BREAKAWAY OVERHEAD SIGN BRIDGES, CRASH TESTING

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This paper describes ten vehicle crash tests that were conducted on an overhead sign bridge. The purpose of these tests was to determine the feasibility of large breakaway supports for these bridges. The behavior of the overhead sign bridge when subjected to vehicle impact loads also was determined during this study. The vehicles ranged in weight from 2,100 to 5,170 lb. Impact speeds ranged from 25.7 to 75.3 mph. These tests indicate that the breakaway safety features of the overhead sign bridge will greatly reduce the forces on impacting vehicles.

• THE ERECTION of the prototype overhead sign bridge with breakaway supports was completed on September 8, 1969. A testing program was begun to determine and evaluate the forces imposed on vehicles colliding with the breakaway supports and to observe and analyze the behavior of the prototype structure under a variety of collision conditions. Ten vehicle crash tests were conducted on the prototype structure shown in Figure 1. Table 1 gives a summary of crash test results. Deceleration forces were measured by accelerometers mounted on the frame of the vehicle.

TEST A

The first vehicle crash test in the development and evaluation program was conducted on September 23, 1969. A 1963 Ford impacted support "A" at a speed of 25.7 mph. The design conditions required that a 28-gage "keeper" plate be installed between the upper

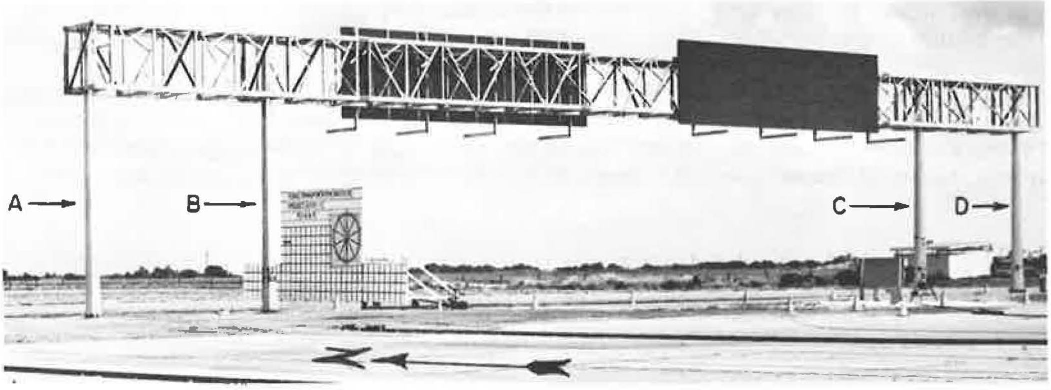

Figure 1. Prototype overhead sign bridge. Supports designated A, B, C, and D.

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TABLE 1

SUMMARY OF VEHICLE CRASH TEST RESULTS

Characteristic	Test No.								
	A	B	C	D	E	F	G	H	I
Vehicle make	Ford	Simca	Ford	Cadillac	Ford	Borgward	Ford	Cadillac	Cadillac
year	1963	1959	1963	1962	1963	1959	1962	1961	1962
Vehicle weight, lb	3,950	2,100	4,090	4,880	3,920	2,350	3,950	5,150	5,170
Impact angle, deg	0	0	0	0	15	15	15	0	15
Initial speed, mph[a]	25.7	44.0	46.5	54.0	28.6	52.0	50.1	75.3	72.0
Change in speed, mph[a]	5.4	14.7[b]	8.9	9.0	7.2	13.6	10.2	11.5	11.2
Avg. decel., g (long.)	3.1	9.6	6.7	7.8	3.7	12.2	5.8	6.9	8.8
g (trans)	—	—	—	—	0.1	1.3	0.6	—	0.4
Peak decel., g (long.)	7.4	22.4	19.1	15.1	8.8	30.8	15.3	17.6	22.4
g (trans)	—	—	—	—	3.4	8.7	3.6	—	4.7
Target support	A	B	B	A	B	A	A	A	B
Max. rotation of support, deg[a]	83	65[c]	63	68	65	59	65	77	70
Height of lower end of support at peak of swing, ft[a]	19.5	12.1	11.5	13.1	12.1	10.2	12.1	16.3	13.5
Approx. rotation of truss, deg[a]	2	3	1	9	1	4	8	60	1.6

[a]From film data.

[b]Change in velocity over the period necessary to activate the breakaway component of the support. Vehicle snagged on lower end of support post and was stopped.

