the bridge railing. By this time the left front tire was returning to the asphalt surface. The vehicle lost contact with the bridge railing at 0.190 s traveling at $50.8 \mathrm{mi} / \mathrm{h}$ $(81.7 \mathrm{~km} / \mathrm{h})$ and 6.4 degrees. The vehicle was in contact with the bridge railing for 8.4 ft $(2.6 \mathrm{~m})$. The brakes on the vehicle were applied at 1.65 s after impact, the vehicle yawed clockwise and subsequently came to rest $150 \mathrm{ft}(46 \mathrm{~m})$ down from and $114 \mathrm{ft}(35 \mathrm{~m})$ in front of the point of impact.

The railing received minimal damage (figure 72). There was no deformation to the metal rail element.

The vehicle sustained damage to the left side (figure 72). Maximum crush at the left front corner at bumper height was $7.5 \mathrm{in}(190 \mathrm{~mm})$ and there was a $1.3-\mathrm{in}(33-\mathrm{mm})$ dent into the occupant compartment at the fire wall. The driver door was deformed outward approximately 4.1 in ( 104 mm ) and there was a small dent in the roof just above the B-pillar. The left front strut and sway bar were damaged, the instrument panel was bent, the windshield cracked, and the A-pillar was bent on the driver side. Also, damage was done to the front bumper, hood, grill, left front and rear quarter panel, left front and rear rim, and left door.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment although there was a 1.3in ( $33-\mathrm{mm}$ ) dent into the occupant compartment at the fire wall. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was $9.1 \mathrm{mi} / \mathrm{h}(14.6 \mathrm{~km} / \mathrm{h})$. The longitudinal occupant impact velocity and the occupant ridedown accelerations were within the limits, however the lateral impact velocity of $25.8 \mathrm{ft} / \mathrm{s}$ was considered marginal. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.


Figure 72. Vehicle and railing for test 7069-35.

Performance of the railing in this test is judged acceptable, as indicated in figure 73 and table 29.


Figure 73. Summary of results for test 7069-35.

Table 29. Evaluation of crash test no. 7069-35.
\{Illinois Side Mounted Bridge Railing [1,800 $1 \mathrm{~b}(817 \mathrm{~kg})|59.9 \mathrm{mi} / \mathrm{h}(96.4 \mathrm{~km} / \mathrm{h})| 20.1$ degrees $]\}$
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
TEST RESULTS

Vehicle was contained Pass
No debris penetrated passenger Pass compartment

Minimal deformation (1.3 in) Pass essentially no deformation

Vehicle did remain upright Pass
Vehicle was smoothly redirected Pass
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ | $\frac{\text { Assessment }}{\text { Good }}$ |
| :--- | :--- |
| $>.26-.35$ | Fair |
| $>.35$ | Marginal |

$\frac{\mu}{.25} \quad \frac{\text { Assessment }}{\text { Good }}$
Pass
G. Shall be less than


| Occupant Impact Velocity - $\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ | Marginal |
| :---: | :---: |
| Longitudinal Lateral |  |
| 15.9 (4.8) 25.8 (7.9) |  |
| Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$ | Pass |
| Longitudinal Lateral |  |
| $-1.7 \quad-6.6$ |  |
| Exit angle was 6.4 degrees | Pass |

* $A, B, C, D$ and $G$ are required. $E, F$, and $H$ are desired. (See table 1)

| Vehicle: | 1986 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia | $5,400 \mathrm{lb}(2452 \mathrm{~kg})$ |
| Gross Static Weight: | $5,565 \mathrm{lb}(2526 \mathrm{~kg})$ |
| Impact Speed: | $60.4 \mathrm{mi} / \mathrm{h}(97.2 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 20.4 deg |

At 0.017 s after impact, the left front tire contacted the lower rail element and at 0.027 s the vehicle began to redirect. At 0.036 s the left front wheel redirected and the tire began to ride along the edge of the asphalt slope on the bridge deck. The dummy's shoulder impacted the door of the vehicle at 0.080 s and the door glass shattered at 0.107 s . By 0.182 s the vehicle was traveling parallel to the bridge railing at a speed of $56.6 \mathrm{mi} / \mathrm{h}(91.1 \mathrm{~km} / \mathrm{h})$, and at 0.189 s the rear of the vehicle contacted the bridge railing. The vehicle lost contact with the bridge railing at 0.291 s traveling at $55.6 \mathrm{mi} / \mathrm{h}(89.5 \mathrm{~km} / \mathrm{h})$ and 9.0 degrees. The vehicle was in contact with the bridge railing for $14.8 \mathrm{ft}(4.5 \mathrm{~m})$. The brakes on the vehicle were applied at 1.4 s after impact. One of the rear wheels locked up causing the vehicle to yaw counter-clockwise into a protective barrier, and it subsequently came to rest 330 ft ( 100 $\mathrm{m})$ down from and $16 \mathrm{ft}(5 \mathrm{~m})$ toward the field side of the point of impact.

The railing received moderate damage (figure 74). There was 1.0 in ( 25 mm ) deformation to the upper rail element and 0.75 in ( 19 mm ) to the lower rail element near post 5 . The flanges on posts 4 and 5 were deformed just above the angles (L6x4x1/4×4) and these angles were bent.

The vehicle sustained damage to the left side. Maximum crush at the left front corner at bumper height was $13.0 \mathrm{in}(330 \mathrm{~mm})$ and there was a $0.4-\mathrm{in}(10-\mathrm{mm})$ dent into the occupant compartment at the fire wall and center tunnel. The frame was bent and the door on the driver side was deformed outward 3.2 in ( 81 mm ). Also, damage was done to the front bumper, hood, grill, radiator, fan, left front quarter panel, left front tire and rim, left door, left rear quarter panel, rear bumper, and left rear rim. Most of the damage to the right side of the vehicle was sustained when the vehicle impacted the protective barrier.

The railing contained the vehicle with minimal lateral movement of the railing. There was no intrusion of railing components into the occupant compartment although there was a $0.4-\mathrm{in}(10-\mathrm{mm})$ dent into the occupant compartment at the fire wall. The vehicle remained upright and relatively stable during the collision. The railing redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was $4.8 \mathrm{mi} / \mathrm{h}(7.7 \mathrm{~km} / \mathrm{h})$. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 75 and table 30.


Figure 74. Vehicle and railing for test 7069-36.



| Test No. . . . . . . . . 7069-36 Date . . . . . . . . . . 03/25/93 |  |
| :---: | :---: |
| , |  |
|  |  |
| Installation Length . . 84 ft (26 |  |
| Test Vehicle . . . . . . 1985 Chevrolet |  |
| Vehicle Weight Pickup |  |
| Test Inertia | 5,400 1b (2 452 kg ) |
| Gross Static . . . . 5,565 lb (2 526 kg ) |  |
| Vehicle Damage Classification |  |
| TAD | $11 F L 4$ \& 11LD4 |
| CDC | 11FLEK3 \& 11LDEW3 |
| Maximum Vehicle Crush | 13.0 in ( 330 mm ) |



Figure 75. Summary of results for test 7069-36.

