IMPACT RESPONSE OF OVERHEAD SIGN BRIDGES MOUNTED ON BREAKAWAY SUPPORTS

J. E. Martinez, R. M. Olson, and E. R. Post, Texas A&M University

Modern roadways must employ signs that relay information to the motoring public in an efficient manner. The overhead sign bridge (OSB) is often used for this purpose, and collisions with these massive structures have caused serious injuries and fatalities as current installations do not employ safety features that limit impact forces incurred during a collision. This paper presents the general design considerations and the results of the mathematical simulation of vehicle collision with overhead sign bridges mounted on breakaway supports. The results were obtained through the use of a mathematical model verified by seven full-scale crash tests. A comparison of model and test results is shown in the report and indicates good agreement. The study was performed on a high-speed electronic computer, and its findings and the results of the crash tests may be summarized as follows:

1. The application of the breakaway concept to the supports of an overhead sign bridge is feasible.
2. The prototype truss possessed the ability to withstand the torsional loads imparted to it by the rotating support, and the structure as a whole remained stable under the impact forces.
3. Vehicle-velocity changes and deceleration rates increase as breakaway base and upper-shear connection resistances increase.
4. Occupants of small to medium-size vehicles could possibly suffer injury in a collision with the prototype support.
5. Larger vehicles were not severely damaged in collisions with the prototype support.

•MANY modern highways employ overhead sign bridges in order to relay information to the motorist in a clear and concise manner. These large and massive structures constitute a safety hazard for the motorist as present installations are not equipped with safety devices that limit the impact forces which a vehicle experiences during a collision. Consequently, collisions with the supports of overhead sign bridges have caused serious injuries and fatalities to vehicle occupants.

The relocation of the support posts offers a solution to the problem. This, however, is usually not economically feasible and other means must be employed in order to eliminate the safety hazard. A concept that has already shown considerable merit when applied to roadside signs and luminaire support structures is the breakaway support which, upon impact, disengages the post from the foundation. Such a concept may be applied to an overhead sign bridge but regard must be given to the possibility of the structure, after impact, falling on the highway and causing an unsafe condition for motorists.

In order to develop a concept into a design that can be utilized under field conditions, it is necessary to investigate its behavior for a variety of cases. For the problem in question this entails evaluation of the effects of different support resistances, and various vehicular weights and impacting velocities. To analyze the different situations a large number of full-scale crash tests may be conducted or else a mathematical model

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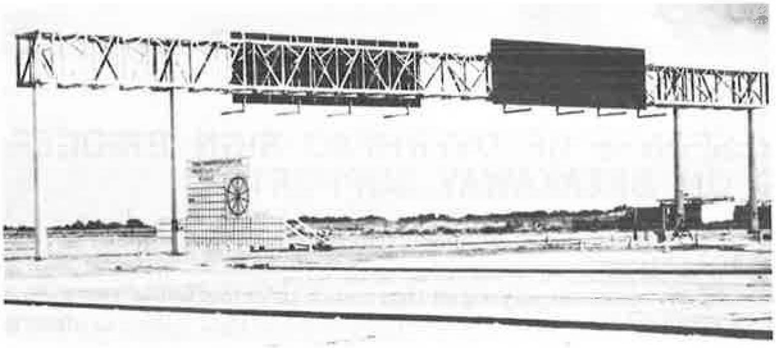


Figure 1. Prototype OSB with four breakaway supports.

that will predict the behavior of the system may be developed. The study described in this paper was carried out on a high-speed computer with the aid of a mathematical model verified by seven full-scale crash tests performed on the prototype overhead sign bridge shown in Figure 1. The model permitted the investigation of a large number of cases and circumvented the high cost associated with performing numerous crash tests.

THE PROTOTYPE OVERHEAD SIGN BRIDGE

The prototype OSB with four breakaway supporting columns is shown in Figure 1. Except for minor modifications, this structure is essentially the same as the preliminary design of Hawkins (1) and is meant to represent a very large OSB structure which might be constructed on modern highways.

The structure under consideration has an overall length of 140 ft. The truss, which is 6 ft in width and depth, is supported by two breakaway exterior and interior columns spaced 20 ft apart. The 100-ft middle section of the structure is of sufficient length to span a four-lane divided highway having standard 12-ft lanes and shoulders, a median width of 18 ft, and a distance of 5 ft from the shoulder edge to the interior columns. The OSB is structurally adequate to resist dead loads and a 100-mph wind load with all four columns in place, whereas, when one of the four columns is disengaged from its foundation, the structure adequately resists dead loads and a wind load of 50 mph.

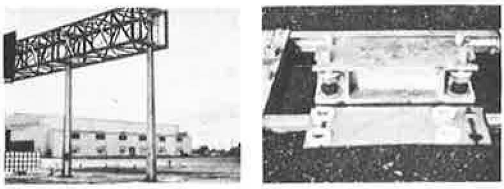
In order to satisfy the condition for a sign area of 650 sq ft (325 sq ft above travel lanes in each direction) which exceeds the sign area of the majority of contemporary installations, breakaway columns weighing nearly 1,500 lb, were needed. These columns have an overall height of approximately 26½ ft above the slip base and were fabricated from a 100,000-psi heat-treated constructional alloy steel (ASTM 514) and tapered in both the flanges and web. Each column was designed to clear a colliding vehicle and rotates about its own $1\frac{7}{16}$-in.-diameter stainless-steel pin connection following the release of the breakaway base connection and the fracturing of four ½-in. A307 bolts in the upper connection. A close-up view of the column connections is shown in Figure 2.

