AN EVALUATION OF THE IMPACT RESPONSE OF VARIOUS MOTORIST-AID CALL SYSTEMS

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In an effort to alleviate the problem of freeway inefficiency resulting from disabled vehicles, several states have installed the motorist-aid call system on urban freeways. These installations are usually situated adjacent to the roadway, and collisions with these installations may prove hazardous if adequate safety features are not incorporated. This paper presents the findings of analytical and experimental studies performed on the Maryland, Illinois, and Ohio call-box configurations. Two experimental tests were conducted for each: a pendulum test and a full-scale crash test. A parameter study was carried out with the aid of a mathematical model verified by the full-scale crash tests. The study employed vehicle weights varying from 2,000 to 5,000 lb and impacting velocities ranging from 20 to 60 mph. The most significant findings of the study may be summarized as follows: (a) The vehicle velocity and momentum changes due to the collision were considerably less than the established tolerable limits to 11 mph and 1,100 lb-sec; (b) vehicle damage was minor; (c) call-box damage is usually severe, and the unit generally has to be completely replaced after a collision; and (d) detachment of call-box assembly components during a collision may produce a hazardous condition.

•THE motorist-aid call system has been installed on some urban freeways in an effort to aid the problem of freeway inefficiency resulting from disabled vehicles and also to serve as a convenience to distressed motorists. Typical installations have the call boxes spaced at approximately ¼-mile intervals on each shoulder and in each direction of travel so that a motorist is not required to cross main lane traffic to place a call.

Because these installations are usually situated next to the roadway, collisions with these installations may be hazardous to the motorist if adequate safety features are not incorporated in the call system design. For example, a nonfrangible base attachment could cause large vehicular deceleration rates and possible injury to the occupants. Also, a call box improperly secured to the support post could come loose after impact and go through the windshield of the impacting vehicle. In addition, the dynamic characteristics of the call box may be such that, upon impact, the entire system rotates and strikes the vehicle compartment in the area of the windshield. Besides the safety considerations, aesthetics and initial and replacement costs of the installation must be duly considered.

This paper presents the results of three full-scale vehicle crash tests, pendulum impact tests, and parameter studies conducted with the aid of a mathematical model. The findings are for call-box installations proposed for use by Illinois, Maryland, and Ohio.

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DESCRIPTIONS OF INSTALLATIONS

Illinois System

The Illinois installation consists of a support post made of 5-in. diameter aluminum tubing with $\frac{1}{4}$-in. thick walls. Two aluminum signs, 3 ft square and 0.08 in. thick each, are bolted to the top as shown in Figure 1, and the cast aluminum base is welded to the support post. The terminal enclosure, also made of cast aluminum, is clamped to the support with steel bands. The entire assembly is approximately 13 ft high (Fig. 1).

Maryland System

The Maryland installation consists of a support post made from 3-in. diameter aluminum tubing with $\frac{1}{4}$-in. thick walls. The base of the post is composed of a 10-in. square aluminum plate with a thickness of 1 in. and gusseted with $4\frac{3}{8}$-in. thick plates. The terminal enclosure (call box) is clamped to the support post by means of two bolts and a steel band, and the antenna is connected to the top of the support post by a friction joint. The structure is more than 18 ft high (Fig. 2).

Ohio System

The Ohio installation consists of a hollow rectangular support post made of steel that has a cast metal base. The terminal enclosure is fixed to the top of the support post, and the assembly is bolted to a concrete foundation by means of four anchor bolts. The structure is approximately $5\frac{1}{2}$ ft high (Fig. 3).

COMPUTER SIMULATION

Each call-box assembly was idealized as a rigid body possessing three degrees of freedom: two translational and one angular. The assumptions are that the call-box assembly undergoes rigid-body planar motion after being struck by a vehicle, and that the vehicle behaves as a single-degree-of-freedom spring-mass system. This type of vehicular representation has produced satisfactory results in the analysis of roadside signs (1), luminaire supports (2), and overhead sign bridge structures (3). It is recognized that the planar motion assumption is not correct for off-center collisions on the structures under consideration; however, the analysis presented here is directed to central impacts and small vehicular approach angles. Under these circumstances the model should yield a satisfactory phenomenological behavior for the dynamic response of the structure and the vehicle.