Table 30. Evaluation of crash test 7069-36.
\{Illinois Side Mounted Bridge Railing [5,400 7b (2 452 kg$)|60.4 \mathrm{mi} / \mathrm{h}(97.2 \mathrm{~km} / \mathrm{h})| 20.4$ degrees]\}
$\qquad$ TEST RESULTS
PASS/FAIL*
TEST RESULTS
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright

Pass
Vehicle was contained
Pass
No debris penetrated passenger
Pass compartment

Minimal deformation of 0.4 in Pass

Vehicle did remain upright
Pass
Vehicle was smoothly redirected
Pass
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction
$\frac{\mu}{.00} \quad \frac{\text { Assessment }}{\text { Good }}$
Pass
G. Shall be less than

| Occupant Impact |  |
| :---: | :---: |
| Lolocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| $30(9.2)$ | Lateral |
|  | $25(7.6)$ |
| Occupant Ridedown | Accelerations |
| Longitudinal | $\mathrm{g}^{\prime} \mathrm{s}$ |
| 15 | Lateral |
|  | 15 |

H. Exit angle shall be less than 12 degrees

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :--- | :---: |
| Longitudinal | Lateral |
| $11.7(3.6)$ | $24.4(7.4)$ |$\quad$ Pass

Occupant Ridedown Accelerations - $g^{\prime} s$ Pass
Longitudinal Lateral
1.0
-12.3
Exit angle was 9.0 degrees

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

| Vehicle: | 1981 Ford Single-Unit Truck |
| :--- | :--- |
| Test Inertia Weight: | $18,000 \mathrm{lb}(8172 \mathrm{~kg})$ |
| Empty Weight: | $10,810 \mathrm{lb}(4908 \mathrm{~kg})$ |
| Impact Speed: | $51.4 \mathrm{mi} / \mathrm{h}(82.7 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 14.7 deg |

Approximately 0.022 s after impact, the left front tire of the vehicle impacted the bridge railing and then rode up and steered into the rail. The vehicle began to redirect at 0.061 s , and by 0.261 s the vehicle was traveling parallel to the bridge railing at a speed of $46.8 \mathrm{mi} / \mathrm{h}(75.3 \mathrm{~km} / \mathrm{h})$. The rear of the vehicle contacted the bridge railing at approximately 0.283 s and the lower edge of the box-van set down on top of the rail at 0.331 s . It rode along in this manner until the vehicle exited the rail. The cab of the vehicle reached a maximum roll angle of about 12 degrees at 0.469 s . At 0.725 s the box-van had rolled to a maximum of about 53 degrees, and at 0.822 s began to right itself. The vehicle rode off the end of the bridge railing and the vehicle subsequently came to rest $165 \mathrm{ft}(50 \mathrm{~m})$ down from and $9 \mathrm{ft}(3 \mathrm{~m})$ toward the field side of the point of impact. The vehicle was in contact with the bridge railing for $69 \mathrm{ft}(21 \mathrm{~m})$.

The railing received moderate damage with most contained within the area between posts 4 through 7. The upper and lower rails sustained gouges between posts 4 and 5 from the lug nuts of the vehicle's wheel. The head of the lower bolt on the top rail at post 5 was torn off and the bolts on the lower element were loose. The angles at post 4 were slightly bent and those at posts 5 and 6 were deformed. The spacers at posts 4 and 5 were knocked loose and down. There was 2.5 in ( 64 mm ) deformation to the upper rail element at post 5 .

The vehicle sustained damage mostly to the left side (figure 76). Maximum crush at the left front corner at bumper height was 8.0 in ( 203 mm ). The front springs, shackles, and U-bolt were damaged and the box-van shifted off the frame approximately 6 in ( 150 mm ). Also, damage was done to the front bumper, left front quarter panel, left front tire and rim, left rear outside tire and rim, and lower edge of the box-van.

The railing contained the vehicle with minimal lateral movement of the railing. There was no intrusion of railing components into the occupant compartment. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered good. The vehicle trajectory at loss of contact indicated no intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 77 and table 31.


Figure 76. Vehicle and railing for test 7069-37.


Figure 77. Summary of results for test 7069-37.

Table 31. Evaluation of crash test no. 7069-37.
\{Illinois Side Mounted Bridge Railing [18,000 lb ( 8172 kg )|51.4 mi/h ( $82.7 \mathrm{~km} / \mathrm{h}$ )|14.7 degrees]\}
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
compartment
C. Passenger compartment must have

No deformation
Pass
Vehicle was contained
No debris penetrated passenger Pass

Pass
D. Vehicle must remain upright

Vehicle remained upright during test.
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  | Assessment |
| :--- | :--- | :--- |
| $.26-.35$ |  | Fair |
| $>.35$ |  | Marginal |

$\frac{\text { Assessment }}{\text { Good }}$
N/A
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |


| Occupant Ridedown Accelerations $-g^{\prime} \mathrm{s}$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| 15 | 15 |

H. Exit angle shall be less than 12 degrees

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $9.1(2.8)$ | $9.7(3.0)$ |$\quad \mathrm{N} / \mathrm{A}$


| Occupant Ridedown Accelerations $-g^{\prime} s$ | $\mathrm{~N} / \mathrm{A}$ |
| :---: | :---: |
| Longitudinal | Lateral |
| -4.3 | -6.3 |

Vehicle exited beind installation N/A

* $A, B$, and $C$ are required. $D, E, F$, and $H$ are desired. (See table 1)


## PERFORMANCE LEVEL THREE RAILINGS

Two railing designs, as shown in table 32, were subjected to strength tests for performance level three.

The 42 -in ( $1.07-\mathrm{m}$ ) vertical-faced concrete parapet was tested with a $50,000-1 \mathrm{~b}$ $(22700-\mathrm{kg})$ tractor-trailer. Acceptable performance was obtained.

The $42-\mathrm{in}(1.07-\mathrm{m})$ F-shape was tested with a $40,000-\mathrm{lb}(18160-\mathrm{kg})$ intercity bus because that was the proposed test vehicle at the time. The railing was then tested with a $50,000-\mathrm{lb}(22700-\mathrm{kg})$ tractor-trailer. Performance was acceptable in both tests.

Table 32. Summary of full-scale crash tests performed on performance level three railings.


## 42-in ( 1.07 -m) Concrete Parapet - Test Number 7069-13

| Vehicle: | Tractor/Trailer |
| :--- | :--- |
| Test Inertia Weight: | $50,050 \mathrm{lb}(22723 \mathrm{~kg})$ |
| Empty Weight: | $27,690 \mathrm{lb}(12571 \mathrm{~kg})$ |
| Impact Speed: | $51.4 \mathrm{mi} / \mathrm{h}(82.7 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 16.2 deg |

The vehicle impacted the parapet at $24 \mathrm{ft}(7.3 \mathrm{~m})$ from the upstream end. At approximately 0.010 s after impact, the right front wheel contacted the parapet, and the left front wheel became airborne at 0.135 s . The right front corner of the trailer contacted the parapet at about 0.178 s . The tractor began to redirect at 0.178 s , and the trailer began to redirect at 0.280 s . The rear wheels of the tractor lost contact with the pavement at 0.285 s , and left rear wheels of the trailer became airborne at 0.349 s . The left side of the tractor remained airborne until 0.417 s when the left front wheel touched down. The right rear trailer wheels contacted the parapet at about 0.684 s . The vehicle attained maximum roll to the right at about 1.165 s and began to roll left. The vehicle rode against the parapet and off the end. The brakes were applied, and the vehicle came to rest on its left side approximately $181 \mathrm{ft}(55 \mathrm{~m})$ downstream from the point of impact.

The parapet received only cosmetic damage (figure 78). There were tire marks on the parapet from just before the impact point extending a total of $85 \mathrm{ft}(26 \mathrm{~m})$ along the face. There was also a piece of the top of the parapet chipped off.

The vehicle sustained extensive damage to the right side. Maximum crush at the right front corner at bumper height was 18.0 in $(457 \mathrm{~mm})$. There was damage to the front axle, Pittman arm, U-bolts, front leaf springs and bolts, front shock mounts, air brake lines, right fuel cell, left rear spring pin and clamp, and exhaust pipe. The cab and left door were bent.

The parapet contained and redirected the vehicle with no lateral movement of the parapet. There were no debris or detached elements. There was no intrusion into the occupant compartment, although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes; however, the vehicle did not remain upright after the collision.

Performance of the parapet in this test is judged acceptable, as indicated in figure 79 and table 33.

This was the only test performed on the $42-\mathrm{in}(1.07-\mathrm{m})$ concrete parapet.


Figure 78. Vehicle and parapet for test 7069-13.


| Test No. | $\begin{array}{r} 7069-13 \\ \cdot 7 / 11 / 88 \end{array}$ |
| :---: | :---: |
| Test Installation | . 42-in (1.07-m) |
|  | Concrete Parapet |
| Installation Length. | 100 ft ( 30 m ) |
| Vehicle | 1979 International |
|  | Tractor w/van-trailer |
| Vehicle Weight |  |
| Empty Weight | 27,690 1b (12 571 kg ) |
| Test Inertia | $50,050 \mathrm{lb}(22723 \mathrm{~kg})$ |
| aximum Vehicle Cr | 18.0 in ( 457 mm ) |

[^7]Impact Speed. . . $51.4 \mathrm{mi} / \mathrm{h}(82.7 \mathrm{~km} / \mathrm{h})$ Impact Angle. . . 16.2 deg
Exit Speed. . . . N/A
Exit Trajectory . 0.0 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . -3.3 g
Lateral. . . . 3.7 g
Occupant Impact Velocity
Longitudinal. . $10.5 \mathrm{ft} / \mathrm{s}(3.2 \mathrm{~m} / \mathrm{s})$
Lateral . . . $12.5 \mathrm{ft} / \mathrm{s}(3.8 \mathrm{~m} / \mathrm{s})$
Occupant Ridedown Accelerations
Longitudinal. . -2.2 g
Lateral . . . . 4.6 g
Figure 79. Summary of results for test 7069-13.