Following the initial 20-mph pilot test, three important features were incorporated into the existing design. They included:

1. The fastening of steel pipe sections to the lower chord members of the truss (Fig. 3) in order to distribute the impact forces and minimize the possibility of serious damage to the truss due to the impact of the rotating column support.
2. The installation of two horizontal angles, which are visible in Figure 3 at approximately middepth of the truss and on each side of the column, in order to guide the flexible column during an angle collision and prevent the column from damaging the vertical truss members.
3. The placing of a thin sheet-metal "keeper plate" between the slip base plates of the column and the stub post as shown in Figure 2c. This was done to eliminate the possibility of the breakaway columns "walking" off their foundation stub posts during vibrations set up by wind and vehicle traffic.

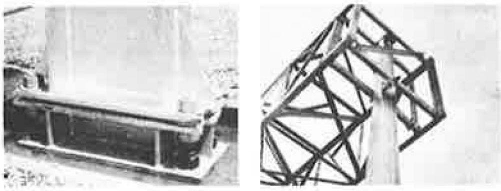
FORMULATION OF PROBLEM

The structure under consideration is shown in Figure 1 and is comprised of approximately 400 members. The solution for the response of this structure subjected to some loading condition requires solving a large number of simultaneous equations; and, even with the facilities of an IBM 360/65 computer having a core capacity of 100 k words, it is usually necessary to employ outside storage facilities in order to perform the static analysis of the structure. An elastic dynamic analysis considering the entire overhead sign bridge not only adds to the information storage difficulties, but makes the computer cost to solve the problem prohibitive. The reason for this is that the solution must be carried out numerically and the response must be followed for a considerable length of time. Consequently, it was decided to employ three mathematical models to describe the behavior of the structure.



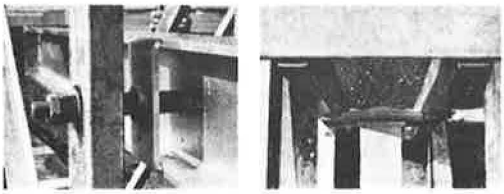
a. COLUMN CONNECTIONS

b. STUB POST



c. SLIP BASE

d. PIN & UPPER CONNECTIONS



e. PIN CONNECTIONS

f. UPPER CONNECTIONS

Figure 2. OSB column connections.

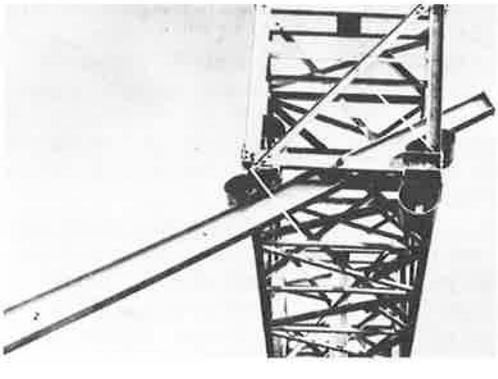


Figure 3. Detail of OSB impact attenuator device.

DISCUSSION OF MATHEMATICAL MODELS

Dynamic Model of Supporting Column

This model assumed the supporting column to be a rigid body having only an angular degree of freedom and being hinged at the truss connection, and idealized the colliding vehicle as a single-degree-of-freedom spring-mass system. This idealized system along with the forces that are taken to act on it is shown in Figure 4.

The forces F_F and F_T in Figure 4 represent shear resistances offered by the base connection and the upper connection to the truss respectively, whereas the force F_S represents the vehicular impact force. A detailed discussion of these forces along with the governing differential equations of motion and the numerical procedure employed to solve them is presented elsewhere (2).

Static Space Truss Model

This model was developed for the purpose of analyzing the overhead sign bridge as a three-dimensional structure under the simultaneous action of weight and wind loads. The effect of the impact force caused by a vehicular collision on the support was considered statically.

The space truss analysis was based on the matrix displacement method of structural analysis and considered the structure to be an assemblage of six-degree-of-freedom truss finite elements. This approach is well established in the literature (3, 4, 5), which also contains a typical element and its stiffness matrix (5, p. 279) and a more complete discussion of this model (2).