The computer program established for the structural and vehicular response solved the equations of motion numerically and required knowledge of the structural geometric and inertia properties and the vehicular mass and geometry. Further, the base resistive-force variation for the structure was required and was obtained from the pendulum test data.

The output information from the computer program consists of the vehicular displacements and velocities and displacements of selected points of the call-box assembly. These values are printed at specified time intervals and also when (a) the base is fractured, (b) the support post loses contact with the vehicle, or (c) the call-box assembly either strikes the ground or recontacts the vehicle. The program automatically terminates when the third condition is met.

EXPERIMENTAL EVALUATION

Pendulum Tests

The pendulum tests were conducted to provide information for the computer simulation. The pendulum consisted of a 1,000-lb concrete-filled cylinder supported by four cables as shown in Figure 4a. These cables supported the ram in such a manner that upon release the ram swung as a pendulum from a height of approximately 15 ft and contacted the call-box support at a distance approximately $1\frac{1}{2}$ ft from the bottom, the

Figure 1. Illinois call-box assembly.

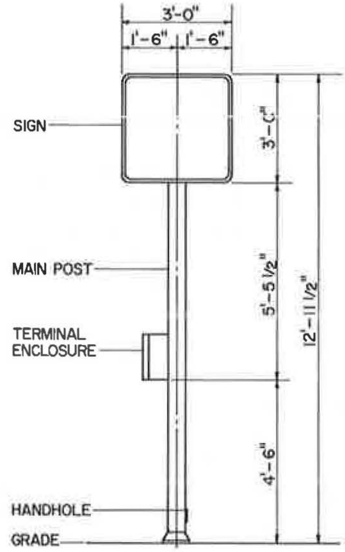


Figure 2. Maryland call-box assembly.

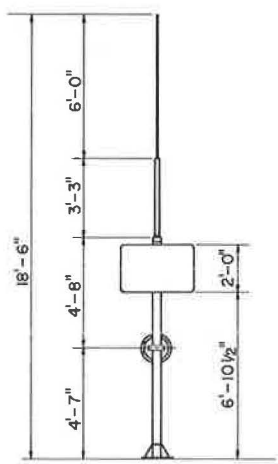


Figure 3. Ohio call-box assembly.

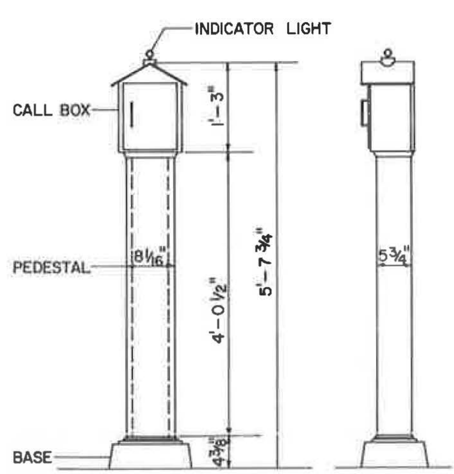
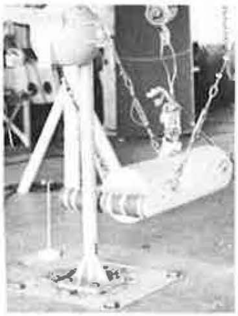
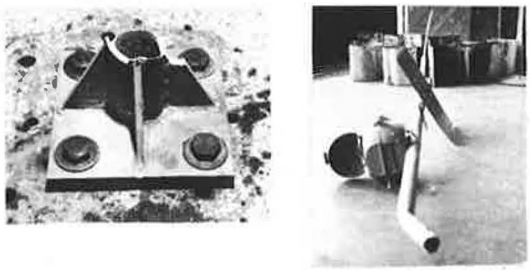