Table 33. Evaluation of crash test no. 7069-13.
$\{42-\mathrm{in}(1.07 \mathrm{~m})$ Concrete Parapet $[50,050 \mathrm{lb}(22723 \mathrm{~kg})|51.4 \mathrm{mi} / \mathrm{h}(82.7 \mathrm{~km} / \mathrm{h})| 16.2$ degrees $]\}$
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment

Pass
Vehicle was contained
No debris penetrated passenger
Pass compartment

Acceptable deformation Pass

Vehicle did not remain upright
Fail
D. Vehicle must remain upright
Vehicle did not renain uprigt Pass
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  |
| :--- | :--- |
| $.26-.35$ | Assessment |
| $>.35$ | Fair |
|  | Marginal |

$\frac{\mu}{0.55} \quad \frac{\text { Assessment }}{\text { Marginal }}$
Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |

Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$
Longitudinal
15
H. Exit angle shall be less than 12 degrees


* $A, B, C$, are required. $D, E, F$, and $H$ are desired. $G$ is not applicable for this test. (See table 1)


## 42-in (1.07-m) F-Shape

Test Number 7069-7

| Vehicle: | 1954 GMC Scenicruiser Bus |
| :--- | :--- |
| Test Inertia Weight: | $40,560 \mathrm{lb}(18414 \mathrm{~kg})$ |
| Empty Weight: | $29,840 \mathrm{lb}(13547 \mathrm{~kg})$ |
| Impact Speed: | $55.7 \mathrm{mi} / \mathrm{h}(89.6 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 15.7 deg |

The vehicle impacted the bridge railing at $35 \mathrm{ft}(10.1 \mathrm{~m})$ from the upstream end. At approximately 0.035 s after impact the right front wheel contacted the bridge railing. The vehicle began to redirect at 0.098 s as the rear end began to slide toward the bridge railing. The rear of the vehicle slapped the bridge railing at 0.3872 s , and by 0.396 s the vehicle was traveling parallel with the bridge railing. The vehicle very briefly lost contact with the bridge railing and contacted it again. The vehicle rode against the bridge railing and off the end. The brakes were applied and the vehicle subsequently came to rest approximately 250 $\mathrm{ft}(76 \mathrm{~m})$ downstream and $40 \mathrm{ft}(12 \mathrm{~m})$ on the field side of the point of impact.

The railing received only cosmetic damage (figure 80). There were tire marks on the bridge railing from just before the impact point extending a total of $25 \mathrm{ft}(7.6 \mathrm{~m})$ along the face. The vehicle then lost contact for $26 \mathrm{ft} \mathrm{( } 7.9 \mathrm{~m}$ ) and contacted the bridge railing for another $21 \mathrm{ft}(6.4 \mathrm{~m})$ when the bridge railing ended. There was also a longitudinal hairline crack along the bridge deck starting approximately at the point of impact for about 35 ft (11 $\mathrm{m})$ running parallel to and nominally $2 \mathrm{ft}(0.6 \mathrm{~m})$ from the base of the railing.

The vehicle sustained extensive damage to the right side. Maximum crush at the right front corner at bumper height was 4.0 in ( 102 mm ). The right front and right rear wheel rims were scratched. The front wheel assembly and suspension was damaged. The door was bent and the windshield was broken out. The right rear panel was dented and scraped.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was no intrusion intọ the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 81 and table 34.


Figure 80. Vehicle and parapet for test 7069-7.

0.000 s


0.192 s


0.384 s




| Test No. . . . . . . . . 7069-7 |  |
| :---: | :---: |
| Test Installation . . . 42-in (1 |  |
|  | ape Bridge Railing |
| Installation LengthVehicle |  |
| Vehicle | 1954 GM |
| Vehicle Weight |  |
|  |  |
| Test Inertia | 40,560 lb (18 41 |
| Vehicle Damage Classification |  |
| TAD | N/A |
| CDC | N/A |
| Maximum Vehicle Crus | rush . 4.0 in ( 102 mm ) |

$55.7 \mathrm{mi} / \mathrm{h}(89.6 \mathrm{~km} / \mathrm{h})$
Impact Angle. . . . 15.7 deg
Exit Speed . . . . $42.5 \mathrm{mi} / \mathrm{h}(68.4 \mathrm{~km} / \mathrm{h})$
Exit Trajctory ... 0 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . . -1.5 g
Lateral . . . . . 6.5 g
Occupant Impact Velocity
Longitudinal. . . $7.9 \mathrm{ft} / \mathrm{s}(2.4 \mathrm{~m} / \mathrm{s})$
Lateral . . . . . $5.4 \mathrm{ft} / \mathrm{s}(1.6 \mathrm{~m} / \mathrm{s})$
0ccupant Ridedown Accelerations
Longitudinal. . . -2.4 g
Lateral . . . . . 21.7 g

Figure 81. Summary of results for test 7069-7.

Table 34. Evaluation of crash test no. 7069-7.
$\{42-\mathrm{in}(1.07 \mathrm{~m}) \mathrm{F}$-shape bridge railing $[40,560 \mathrm{lb}(18414 \mathrm{~kg})|55.7 \mathrm{mi} / \mathrm{h}(89.6 \mathrm{~km} / \mathrm{h})| 15.7$ degrees $]\}$

CRITERIA *
TEST RESULTS
PASS/FAIL
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

| TEST RESULTS | PASS/FAIL |
| :---: | :---: |
| Vehicle was contained | Pass |
| No debris penetrated passenger compartment | Pass |
| Acceptable deformation | Pass |
| Vehicle remained upright | Pass |
| Vehicle was smoothly redirected | Pass |
| $\frac{\mu}{.31} \quad \frac{\text { Assessment }}{\text { Fair }}$ | Pass |
| Occupant Impact Velocity - $\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ | N/A |
| Longitudinal Lateral <br> $7.9(2.4)$ $5.4(1.6)$ |  |
| Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$ Longitudinal -2.4 | N/A |
| Exit angle was 0 degrees | Pass |

* $A, B, C$, and $D$ are required. $E, F$, and $H$ are desired. $G$ is not applicable for this test. (See table 1)

Test Number 7069-10
Vehicle: Tractor/Trailer
Test Inertia Weight: $50,000 \mathrm{lb}(22.700 \mathrm{~kg})$
Empty Weight: $\quad 29,900 \mathrm{lb}(13574 \mathrm{~kg})$
Impact Speed: $\quad 52.2 \mathrm{mi} / \mathrm{h}(84.0 \mathrm{~km} / \mathrm{h})$
Impact Angle: $\quad 14.0 \mathrm{deg}$
The vehicle impacted the bridge railing (figure 82) at $35 \mathrm{ft}(10.1 \mathrm{~m})$ from the upstream end. At approximately 0.005 s after impact the right front wheel contacted the bridge railing and began to ride up the face of the bridge railing. The right front wheel left the pavement at 0.032 s , and the left front wheel left the pavement at 0.120 s . The vehicle began to redirect at 0.124 s as the rear end began to slide toward the bridge railing. At 0.260 s the right front corner of the trailer contacted the top of the bridge railing. The rear wheels of the tractor lost contact with the pavement at 0.309 s , and the tractor remained airborne until 0.594 s when the front wheels touched down. The rear trailer wheels contacted the bridge railing at about 0.785 s . The vehicle rode against the bridge railing and off the end. The brakes were applied and the vehicle subsequently came to rest approximately $300 \mathrm{ft}(91 \mathrm{~m})$ downstream from the point of impact.

The railing received only cosmetic damage (figure 83). There were tire marks on the bridge railing from just before the impact point extending a total of $72 \mathrm{ft}(21.9 \mathrm{~m})$ along the face. There was also a piece of the top of the bridge railing chipped off where the edge of the trailer impacted.