[c]Impact load distributors were installed in this and all following tests.

and lower base plates and that the base bolts be tightened to 200 lb-ft (Fig. 2). Preliminary calculations and analysis of the record films led to the conclusion that the bolt keeper plate and base-bolt torque do not affect the vehicle-support behavior. These conditions (28-gage bolt keeper plate and 200 lb-ft base-bolt torque) were established for the remainder of the regular crash test series.

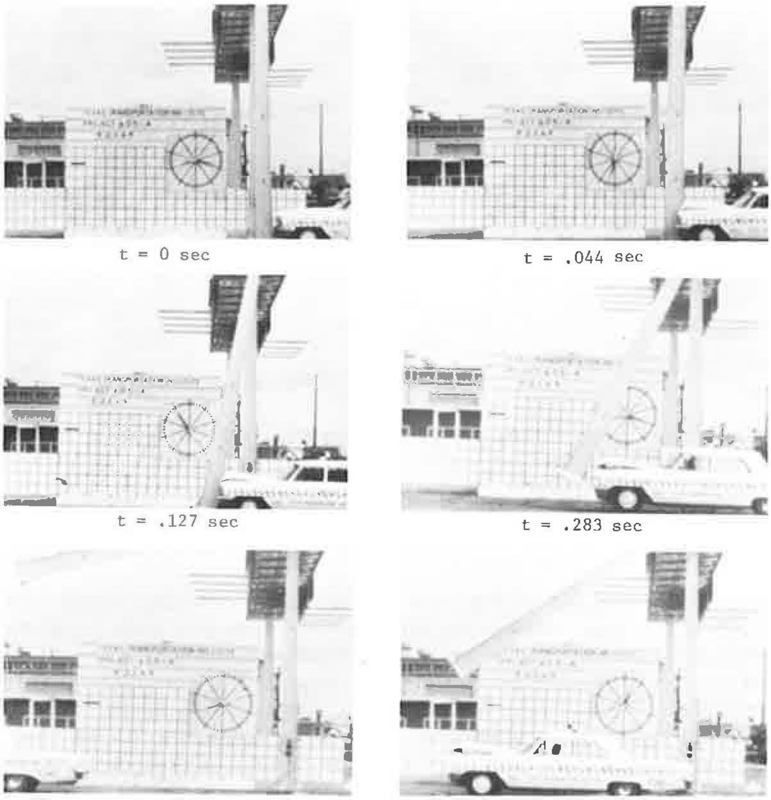
The reaction of the support was predicted by mathematical simulation. The support rotated through 83 deg (observed), allowing the vehicle to pass underneath. Damage to the vehicle was slight as shown in Figure 3. Sequential photographs of the interaction of the overhead sign bridge (OSB) with the test vehicle during the test are shown in Figure 4.

TEST B

In evaluating the breakaway features of the overhead sign bridge and the functioning of the bridge structure, two distinct areas of interaction are apparent: (a) the interaction of the vehicle with the support; and (b) the interaction of the rotating OSB support with the lower chord members of the truss. The first test showed that the interaction of the vehicle with the support leg could be predicted with reasonable accuracy by use of computer simulation. The interaction of the rotating support with the truss then became a matter of major concern. For vehicle velocities greater than 25 mph, the

Figure 2. Details of breakaway base connection.

Figure 3. Vehicle after Test A.



t = 0 sec

t = .044 sec

t = .127 sec

t = .283 sec

t = .627 sec

t = 1.144 sec

Figure 4. Sequential photographs of Test A.

computer simulation predicted that the support would possess significant kinetic energy when it impacted the lower chords of the truss (1). The protection of the lower chord members by distribution of the impact force and by dissipation of excess energy was carefully considered. To provide the required distribution and dissipation a steel-tube load distributor was designed which could be placed to protect the lower chord members of the truss. Static laboratory and field tests were run to verify the function of these distributors before crash tests were conducted. A close-up of the load distributor before it was placed on the truss is shown in Figure 5, and typical installations on the truss are shown in Figures 6 and 7. Selection of the channel sections was made (a) to provide adequate load distribution to the truss, and (b) to provide a flat bearing surface for the cylindrical tubes during impact loading. The design of the connection provided both conditions, as can be seen in Figure 8. No damage to the lower chord occurred

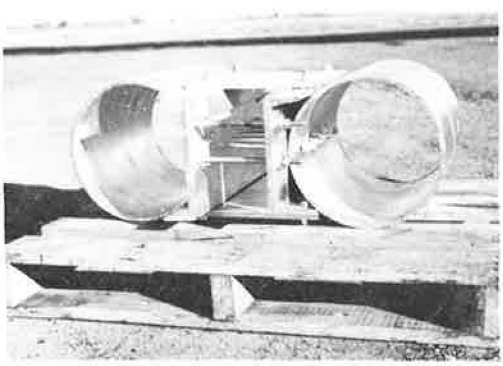


Figure 5. Load distributor (steel tubing with 3/8-in. wall thickness, 12 3/4-in. outside diameter, and 17 in. long).