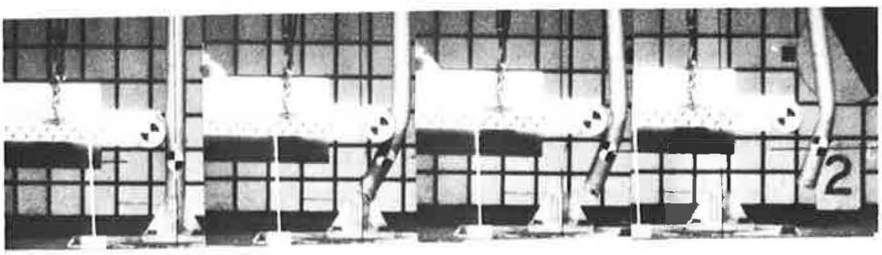
Figure 4. Maryland call-box assembly pendulum test.



a. Impacting Ram



b. Results of test



c. Sequence Photographs of Test

Table 1. Comparison of model and crash test results.

Test	Vehicle Weight (lb)	Velocity (mph) Initial	Velocity (mph) Change	Time to Fracture Base (sec)	Post Contact With Vehicle Roof: Time (sec)	Post Contact With Vehicle Roof: Vehicle Translation (ft)	Post Contact With Vehicle Roof: Post Rotation (deg)	Comment
Maryland								
Crash	2,870	43.2	2.3	0.039	0.192	11.6	81	Post contacts roof above windshield with point 10.8 ft from top of assembly.
Model	2,870	43.2	2.4	0.029	0.191	11.5	78	Post contacts roof above windshield with point 10.5 ft from top of assembly.
Illinois								
Crash	2,870	41.2	3.2	0.038	0.363			Post contacts left rear edge of roof as shown in Figure 5 after 0.363 sec.
Model	2,870	41.2	3.6	0.042	0.289			Post contacts roof 2.5 ft forward of rear window after 0.289 sec.
Ohio								
Crash	2,840	41.1	3.90	0.059				
Model	2,840	41.1	3.83	0.057				Post rides front end of vehicle rotating slightly toward the vehicle, then drops and hits ground in front of vehicle.

normal bumper height for most vehicles. The purpose of the tests was to supply base force-deformation data that could be used to simulate a vehicle crash test.

The instrumentation employed to obtain the test data consisted of an accelerometer attached to the back end of the impacting ram and a high-speed camera that photographed the test from a direction perpendicular to the plan of ram travel. Selected sequential photographs obtained with this camera for the test of the Maryland system are shown in Figure 4c. Figure 4b shows the results of the test and clearly indicates the mode of failure of the base. The pendulum tests have always provided valuable information concerning the force-deformation characteristics of a structure.

Vehicle Crash Tests

To evaluate the computer simulation, we conducted full-scale vehicle crash tests for each call-box assembly. The impact on each support was head on, and contact was made at the center of the front end of the vehicle. Figure 5 shows sequence photographs of the crash tests, and Table 1 gives a summary of model and crash test results.

Each vehicle was instrumented with two strain-gauge accelerometers, one on each longitudinal frame member, to measure longitudinal decelerations. In addition, a mechanical impact-o-graph was mounted in the vehicle trunk as a secondary source of acceleration data. An Alderson anthropometric dummy secured by a seat belt simulated the driver. The seat-belt assembly included a load cell that measured the seat-belt force. Two high-speed cameras, aligned perpendicular to the direction of vehicle travel, were used to obtain the photographic data. Documentary low-speed cameras provided additional test coverage.

Illinois Call-Box Crash Test

Figure 5a shows sequence photographs of the crash test that indicates that the motion of the assembly was not planar because the assembly rotated not only about an axis perpendicular to the vertical plane containing the path of the vehicle but also about its own longitudinal axis. This phenomenon permits the assembly to remain in the air longer and moves the point of secondary impact toward the rear of the vehicle. From this figure it can also be noted that the component parts of the assembly did not become detached during the collision; however, it should be emphasized that the collision occurred at a speed of 40 mph. At higher speeds some of the component parts can become detached if they are not properly secured.