The vehicle sustained extensive damage to the right side (figure 83). Maximum crush at the right front corner at bumper height was 18.0 in ( 457 mm ). Both outside right rear wheel rims of the tractor were bent and the tires were deflated. The front wheel assembly and suspension were damaged. The shock mounts were broken, the tie rods bent, the steering rod was bent, and the springs were loose. The right side door was dented.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 84 and table 35.


Figure 82. Vehicle and parapet before test 7069-10.


Figure 83. Vehicle and parapet after test 7069-10.


$1 \mathrm{in}=25.4 \mathrm{~mm}$



Figure 84. Summary of results for test 7069-10.

Table 35. Evaluation of crash test no. 7069-10.
$\{42-$ in ( 1.07 m ) F-shape bridge railing $[50,000 \mathrm{lb}(22700 \mathrm{~kg})|52.2 \mathrm{mi} / \mathrm{h}(84 \mathrm{~km} / \mathrm{h})| 14.0$ degrees $]\}$
$\qquad$
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

TEST RESULTS
PASS/FAIL*
Vehicle was contained $\quad$ Pass
No debris penetrated passenger Pass compartment

Acceptable deformation
Pass

Vehicle remained upright Pass
Vehicle was smoothly redirected Pass


N/A

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |  |
| :---: | :---: | :---: |
| Longitudinal | Lateral |  |
| $9.1(2.8)$ | $9.3(2.8)$ | $\mathrm{N} / \mathrm{A}$ |


| Occupant Ridedown | Accelerations $-\mathrm{g}^{\prime} \mathrm{s}$ | Longitudinal |
| :---: | :---: | :---: |
| Lateral |  |  |
| -4.7 | 3.7 |  |

about 0 degrees
Pass

## TRANSITIONS

Two transition designs were tested, one for performance level one and one for performance level two, as shown in table 36.

The Oregon thrie-beam transition was designed to transition between a standard W beam guardrail and the Oregon side-mounted thrie-beam bridge railing. It was tested to performance level one requirements and showed acceptable performance.

The $32-\mathrm{in}(813-\mathrm{mm})$ thrie-beam transition was designed to transition between a standard W-beam guardrail and a performance level two bridge railing. It was tested to and meets requirements of performance level two. For testing, the transition was mounted on the end of the $32-\mathrm{in}(813-\mathrm{mm}$ ) concrete parapet, but it should be useable on other performance level two bridge railings if suitable attachment to the bridge railing can be made.

Table 36. Summary of tests performed on transitions.

| RAILING DESIGN | $\begin{aligned} & \text { TEST } \\ & \text { NO. } \end{aligned}$ | $\begin{aligned} & \text { TEST } \\ & \text { DATE } \end{aligned}$ | ACTUAL CONDITIONS | DESIGN CONDITIONS | COMMENTS |
| :---: | :---: | :---: | :---: | :---: | :---: |
| OREGON TRANSITION | 7069-27 | 6/16/92 | $1,970 \mathrm{lb}\|51.6 \mathrm{mi} / \mathrm{h}\| 19.9 \mathrm{deg}$ <br> ( $894 \mathrm{~kg}\|83.0 \mathrm{~km} / \mathrm{h}\| 19.9 \mathrm{deg}$ ) | $\begin{gathered} 1,800 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (817 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Acceptable |
|  | 7069-28 | 6/16/92 | $\begin{gathered} 5,565 \mathrm{lb}\|47.7 \mathrm{mi} / \mathrm{h}\| 19.0 \mathrm{deg} \\ (2527 \mathrm{~kg}\|76.7 \mathrm{~km} / \mathrm{h}\| 19.0 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 5,400 \mathrm{lb}\|45 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (2452 \mathrm{~kg}\|72.4 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \\ \hline \end{gathered}$ | Acceptable |
| 32-in (813mm ) THRIEBEAM TRANSITION | 7069-19 | 10/2/90 | $1,970 \mathrm{lb}\|60.5 \mathrm{mi} / \mathrm{h}\| 19.9 \mathrm{deg}$ ( $894 \mathrm{~kg}\|97.3 \mathrm{~km} / \mathrm{h}\| 19.9 \mathrm{deg}$ ) | $\begin{gathered} 1,800 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (817 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Marginal |
|  | 7069-20 | 10/19/90 | $\begin{gathered} 5,570 \mathrm{lb}\|62.7 \mathrm{mi} / \mathrm{h}\| 19.0 \mathrm{deg} \\ (2529 \mathrm{~kg}\|100.9 \mathrm{~km} / \mathrm{h}\| 19.0 \mathrm{deg}) \\ \hline \end{gathered}$ | $\begin{gathered} 5,400 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (2452 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \\ \hline \end{gathered}$ | Unacceptable |
|  | 7069-21 | 3/17/92 | $\begin{gathered} 5,565 \mathrm{lb}\|61.4 \mathrm{mi} / \mathrm{h}\| 18.3 \mathrm{deg} \\ (2527 \mathrm{~kg}\|98.8 \mathrm{~km} / \mathrm{h}\| 18.3 \mathrm{deg}) \\ \hline \end{gathered}$ | $\begin{gathered} 5,400 \mathrm{lb}\|60 \mathrm{mi} / \mathrm{h}\| 20 \mathrm{deg} \\ (2452 \mathrm{~kg}\|96.5 \mathrm{~km} / \mathrm{h}\| 20 \mathrm{deg}) \end{gathered}$ | Acceptable |
|  | 7069-29 | 6/5/92 | $\begin{gathered} 18,000 \mathrm{lb}\|51.6 \mathrm{mi} / \mathrm{h}\| 14.6 \mathrm{deg} \\ (8172 \mathrm{~kg}\|83.0 \mathrm{~km} / \mathrm{h}\| 14.6 \mathrm{deg}) \end{gathered}$ | $\begin{gathered} 18,000 \mathrm{lb}\|50 \mathrm{mi} / \mathrm{h}\| 15 \mathrm{deg} \\ (8172 \mathrm{~kg}\|80.5 \mathrm{~km} / \mathrm{h}\| 15 \mathrm{deg}) \\ \hline \end{gathered}$ | Acceptable |

## Oregon Thrie-Beam Transition

Test Number 7069-27

| Vehicle: | 1983 Honda Civic |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,970 \mathrm{lb}(894 \mathrm{~kg})$ |
| Impact Speed: | $51.6 \mathrm{mi} / \mathrm{h}(83.0 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 19.9 deg |

At 0.017 s after impact the bumper of the vehicle began to shift to the right, and at 0.029 s the front of the vehicle began to deform to the right. The vehicle began to redirect at 0.050 s after impact, and at the same time the vehicle contacted post 1 . By 0.133 s the vehicle was traveling parallel to the transition at a speed of $44.9 \mathrm{mi} / \mathrm{h}(72.2 \mathrm{~km} / \mathrm{h})$, and at 0.150 s the rear of the vehicle impacted the transition at the post 2 location. At 0.176 s the dummy's shoulder shattered the window glass on the driver side. The vehicle lost contact with the transition at 0.245 s traveling at $44.3 \mathrm{mi} / \mathrm{h}(71.3 \mathrm{~km} / \mathrm{h})$ and 9.1 degrees. The vehicle was in contact with the transition for $9.0 \mathrm{ft}(2.7 \mathrm{~m})$. The brakes were applied at 1.4 $s$ after impact and subsequently stopped ( 32 m ) from the point of impact, resting against another barrier.

The transition received minimal damage (figure 85). Maximum lateral permanent deformation was 0.5 in ( 13 mm ).

The vehicle sustained damage to the left side as shown in figure 8. Maximum crush at the left front corner at bumper height was 8.0 in ( 203 mm ), and the driver door was deformed outward approximately 8.0 in ( 203 mm ). The driver side window was broken out and the door was jammed. Also, damage was done to the front bumper, hood, grill, left front quarter panel, left rear quarter panel, and left front tire and rim.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of transition components into the occupant compartment. The vehicle remained upright and relatively stable during the collision. The transition redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was $7.3 \mathrm{mi} / \mathrm{h}(11.7 \mathrm{~km} / \mathrm{h})$. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged acceptable, as indicated in figure 86 and table 37.