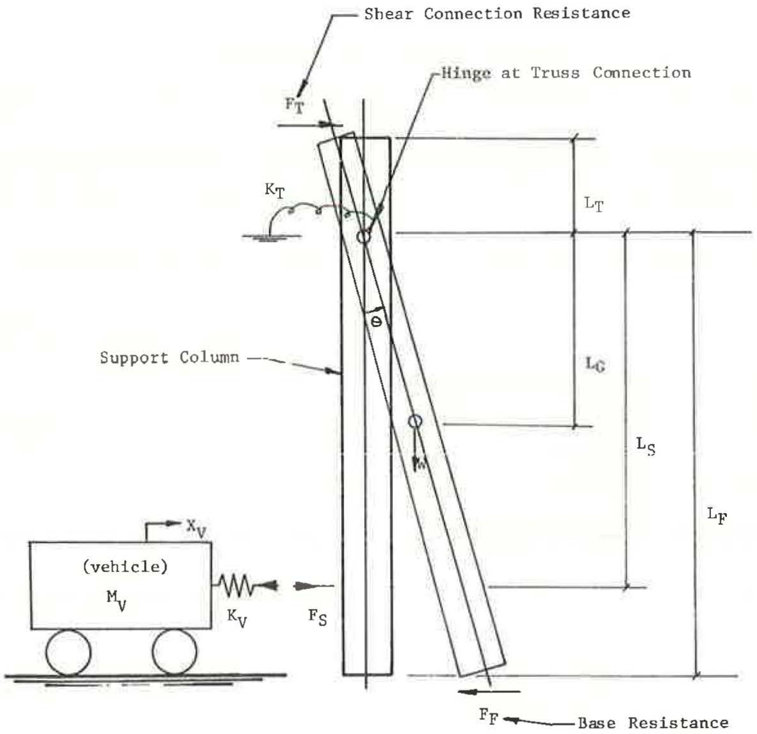


Figure 4. Vehicle and support column idealization.

Torsional Model

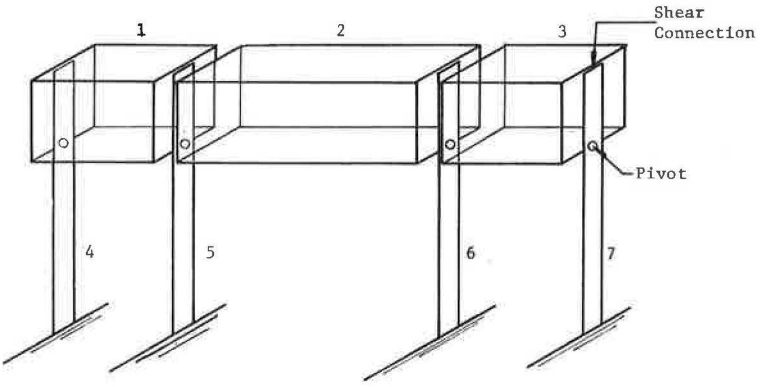
A preliminary torsional analysis of the truss portion of the overhead sign bridge has been performed by dividing the structure into substructures and employing static test data obtained from field tests performed at the Texas Transportation Institute on the prototype sign bridge (6). The data permitted the use of realistic stiffness properties in developing a finite element model that circumvented the use of a computer.

The entire structure was subdivided into the substructures shown in Figure 5a which produced the idealized model shown in Figure 5b. For the mathematical modeling, it was assumed that either inner or outer column supports could be struck by a vehicle, but not simultaneously.

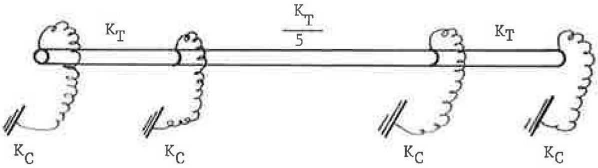
Based upon results presented elsewhere (6), values of 750 ft-kips/deg and 79 ft-kips/deg were used for the column pivot stiffness and a 20-ft section of truss respectively. The analysis was conducted by allowing the column supports to offer a resistance only while the shear connection was effective. Empirical values obtained for the torque and the rotation (6) revealed that it was realistic to assume failure at a shear connection when a column bending moment of 230 ft-kips was developed at a point directly below the pivot.

Assuming a collision with an outer support and a shear connection failure at an adjacent inner support produces the model shown in Figure 6a. A further shear-connection failure results in the model depicted in Figure 6b.

It should be emphasized that inelastic action has been precluded in establishing this preliminary model. Under actual field conditions this is not necessarily true and thus the truss may be capable of absorbing more energy than is indicated by this analysis and shown in Figure 7. However, it is felt that the analysis produces energy values that are indicative of what the structure will contain if realistic stiffness coefficients



a. Representation by series of substructures



*K_T = Truss Stiffness for 20ft. Section.
*K_C = Stiffness of Column Support.

b. Idealized torsion model

Figure 5. Overhead sign bridge.

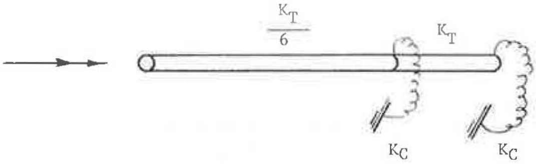
can be determined. Significant variations in the empirical values used in this analysis could produce a sizeable change in the energy-absorbing capability of the truss.

It should be noted that the accuracy of the results obtained with this model is dictated by the values of the stiffness coefficients that are employed. To date, a good correlation between stiffness coefficients obtained from the static space truss model and the test results (6) has not been possible. This can partially be attributed to the manner in which the boundary conditions are imposed on the model. A study to obtain a model that will accurately predict these coefficients appears to be extremely worthwhile but has presently not been undertaken.

