Dynamic Full-Scale Impact Tests of Bridge Barrier Rails

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Five full-scale dynamic impact tests were made on two basic geometric designs and one trial design of bridge barrier rails.

The three geometric designs included a standard California Type 1, a standard California Type 2, and an experimental modified Type 1 bridge barrier rail (Exhibit 1). Each was tested utilizing extruded aluminum pipe rail and cast aluminum posts mounted on a concrete parapet. The concrete parapet used for the aforementioned Type 1 test was repaired and the rail design was modified for two additional tests, one with steel pipe railing on welded steel plate posts (Type 1-A) and one with extruded aluminum pipe railing on malleable iron posts (Type 1-B).

This report describes the test procedures, instrumentation and test results based on the data secured from five high-speed oblique angle impacts on the five bridge barrier rail designs.

The test results indicated that all of the bridge barrier rails tested could effectively withstand the impact of a 4,300-lb passenger vehicle at speeds in excess of 75 mph. Minor cracking and spalling of the concrete portion of the Type 1 barrier was successfully repaired with epoxy/aggregate patches for use in two additional tests.

Specific recommendations are made for a balanced design bridge barrier rail system. (Exhibits are given in the Appendix).

•THE FIRST dynamic impact full-scale testing of bridge barrier rail systems was conducted by the State of California in 1955 (1). These bridge barrier rail tests were preceded by a preliminary test project in which 47 impact tests were conducted at various speeds and angles on 4 barrier curb designs with heights of from 9 to 12 in. The purpose of this preliminary test series was to evaluate the efficiency of various combinations of barrier curb faces and heights in retaining and deflecting a 50 to 60 mph impacting vehicle (2). Minimum curb height and face contour for the first bridge barrier rail designs were determined from the data recorded during these preliminary curb tests. The basic test procedures established during the 1955 test series have remained relatively constant over the past eight years and have also been used by other states, research organizations, and other countries as a basis for conducting similar studies of guardrails, barrier rails, and bridge barrier rails. A recently completed full-scale barrier test project conducted in England (3) using these test procedures produced excellent correlation with the results of the State of California's recent flexible barrier study.

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In 1958 California adopted two standard barrier-type railings (Exhibit 1A and B). The details of this railing evolved from data secured in the 1955 full-scale dynamic tests as well as actual operational experience with barrier prototypes (Exhibits 2 and 3A). The metal portion of the barrier prototypes consisted of posts and pipe welded together. This arrangement was found to be heavy and cumbersome and required special handling during shipping and erection. Prefabricated post castings with pipe rail attached by means of bolt fasteners alleviated these problems.

These modifications provided a more efficient and economical bridge rail system but did not reflect a radical departure from geometric features of the original prototype designs. These were considered more as a utilization of the various new materials, techniques and construction methods advanced by the Division of Highways and the industry during the ensuing years.

In 1959 and 1960 three additional designs submitted by the Bridge Department were dynamically tested (4). It was during this 1959-60 test series that the inadequacy of the existing baluster-type rail in retaining a moderately high-speed vehicle was confirmed (Exhibit 3B). By comparing the test results from this 1959 series with those of the 1955 series, it was apparent that a solid, non-yielding smooth-wall barrier is more efficient and effective than a barrier containing balusters or any other type of opening that would trap the solid portions of the impacting vehicle.

OBJECTIVES

The basic objectives of the latest (1963) dynamic impact series were as follows:

1. To test the overall effectiveness of the California standard bridge barrier rail (Tests B-1 and B-2);
2. To determine the difference in performance between two reinforced-concrete parapet heights (Tests B-2 and B-4);
3. To determine the effect a curb has on the point of impact at the parapet (Test B-1);
4. To rate the relative effectiveneness of various combinations of metals used in posts and rails (B-3 and B-5); and
5. Compile factual data that would be of use in updating the railing specifications contained in the 1961 edition of AASHO.

CONCLUSIONS

The operational efficiency of any bridge barrier rail system in effectively resisting a severe passenger vehicle impact can be summarized and evaluated on the basis of meeting the four structural conditions listed below:

1. The bridge barrier system should retain the vehicle on the structure. The impacting vehicle should not penetrate or climb over the barrier.
2. The impact should not dislodge any parts of the barrier system. Rails, posts, and concrete should remain intact and not break away and fall to the pavement or over the side of the structure.
3. While in contact with the bridge barrier, the vehicle should progress smoothly along the rail with a minimum of snagging on any part of the system or pocketing of the elements. The barrier system should be designed to resist any severe deflection that could contribute to a post-impact roll of the vehicle.
4. All elements of a barrier system should be so designed that if repairs are necessary to place a damaged section in operating condition, they can be effected quickly and with a minimum of special equipment.

Table 1 gives the results of the five bridge barrier tests in reference to these four conditions.

As a result of this test series, new design loading specifications have been adopted and a laboratory test method for a static load test of the barrier posts has been developed (Exhibits 4A and B). The malleable iron posts dynamically tested in this series are now being used on 1963 state contracts.

TABLE 1

RESULTS OF BRIDGE BARRIER TESTS

Item	Test No.				
	B-1	B-2	B-3	B-4	B-5
Barrier type	2	1	1-A	Modified 1	1-B
Railing material	Extruded aluminum pipe	Extruded aluminum pipe	Steel pipe	Extruded aluminum p pipe	Extruded aluminum pipe
Post material	Cast aluminum	Cast aluminum	Welded steel plate	Cast aluminum	Malleable iron
Retained by barrier	Yes	Yes	Yes	Yes	Yes
Elements dislodged	None	3 railing sections and 3 posts	None	None	None
Smooth progression	Good	Fair	Good	Good	Good
Dynamic horizontal deflection of pipe railing	3 in.	20 in. before failure	3½ in.	2 in.	6½ in.
Vehicle rise	2½ in.	12 in.	3 in.	3 in.	10 in.
Ease of repair	Good	Fair	Good	Good	Good

DISCUSSION

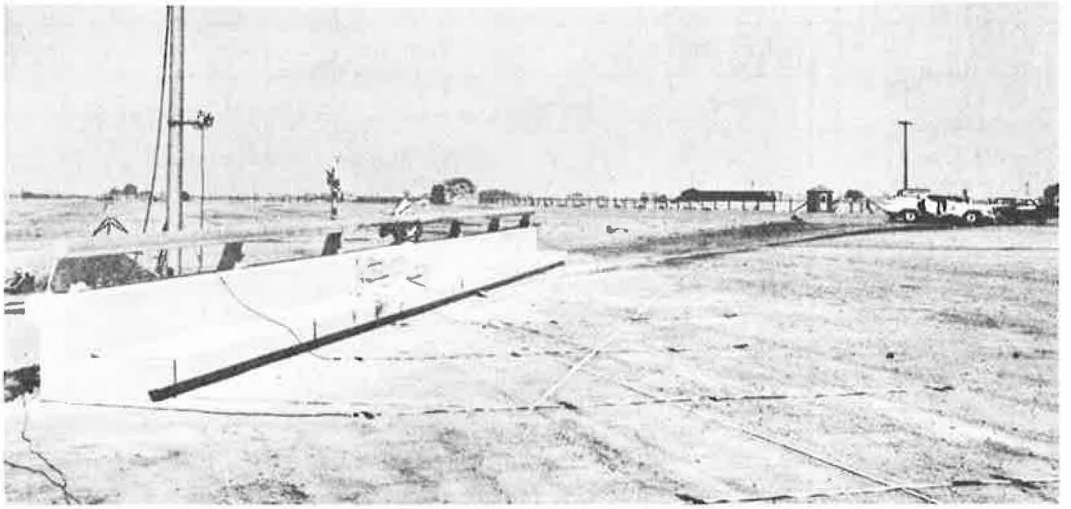
As indicated in the conclusions, the four basic conditions were met on all points by bridge barrier rail designs Type 2 and Type 1 modified. The Type 1-A design fulfilled all conditions to some degree and would be considered an effective design. The Type 1-B design was nearly as effective as the Type 1-A and utilized a more economical combination of post and railing materials.

The results of previous full-scale dynamic impact tests conducted at speeds below 60 mph proved that excessive deflection of a barrier system can result in post-impact roll-over (5). It is necessary to examine carefully the overall heights of the five barrier designs included in the 1963 study where the test vehicles impacted at speeds in excess of 75 mph. For example, it was noted that when the barrier parapet was of sufficient height to take a major portion of the impact load (barrier Type 2 and modified Type 1) there was no tendency for the impacting vehicle to climb. There was a tendency, however, for the vehicle to roll into contact with the modified Type 1 barrier due to severe deformation of the body and frame (Exhibit 12A).

At a parapet height of 28 in. these two barriers present smooth surfaces, well above the center of gravity of the impacting vehicle. However, even when the height of the concrete parapet was below the center of gravity of the vehicle, if the deflection of the posts and pipe railing was a minimum as in Test B-3 on the Type 1-A barrier, there was no tendency for the impacting vehicle to rise. When the parapet height was below the center of gravity of the vehicle and the pipe rail deflection was greater (as in Test B-5 on Type 1-B) or the posts failed (as in Test B-2 on Type 1), the vehicle had a tendency to climb. In the latter case where railing deflection was excessive, the vehicle almost vaulted the rail. However, other considerations such as sight distance, esthetics and cost also influence the overall design. It also should be realized that the impact forces applied during these tests represented the most severe to be reasonably encountered under normal operating conditions.

The following portion of the discussion is a detailed evaluation of the bridge barrier rail and vehicle performance in each of the five tests with reference to the four conditions outlined in the conclusions.