Figure 85. Vehicle and transition for test 7069-27.

0.000 s

-

0.143 s


0.250 s



Test
Date
7069-27
Date . . . . . . . . . . 06/16/92
Test Installation . . . Oregon Thrie-beam
Installation Length . . $85 \mathrm{ft}(26 \mathrm{~m})$
Test Vehicle . . . . . . 1983 Honda Civic
Vehicle Weight
Test Inertia. . . . . . 1,800 lb (817 kg)
Gross Static . . . . . 1,970 1b (894 kg)
Vehicle Damage Classification
TAD . . . . . . . . . 11LFQ4 \& 11LD1
CDC . . . . . . . . . 11FLEK2 \& 11LDEW3
Maximum Vehicle Crush . 8.0 in ( 203 mm )

> Impact Speed. . . . $51.6 \mathrm{mi} / \mathrm{h}(83.0 \mathrm{~km} / \mathrm{h})$ Impact Angle. . . . 19.9 deg
> Speed at Paralle1 . $44.9 \mathrm{mi} / \mathrm{h}(72.2 \mathrm{~km} / \mathrm{h})$ Exit Speed . . . . $44.3 \mathrm{mi} / \mathrm{h}(71.3 \mathrm{~km} / \mathrm{h})$
> Exit Trajectory . . 9.1 deg
> Vehicle Accelerations
> (Max. 0.050-sec Avg) at true c.g.
> Longitudinal. . . -5.3 g
> Lateral . . . . .-10.9 g
> Occupant Impact Velocity at true c.g.
> Longitudinal. . . $13.1 \mathrm{ft} / \mathrm{s}(4.0 \mathrm{~m} / \mathrm{s})$
> Lateral . . . . $23.7 \mathrm{ft} / \mathrm{s}(7.2 \mathrm{~m} / \mathrm{s})$
> Occupant Ridedown Accelerations
> Longitudinal . . 1.0 g
> Lateral . . . . . -9.6 g

Figure 86. Summary of results for test 7069-27.

Table 37. Evaluation of crash test no. 7069-27. \{Oregon transition [1,800 $1 \mathrm{~b}(817 \mathrm{~kg})|51.6 \mathrm{mi} / \mathrm{h}(83.0 \mathrm{~km} / \mathrm{h})| 19.9$ degrees $\}$

CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle

Vehicle was contained Pass
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle

| TEST RESULTS | PASS/FAIL* |
| :--- | :---: |
| Vehicle was contained | Pass |
| No debris penetrated passenger <br> compartment | Pass |
| No deformation | Pass |

F. Effective coefficient of friction
$\frac{\mu}{0-.25}$
$.26-.35$
$\frac{\text { Assessment }}{\text { Good }}$
Fair
Marginal


Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |


| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $13.1(4.0)$ | $23.7(7.2)$ |

Pass 30 (9.2)

Vehicle did remain upright
Pass
Vehicle was smoothly redirected Pass

Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$
$\frac{\text { Occupant Ridedown Accelerations - } \mathrm{g}^{\prime} \mathrm{s}}{\text { Longitudinal }}$
Longitudinal
Lateral
15
15
H. Exit angle shall be less than 12 degrees

Exit angle was 9.1 degrees

* A, B, C, D and G are required. E, F, and H are desired. (See table l)

| Vehicle: | 1985 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,400 \mathrm{lb}(2452 \mathrm{~kg})$ |
| Gross Static Weight: | $5,565 \mathrm{lb}(2527 \mathrm{~kg})$ |
| Impact Speed: | $47.7 \mathrm{mi} / \mathrm{h}(76.7 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 19.0 deg |

The vehicle began to redirect at 0.062 s after impact, and at 0.129 the right front tire left the roadway. By 0.192 s the vehicle was traveling parallel to the transition at a speed of $45.5 \mathrm{mi} / \mathrm{h}(73.2 \mathrm{~km} / \mathrm{h})$, and at 0.205 s the rear of the vehicle impacted the transition. The transition reached a maximum deflection of 0.9 ft at 0.271 s after impact, and the right rear wheel lost contact with the roadway at 0.298 s . The vehicle lost contact with the transition at 0.370 s traveling at $42.8 \mathrm{mi} / \mathrm{h}(68.9 \mathrm{~km} / \mathrm{h})$ and 8.9 degrees. The vehicle was in contact with the transition for $14.0 \mathrm{ft}(4.3 \mathrm{~m})$. The right side of the vehicle regained contact with the roadway at 0.576 s . The brakes were applied at 1.5 s after impact and subsequently came to rest $285 \mathrm{ft}(87 \mathrm{~m})$ down from and $98 \mathrm{ft}(30 \mathrm{~m})$ in front of the point of impact.

The transition received minimal damage (figure 87). Maximum lateral permanent deformation was 3.5 in ( 89 mm ).

The vehicle sustained damage to the left side (figure 87). Maximum crush at the left front corner at bumper height was 8.0 in ( 203 mm ), and the driver door was deformed outward approximately 1.0 in ( 25 mm ). The frame was bent and the cab was deformed. The driver side window was broken out and the door was jammed. Also, damage was done to the front bumper, hood, grill, left front quarter panel, left rear quarter panel, rear bumper, and left front tire and rim.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of railing components into the occupant compartment. The vehicle remained upright and relatively stable during the collision. The transition redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was $4.9 \mathrm{mi} / \mathrm{h}(7.9 \mathrm{~km} / \mathrm{h})$. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged acceptable, as indicated in figure 88 and table 38.


Figure 87. Vehicle and transition for test 7069-28.


Table 38. Evaluation of crash test no. 7069-28. \{Oregon transition [5,400 $\mathrm{lb}(2452 \mathrm{~kg})|47.7 \mathrm{mi} / \mathrm{h}(76.7 \mathrm{~km} / \mathrm{h})| 19.0$ degrees] \}
$\qquad$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle

Vehicle was contained
Pass
B. Debris shall not penetrate

No debris penetrated passenger
Pass passenger compartment compartment
C. Passenger compartment must have

No deformation Pass essentially no deformation
D. Vehicle must remain upright

Vehicle did remain upright
Pass
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
Pass
F. Effective coefficient of friction

| $\mu$ | Assessment |
| :---: | :---: |
| 0-. 25 | Good |
| . $26-.35$ | Fair |
| > . 35 | Marginal |

$\frac{\mu}{02} \quad$ Assessment
Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |

$\begin{array}{cc}\text { Occupant Ridedown Accelerations }-\mathrm{g}^{\prime} \mathrm{s} \\ \text { Longitudinal } & \text { Lateral } \\ 15 & 15\end{array}$
H. Exit angle shall be less than 12 degrees

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $7.2(2.2)$ | $16.2(4.9)$ |$\quad$ Pass



Exit angle was 8.9 degrees Pass

* $A, B, C$, and $D$ are required. $E, F, G$, and $H$ are desired. (See table 1)


## 32-in (813-mm) Thrie-Beam Transition

## Test Number 7069-19

| Vehicle: | 1983 Honda Civic |
| :--- | :--- |
| Test Inertia Weight: | $1,800 \mathrm{lb}(817 \mathrm{~kg})$ |
| Gross Static Weight: | $1,970 \mathrm{lb}(894 \mathrm{~kg})$ |
| Impact Speed: | $60.5 \mathrm{mi} / \mathrm{h}(97.3 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 19.9 deg |

The vehicle impacted the transition approximately $0.4 \mathrm{ft}(0.1 \mathrm{~m})$ down from post 2 . The vehicle began to redirect at 0.030 s after impact. At approximately 0.050 s the vehicle began to deform at the A-pillar, and at 0.088 s the door glass shattered. By 0.137 s the vehicle was traveling parallel to the transition at a speed of $51.0 \mathrm{mi} / \mathrm{h}(82.1 \mathrm{~km} / \mathrm{h})$, and at the same time the rear of the vehicle impacted the transition. The vehicle lost contact with the transition at 0.219 s traveling at $47.7 \mathrm{mi} / \mathrm{h}(76.7 \mathrm{~km} / \mathrm{h})$ and 6.9 degrees. The vehicle was in contact with the transition for $8.5 \mathrm{ft}(2.6 \mathrm{~m})$. The brakes were applied, the vehicle yawed clockwise, and it subsequently came to rest $240 \mathrm{ft}(73 \mathrm{~m})$ down and $100 \mathrm{ft}(30 \mathrm{~m})$ in front of the point of impact.