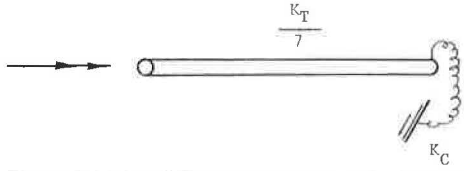
Correlation—Space Truss

Presently, the information obtained from the static space truss model has been mostly limited to checking out the design of the prototype truss for wind and gravity loads, and the results obtained for the deflections and stresses indicate that the design is adequate. The model may also be employed to determine stiffness coefficients for the truss; however, as mentioned previously, adequate correlation between model and field test results has not been obtained. A stability analysis of the truss is not beyond the scope of the model and this capability could be incorporated into the existing computer code if such an analysis became warranted.

The results obtained from the torsional model are based on the limited amount of test data available and may be summarized by the torque-rotation curve shown in Figure 7. This curve shows that the truss is capable of absorbing approximately 145 ft-kips of energy and rotating through 25 deg before failure at the upper shear connection C occurs. It is felt that this amount of energy-absorbing capability is sufficient to cope with a collision by a 5,000-lb vehicle traveling at 60 miles per hour and having an approach angle of zero.



a. For collision with outer support and shear-connection failure at adjacent inner support



b. For collision with outer support and shear-connection failure at both inner supports

Figure 6. Torsion models of overhead sign bridge.

Correlation—Support

In order to validate the dynamic model of the supporting column, the results obtained from the computer solution were compared with the results obtained from seven full-scale crash tests performed by the Texas Transportation Institute; comparisons are given in Tables 1 and 2. The tables give a summary of crash test data and compare test results with mathematical simulation predictions for the response of the structure when subjected to vehicular impact. These values offer a comparison of the model with crash test data for various situations and provide information that illustrates the limitations of the results.

Table 1 gives a comparison of the vehicular velocity changes, deceleration rates, and time the post and vehicle are in contact, whereas Table 2 gives values obtained for the maximum post penetration and comments on the rotation of the support.

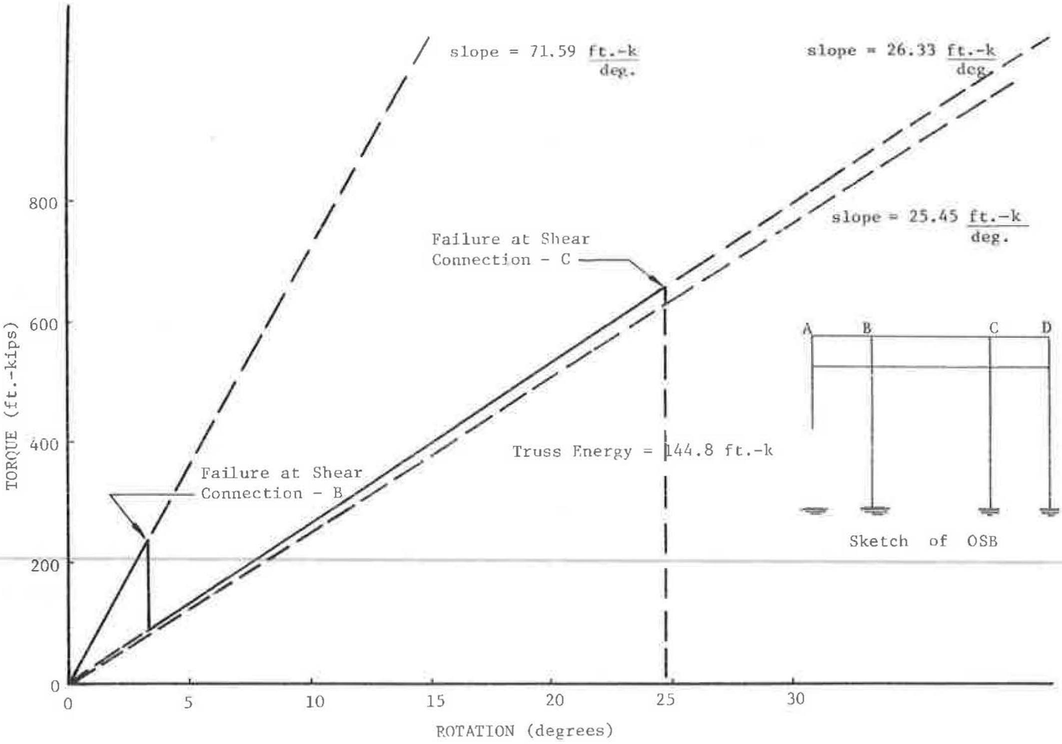


Figure 7. Torque-rotation curve for collision with outer support.