Test B-1 Type 2 Bridge Barrier Rail



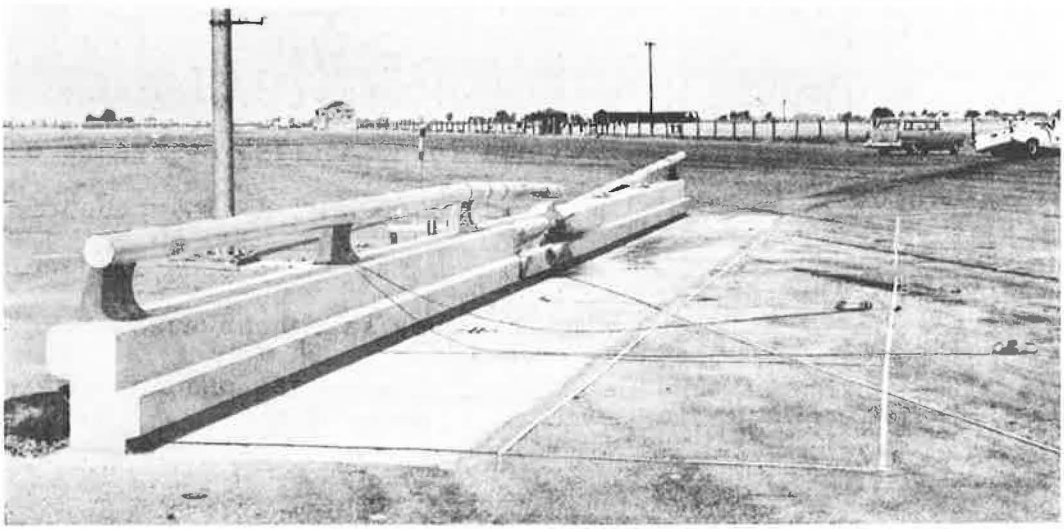
Bridge Rail: Standard Type 2 with aluminum posts and pipe railing. Height of concrete parapet: 28 in. Height of walkway: 10 in. Overall height of barrier: 43 in.

Purpose: To test the structural stability of the concrete parapet (as currently designed) in combination with aluminum posts and pipe railing, and to determine the jump that would be imparted to an impacting vehicle when crossing the two foot wide walkway at high speed and oblique angle.

Performance:

1. The vehicle did not penetrate the barrier rail. There was no evidence of rising even after crossing the walkway (Exhibit 5). However, it should be noted that previous tests (2) showed that there was a tendency to jump when the 10-in. high curb is struck at lower speeds and flatter angles.
2. All parts of the system remained intact. Damage to the concrete was minimal consisting of slight spalling and cracking.
3. There was a smooth progression of the vehicle through impact, even though the fender was torn from the body and lodged between the rail and parapet at the impact post (Exhibit 19).
4. Evidence of a slight spalling and scraping of the concrete was confined to the immediate impact area. Cracking occurred at the junction of the backwall and the walkway. The web of the first post contacted was ripped its entire length adjacent to the base. One section of the aluminum pipe railing was slightly gouged by the vehicle fender and was bent approximately 2 inches (Exhibit 6).

Test B-2 Type 1 Bridge Barrier Rail



Bridge Rail: Standard Type 1 with aluminum posts and pipe railing. Height of concrete: 21 in. Overall height of barrier: 36 in.

Purpose: To test the current design for structural stability of the concrete and aluminum railing element combination.

Performance:

1. Although the vehicle did not penetrate the barrier, it rose approximately 12 in. within 6 ft after initial contact due to excessive deflection of the railing (20 in.). This rise placed critical loading on the railing elements which resulted in their subsequent failure (Exhibit 7).

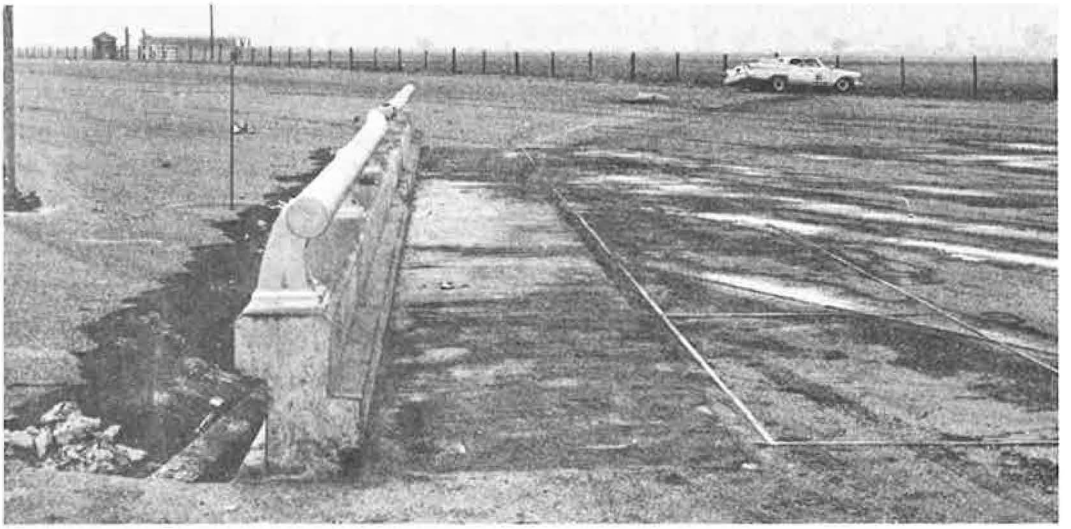
2. Three posts and three sections of the aluminum pipe railing were torn from the parapet and dropped to the ground behind the barrier. Major cracks developed in the concrete parapet.

3. The vehicle progressed fairly smoothly through impact even though the frame dragged on top of the parapet and sheared three posts before leaving the barrier (Exhibit 20). Excessive deflection of the railing elements and resultant vehicle jump imparted a rolling moment to the vehicle that almost caused a post-impact roll over.

4. Deep spalling and severe cracking of the concrete occurred in the impact area. Three posts were completely sheared from the barrier, and the web of the last post struck was bent. Three sections of the aluminum pipe rail were knocked to the ground behind the barrier; however, the sections remained intact and connected to the last post. Had there been adequate clearance behind the barrier for the pipe to drop, it is felt that the three pipe sections would have broken from the system and fallen to the ground (see Exhibit 8).

The cracking of the concrete parapet was not considered serious enough to necessitate complete replacement of the 5-ft cracked section adjacent to the expansion joint. Based on operational experience, it was felt that an epoxy resin bonding agent pumped into the cracks would have been sufficient to place the barrier in operating condition. However, as this parapet was to be used for two additional tests and a failure in this section would have influenced the test results, the concrete was jackhammered out, leaving the reinforcing bars intact. Plywood forms were clamped across the open section and a new concrete repair section was poured. The new concrete was bonded to the existing section with an epoxy adhesive applied to the exposed edges. An epoxy-sand mixture was used in resetting the damaged anchor bolts on the fourth post ahead of impact.

Test B-3 Type 1-A Bridge Barrier Rail



Bridge Rail: Type 1 parapet with welded steel plate posts and steel pipe railing. Height of concrete: 21 in. (repaired after Test B-2). Overall height of barrier: 36 in.

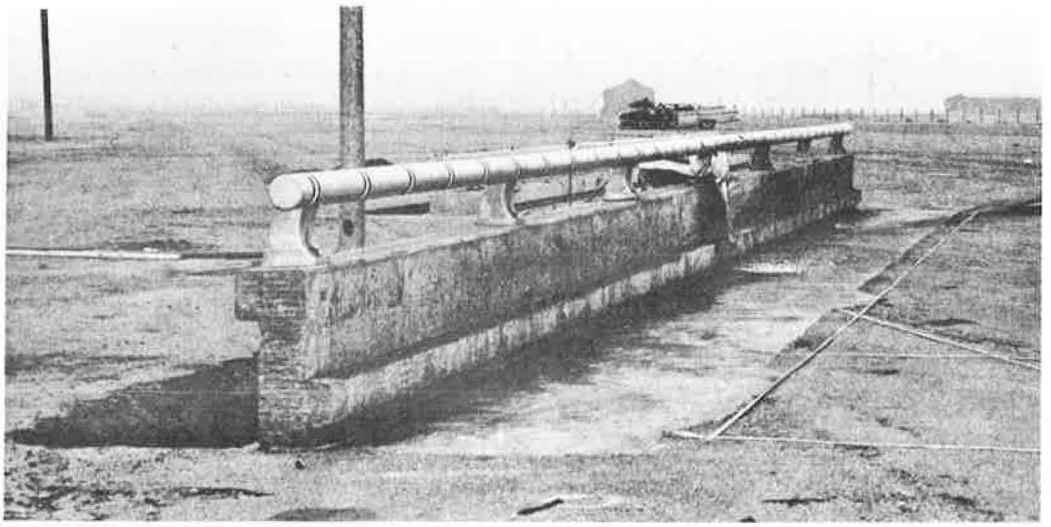
Purpose: To test the currently designed parapet with the steel posts and steel pipe rail. The posts and rail were purposely overdesigned so that they would not fail under impact loading. It was felt that this test would indicate the maximum performance of the concrete parapet and would assist in determining the relative loading on each part of the system.

Performance:

1. The vehicle did not penetrate the barrier. There was very little tendency for the vehicle to rise and no tendency to climb (Exhibit 9).
2. All parts of the barrier remained intact.
3. The vehicle progressed smoothly through impact with no tendency to roll (Exhibit 21).
4. The concrete developed deep cracks behind the first steel post contacted and required replacement of a small section of concrete around the anchor bolts. The front face of the concrete parapet was severely scraped and spalled in the impact area. One section of the steel railing was bent approximately 4 in. and deeply gouged. The welded steel plate posts sustained the impact with no evidence of damage (Exhibit 10).

The section repaired after the previous test withstood the impact with no evidence of cracking. From a design standpoint it is interesting to note that two anchor bolts effectively developed the strength of the relatively strong welded steel post.