The transition received minor damage, most of which was cosmetic in nature (figure 89). Maximum lateral deformation was 0.5 in $(13 \mathrm{~mm})$ at the post 2.

The vehicle sustained damage to the left side (figure 89). Maximum crush at the left front corner at bumper height was 11.0 in ( 279 mm ). The strut and constant velocity joint on the left side were damaged and the roof was bent. The left front wheel was canted inward at the bottom and pushed back into the fender well. The left side window was broken out by the dummy's head. Also, damage was done to the front bumper, hood, grill, radiator and fan, left front quarter panel, left door, left rear quarter panel, and left rear tire and rim.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion into the occupant compartment with minimal (but acceptable) deformation of the passenger compartment. The vehicle remained upright and relatively stable during the collision. The transition smoothly redirected the vehicle and the effective coefficient of friction was considered fair. The lateral occupant impact velocity of $25.9 \mathrm{ft} / \mathrm{s}$ ( $7.9 \mathrm{~m} / \mathrm{s}$ ) in this test did not meet with the AASHTO specifications. The longitudinal occupant impact velocity and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged acceptable, as indicated in figure 90 and table 39.


Figure 89. Vehicle and transition for test 7069-19.


Table 39. Evaluation of crash test no. 7069-19.
$\{32-$ in $(813-\mathrm{mm})$ thrie-beam transition $[1,8001 \mathrm{~b}(817 \mathrm{~kg})|60.5 \mathrm{mi} / \mathrm{h}(97.3 \mathrm{~km} / \mathrm{h})| 19.9$ degrees $]\}$
CRITERIA
TEST RESULTS
PASS/FAIL*
A. Must contain vehicle

Vehicle was contained Pass
B. Debris shall not penetrate

No debris penetrated passenger Pass passenger compartment
compartment
C. Passenger compartment must have

Acceptable deformation
Pass essentially no deformation

Vehicle did remain upright
D. Vehicle must remain upright

Vehicle was smoothly redirected
F. Effective coefficient of friction

| $\frac{\mu}{0-.25}$ |  |
| :--- | :--- |
| Assessment  <br> $.26-.35$ Good <br> $>.35$  <br>  Mairginal Mar |  |

$\frac{\mu}{.29} \quad \frac{\text { Assessment }}{\text { Fair }}$
G. Shall be less than

| Occupant Impact Velocity - ft/ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| 30 (9.2) | 25 (7.6) |
| Occupant Ridedown Accelerations - g |  |
| Longitudinal | Lateral |
| 15 | 15 |


H. Exit angle shall be less than 12 degrees

Exit angle was 6.9 degrees

* $A, B, C, D$ and $G$ are required. $E, F$, and $H$ are desired. (See table 1)

| Vehicle: | 1981 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia; | $5,400 \mathrm{lb}(2452 \mathrm{~kg})$ |
| Gross Static Weight: | $5,570 \mathrm{lb}(2529 \mathrm{~kg})$ |
| Impact Speed: | $62.7 \mathrm{mi} / \mathrm{h}(100.9 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 19.0 deg |

The vehicle impacted the transition approximately $7 \mathrm{ft}(2.1 \mathrm{~m})$ upstream from the end of the concrete parapet (figure 91). The vehicle began to redirect at 0.022 s after impact. At approximately 0.103 s the left door began to come open, and at 0.135 s the front edge of the door began to peel away from the hinges. By 0.204 s the vehicle was traveling parallel to the transition at a speed of $46.8 \mathrm{mi} / \mathrm{h}(75.3 \mathrm{~km} / \mathrm{h})$, and at the same time the rear of the vehicle impacted the transition. Maximum lateral deflection of $0.9 \mathrm{ft}(0.3 \mathrm{~m})$ occurred at 0.231 s . The vehicle lost contact with the transition at 0.308 s traveling at $41.9 \mathrm{mi} / \mathrm{h}(67.4$ $\mathrm{km} / \mathrm{h}$ ) and 9.0 degrees. The vehicle was in contact with the transition for $8.5 \mathrm{ft}(2.6 \mathrm{~m})$. The brakes were applied, the vehicle yawed counter-clockwise, and it subsequently came to rest $135 \mathrm{ft}(41 \mathrm{~m})$ down from the point of impact.

The transition received moderate damage (figure 92). Maximum lateral deformation was 6.5 in ( 165 mm ).

The vehicle sustained damage to the left side (figure 92). Maximum crush at the left front corner at bumper height was 22.0 in ( 559 mm ). The sway bar and upper and lower control arm on the left side were damaged and the roof was bent. The left front wheel was canted inward at the bottom and pushed back into the fender well. The left side window was broken out. The door was separated from the vehicle and remained affixed to the transition at the terminal connector. Also, damage was done to the front bumper, hood, grill, radiator and fan, left front quarter panel, left rear quarter panel, and left rear tire and rim.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of railing components into the occupant compartment; however, the door was detached from the vehicle and remained lodged on the railing. The vehicle remained upright and relatively stable during the collision. The transition redirected the vehicle but the effective coefficient of friction was quite high. Velocity change of the vehicle during the collision was $20.8 \mathrm{mi} / \mathrm{h}$. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged unacceptable, as indicated in figure 93 and table 40.


Figure 91. Vehicle and transition before test 7069-20.


Figure 92. Vehicle and transition after test 7069-20.

$1 \mathrm{in}=25.4 \mathrm{~mm}$ $1 \mathrm{ft}=0.305 \mathrm{~m}$

Figure 93. Summary of results for test 7069-20.

Table 40. Evaluation of crash test no. 7069-20.
$\{32-$ in $(813-\mathrm{mm})$ thrie-beam transition $[5,400 \mathrm{lb}(2452 \mathrm{~kg})|62.7 \mathrm{mi} / \mathrm{h}(100.9 \mathrm{~km} / \mathrm{h})| 19.0$ degrees $]\}$
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction
$\qquad$
Vehicle was contained Pass
No debris penetrated passenger Pass compartment

Moderate deformation Fail
Door detached
Vehicle did remain upright Pass
Vehicle was smoothly redirected Pass
$\frac{\mu}{.61} \quad \frac{\text { Assessment }}{\text { Marginal }}$
Fail
Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$
Longitudinal
Lateral
$19.3(5.9)$
$17.3(5.3)$
Occupant Ridedown Accelerations - $g^{\prime} s \quad$ Pass

Longitudinal Lateral
$-5.4$
$-13.0$

Exit angle was 6.9 degrees
Pass
Pass
H. Exit angle shall be less than 12 degrees


| Occupant Ridedown Accelerations - $\mathrm{g}^{\prime} \mathrm{s}$ |
| :---: |
| Longitudinal |
| 15 |


G. Shall be less than

* $A, B, C$, and $D$ are required. $E, F, G$, and $H$ are desired. (See table 1)

Test Number 7069-21

| Vehicle: | 1984 Chevrolet Pickup |
| :--- | :--- |
| Test Inertia Weight: | $5,400 \mathrm{lb}(2452 \mathrm{~kg})$ |
| Gross Static Weight: | $5,565 \mathrm{bb}(2527 \mathrm{~kg})$ |
| Impact Speed: | $61.4 \mathrm{mi} / \mathrm{h}(98.8 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 18.3 deg |

[NOTE: For tests 7069-21 and 29, the modified terminal connector was used.]
The vehicle impacted the transition 25 in ( 635 mm ) upstream of post 2 (figure 94). The vehicle began to redirect at 0.026 s after impact, and at 0.042 s the vehicle contacted post 1. Maximum lateral deflection of $0.8 \mathrm{ft}(0.3 \mathrm{~m})$ occurred at 0.060 s . At approximately 0.070 s the vehicle impacted the end of the concrete parapet. The left front wheel snagged on the end of the parapet at 0.099 s causing a severe steering input to the vehicle and the passenger side of the vehicle became airborne. At approximately 0.110 s the windshield shattered, and at 0.140 s the door glass on the driver's side was broken by the dummy's head. By 0.178 s the vehicle was traveling parallel to the transition at a speed of $50.3 \mathrm{mi} / \mathrm{h}$ $(80.9 \mathrm{~km} / \mathrm{h})$, and at 0.188 s the rear of the vehicle impacted the transition. At 0.210 s the dummy's head was at its maximum distance outside the vehicle (approximately 16 in (406 mm ). The tailgate of the vehicle came loose at 0.267 s and, as the vehicle continued forward, the tailgate came off and traveled with the vehicle. The vehicle lost contact with the transition at 0.314 s traveling at $50.0 \mathrm{mi} / \mathrm{h}(80.5 \mathrm{~km} / \mathrm{h})$ and 8.2 degrees. The vehicle was in contact with the transition for $14.0 \mathrm{ft}(4.2 \mathrm{~m})$. The dummy's head impacted against the outside of the door of the vehicle as it was re-entering the vehicle at 0.440 s . The brakes were applied as the vehicle left the installation and subsequently came to rest $195 \mathrm{ft}(41 \mathrm{~m})$ from the point of impact.