Figure 6. Load distributor bolted in place on lower truss chord at support A.

Figure 7. Load distributors at support B before Test B.

and the energy absorbers were crushed against the channel sections, as had been anticipated.

On the basis of an analysis of the OSB subjected to torsional loads and the empirical data developed in static load tests (2), the torsional stiffness coefficients for various components of the overhead sign bridge were determined. Using these coefficients, the amount of energy which the truss could be expected to absorb before fracturing connection bolts at the top of all four supports was estimated to be 145 kip-ft. However, it was decided that the validity of this analysis should be tested and that the energy level of the impacting vehicle, and therefore the energy of the subsequently rotating support, should be increased gradually until the dynamic functioning of the tube load distributors and the energy-absorption capability of the OSB were further verified. For this reason, the speed of the impacting vehicle in Test B was increased to 44 mph. A 1959 Simca weighing 2,100 lb was used in this test to ascertain the interaction between the breakaway support and a lightweight, compact vehicle. The truss and support conditions were the same as in Test A, except that support B was the target.

An unexpected incident occurred during Test B: the front of the vehicle was deformed significantly in the collision, remained in contact with the support, and the vehicle was lifted at the front end by the support finally wedging itself between the ground and support in a nearly vertical position. The post penetrated 21 in. toward the engine and the front frame cross member was bent, forcing the two longitudinal frame members to come together, thus clamping the support in a pincer-like action. This pincer-like action prevented the support from springing away from the vehicle after the connections at the base and top of the support broke away. As the support rotated, while maintaining contact with the automobile, the upper baseplate elevated, and the slotted projections of this base plate acted as a hook which caught the front end of the vehicle and raised it to the maximum elevation shown at t = 0.781 second in Figure 9.

Close-up views of the front end of the car are shown in Figures 10 and 11. Examination of data from accelerometers indicated that the average deceleration was 9.6 g over 0.068 second. The peak deceleration was 22.4 g occurring at ap-

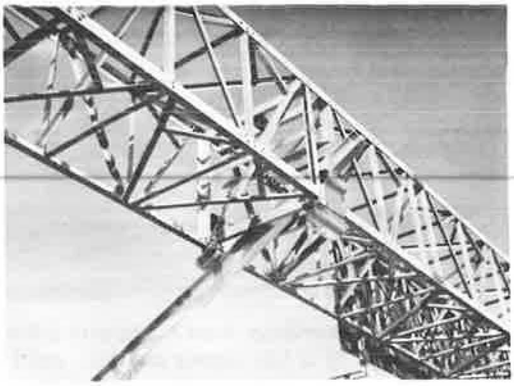


Figure 8. Load distributor at support B after Test B.

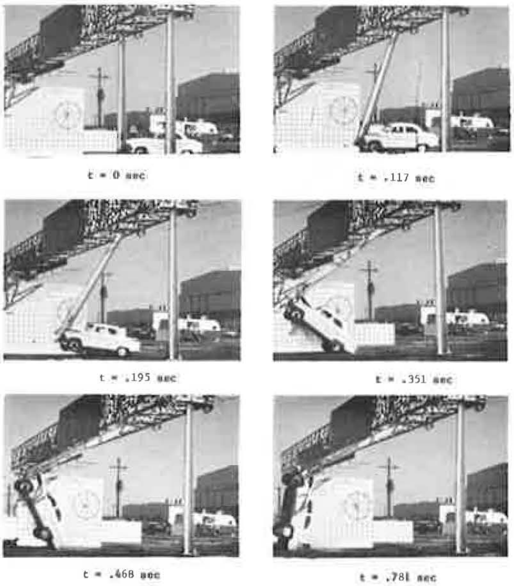


Figure 9. Sequential photographs of Test B.