Test B-4 Type 1 Modified Bridge Barrier Rail



Bridge Rail: Modified Type 1 concrete parapet with aluminum posts and aluminum pipe railing. Height of concrete: 28 in. Overall height of barrier: 43 in.

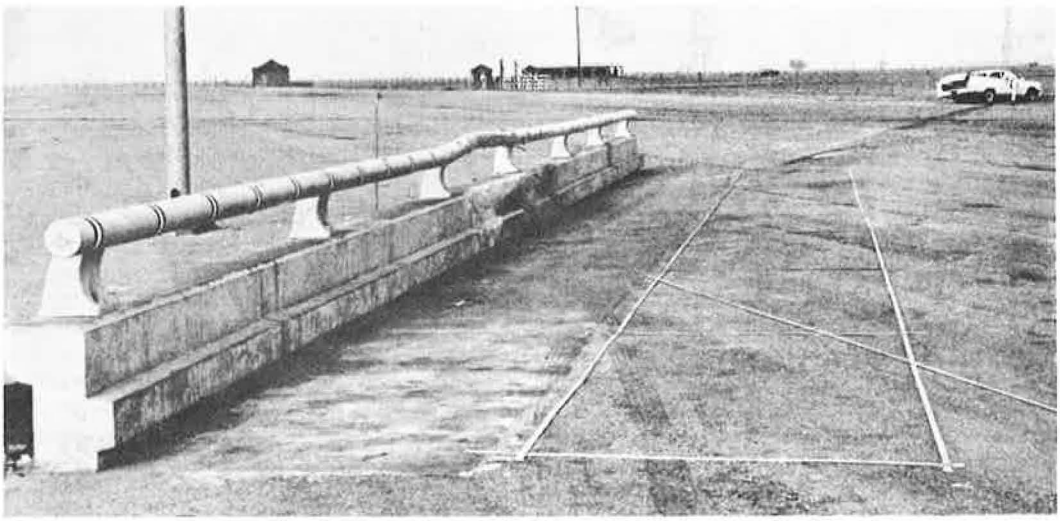
Purpose: To test and observe the effects of increasing the concrete parapet wall height of the Type 1 bridge rail from 21 in. to 28 in. while retaining the aluminum posts and pipe railing from the previous Type 1 test and to evaluate the effect of a 28-in. parapet height without safety walkway by comparison with Test B-1.

Performance:

1. The vehicle did not penetrate the barrier. There was very little tendency for the vehicle to rise and no tendency to climb (Exhibit 11).
2. There was no structural failure in any of the barrier elements.
3. The vehicle progressed reasonably smoothly through impact considering that the front left fender and door panel were torn from the vehicle and lodged between the pipe rail and parapet at the first post after impact (Exhibit 22).
4. Slight spalling and scraping of the concrete was confined to the immediate impact area. The flange of the first post contacted was bent and would have required replacement; however, there was no evidence of failure. One section of the aluminum pipe rail was bent 2 in. (Exhibit 12).

No repairs to the concrete parapet would have been required to place the barrier in operating condition.

Test B-5 Type 1 Bridge Barrier Rail



Bridge Rail: Type 1 parapet with malleable iron posts and aluminum pipe railing. Height of concrete: 21 in. (repaired after Test B-3). Overall height of barrier: 36 in.

Purpose: To determine the efficiency of the currently designed parapet with malleable iron posts under impact loading conditions similar to that of Test B-2.

Performance:

1. The vehicle did not penetrate the barrier. Deflection of the aluminum pipe rail (6½ in.) contributed to the 10 in. rise of the vehicle. This rise was considerably higher than that recorded in Test No. B-3, the same parapet with a steel pipe rail and steel plate posts (Exhibit 13).
2. All elements of the barrier system remained intact.
3. The vehicle progressed smoothly through impact with no tendency to roll (Exhibit 23).
4. A moderate amount of spalling of the concrete behind the anchor bolts on the first post after impact would have required an epoxy-sand patch and resetting of the anchor bolts to place the barrier in operating condition (Exhibit 14). The epoxy-sand anchor bolt repair from Test B-3 withstood direct impact with no evidence of failure.

TABLE 2

APPARENT EFFECTIVENESS

Barrier Design	Parapet Height (in.)	Post/Pipe Railing
Type 2	28	Cast alum., extruded alum.
Type 1 (mod.)	28	Cast alum., extruded alum.
Type 1-A	21	Welded steel plate, steel pipe
Type 1-B	21	Malleable iron, extruded alum. pipe
Type 1	21	Cast alum., extruded alum.

RECOMMENDATIONS

The five barrier designs are rated in Table 2 in order of their apparent effectiveness in meeting the forementioned structural conditions.

Specific recommendations for balanced design are as follows:

1. Barrier Height: The 21-in. parapet height (36-in. overall height) in the Type 1 bridge barrier rail and the 28-in. parapet height (43-in. overall height) in the Type 2 bridge barrier rail with safety walkway are adequate providing the pipe railing elements will sustain at least a 20,000-lb static loading, as indicated in Exhibit 4B and provided the metal posts are ductile enough to test to 10 percent minimum elongation (see Exhibit 4A and B for specifications and test methods).

2. Beam Strength of Parapet Wall: All three impacts on the Type 1 rail were made at the same concrete parapet wall expansion joint. There was only one structural failure of the wall and the vehicle did not penetrate. Therefore, it is felt the thickness and the size and distribution of the reinforcing steel is adequate. No changes are recommended in the basic structural design of the parapet wall.

3. Rubbing Curb: Based on the results of this test series on the Type 1 and Modified 1 bridge barrier rails, the rubbing curb is considered an unnecessary feature that complicates the forming for construction and adds to the cost. This rubbing curb does not function as a wheel deflector as originally intended. In all but the most narrow-angle low-speed contacts, the front and side overhang on the modern domestic passenger vehicle prevents the tire from contacting this curb before the body scrapes the parapet. Should the face be extended to more than the present 4 in., in an attempt to redirect the vehicle wheel in casual impacts, there is a strong possibility that a vehicle contacting the Type 1 at a narrow angle would mount the curb, climb the 21-in. high parapet, and vault the barrier. Therefore, if a wider rubbing curb is desired, the parapet wall should be 28 in. high as provided in the Type 2 design.

4. Repairs to Damaged Concrete Parapet: The epoxy-aggregate method of repairing damaged sections of concrete barriers has been used in the field for several years. The success of this repair method has been confirmed by the results of these controlled impact tests in which two successive impacts were concentrated on a repaired section with no evidence of cracking in the repaired joint.

CONSTRUCTION

Each of the three bridge barrier parapets was constructed on a reinforced-concrete deck section cantilevered from a 3-ft × 3-ft concrete anchor block (Exhibit 15). The earth was removed under and in back of this simulated bridge deck section so that there would be no restriction of the barrier/deck sections during impact. Bridge barrier rail Type 2 was constructed on the deck section after a bonding release agent had been sprayed over the entire area. The bonding release agent would be used to simplify curb removal for future widening. This test series indicated that use of this agent has no adverse effect on the structural strength of the construction joint. Reinforcing bar dowels, embedded in the slab during the anchor block construction, withstood the full impact loading, with the construction joint offering no other resistance to the load.

The Type 2 barrier rail resisted the full loading of the impact with no evidence of separation of the safety walk or parapet from the deck.

The Type 1 and Type 1 Modified barrier rail parapets were erected approximately

7 days after the deck section was poured and were provided with conventional construction joints. There were no evidences of failures in the construction joints of either the Type 1 Modified barrier after one impact or in the Type 1 barrier after 3 impacts.

Type A concrete with 1½-in. maximum aggregate and 6 sacks of cement per cubic yard was used on the anchor block, deck section and barrier parapet walls for all installations. Concrete test cylinders showed 28 day compressive strengths in excess of 3,500 psi.

INSTRUMENTATION

Test Vehicles

The five test vehicles used in this 1963 research project were selected from a group of retired California Highway Patrol Dodge sedans, 1959 and 1960 models. The center of gravity of this special police pursuit model is approximately 22 in. above the pavement and at 4,000-lb is slightly heavier than the standard Dodge sedan available to the public. These models were fitted with special sway bars for increased stability in making short-radius high-speed turns. Consideration was given to the effect of this increase in stability on correlation of the test results with previous bridge barrier tests which were conducted with standard models. However, since this test series was conducted primarily to determine the efficiency of the various barrier designs in effectively retaining vehicles at high-speed oblique impact, it was felt that this added stability would not affect the test results. This vehicle also offered other advantages over standard sedans that would have been selected from used car lots. The superior acceleration allowed the use of a very short impact course. Smoothness of the automatic shift permitted the cars to be started in gear with the engine running, rather than pushing to start as in previous test series. Since more than 100 vehicles were available, it was possible to select vehicles with similar steering, acceleration, and shifting responses.

The test vehicles were modified for remote radio control as follows:

1. A solenoid-valve actuated CO_2 system was connected directly to the brake line for fast remote brake application. With 700 psi in the accumulator tank, the brakes could be locked in less than 100 milliseconds. By pulsing the braking system, the car could be brought to a normal stop (if a run was aborted) with no tendency to slide or spin.
2. The throttle linkage was attached to a linear actuator energized by manually throwing a switch mounted on the trunk deck of the test car.
3. The ignition system was connected to the brake relay in a fail-safe interlock system. When the brakes were applied, the ignition was switched off. Any loss of radio signal or failure in the transmitting or receiving equipment would automatically energize the brake relay and switch off the ignition.
4. The gas tank was removed and replaced by a one gallon fuel tank equipped with a special cut-off valve to prevent fuel leakage in the case of a fire or roll-over.
5. Steering was controlled by a 2-HP gear-head motor (mounted on the front floorboard on the passenger side) through a V-belt connected to a pulley clamped on the steering wheel.
6. Two 12-volt storage batteries mounted on the floor of the rear seat supplied power to the remote control equipment.
7. The remote radio control receiver, tone actuated relays, steering pulse, and handi-talkie were mounted on a plywood panel in the trunk compartment. Whip antennae were mounted on the rear fender wings.