The transition received moderate damage (figure 95). Maximum lateral permanent deformation was 5.0 in ( 127 mm ).

The vehicle sustained damage to the left side (figure 95). Maximum crush at the left front corner at bumper height was 15.0 in ( 381 mm ) and the right front corner was deformed outward approximately $4.75 \mathrm{in}(121 \mathrm{~mm})$. The sway bar and A-arms on the left side and gas tank were damaged, and the drive shaft, frame, and roof were bent. The floor pan was pushed into the occupant compartment approximately 5 to 7 in ( 130 to 180 mm ) and the dash moved inward approximately 3 in ( 80 mm ). The left front wheel was canted inward at the bottom and pushed back into the fender well reducing the wheelbase on the driver side by 14.0 in ( 356 mm ). The driver side window was broken out and the door was jammed. Also, damage was done to the front bumper, hood, grill, radiator and fan, left front quarter panel, left rear quarter panel, and left rear tire and rim. The tailgate came off the vehicle during the test.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of railing components into the occupant compartment; however, the floor pan was deformed into the vehicle approximately 5 to 7 in (130 to 180 mm ) and the instrument panel was pushed inward approximately 3 in ( 80 mm ). The vehicle remained


Figure 94. Vehicle and transition before test 7069-21.


Figure 95. Vehicle and transition after test 7069-21.
upright and relatively stable during the collision. The transition redirected the vehicle but the effective coefficient of friction was quite high. Velocity change of the vehicle during the collision was $11.1 \mathrm{mi} / \mathrm{h}(17.9 \mathrm{~km} / \mathrm{h})$. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged marginally acceptable, as indicated in figure 96 and table 41.


Figure 96. Summary of results for test 7069-21.

Table 41. Evaluation of crash test no. 7069-21.
$\{32-\mathrm{in}(813-\mathrm{mm})$ thrie-beam transition $[5,400 \mathrm{lb}(2452 \mathrm{~kg})|61.4 \mathrm{mi} / \mathrm{h}(98.8 \mathrm{~km} / \mathrm{h})| 18.3$ degrees $]\}$
$\qquad$
A. Must contain vehicle
B. Debris shall not penetrate passenger compartment
C. Passenger compartment must have essentially no deformation
D. Vehicle must remain upright
E. Must smoothly redirect the vehicle
F. Effective coefficient of friction

| TEST RESULTS |  |
| :--- | :---: |
| Vehicle was contained | Pass |
| No debris penetrated passenger <br> compartment | Pass |
| Moderate deformation <br> (approx. 5-7 in at floorpan) | Fail |
| Vehicle did remain upright | Pass |
| Vehicle was smoothly redirected | Pass |

$\frac{\mu}{.41} \quad \frac{\text { Assessment }}{\text { Marginal }}$

Pass
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Lateral |
| $30(9.2)$ | $25(7.6)$ |

$\frac{\text { Occupant Ridedown Accelerations }-\mathrm{g}^{\prime} \mathrm{s}}{\text { Longitudinal }} \frac{\text { Lateral }}{15}$
H. Exit angle shall be less than 12 degrees


Exit angle was 8.2 degrees
Pass

* $A, B, C$, and $D$ are required. $E, F, G$, and $H$ are desired. (See table 1)

| Vehicle: | 1981 Ford Single-Unit Truck |
| :--- | :--- |
| Test Inertia Weight: | $18,000 \mathrm{lb}(8172 \mathrm{~kg})$ |
| Empty Weight: | $10,790 \mathrm{lb}(4899 \mathrm{~kg})$ |
| Impact Speed: | $51.6 \mathrm{mi} / \mathrm{h}(83.0 \mathrm{~km} / \mathrm{h})$ |
| Impact Angle: | 14.6 deg |

The vehicle impacted the transition $11 \mathrm{ft}(3.4 \mathrm{~m})$ upstream from the end of the concrete parapet. At 0.071 s after impact the front wheels received a steer input to the left, and the vehicle began to redirect at 0.118 s after impact. At 0.155 s the vehicle contacted the end of the concrete parapet, and at 0.226 s a severe steer input to the vehicle occurred. By 0.262 s the vehicle was traveling parallel to the transition at a speed of $48.9 \mathrm{mi} / \mathrm{h}(78.7$ $\mathrm{km} / \mathrm{h}$ ), and at 0.341 s the rear of the vehicle impacted the transition. The vehicle lost contact with the terminal connector at 0.585 s ; however, the van-box remained in contact with the top of the concrete parapet until 1.718 s after impact. Total length of contact with the transition was $18.5 \mathrm{ft}(5.6 \mathrm{~m})$ As the vehicle continued forward, it began to yaw clockwise and roll counterclockwise. The brakes were applied at 2.5 s after impact and the vehicle subsequently came to rest on its left side $165 \mathrm{ft}(50 \mathrm{~m})$ down and $45 \mathrm{ft}(14 \mathrm{~m})$ in front of the point of impact.

The transition received moderate damage (figure 97). Maximum lateral permanent deformation to the transition was 10.0 in ( 254 mm ). The end of the concrete parapet where the terminal connector attached was cracked.

The vehicle sustained damage to the left side. Maximum crush at the left front corner at bumper height was 13.0 in ( 330 mm ). The floor pan was pushed inward and the cab was bent and twisted. The windshield and rear glass were broken. The frame at the rear axle was bent and the van-box was twisted and torn. The driver side window was broken out and the door was jammed. Also, damage was done to the front bumper, hood, left front quarter panel, and outer left rear tire and rim. The right door was also jammed.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of railing components into the occupant compartment; however, the floor pan was slightly deformed into the vehicle. The vehicle remained upright and relatively stable during the collision; however, after exiting the test installation the vehicle rolled onto its left side $45 \mathrm{ft}(14 \mathrm{~m})$ forward of the transition. The transition redirected the vehicle with the effective coefficient of friction rated as good. The vehicle trajectory at loss of contact indicated some intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged acceptable, as indicated in figure 98 and table 42.


Figure 97. Vehicle and transition for test 7069-29.


Figure 98. Summary of results for test 7069-29.

Table 42. Evaluaiton of crash test no. 7069-29.
$\{32-\mathrm{in}(813-\mathrm{mm})$ thrie-beam transition $[18,000 \mathrm{lb}(8172 \mathrm{~kg})|51.6 \mathrm{mi} / \mathrm{h}(83.0 \mathrm{~km} / \mathrm{h})| 14.6$ degrees $]\}$
$\qquad$

| TEST RESULTS |  | PASS/FAIL* |
| :--- | :---: | :---: |
| Vehicle was contained | Pass |  |
| No debris penetrated passenger <br> compartment | Pass |  |
| Minimal deformation | Pass |  |

D. Vehicle must remain upright

Vehicle remained upright during test. N/A Rolled after exiting test site.
E. Must smoothly redirect the vehicle

Vehicle was smoothly redirected
F. Effective coefficient of friction

| $\mu$ | Assessment |
| :---: | :---: |
| 0-. 25 | Good |
| . 26 - . 35 | Fair |
| > . 35 | Marginal |

$\frac{\text { Assessment }}{\text { Good }} \quad$ N/A
G. Shall be less than

| Occupant Impact Velocity $-\mathrm{ft} / \mathrm{s}(\mathrm{m} / \mathrm{s})$ |  |
| :---: | :---: |
| Longitudinal | Latera1 |
| $30(9.2)$ | $25(7.6)$ |


H. Exit angle shall be less than 12 degrees

Exit angle was 11 degrees N/A

* $A, B$, and $C$ are required. $D, E, F$, and $H$ are desired. (See table 1)


## CHAPTER 7. SUMMARY OF STATIC LOAD TESTS OF THRIE- AND W-BEAM TERMINAL CONNECTORS

In some railing/transition designs, more than two thicknesses of thrie- or W-beam are lapped together. One common situation where this occurs is where a double thickness of rail element is bolted to a terminal connector. The three thicknesses of material cannot be bolted together if conventional hole patterns are used. A proposed remedy for this problem is to provide slotted holes in the terminal connector with the holes slanted at about 45 degrees to the longitudinal axis of the connector. Such a hole pattern allows the three layers to be bolted together, but the strength of such a terminal connector was questioned.