TABLE 1

SUMMARY OF CRASH TEST DATA AND MODEL SIMULATION

Test Conditions						Comparison of Results					
Test Number	Date of Test	Year, Make, and Type of Vehicle	Vehicle Weight (lb)	Vehicle Approach Angle (deg)	Impact Velocity (mph)	Change in Vehicle Velocity (mph)		Time Post and Vehicle Were in Contact (sec)		Average Deceleration (g)	
						Test	Model	Test	Model	Test	Model
605-A	09-23-69	1963 Ford 2-door sedan	3,960	0	25.7	5.4	5.9	0.091	0.082	2.9	2.9
605-B	12-11-69	1959 Simca 4-door sedan	2,100	0	44.0	14.8	16.2	0.080[a]	0.139	8.7	5.3
605-C	12-18-69	1963 Ford 4-door sedan	4,090	0	46.5	9.1	9.3	0.080	0.099	5.7	4.3
605-D	02-03-70	1962 Cadillac 4-door sedan	4,880	0	54.0	9.0	9.1	0.080	0.087	4.2	4.7
605-E	02-09-70	1963 Ford 4-door sedan	3,920	15	28.6	7.2	7.0	0.085	0.095	4.1	3.4
605-F	02-17-70	1959 Borgward 2-door sedan	2,350	15	52.0	13.6	16.7	0.119	0.130	5.8	5.8
605-G	04-07-70	1962 Ford 2-door sedan	3,950	15	50.1	10.2	10.4	0.059	0.093	7.9	5.1

[a] Time during which breakaway components were activated. Vehicle snagged lower end of support post, was lifted and pulled to a stop, wedged between support post and the ground.

The crash test data were obtained from electronic instrumentation and high-speed film, and these data have been found to agree reasonably well with the computer simulation. Some of the differences between test results and mathematical simulation can be attributed to data reduction and analysis techniques. For example, values of the contact time and vehicle translation during contact are obtained by observation of the high-speed film and it is difficult to establish precisely the time when contact is lost. The relative precision of test results is being studied by other members of the Texas Transportation research team and is reported elsewhere (6).

The first four tests were head-on impacts, whereas with the last three the vehicular approach was at an angle of 15 deg. In all cases, head-on impact was assumed by the mathematical model without any appreciable difference between model and test results.

From the values shown in Tables 1 and 2, it is evident that collisions by medium-weight vehicles traveling in excess of 25 mph cause the support post to strike the truss.

TABLE 2

SUMMARY OF CRASH TEST DATA AND MODEL SIMULATION

Test Conditions					Comparison of Results			
Test Number	Year, Make, and Type of Vehicle	Vehicle Weight (lb)	Vehicle Approach Angle (deg)	Impact Velocity (mph)	Maximum Post Penetration (ft)		Remarks	
					Test	Model	Test	Model
605-A	1963 Ford 2-door sedan	3,960	0	25.7	0.96	0.97	Post hits truss	Post hits truss E_k = 3.1 ft-kip[b]
605-B[a]	1959 Simca 4-door sedan	2,100	0	44.0	1.75	2.15	Post hits truss	Post hits truss E_k = 19.1 ft-kip[b]
605-C	1963 Ford 4-door sedan	4,090	0	46.5	1.25	1.63	Post hits truss	Post hits truss E_k = 38.5 ft-kip[b]
605-D	1962 Cadillac 4-door sedan	4,880	0	54.0	1.50	1.60	Post hits truss	Post hits truss E_k = 62.86 ft-kip[b]
605-E	1963 Ford 4-door sedan	3,920	15	28.6	0.85-1.1	1.13	Post hits truss	Post hits truss E_k = 6.5 ft-kip[b]
605-F	1959 Borgward 2-door sedan	2,350	15	52.0	1.5-1.8	2.30	Post hits truss	Post hits truss E_k = 37.0 ft-kip[b]
605-G	1962 Ford 2-door sedan	3,950	15	50.1	1.60	1.76	Post hits truss	Post hits truss E_k = 48.9 ft-kip[b]

[a] Vehicle snagged support base and was lifted by it.

[b] Angular kinetic energy of post.

In tests conducted to date, the contact made with the truss by the support has not damaged the truss. This can be attributed partially to the energy-absorbing, load-distributing devices attached to the truss, as shown in Figure 3. However, it is possible for a high-speed collision to cause severe local damage to truss members unless adequate load-distributing devices are installed on the truss. To provide a satisfactory design, such devices must allow the support to rotate through an angle large enough to clear the vehicle and yet be able to absorb a sufficient amount of the rotational kinetic energy of the support. A device made from 12-in.-diameter, $^3/_8$-in.-wall-thickness pipe was installed on the truss. In addition, 4 in. by 4 in. by 12 in. angles were installed to prevent the upper portion of the support from contacting the vertical truss members. These and other design details are discussed elsewhere (7).

The average deceleration rates obtained from the crash tests agree quite well with the results obtained from the computer model. An unexpected incident occurred in Test 605-B; in this test, the vehicle snagged the support post and was lifted by it. Contact between the vehicle and the support was never lost. The average vehicle deceleration is based on film observation (Table 1).

The agreement in values obtained for the maximum post penetration is very satisfactory (Table 2). The softer front ends of the lightweight vehicles permit a larger post penetration than do the sturdier medium- and heavy-weight vehicles; however, all penetrations are small when compared with similar penetration by a fixed post.

In an earlier study (8), several vehicles were crashed into a fixed support, and maximum post penetrations were recorded. For similar conditions, post penetration by a fixed post was much greater than that measured in the current series of tests on a breakaway support. For example, the fixed-post penetration into a 1959 Simca 4-door sedan, traveling 45 mph was 4.25 ft compared with 1.75-ft penetration by the breakaway support in the current series; and a 1959 4-door Cadillac, traveling 44 mph was penetrated 4.50 ft by the fixed post compared with 1.50 ft in the current tests. These comparisons are indicative of the relative severity of collisions with a fixed support and with the breakaway support.