After five years of experience, the required time for remote control installation has been reduced to less than eight manhours per vehicle.

The three basic functions considered necessary for the safe, flexible operation of a crash car are: brakes on-off, ignition, on-off, steer right-left.

Control of the vehicle along the impact course was accomplished by a remote operator following 200 ft behind the test vehicle in a control car equipped with a tone transmission system. After sustaining more than 50 high-speed impacts over a period of 10 years, this remote control radio equipment continues to function efficiently with damage limited to an occasional shorted tube or broken solder joint.

Acceleration Instrumentation

Acceleration data representative of the forces a human driver would sustain under similar impact conditions were recorded by means of a triaxial mechanical-stylus accelerometer mounted in the chest cavity of a Sierra Engineering Co., Model 157, anthropometric dummy. The dummy was placed in the driver's seat and restrained by a lap belt and/or shoulder harness system. No attempt was made to relate deceleration information or dummy injuries to actual injuries that would have been sustained by a human counterpart. The primary function of the dummy was to evaluate the relative efficiency of various restraint systems in the prevention of partial ejection.

Photographic Instrumentation

The primary concern when considering the instrumentation for a research project of this scope is that an efficient method of gathering the pertinent data be provided. Experience has indicated that photographic records provide the most effective and dependable data coverage. In order to cover the event effectively with a minimum of cameras, it is essential to use cameras with a reliability approaching 100 percent. The six Photosonic Model 1-B 16-mm data cameras used for data coverage in this test series proved to be 100 percent reliable.

Equally important is the provision for recording significant data for documentary presentation. It has been found that curves and graphs based on data film records supplemented with documentary photographs provide an effective method of presentation. Documentary coverage for the past four test projects has been provided by a scaffold-mounted 70-mm sequence camera recording at 20 frames per second and at a shutter speed of 1/2,000 sec. During this 1963 test series, a cloud of concrete dust was produced by the vehicle impact and abrasion. Attempts to remedy this situation by the application of various penetrating oil dust palliatives proved unsuccessful. This dust obscured much of the action from the documentary sequence camera. Therefore, this camera will be located ahead of impact in future testing of concrete barriers.

In reducing data for past test series, it has been difficult to recover significant information, other than roll and jump data, from the ground-mounted data cameras. Since camera placement is not critical for gathering roll and jump data, ground positions for these cameras were not located by triangulation. To protect them from damage, the two ground-mounted data cameras equipped with 4-in. telephoto lenses and placed on line with the barrier face at locations 200 ft behind and 200 ft ahead of the point of impact. Although the 4-in. lens restricted angular coverage, it was felt that, for data reduction, the large image provided by this type of lens would be more useful than unrestricted coverage.

The three overhead data cameras, however, were carefully oriented and sighted-in for accurate recording of all data considered of any importance to this type of study. These cameras, mounted on a 35-ft tower, furnished coverage from 25 ft ahead of the point of impact to 25 ft beyond (Exhibits 19 through 23). For data reduction from the overhead cameras, a cloth tape grid was placed on the ground in the impact area. Preliminary static shots of the vehicle progressing in 5-ft increments through the impact area prior to each test were later projected and drawn on a screen for ground correlation of the vehicle through impact. Tape switches placed at 10-ft intervals leading into the point of impact were actuated by the approaching vehicle. Tire contact with the tape switches triggered a series of five flash bulbs located in view of all data cameras. These flash bulbs were also viewed by the crash-car mounted data camera to provide frame rate and event correlation with the ground-mounted and overhead data cameras. Table 3 gives information concerning the cameras used in this series.

All data cameras and the Hulcher documentary camera were motor driven and, with the exception of the crash car mounted data camera, were manually actuated from the central control console (Exhibit 16). The Bolex and Arriflex documentary cameras were motor driven and hand panned through impact. The crash-car mounted data camera was actuated along with the dummy accelerometer recorder by means of a release-pin-triggered switch on the bumper of the crash vehicle. The release pin was attached to a 50-ft length of nylon line anchored in the pavement directly behind the car.

TABLE 3

CAMERA INFORMATION

Camera	Type	FPS	Lens	Film	Location	Function
1	Photosonics 1-B	400	4 in.	16 mm	Front gnd.	Data
2	Photosonics 1-B	400	4 in.	16 mm	Rear gnd.	Data
3	Photosonics 1-B	400	½ in.	16 mm	Tower	Data
4	Photosonics 1-B	400	½ in.	16 mm	Tower	Data
5	Photosonics 1-B	400	½ in.	16 mm	Tower	Data
6	Photosonics 1-B	250	5.6 mm	16 mm	Crash vehicle	Data
7	Hulcher 70	20	6 in.	70 mm	Rear scaffold	Doc.
8	Bolex	24	Various	16 mm	Various	Doc.
9	Arriflex	24	Various	16 mm	Various	Doc.

After the crash vehicle had progressed 50 ft down the impact course, the pin was pulled from the switch and all data recording equipment including accelerometers were energized.

Data Correlation

With the exception of the crash-car mounted camera, all data cameras were provided with a 1,000-cycle timing pulse projected on the data film records. The tape-switch actuated flash bulbs provided event correlation between all stationary cameras and were also used to establish frame rate and event correlation for the data camera located in the test vehicle. Flash bulbs mounted in the taillights of the test vehicle were used to establish vehicle location and the time at which the brakes were applied. The bulbs also served to alert the control car driver that the test car brakes had been applied. These flash bulbs were fired when the brake actuating relay was pulsed by the remote operator or when the remote radio equipment failed. This brake pulse was also connected to a solenoid-actuated stylus in the accelerometer recorder that provided an event marker on the recorder paper. The recorder chart drive in the accelerometer unit was governor-controlled to a chart speed of 1 in./sec. The oscillograph recordings from the strain gages attached to steel reinforcing bars in the concrete barrier installations were also correlated to the event by means of the flash bulb pulses from the tape switches. These pulses, recorded on the oscillograph chart, provided an accurate method of correlation with the data cameras and (as a convenience) an immediate check on the average vehicle velocity over the 50-ft section prior to impact. The tape switch/flash bulb method of event and timing correlation is considered sufficiently accurate for this type of information and is readily reducible from the various data film and oscillograph records.

Stress-Strain Instrumentation

For each of the three basic types of concrete barrier parapet, reinforcing bar dowels in the impact area were instrumented with Baldwin bonded-type strain gages installed (Exhibit 17A). In order to determine the effect of dynamic loading on each bridge barrier rail and deck as a system, the barriers were constructed on a cantilevered anchor block (Exhibit 17B). These dynamic readings showed that the maximum stress occurred on the vertical reinforcing bars located approximately 4 ft beyond the point of impact. By using mechanical stylus gages, it was also possible to obtain direct measurement of the movement sustained by the entire system. These gages were cast in the concrete parapet and referenced to the ground behind the installation (Exhibit 17C). The stylus arms were constructed of ¼-in. brass rods with a short length of piano wire for the marking stylus. Deflection curves were recorded on a special waxed paper attached to stakes driven in the ground behind the barrier. Exhibit 18A shows a typical recording at a single gage point. Exhibit 18B shows the horizontal and vertical deflections

recorded under impact at deck and parapet wall locations over the entire length of the Type 1-B barrier rail. These recordings are typical.

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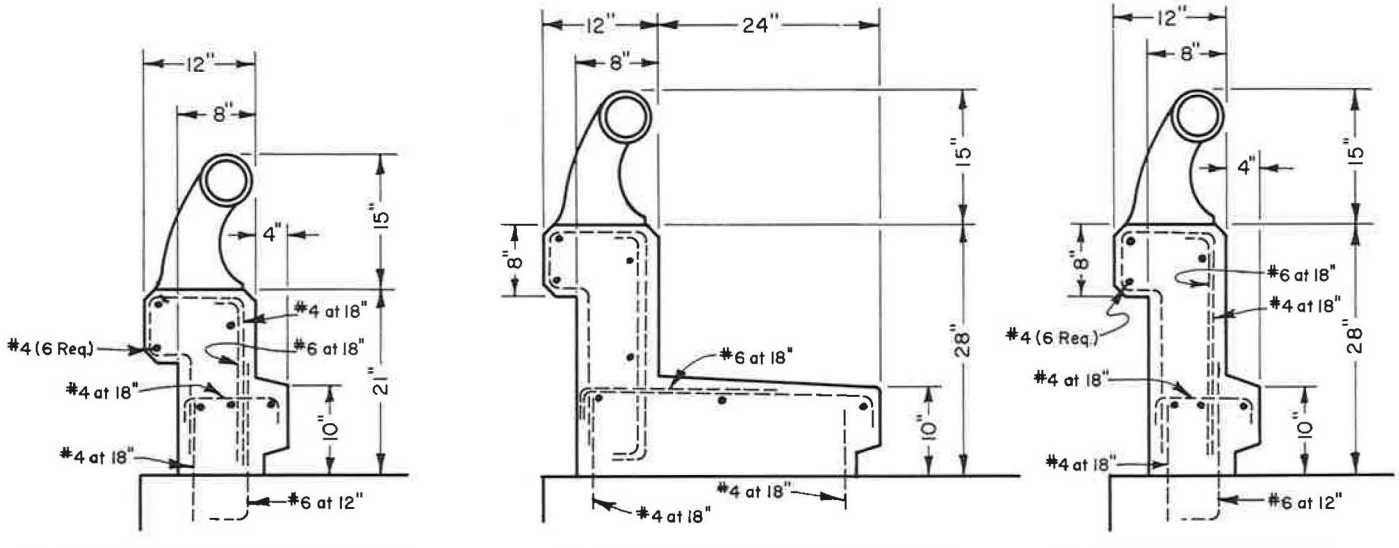
5. Beaton, J. L., and Field, R. N. Dynamic Full-Scale Tests of Median Barriers. HRB Bull. 266, 78-91, 1960.