Static axial load tension tests were performed on several thrie- and W-beam terminal connectors (figure 99) to determine their strengths and failure modes. The results are summarized in table 43 and additional details are presented in appendix $M$.


SAMPLE 1
Manufacturer \#1
Thickness $=10$ gauge
Splice slots - $1^{\prime \prime} \times{ }^{\circ}$


SAMPLES 2-3-4-6
Manufacturer \#2
Thickness $=12$ gauge
Splice slots - $1^{n} \times 17 / 8^{n}$


SAMPLE 5
Manufacturer \#3
Thickness $=10$ gauge
Splice slots - 29/32"X 1 1/8"


SAMPLE 7
Manufacturer \#2
Thickness $=10$ gauge
Splice slots - $1^{1 \times} \times 17 / 8^{\prime \prime}$

$$
1 \mathrm{in}=25.4 \mathrm{~mm}
$$

Figure 99. Terminal connector test specimens.


SAMPLES 8-9
Manufacturer \# ${ }^{\#}$
Thickness $=10$ gauge
Splice slots - $1^{\prime \prime} \times 3^{\circ}$

SAMPLES 10-11
Manufacturer \#2
Thickness $=12$ gauge
Splice slots - $1^{\circ} \times 1$ /8́



SAMPLE 12
Manufacturer ${ }^{2} 2$
Thickness $=12$ gauge
Splice slots - $1^{n} \times 3^{3}$


SAMPLES 13-14-15
Manufacturer \#2
Thickness $=10$ gauge
Splice slots - $1^{+1 \times 1} 17 / \mathbb{B n}^{n}$
$1 \mathrm{in}=25.4 \mathrm{~mm}$

Figure 99. Terminal connector test specimens. (continued)

Table 43. Ultimate loads and properties of $\mathbf{W}$-beam and thrie-beam terminal connectors.

| SAMPLE NO. | MANUFACTURER | MODEL | HOLE PATTERN | THICKNESS | NO. HOLES | ULTIMATE LOAD |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | NUMBER ONE | THRIE-BEAM | ST. LONG SLOTS | 10 GAUGE | $5^{1}$ | 95.9 KIPS ( 426.6 kN ) |
| 2 | NUMBER TWO | THRIE-BEAM | ANGLED SLOTS | 12 GAUGE | $9^{2}$ | 132.6 KIPS ( 589.8 kN ) |
| 3 | NUMBER TWO | THRIE-BEAM | ANGLED SLOTS | 12 GAUGE | $9^{2}$ | 126.9 KIPS ( 564.5 kN ) |
| 4 | NUMBER TWO | THRIE-BEAM | ANGLED SLOTS | 12 GAUGE | $9^{2}$ | 133.7 KIPS ( $594.7 \mathrm{kN} \mathrm{)}$ |
| 5 | NUMBER THREE | THRIE-BEAM | ST. SHORT SLOTS | 10 GAUGE | $5^{1}$ | 116.7 KIPS ( 519.1 kN ) |
| 6 | NUMBER TWO | THRIE-BEAM | ANGLED SLOTS | 12 GAUGE | $9^{1}$ | 83.3 KIPS ( $370.5 \mathrm{kN} \mathrm{)}$ |
| 7 | NUMBER TWO | THRIE-BEAM | ANGLED SLOTS | 10 GAUGE | $9^{1}$ | ${ }^{4}$ |
| 8 | NUMBER ONE | THRIE-BEAM | ST. LONG SLOTS | 10 GAUGE | $7^{1}$ | 93.8 KIPS (417.2 kN) |
| 9 | NUMBER ONE | THRIE-BEAM | ST. LONG SLOTS | 10 GAUGE | $7{ }^{1}$ | 87.7 KIPS ( $390.1 \mathrm{kN} \mathrm{)}$ |
| 10 | NUMBER TWO | W-BEAM | ANGLED SLOTS | 12 GAUGE | $4^{3}$ | 65.9 KIPS ( 293.1 kN ) |
| 11 | NUMBER TWO | W-BEAM | ANGLED SLOTS | 12 GAUGE | $4^{3}$ | 66.4 KIPS ( 295.4 kN ) |
| 12 | NUMBER TWO | W-BEAM | ST. LONG SLOTS | 12 GAUGE | $4^{3}$ | 71.1 KIPS ( $316.3 \mathrm{kN} \mathrm{)}$ |
| 13 | NUMBER TWO | THRIE-BEAM | ANGLED SLOTS | 10 GAUGE | $9^{1}$ | 102.4 KIPS ( 455.5 kN ) |
| 14 | NUMBER TWO | THRIE-BEAM | ANGLED SLOTS | 10 GAUGE | $9^{1}$ | 99.3 KIPS (441.7 kN) |
| 15 | NUMBER TWO | THRIE-BEAM | ANGLED SLOTS | 10 GAUGE | 91 | $101.8 \mathrm{KIPS}(452.8 \mathrm{kN})$ |

NOTES:

1. Terminal connectors tested with 5 -SAE Grade $8,7 / 8-\mathrm{in}(22-\mathrm{mm})$ bolts at the flat section.
2. Terminal connectors tested with 7 -SAE Grade $8,7 / 8-\mathrm{in}(22-\mathrm{mm})$ bolts and 2-SAE Grade $8,3 / 4-\mathrm{in}(19-\mathrm{mm})$ bolts at the flat section.
3. Terminal connectors tested with 4 -SAE Grade $8,7 / 8-\mathrm{in}(22-\mathrm{mm})$ bolts at the flat section.
4. Sample 7 was used in crash test 7069-29.

## CHAPTER 8. SUMMARY AND CONCLUSIONS

Bridge railing designs that satisfy requirements for each of three performance levels called for in the 1989 Guide Specifications for Bridge Railings have been designed, tested, and evaluated. ${ }^{(3)}$ Three railing designs for performance level one, seven railing designs for performance level two, three railing designs for performance level three, a transition for performance level one, and a transition for performance level two have been designed, tested, and evaluated.

Recommended design criteria for each of the three performance levels have been set forth and were used in analyzing the railings evaluated herein. The criteria include magnitude, distribution, and location of collision forces in addition to geometric requirements for various impact conditions. The recommended forces with no factor of safety (i.e., load factor $=1.0$ ) are used in ultimate strength analysis procedures. Railings designed by this procedure have been found to be generally adequate and have shown little or no structural distress in full-scale crash tests.

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[^0]:    Sil is the symbol for the international System of Units. Appropriate

[^1]:    $1 \mathrm{in}=25.4 \mathrm{~mm}$
    $1 \mathrm{ft}=0.305 \mathrm{~m}$

[^2]:    $1 \mathrm{in}=25.4 \mathrm{~mm}$
    $1 \mathrm{ft}=0.305 \mathrm{~m}$

[^3]:    $1 \mathrm{in}=25.4 \mathrm{~mm}$
    $1 \mathrm{ft}=0.305 \mathrm{~m}$

[^4]:    * $A, B, C$, are required. $D, E, F$, and $H$ are desired. $G$ is not applicable for this test. (See table 1)

[^5]:    $1 \mathrm{in}=25.4 \mathrm{~mm}$

[^6]:    * $A, B, C$, and $D$ are required. $E, F$, and $H$ are desired. $G$ is not applicable for this test. (See table l)

[^7]:    $1 \mathrm{in}=25.4 \mathrm{~mm}$