Figure 6a shows the remains of the base after the crash test and clearly indicates that three of the anchor bolts were fractured. A similar failure mode was observed in the pendulum test. The shaft of the assembly was not severely bent. The vehicle damage was slight and the vehicular velocity, momentum, and deceleration changes encountered during the collision were quite low and should not prove hazardous to vehicle occupants experiencing a similar collision.

Maryland Call-Box Crash Test

Figure 5b shows that the call-box door was detached as a result of the impact but did not strike the windshield area of the vehicle. Figure 6b shows the base after the test and indicates its mode of failure. The anchor bolts, in this case, were not damaged. A similar failure mode had been observed in the pendulum test.

The vehicle damage was minor and the vehicular velocity, momentum, and deceleration changes encountered during the collision were again quite low. Individual parts of the assembly could become detached during a collision, which would create a hazard for vehicle occupants.

Ohio Call-Box Crash Tests

Figure 5c shows that the call box became detached from the support post during the collision but did not strike the vehicle. The assembly translated in the direction of the impact and rotated away from the vehicle because of the relatively low center of mass of the assembly produced by the detachment of the call box. If the call box had not become detached, the assembly could have rotated toward the vehicle.

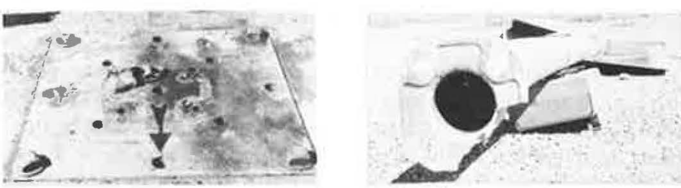
Figure 5. Sequence photographs of crash tests.

a. Illinois

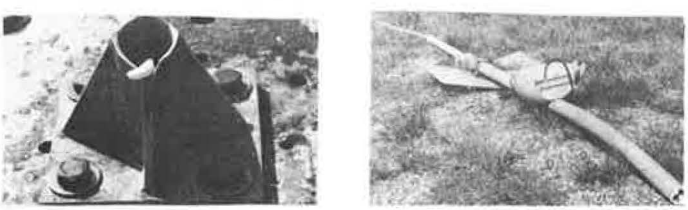
b. Maryland

c. Ohio

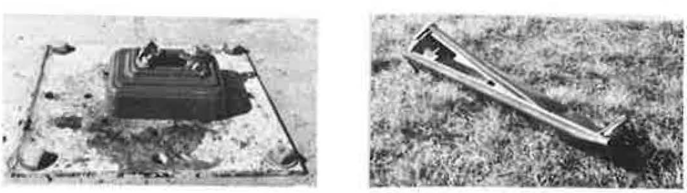
Figure 6. Crash test results.



a. Illinois



b. Maryland



c. Ohio

The support post, in this case, was severely damaged. The four anchor bolts of the base were severely damaged and would require replacement or extensive repair work (Fig. 6c).

The vehicle damage was again minor and, as in the previous tests, the vehicular velocity, momentum, and deceleration changes were well within tolerable limits.

CORRELATION OF MATHEMATICAL MODEL AND CRASH TEST RESULTS

From the values given in Table 1, it is apparent that the agreement between the mathematical model and the crash tests is quite good. Although the tests revealed that the support post is deformed significantly even though the model precludes this effect, the overall behavior of the assembly is satisfactorily represented by the model.

The agreement in the vehicular velocity changes and deceleration rates was excellent considering the degree of approximation that was used in the vehicle idealization. Thus, based on these findings, the parameter study presented in the next section was performed with the aid of the mathematical model.