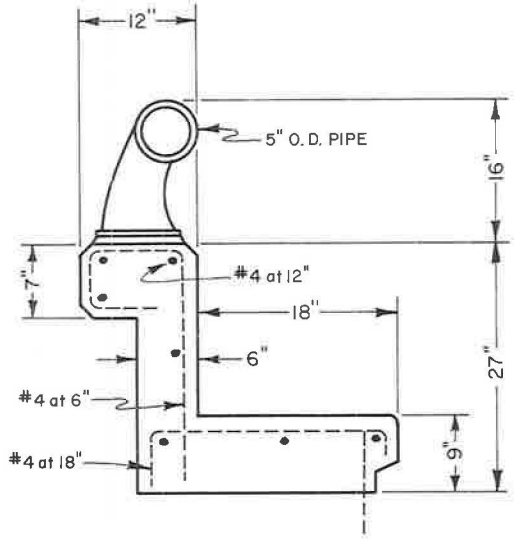
A. CALIFORNIA STANDARD BRIDGE BARRIER RAILING TYPE 1

B. CALIFORNIA STANDARD BRIDGE BARRIER RAILING TYPE 2

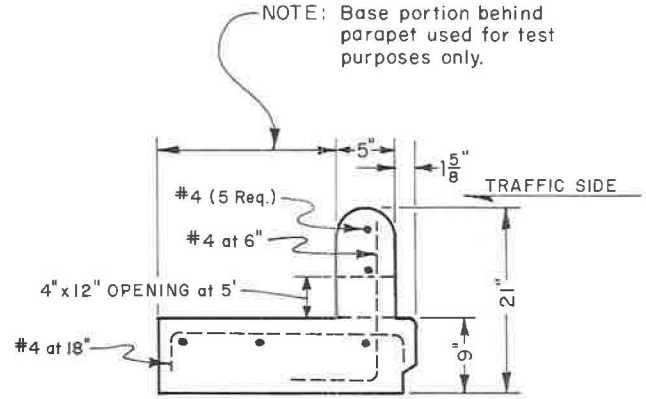
C. EXPERIMENTAL BRIDGE BARRIER RAILING MODIFIED TYPE 1

EXHIBIT 1

1963 BRIDGE BARRIER RAIL TESTS



A



B

BRIDGE RAIL & CURB PROTOTYPES

EXHIBIT 2

Exhibit 3

A. Early Barrier Prototype showing insufficiency of reinforcing steel in parapet. (Also see Exhibit 2A).

B. Baluster type railtested during the 1959 test series. Impact speed 57 mph at 28 degrees approach angle.

EXHIBIT 4A

PERTINENT BRIDGE BARRIER RAIL SPECIFICATIONS

Metal railing shall be steel pipe with steel rail caps or aluminum pipe with aluminum rail caps, and metal posts. Steel rail caps may be either cast steel or malleable iron, or nodular iron.

Bolts and nuts for attaching the pipe to the posts and anchor bolt assemblies shall be steel.

Pipe and posts may be of the same or dissimilar metal, but on each bridge or retaining wall the metal railing shall be all of the same details and the same combination of metals.

Post material and the completed posts shall conform to the following:

1. Material shall be a ferrous or aluminous metal. The chemical and physical properties as required to conform to the provisions of this section shall be selected by the Contractor.
2. Metal cut from the side flanges of the post shall have an elongation of 10 percent minimum, when sampled and tested in accordance with Test Method No. Calif. 654-A.
3. Posts shall support a load of 20,000 pounds when the load is applied and the test conducted in accordance with Test Method No. Calif. 654-A.
4. The dimensions and thicknesses of metal shown on the plans shall be the minimum permitted.
5. The sections of the post may be increased in thickness at the option of the Contractor as required to provide a post that will comply with the test requirements of Test Method No. Calif. 654-A.

The outside dimensions of the post shall not be increased. Increasing the thickness of vertical flanges and top member shall be done uniformly. Bulbs or ribs in addition to those shown on the plans will not be permitted.

The materials, except for posts, shall conform to the following requirements:

Material	ASTM Designation
Steel pipe	A 139
Steel structural tubing	A 53
Steel rail caps and block washers	A 27, Grade 65-35; or A 47, Grade 32510; or A 395
Steel bolts and Nuts	A 307
Aluminum pipe	B 235, 6063-T6
Aluminum rail caps and block washers	B 108, SG70B; or B26, SG70A

1. Steel pipe and tubing shall have a wall thickness not less than $^3/_{16}$ inch.

   Steel tubing conforming to American Petroleum Institute Specifications, 5L or 5LX will be accepted.

2. Aluminum pipe for single pipe railings shall have a wall thickness not less than $^1/_4$ inch.

   Aluminum pipe for multiple pipe railings shall have a wall thickness not less than $^3/_{16}$ inch.

EXHIBIT 4B

Test Method No. Calif. 654-A
September 1963

State of California
Department of Public Works
Division of Highways
MATERIALS AND RESEARCH DEPARTMENT

METHOD FOR TESTING BARRIER RAILING POSTS

Scope

This test method describes the procedures to be used in testing barrier railing posts. The tests include a strength test of the completed post and an elongation test on a specimen cut from the post.

Procedure

A. Apparatus

1. For the strength test of the post, use a static test jig which will provide for loading as shown in Figures A, B, and C. Apply the load by means of a compression testing machine or similar apparatus.

2. Refer to ASTM Designation: E8 for description of apparatus used to determine percent elongation.

B. Test Procedure

1. Bolt barrier railing post in test jig, apply test load to railing post as shown in Figure D and measure maximum load that the post will support without failure.

2. Take test sample from the railing post for determining the elongation, as shown in Figure E. Prepare standard test specimen and determine percent elongation as described in ASTM Designation: E8.

Reporting of Results

Report test results on Form T-616.

REFERENCE

ASTM Designation: E8
End of Text on Calif. 654-A

Exhibit 5

TEST B-1

I+.320 sec.

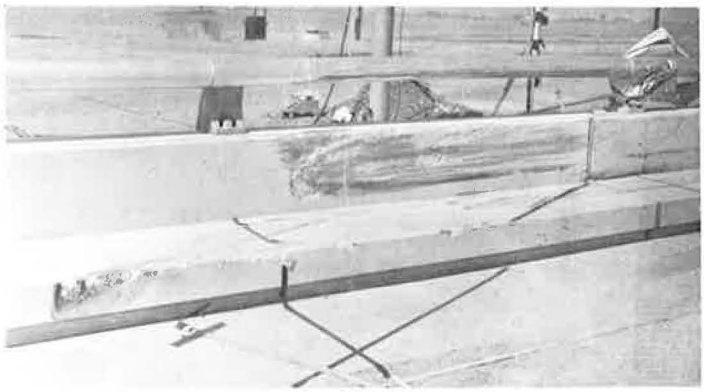
I+.649 sec.

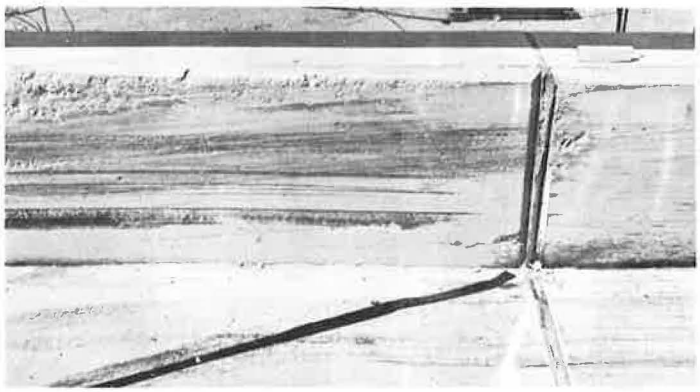
I-.023 sec.

I+.011 sec.

I+.143 sec.

Exhibit 6

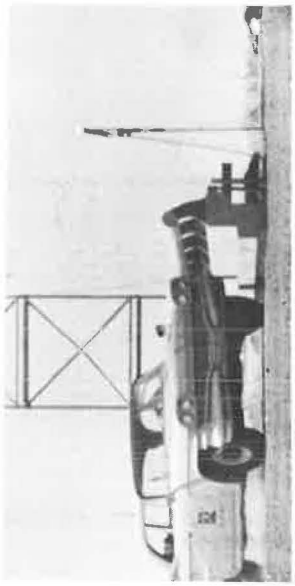




TEST B-1 VEHICLE & BARRIER DAMAGE

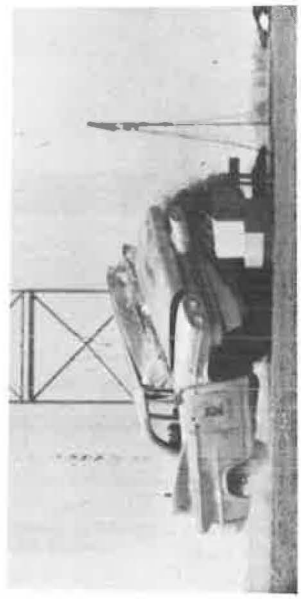
Exhibit 7

TEST B-2

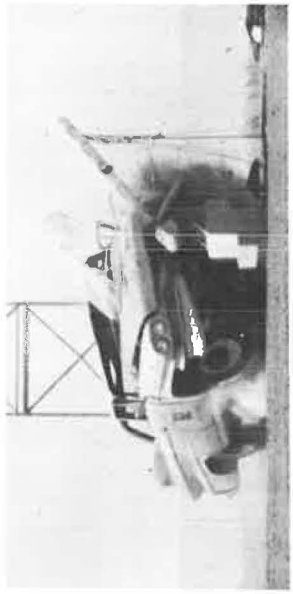


I+.006 sec.