The comparison shown for the seven tests reveals that good agreement exists between the computer model and the field tests. Further, the feasibility of the breakaway concept for the supports of an overhead sign bridge has been demonstrated.

PARAMETER STUDY

The parameter study revealed that lower vehicular velocity changes and deceleration rates may be expected for lower values of the base and shear connection resistances (2). However, due to the massiveness of the support, the major portion of the change in the vehicle response can be attributed to the inertia of the column. This is particularly true for the higher impact velocities. The decrease in the resistance offered by the column also normally results in a higher kinetic energy being imparted to the support. This produces a larger rotation of the support and could cause interference between the truss and the support. The impact on the truss by the column can conceivably cause damage to the truss.

The vehicle deformation is likewise primarily caused by the large mass of the support. For a given base and shear-connection resistance, the vehicle deformation increases with an increase in the impact velocity and reaches a maximum of 2.80 ft for the case of the 2,000-lb vehicle having an impact velocity of 60 mph (Table 5). It should be noted that the model assumes the vehicle spring constant to be equal to ten times the vehicle weight and consequently the lighter vehicle has a relatively soft spring which produces larger deformations.

Light- and medium-weight vehicles experience a secondary collision with the support when it is impacted at a velocity of 15 mph (Table 3). These collisions should be interpreted as hazardous because the secondary collision will occur in the area of the passenger compartment and could cause injury to the occupants. The remainder of the cases presented disclose that the post always clears the vehicle. This is desirable from the standpoint of circumventing a secondary impact; however, the vehicular velocity changes may be excessive or the vehicle may impart such a large amount of energy to the support that damage to the truss is produced.

TABLE 3

PARAMETER STUDY—RESULTS FOR HEAD-ON COLLISION AT A VEHICULAR VELOCITY OF 15 MPH AND 22 K SHEAR-CONNECTION RESISTANCE

Vehicle Weight (lb)	Base Resistance (kips)	ΔV (mph)	Average g	Contact Time (sec)	Maximum Post Penetration (ft)	Comments
2,000	0	6.19	1.94	0.146	0.77	Post hits top of vehicle
2,000	2	7.15	2.26	0.145	0.84	Post hits top of vehicle
2,000	7	12.72	5.01	0.116	1.01	Post hits hood of vehicle
2,000	10	15.0	5.6	0.084	1.03	Vehicle was stopped
3,500	0	3.7	1.6	0.106	0.60	Post clears vehicle
3,500	2	4.1	1.7	0.111	0.62	Post hits top of vehicle
3,500	7	5.6	2.4	0.104	0.75	Post hits top of vehicle
3,500	10	7.1	3.4	0.096	0.80	Post hits top of vehicle
5,000	0	2.8	1.7	0.076	0.50	Post clears vehicle
5,000	2	3.0	1.7	0.079	0.50	Post clears vehicle
5,000	7	3.7	2.1	0.082	0.60	Post clears vehicle
5,000	10	4.5	2.5	0.078	0.64	Post clears vehicle

It has been suggested in the literature (9) that vehicular velocity changes in excess of 11 mph should be avoided if a hazardous condition that could cause injury to the vehicle occupants is to be prevented. Thus, based on this criterion, hazardous collisions occur when lightweight, slow-moving vehicles or light- and medium-weight vehicles traveling at high speeds impact the column support. In all these cases the vehicular velocity changes exceed 11 mph and reach a maximum of 21 mph for a case shown in Table 5.

The values of E_k given in Tables 3 through 6 represent the angular kinetic energy of the support at the instant it has rotated through an angle large enough to cause the support and the truss to interfere. This condition was taken to occur at a support rotation of 81.5 deg. These values can become quite large as the impact velocity is increased, and for the higher velocities an energy absorber should be placed on the truss. This absorber would take in some of the angular kinetic energy of the support and keep the truss from having to cope with such a large amount of energy.

TABLE 4

PARAMETER STUDY—RESULTS FOR HEAD-ON COLLISIONS AT A VEHICULAR VELOCITY OF 30 MPH AND 22 K SHEAR-CONNECTION RESISTANCE

Vehicle Weight (lb)	Base Resistance (kips)	ΔV (mph)	Average g	Contact Time (sec)	Maximum Post Penetration (ft)	Comments
2,000	0	10.26	3.38	0.139	1.36	Post hits truss E_k = 1.84 ft-kip
2,000	2	10.8	3.48	0.142	1.42	Post hits truss E_k = 1.40 ft-kip
2,000	7	12.4	3.86	0.147	1.58	Post hits truss E_k = 0.08 ft-kip
2,000	10	13.96	4.37	0.146	1.70	Post clears vehicle
3,500	0	6.5	2.90	0.103	1.07	Post hits truss E_k = 7.13 ft-kip
3,500	2	6.8	3.10	0.099	1.10	Post hits truss E_k = 7.66 ft-kip
3,500	7	7.4	3.00	0.112	1.20	Post hits truss E_k = 6.03 ft-kip
3,500	10	7.8	3.10	0.113	1.20	Post hits truss E_k = 5.82 ft-kip
5,000	0	4.9	2.90	0.078	0.91	Post hits truss E_k = 11.33 ft-kip
5,000	2	4.96	2.70	0.083	0.93	Post hits truss E_k = 10.33 ft-kip
5,000	7	5.3	2.90	0.085	0.99	Post hits truss E_k = 10.16 ft-kip
5,000	10	5.7	3.08	0.084	1.00	Post hits truss E_k = 10.68 ft-kip