PARAMETER STUDY

Based on the mathematical model verified by the full-scale crash tests, a parameter study was conducted to obtain the response of the assemblies and the impacting vehicle for a variety of cases. The study employed vehicles weighing from 2,000 to 5,000 lb and considered impacting speeds of 20, 40, and 60 mph. The results obtained for 2,000- and 5,000-lb vehicles are shown in Figures 7 and 8.

The findings of the study reveal that, for all the cases considered, the vehicular velocity changes, deceleration rates, and momentum changes are quite low and always remain well below the limits that have been suggested as being tolerable. These limits are 11 mph for the vehicular velocity change (4) and 1,100 lb-sec for the momentum change (5).

The Illinois assembly study revealed that the point of secondary impact by the post on the roof of the vehicle tends to move toward the rear windshield area as the speed and weight of the vehicle are increased. For the lighter vehicles, the tendency is for the post to strike somewhat further toward the front of the vehicle. However, it should be noted that the crash test demonstrated that the post did not exhibit planar motion because a rotation about its longitudinal axis took place. If this occurs in all cases, the simulation would normally predict shorter secondary impact times and a secondary impact point that is closer to the front of the vehicle. Thus, for this assembly, it appears that unless the assembly strikes the rear windshield of the vehicle, the secondary impact will not create a hazardous situation.

Figures 7b and 8b indicate that the Maryland call-box assembly behaves similarly to the Illinois assembly (Figs. 7a and 8a). The point of secondary impact by the post on the top of the vehicle tends to move toward the rear windshield area as the speed of the heavier vehicle is increased and strikes above the front windshield area for most lightweight vehicles traveling at low and medium speeds. Thus, it appears that, for the vehicles and speeds considered, a collision with a Maryland call-box assembly does not create a hazardous situation. However, due regard must be given to the possibility of component parts of the assembly becoming detached during the collision and striking the windshield of the vehicle.

Two systems, one of which included the properties of the call box, were considered for the Ohio call-box configuration; this simulated the condition observed in the crash test. The two systems behaved in a very similar manner for all the cases considered. As shown in Figures 7c and 8c, the call-box system rides the vehicle front end, rotates slightly toward the vehicle, and then drops to the ground in front of the vehicle. The system that contains the effects of the mass of the call box shows a stronger tendency to rotate toward the vehicle; however, because of the geometric and inertia properties of the assembly, it does not appear that the trajectory would be appreciably changed under actual field conditions. Thus, based on the parameter study and observation of the crash test, it appears that a hazardous situation is not created unless component

Figure 7. Parameter study results for 2,000-lb vehicle.