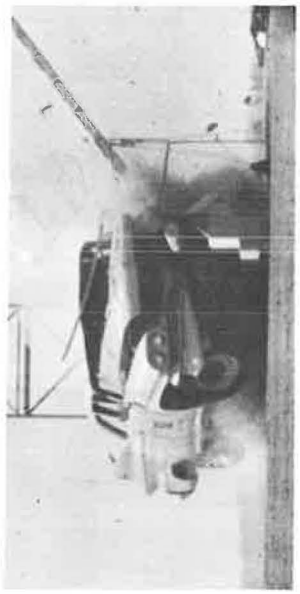
I+.036 sec.



I+.094 sec.



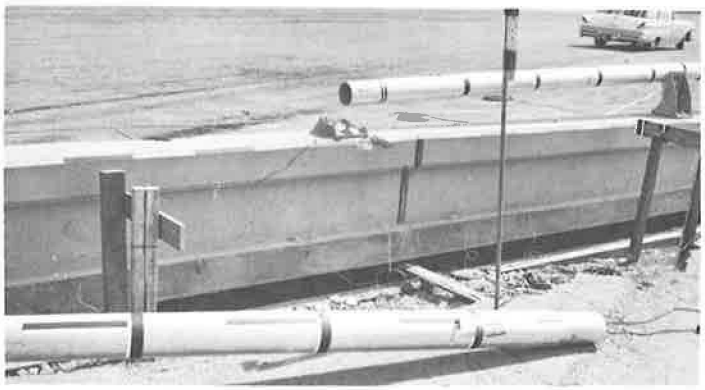
I+.194 sec.



I+.300 sec.

I+.556 sec.

Exhibit 8



TEST B-2 VEHICLE & BARRIER DAMAGE

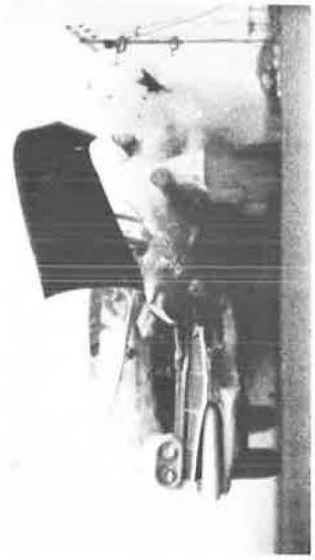
Exhibit 9

TEST B-3

I+.006 sec.

I+.065 sec.

I+.152 sec.

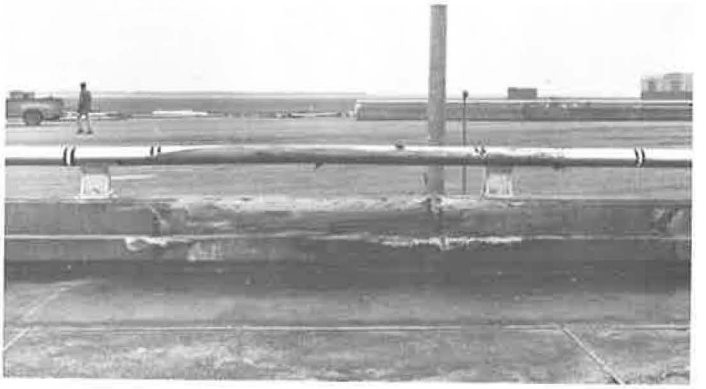


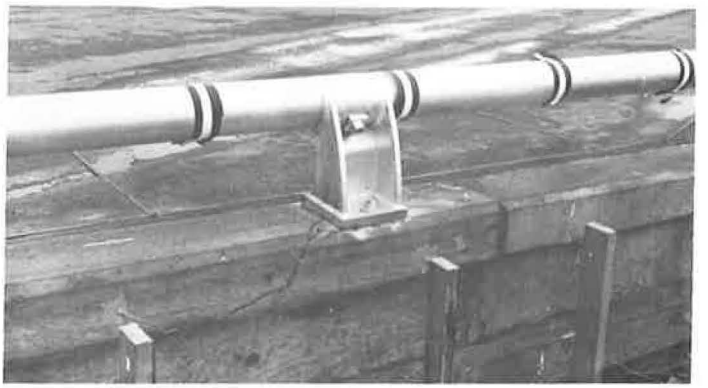
I+.256 sec.

I+.390 sec.

I+.575 sec.

Exhibit 10





TEST B-3 VEHICLE & BARRIER DAMAGE

Exhibit 11

TEST B-4

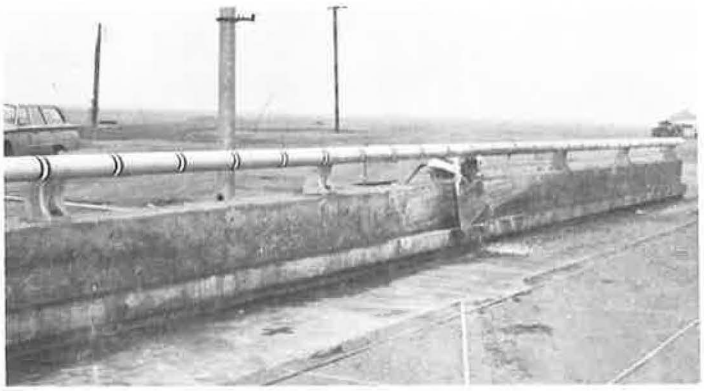
I+.211 sec.

I+.422 sec.

Impact

I+.069 sec.

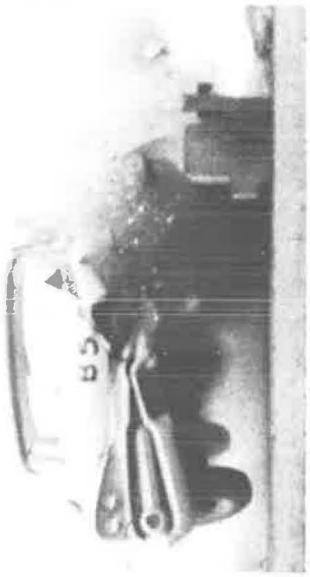
Exhibit 12



TEST B-4 VEHICLE & BARRIER DAMAGE

TEST B-5

Exhibit 13



I-.057 sec.

I+.063 sec.

I+.169 sec.

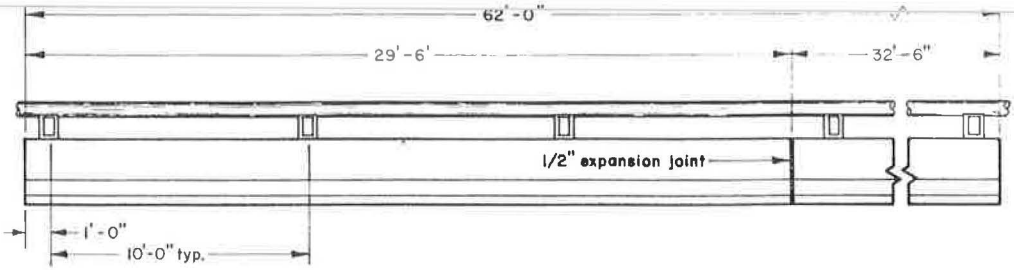
I+.329 sec.

I+.571 sec.

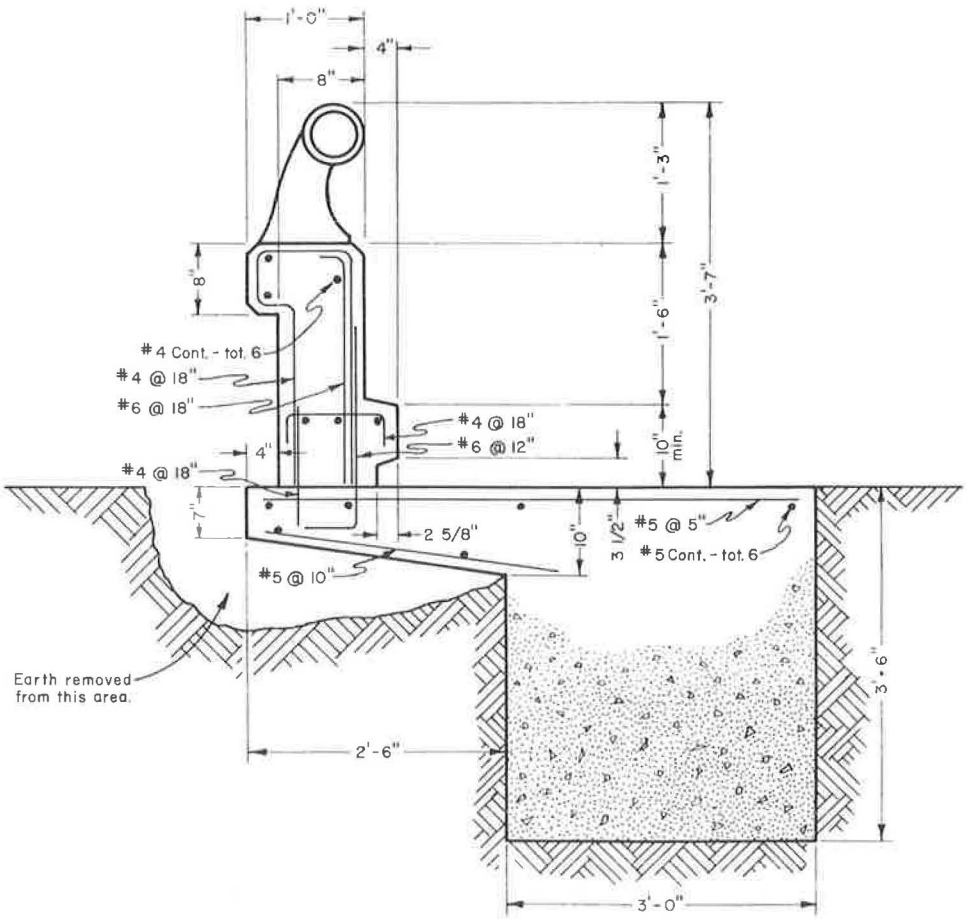
Exhibit 14

TEST B-5 VEHICLE & BARRIER DAMAGE

EXHIBIT 15



FRONT VIEW



CROSS-SECTION
BARRIER INSTALLATION FOR MODIFIED TYPE 1 BRIDGE RAIL

View of Test Site showing general layout. Control center is between camera scaffold and instrumentation trailer.