TABLE 5

PARAMETER STUDY—RESULTS FOR HEAD-ON COLLISION AT A VEHICULAR VELOCITY OF 60 MPH AND 22 K SHEAR-CONNECTION RESISTANCE

Vehicle Weight (lb)	Base Resistance (kips)	ΔV (mph)	Average g	Contact Time (sec)	Maximum Post Penetration (ft)	Comments
2,000	0	19.00	4.68	0.185	2.60	Post hits truss E_k = 48.86 ft-kip
2,000	2	19.20	4.63	0.189	2.60	Post hits truss E_k = 47.76 ft-kip
2,000	7	20.20	5.30	0.174	2.70	Post hits truss E_k = 46.82 ft-kip
2,000	10	21.10	6.10	0.157	2.80	Post hits truss E_k = 46.57 ft-kip
3,500	0	12.30	5.00	0.111	2.00	Post hits truss E_k = 69.12 ft-kip
3,500	2	12.40	4.80	0.116	2.08	Post hits truss E_k = 67.79 ft-kip
3,500	7	13.00	5.70	0.103	2.10	Post hits truss E_k = 71.14 ft-kip
3,500	10	13.20	5.50	0.110	2.20	Post hits truss E_k = 68.81 ft-kip
5,000	0	9.20	5.07	0.083	1.70	Post hits truss E_k = 83.22 ft-kip
5,000	2	9.30	5.04	0.084	1.77	Post hits truss E_k = 82.41 ft-kip
5,000	7	9.50	4.80	0.090	1.80	Post hits truss E_k = 79.49 ft-kip
5,000	10	9.90	5.70	0.080	1.80	Post hits truss E_k = 86.28 ft-kip

The angular kinetic energy values (E_k) presented in Tables 2 through 6 are taken at an instant when the support has rotated through an angle large enough to cause the truss and the support to interfere. They reveal that, according to the mathematical model, the relationship between angular kinetic energy of the support and vehicle impacting velocity is almost linear for a given vehicular weight.

Table 6 presents the results from some extreme cases. Here, 10,000-lb and 20,000-lb vehicles have been selected and the base and shear-connection resistances have been taken as 10 k and 22 k respectively. The 10,000-lb vehicle was assumed to have a height of 11 ft and a length of 27 ft, whereas the 20,000-lb vehicle has 11 ft and 36 ft values. The vehicular spring constant was taken as 100,000 lb/ft for both vehicles.

TABLE 6

PARAMETER STUDY—RESULTS FOR HEAD-ON COLLISIONS BY 10,000- AND 20,000-LB VEHICLES

Vehicle Weight (lb)	Vehicle Velocity (mph)	ΔV (mph)	Average g	Contact Time (sec)	Maximum Post Penetration (ft)	Comments
10,000	15	2.20	2.0	0.049	0.040	Post hits vehicle
10,000	30	2.90	2.5	0.053	0.070	Post hits truss E_k = 17.8 ft-kip
10,000	45	4.10	3.5	0.053	1.00	Post hits truss E_k = 55.3 ft-kip
10,000	60	5.40	4.8	0.051	1.30	Post hits truss E_k = 111.8 ft-kip
20,000	15	1.20	1.6	0.033	0.23	Post hits truss E_k = 4.0 ft-kip
20,000	30	1.77	2.6	0.031	0.50	Post hits truss E_k = 36.9 ft-kip
20,000	45	2.10	1.9	0.051	1.00	Post hits truss E_k = 64.9 ft-kip
20,000	60	2.70	2.3	0.055	1.30	Post hits truss E_k = 114.6 ft-kip

Note: These results are for a base resistance of 10 k and a shear-connection resistance of 22 k.

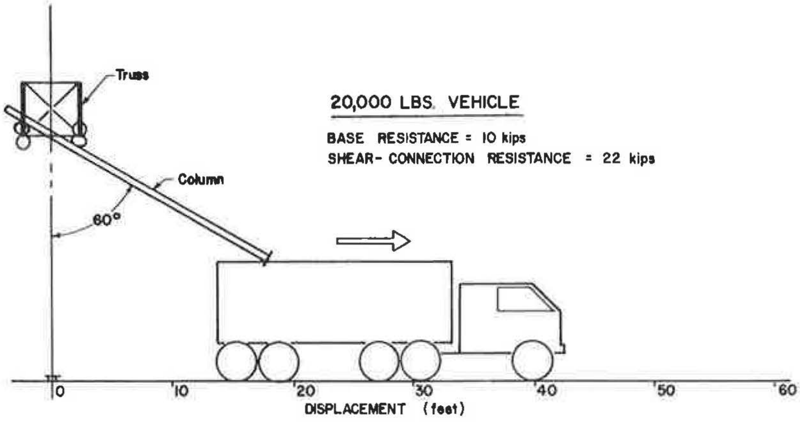


Figure 8. Column response for impact at 30 mph (simulated head-on impact).