Figure 10. Vehicle wedged between support and ground (Test B).

proximately 0.050 second. The load distributors functioned as expected, and there was no apparent damage to the truss.

The events and behavior just described resulted in considerable discussion concerning ways to (a) eliminate the "hooking" of automobiles, or (b) determine whether larger automobiles would behave as the small vehicle had. The latter determination took priority and the next test was scheduled without changes to the prototype structure.

Figure 11. Vehicle after Test B.

TEST C

A 1963 Ford weighing 4,090 lb impacted support B head-on at a speed of 46.5 mph, and the vehicle and support interaction was similar to that reported for Test A. The breakaway devices at the base and top of support B performed as anticipated, allowing the support to rotate up and away from the vehicle. During the time from initial vehicle contact until the upper bolts fractured, the truss rotation was approximately 1 deg. The vehicle passed under the support with a clearance of approximately 6 ft. After swinging through an angle of 50 deg, the support made contact with the load distributors and proceeded to crush them until the support rotation had increased to 63 deg. During the crushing of the load distributors, the rotation of the truss was less than 1 deg; thus the steel tubes absorb some energy but function primarily as load distributors.

The average vehicle deceleration was determined to be 6.7 g over 0.064 second, and a peak deceleration of 19.1 g, occurring at t = 0.050 second, was observed on the accelerometer trace. The vehicle's speed was reduced 8.9 mph by the collision. Damage to the vehicle is shown in Figure 12.

It was observed that the truss deflects downward at inner support B following impact, and as a result the support comes to rest at the lower base plate sooner than when an outer support is struck. The conditions following this test are shown in Figure 13. Similar behavior was observed in later tests, and it was found that, when the outer support is struck, the support post continues to swing as a pendulum for several seconds after impact.

Figure 12. Vehicle after Test C.

TEST D

Computer simulation predictions (1) indicated that a head-on collision involving a heavy automobile would produce tolerable damage to the colliding vehicle and the prototype structure. To verify this prediction a 4,880-lb automobile, traveling 54 mph, struck the outer support A. The sign bridge functioned as predicted; vehicle damage was slight as shown in Figure 14, and no structural damage to the truss or support leg was observed. The truss rotation from the time the vehicle contacted the support until the upper connection bolts fractured at support A was less than 1 deg. The maximum rotation of the truss was 9.4 deg as support A rotated upward through 68 deg. During this rotation, the upper connection bolts at support B also fractured. The rotation of the truss at this time is shown in Figure 15 at t = 0.453 second.

Using photographic analysis, the angular velocity of the support was estimated at first contact with the load distributors, and the kinetic energy of the support at this time was determined to be 49.8 kip-ft. An energy of 62.8 kip-ft had been predicted by computer simulation. Under the action of the rotating support, the truss was twisted approximately 9 deg. Using methods described in the Final Report of this study (2), the energy absorbed by the truss was estimated to be 25.8 kip-ft. The change in potential energy of the support from first contact with the load distributors to its maximum elevation was 4.6 kip-ft. The difference between gravitational potential energy plus the energy absorbed by the truss is 19.4 kip-ft, which is the estimated energy absorbed by the load distributors.

Figure 13. Impact area after Test C.

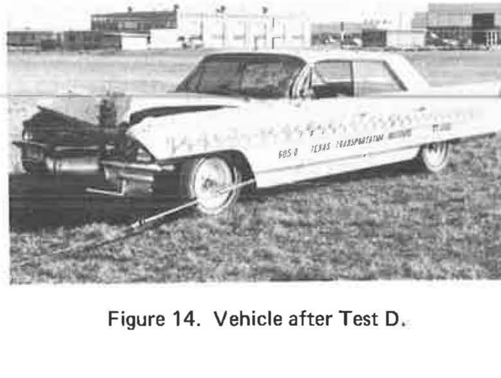


Figure 14. Vehicle after Test D.