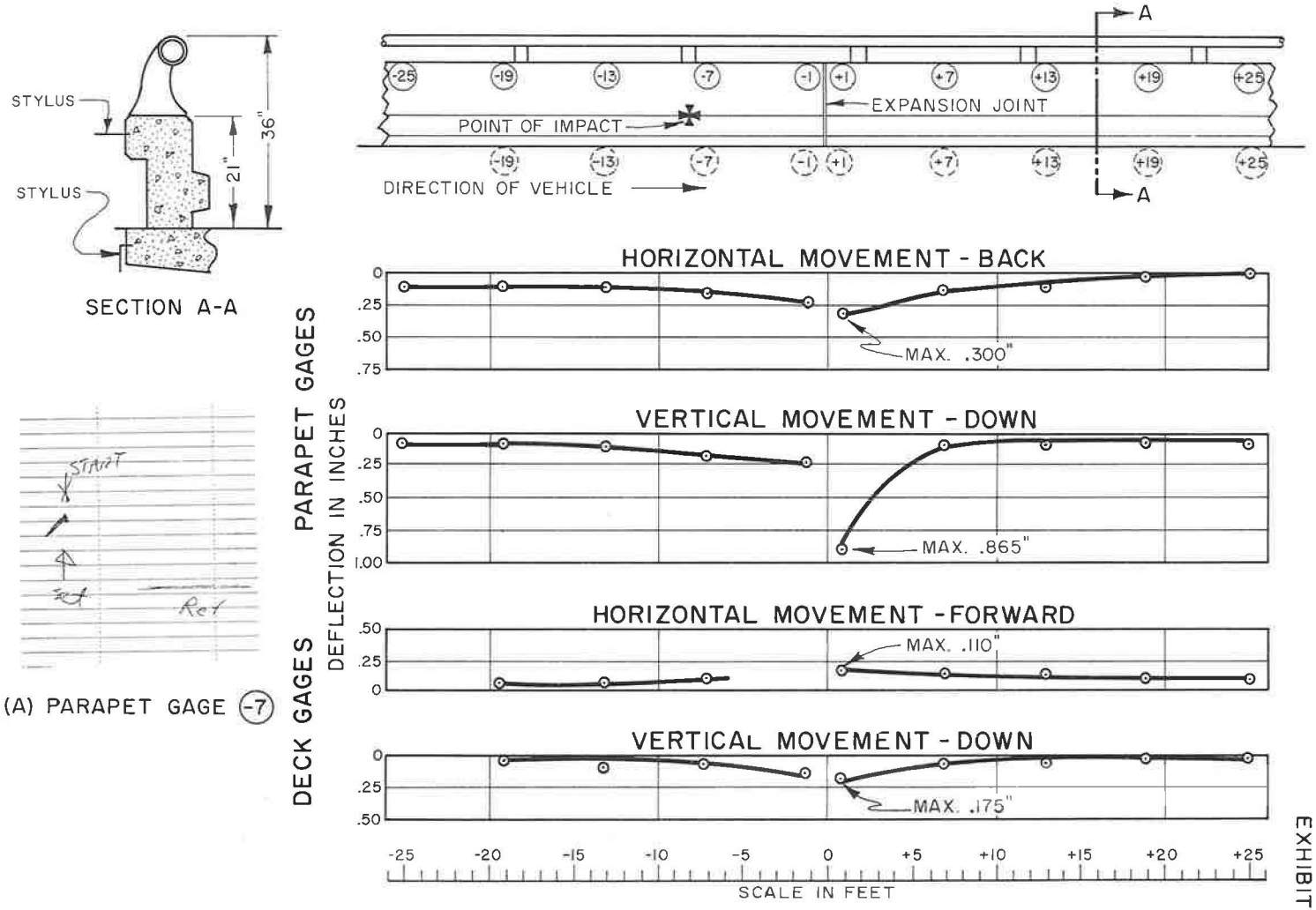
Exhibit 16

Exhibit 17

A, Installing strain gage instrumented re-bar dowels for barrier Type 2.

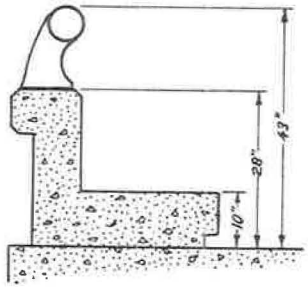
B. Barrier installation from rear showing cantelevered deck section and strain gage leads.

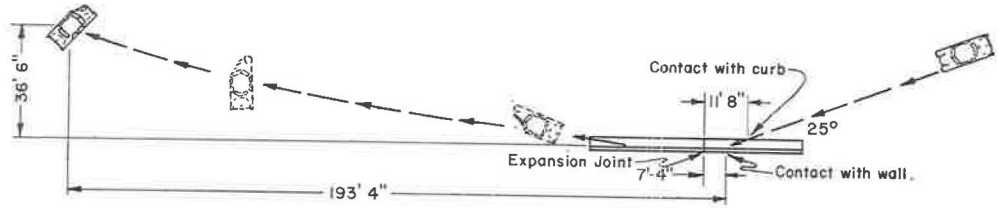
C. Deflection gage installation on Type 1 Modified Barrier Rail.



(B) DYNAMIC DEFLECTION OF PARAPET & DECK - RUN B-5

EXHIBIT 18



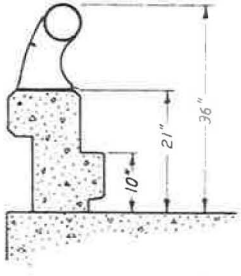


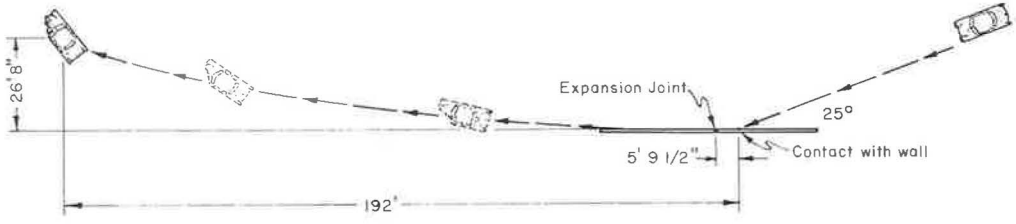
BRIDGERAIL	Type 2
ANCHOR BOLTS	Steel
POST	Aluminum cast
FASTENING BOLTS	Aluminum
RAIL	Aluminum
POST SPACING	10' O.C.
LENGTH OF INSTALLATION	62'

LENGTH OF CONTACT	35'
WALL DAMAGE	Minor spalling and cracking where wall joins walkway.
POST DAMAGE	One post ripped thru entire web width adjacent to base.
PERMANENT DEFORMATION IN RAIL	1 1/2"

TEST NO.	B-1
DATE	9-21-62
VEHICLE	1960 Dodge
SPEED	76 mph
IMPACT ANGLE	25°
VEHICLE WEIGHT (W/ DUMMY & INSTRUMENTATION)	4300 lbs.

EXHIBIT 19



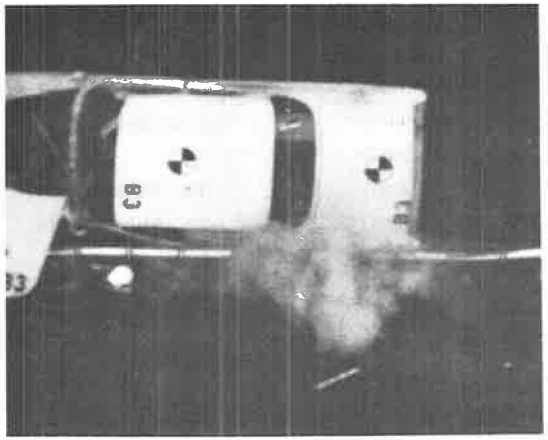


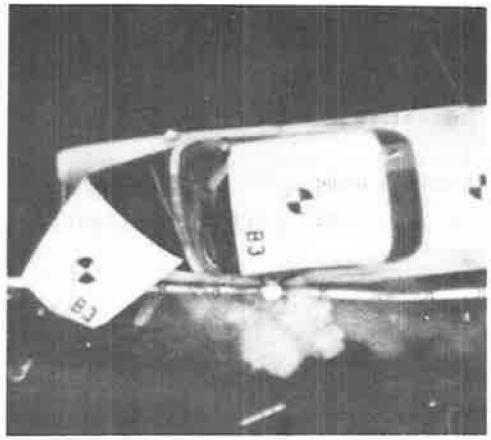
BRIDGERAIL	Type 1
ANCHOR BOLTS	Steel
POST	Aluminum cast
FASTENING BOLTS	Aluminum
RAIL	Aluminum
POST SPACING	10' O.C.
LENGTH OF INSTALLATION	62'

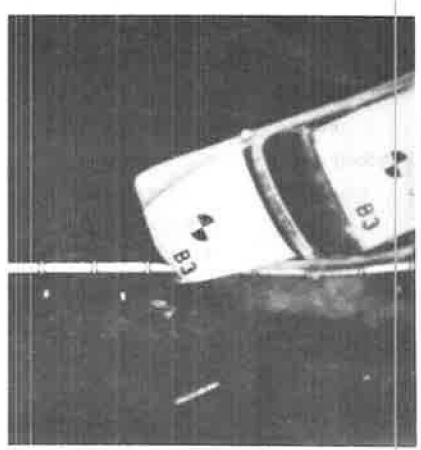
LENGTH OF CONTACT	Entire length of rail from point of impact.
WALL DAMAGE	Severe cracking adjacent to post #4. Req. replacement of 5' of concrete wall.
POST DAMAGE	Post nos. 4, 5 & 6 sheared at base; 1 web slightly bent.
PERMANENT DEFORMATION IN RAIL	3 sections of rail pulled out of posts.