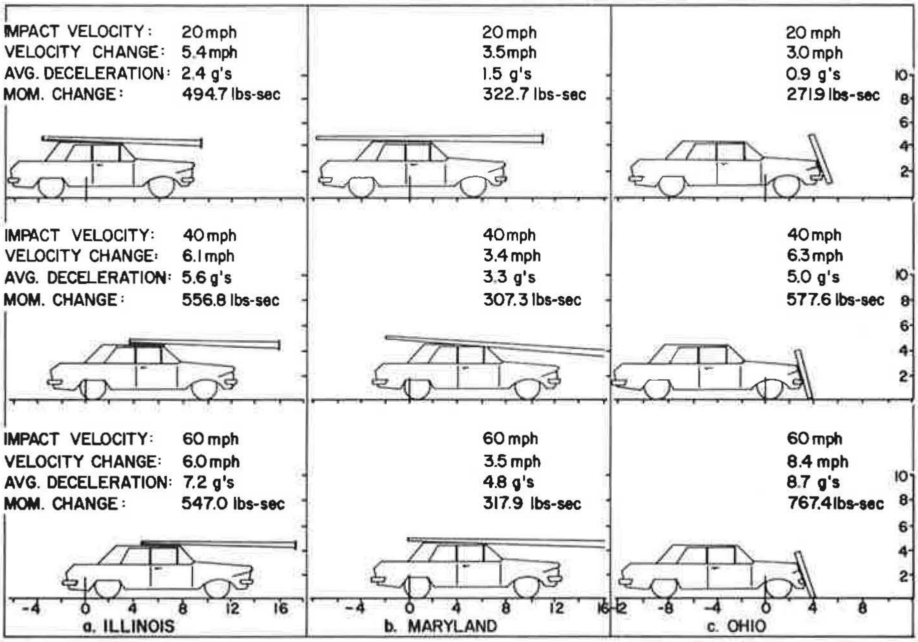
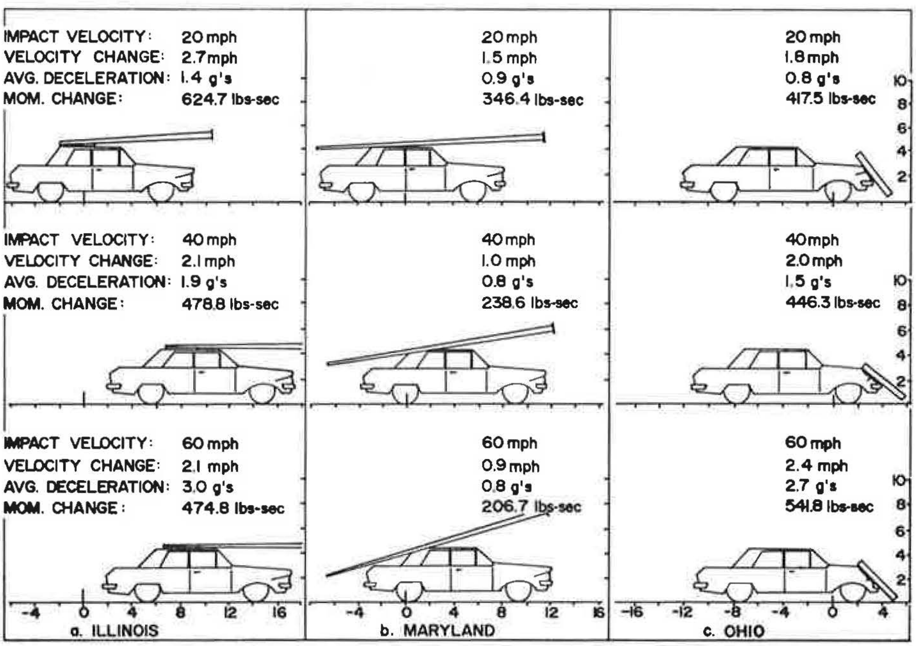


Figure 8. Parameter study results for 5,000-lb vehicle.



parts of this assembly become detached during the collision and strike the windshield area of the vehicle.

CONCLUSIONS AND RECOMMENDATIONS

The general conclusions stated here are based on the cases investigated analytically by computer simulation, observation of the vehicle crash tests, and comparison to vehicular velocity and momentum changes that have been suggested as being tolerable. These values are 11 mph (4) and 1,100 lb-sec (5) respectively.

For the cases studied, which covered a range of vehicle weights from 2,000 to 5,000 lb and impacting velocities of from 20 to 60 mph, the following conclusions were reached:

1. Vehicular velocity, deceleration, and momentum changes are well within the published tolerable limits for restrained occupants.
2. Vehicle damage is minor.
3. Damage to the call-box assemblies is severe, and the units would probably have to be completely replaced after a collision. The base anchor bolts of the Maryland assembly remain undamaged and should make replacement relatively easy, but those of the Illinois and Ohio configurations experience considerable damage and would require replacement or extensive repair work.
4. A hazardous condition created by the secondary impact of the post on the top of the vehicle will not normally occur.
5. A potentially hazardous condition arises as a result of components of the Maryland and Ohio assemblies becoming detached during a collision. Detached components must be considered a hazard to vehicle occupants.

It is recommended that the component parts of the call-box assemblies be adequately secured so that they will not become detached during a collision. In particular, the attachments of the call box to the support post and the hinges of the call-box door should be strengthened.

ACKNOWLEDGMENTS

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