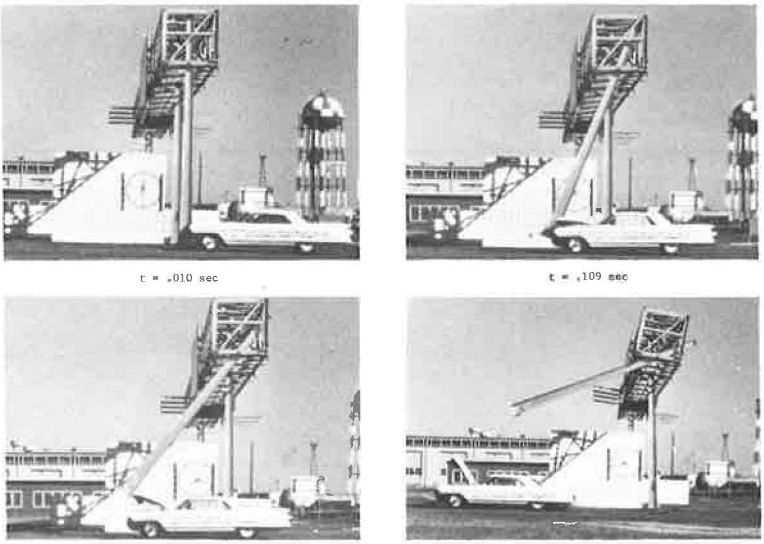


Figure 15. Sequential photographs of Test D.

Laboratory investigations indicated that the load distributors are capable of absorbing 40 kip-ft, and the potential of the OSB to absorb torsional energy is estimated to be 145 kip-ft. Under these conditions the upper connection bolts at support C should fracture.

After consultations with members of the Project Policy Committee and the Technical Subcommittee, it was decided to conduct crash tests at an impact angle of 15 deg with the support posts. (The 15-deg angle was the maximum angle permitted by the existing test facility.) The results of three angle impact tests follow.

TEST E

The vehicle in this test was directed into inner support B at a speed of 28.6 mph. The 3,920-lb Ford activated the breakaway connections satisfactorily and the support cleared the vehicle adequately. The load distributors were deformed very slightly and the truss rotated only 1 deg. The results of this low-speed, 15-deg angle test were similar to those observed in head-on Test A conducted at nearly the same impact speed. Damage to the test car, shown in Figure 16, was produced by a decelerative unit force of 3.7 g; and the peak decelerations were observed on electronic records to be 8.8 g (longitudinal) and 3.4 g (transverse).

TEST F

This test was conducted because in an earlier test the compact vehicle snagged the breakaway support. The 2,350-lb Borgward used in this test is similar in appearance to the 2,100-lb Simca which was tested earlier. Vehicle speed was 52 mph. During the interaction between vehicle and support, a slight lifting of the vehicle was observed. The front of the vehicle was elevated approximately 8 in. off the ground, but the support then rotated

Figure 16. Vehicle after Test E.

Figure 17. Vehicle after Test F.

Figure 18. Damage to truss guide angle (Test F).

away from the vehicle, allowing it to clear the car. The average longitudinal deceleration was 12.2 g; the maximum observed longitudinal deceleration was 30.8 g, occurring at 0.041 second after impact, and the maximum transverse deceleration of 9 g occurred at about the same time. These deceleration levels, bordering on the unacceptable from a passenger tolerance point of view, illustrate the problem inherent in interactions with small vehicles (that is, interactions having a low ratio of vehicle-mass to support-mass). Vehicle damage is shown in Figure 17.

A new development in this test was the contact between the support and guide angles. Guide angles were installed in the truss, as shown in Figure 18, to prevent the support from striking vertical truss members during an angle hit. In this test, when the portion of the support above the hinge point contacted the guide angle, a chunk of steel, shown in Figure 19, was peeled from the toe of the angle, but there was no damage to the support. The damage to the guide angle had no effect on the structural integrity of the truss. However, some energy was absorbed by this action. The support deformed the load distributors on the lower truss chords significantly and twisted the truss through an angle of 4 deg. The upper connection bolts at support B were fractured. The support-post behavior in an angle impact with an outer support is shown in Figure 20, and the pendulum action of the support is clearly demonstrated as the post rotates about its pin connection first in the direction of the colliding vehicle, then past the lower base connection (t = 2.000 sec). As noted earlier, this swinging action continues for several seconds following impact with an outside support.

TEST G

A Ford weighing 3,950 lb collided with support A at 50.1 mph and an impact angle of 15 deg. The vehicle was slowed 10.2 mph as a result of the collision. The average decelerative unit force on the vehicle was 5.8 g, and the peak decelerations were observed to be 15.3 g (longitudinal) and 3.5 g (transverse). These peaks occurred at approximately 0.040 second after impact. Damage to the crash vehicle is shown in Figure 21.