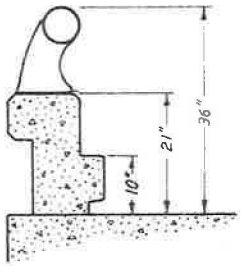
TEST NO.	B-2
DATE	9-27-62
VEHICLE	1960 Dodge
SPEED	76 mph
IMPACT ANGLE	25°
VEHICLE WEIGHT (W/ DUMMY & INSTRUMENTATION)	4300 lbs.

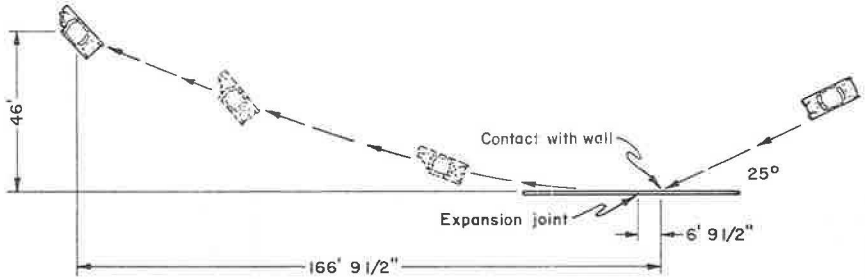
EXHIBIT 20









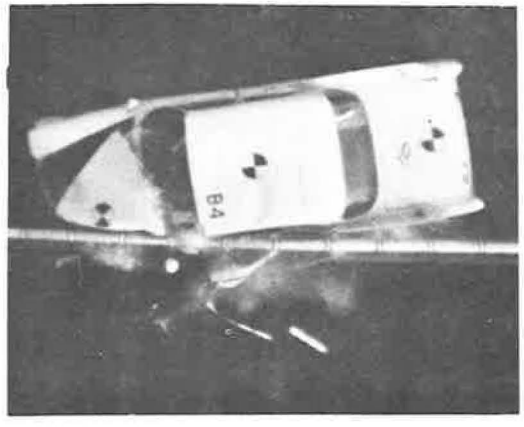


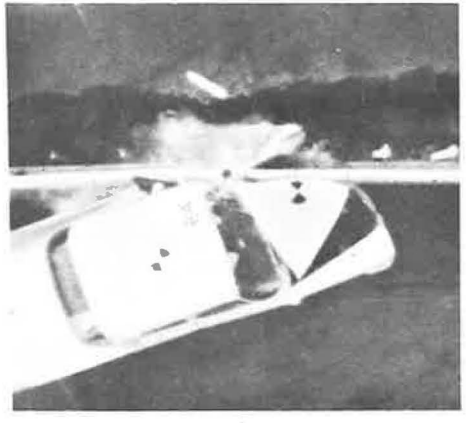
BRIDGERAIL	Type I
ANCHOR BOLTS	Steel
POST	Steel plate (Welded)
FASTENING BOLTS	Steel
RAIL	Steel
POST SPACING	10' O.C.
LENGTH OF INSTALLATION	62'

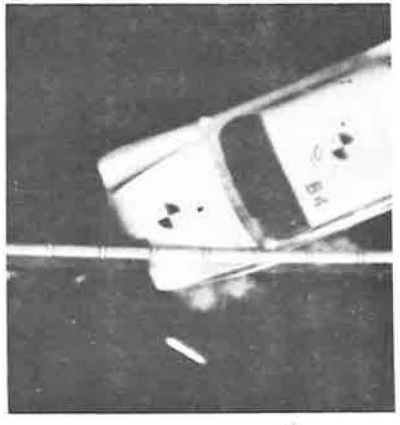
LENGTH OF CONTACT	26'
WALL DAMAGE	Deep spalling & cracking at post #4. Reg. epoxy/agg. patch & replacement of post anchor bolts.
POST DAMAGE	No visible damage.
PERMANENT DEFORMATION IN RAIL	3"

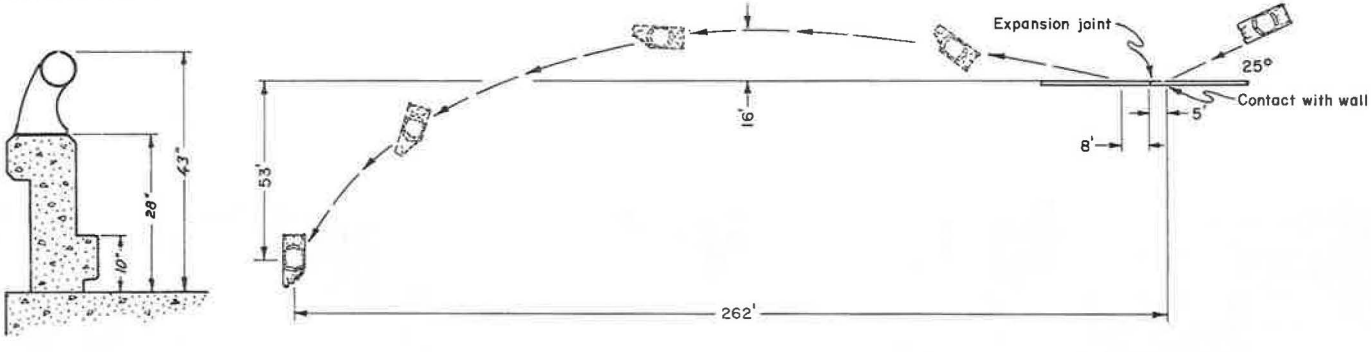
TEST NO.	B-3
DATE	1-10-63
VEHICLE	1960 Dodge
SPEED	73 mph
IMPACT ANGLE	25°
VEHICLE WEIGHT (W/ DUMMY & INSTRUMENTATION)	4300 lbs.

EXHIBIT 21







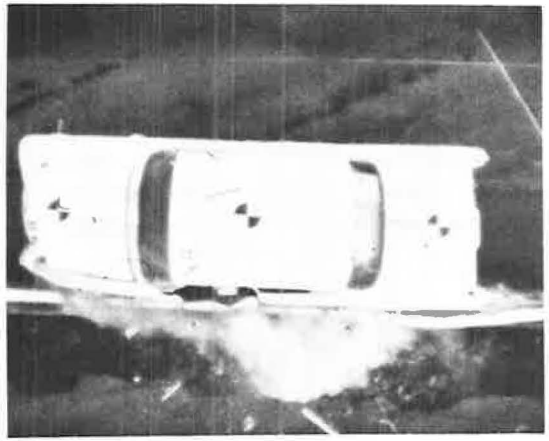


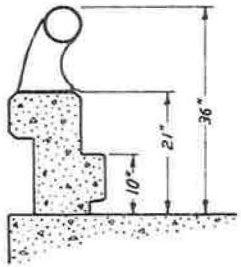
BRIDGERAIL	Type 1, modified
ANCHOR BOLTS	Steel
POST	Aluminum cast
FASTENING BOLTS	Aluminum
RAIL	Aluminum
POST SPACING	10' O.C.
LENGTH OF INSTALLATION	62'

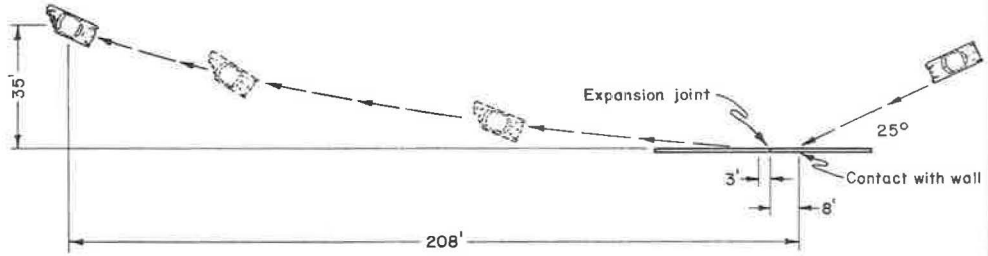
LENGTH OF CONTACT	20'
WALL DAMAGE	Slight spalling.
POST DAMAGE	One flange bent.
PERMANENT DEFORMATION IN RAIL	1"

TEST NO.	B-4
DATE	1-24-63
VEHICLE	1960 Dodge
SPEED	77 mph
IMPACT ANGLE	25°
VEHICLE WEIGHT (W/ DUMMY & INSTRUMENTATION)	4300 lbs.

EXHIBIT 22







BRIDGERAIL	Type I
ANCHOR BOLTS	Steel
POST	Malleable cast iron
FASTENING BOLTS	Steel
RAIL	Aluminum
POST SPACING	10' O.C.
LENGTH OF INSTALLATION	62'

LENGTH OF CONTACT	19'
WALL DAMAGE	Cracked around #4 post anchor bolts.
POST DAMAGE	One post web slightly dented.
PERMANENT DEFORMATION IN RAIL	5 1/2"

TEST NO.	B-5
DATE	2-7-63
VEHICLE	1959 Dodge
SPEED	78 mph
IMPACT ANGLE	25°
VEHICLE WEIGHT	4300 lbs.

(W/ DUMMY & INSTRUMENTATION)

EXHIBIT 23