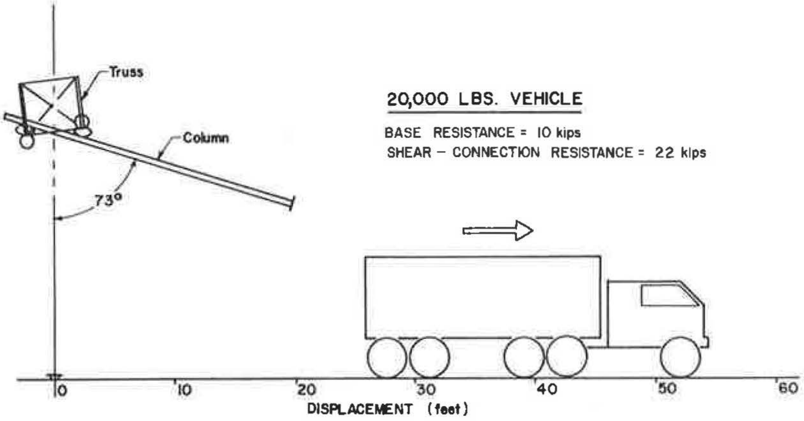


Figure 9. Column response for impact at 60 mph (simulated head-on impact).

The results in Table 6 reveal that the two 15-mph cases and the 10,000-lb vehicle traveling at 30 mph encounter a secondary collision with the support. Figure 8 shows a case where a secondary collision is encountered, whereas Figure 9 shows an example of a support clearing the vehicle.

The energy values, E_k, to which the truss is subjected when struck at high impact speeds are quite large, and indicate that, as the vehicle velocity is increased, the effect of the vehicle mass on the angular kinetic energy of the support becomes less significant. For example, at an impact velocity of 60 mph the angular kinetic energy of the support, at the instant it encounters the truss, is only increased from 111.8'k to 114.6'k as the vehicle mass is increased from 10,000 to 20,000 lb. This fact may be used to set up design criteria for energy absorbers that could be placed on the truss.

CONCLUSIONS

The general conclusions listed in this section are based on the mathematical models developed, observations of full-scale crash tests, and the results of the parameter study.

They may be summarized as follows:

1. The application of the breakaway concept to the supports of an overhead sign bridge is feasible.
2. The prototype truss possessed the ability to withstand the torsional loads imparted to it by the rotating support and the structure as a whole remained stable under the impact forces.
3. Vehicle velocity changes and deceleration rates increase as breakaway base and upper shear-connection resistances increase.
4. Vehicle velocity changes, deceleration rates, and vehicle damage resulting from a collision increase as column support weight increases.
5. Occupants of small to medium-size vehicles may suffer injury in a collision with the prototype support.
6. Larger vehicles are not severely damaged in collisions with the prototype breakaway support.
7. The damage to vehicles in impacts with breakaway supports was appreciably less than that to similar vehicles which struck a fixed support post.

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REFERENCES

1. Hawkins, D. L. Preliminary Calculations for a Prototype Overhead Sign Bridge With Breakaway Supports. Dated October 1965, and forwarded to the Texas Transportation Institute for consideration.
2. Martinez, J. E., Jumper, J. J., and Baskurt, F. Y. Safety Provisions for Support Structures on Overhead Sign Bridges—Mathematical Simulation and Correlation. Technical Memorandum 605-2, Texas Transportation Institute, Texas A&M University, College Station, December 1969.
3. Przemieniecki, J. S. Theory of Matrix Structural Analysis. McGraw-Hill Book Co., Inc., New York, 1968.
4. Martin, H. C. Introduction to Matrix Methods of Structural Analysis. McGraw-Hill Book Co., Inc. New York, 1966.
5. Gere, J. M., and Weaver, W. Analysis of Framed Structures. D. Van Nostrand Co., Inc., Princeton, N. J., 1965.
6. Ivey, D. L., Olson, R. M., Buth, E., and Hirsch, T. J. Safety Provisions for Support Structures on Overhead Sign Bridges—Testing Program. Technical Memorandum 605-4, Texas Transportation Institute, Texas A&M University, College Station, May 1970.
7. Post, E. R., Garner, C. P., and Olson, R. M. Safety Provisions for Support Structures on Overhead Sign Bridges—Design, Analysis and Construction. Technical Memorandum 605-1, Texas Transportation Institute, Texas A&M University, College Station, December 1969.
8. Edwards, T. C., Hirsch, T. J., and Olson, R. M. Break-Away Sign Support Structures. Volume 1, Final Report on Highway Sign Support Structures, Project HPR-2(104), Texas Transportation Institute, Texas A&M University, College Station, July 1967, p. 8:103.
9. Patrick, L. M., et. al. Knee, Chest, and Head Impact Loads, Proceedings of the 11th Stapp Car Crash Conference. Anaheim, Calif., October 10-11, 1967, p. 116.