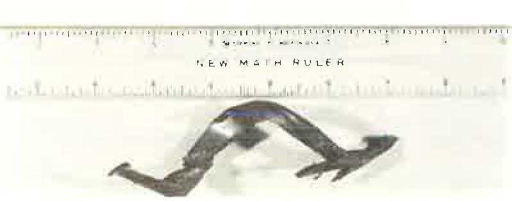


Figure 19. Splinter from guide angle.

The truss twisted through 8 deg and the upper connection bolts at support B were fractured. Upper connection bolts at sup-

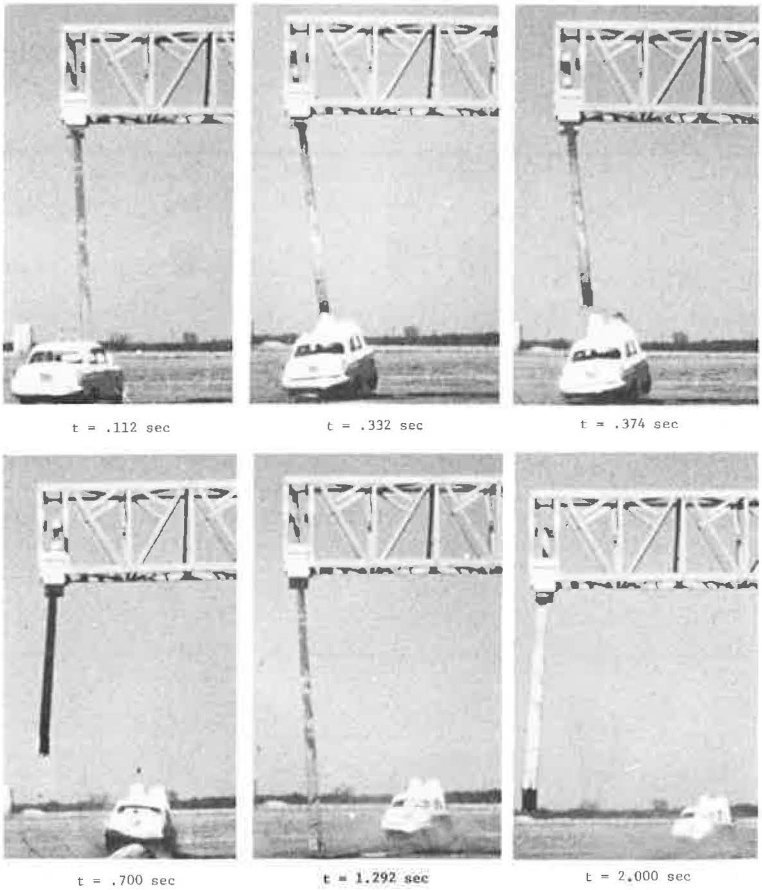


Figure 20. Sequential photographs of Test F.

ports C and D were removed, examined, and found to be undamaged. The structure remained erect and in good condition.

This test was conducted during a meeting of the Technical Subcommittee, at which two additional tests were proposed. Much discussion was devoted to the stability of the prototype structure when subjected to heavy vehicle loads at high impact speeds. At a later meeting of the Project Policy Committee it was decided to conduct two additional tests using heavy automobiles colliding with an outer and inner support.

Figure 21. Vehicle after Test G.

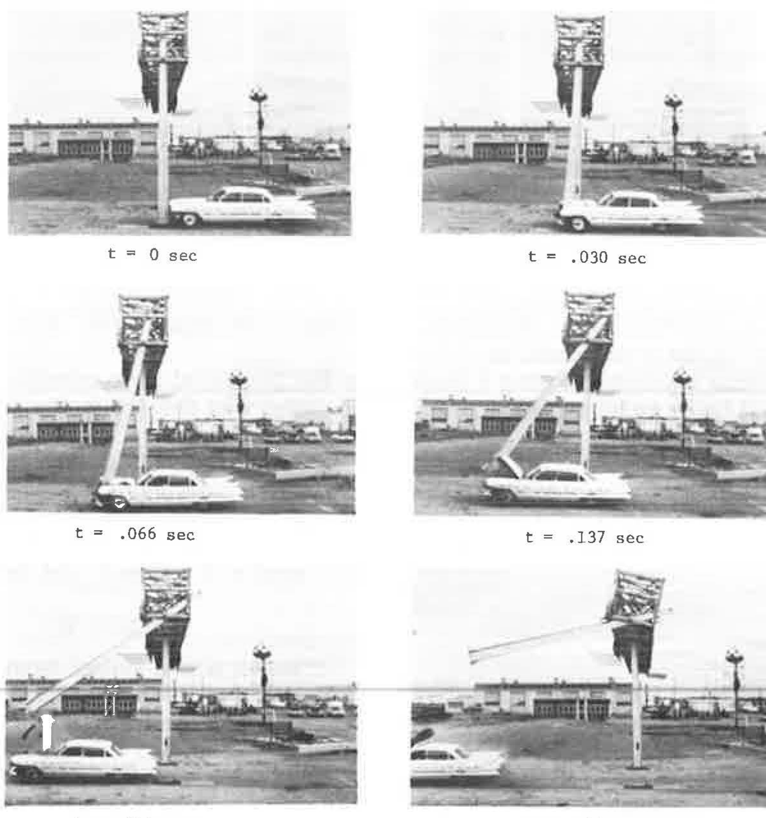
TEST H

Column A was struck head-on by a 5,150-lb Cadillac traveling at 75.3 mph. The upward rotating support ripped the hood from the car, continued upward, deformed the load distributors, and caused the truss to rotate about the pin connections. The upper connection bolts at columns B, C, and D fractured, and the truss continued to rotate until it came to rest in the position shown in Figure 22.

Figure 22. Condition of structure after Test H.

Figure 23. Crash vehicle after Test H.

The vehicle damage is shown in Figure 23. The average deceleration was 6.9 g and a peak of 17.6 g was observed on the accelerometer trace. The car was slowed 11.5 mph by the collision. The post penetrated the vehicle 2.08 ft. The entire structure remained upright following the collision, although the catwalk and lighting supports restricted clearance to approximately 12 ft.



t = 0 sec

t = .030 sec

t = .066 sec

t = .137 sec

t = .211 sec

t = .386 sec

Figure 24. Sequential photographs of Test H.

Figure 25. Damaged vehicle after Test I.

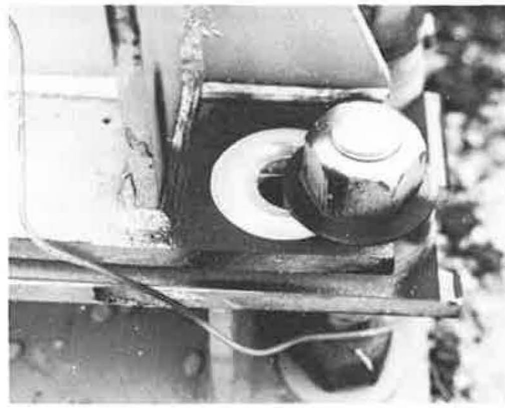


Figure 26. Breakaway base movement at column C (Test I).

TEST I

This final crash test was conducted on January 28, 1971. A 5,170-lb Cadillac struck column B at 72.0 mph and was slowed 11.2 mph by the impact. The sequence of events in the collision incident are shown in Figure 24, and damage to the car is shown in Figure 25. The average and peak decelerations are given in Table 1. The maximum post penetration was 2.6 ft.

Following the test, it was observed that the upper plate of the breakaway base at column C (Fig. 26) had slipped approximately 2 in. in the direction of vehicle impact. However, the truss and structure remained erect.

SUMMARY

At the outset this study was primarily concerned with the loads imposed by an automobile colliding with a breakaway overhead sign bridge support. Damage to the colliding vehicle, decelerative forces, and change in speed were of primary concern. As the study developed, it became clear that the behavior of the prototype truss and supports during a high-speed collision incident needed careful attention. Consequently, inside and outside supports were struck at angles of zero and 15 deg and load distributors and guide angles were developed and incorporated into the prototype structure.

CONCLUSIONS

1. The breakaway safety features of the overhead sign bridge reduce the collision forces on a standard-size vehicle to a level which is considered survivable for restrained passengers.
2. The prototype structure remained erect and suffered only localized damages during the series of tests reported.

ACKNOWLEDGMENTS

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At an early meeting, the deliberations of these engineers, administrators, and researchers led to a decision to conduct the testing program on the basis of increasingly severe conditions of impact, thus permitting interim evaluation of successive tests. As a result, damage to impacting vehicles and to parts of the prototype structure could be

observed and evaluated. Certain changes in the original design were necessary during the testing program.

The authors are deeply indebted to the members of the Project Policy Committee and the Technical Subcommittee and to the Contract Manager for their patience and counsel; furthermore, we thank them and their agencies for making this research effort possible.

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