TEXAS TRANSPORTATION INSTITUTE
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TECHNICAL MEMORANDUM 605-6

SUPPLEMENTARY STUDIES

SAFETY PROVISIONS FOR SUPPORT STRUCTURES

ON OVERHEAD SIGN BRIDGES

By

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F O R E W O R D

This supplementary report contains a brief description of information previously published in Volumes 1 through 5 listed in the following table.

TECHNICAL MEMORANDUM NUMBER	AUTHOR(S)	TITLE
605-1 (Volume 1 of 5)	E. R. Post C. P. Garner, Jr. R. M. Olson	DESIGN, ANALYSIS AND CONSTRUCTION
605-2 (Volume 2 of 5)	J. E. Martinez J. J. Jumper F. Y. Baskurt	MATHEMATICAL SIMULATION AND CORRELATION
605-3 (Volume 3 of 5)	R. H. Gunderson A. Cetiner	A STUDY OF BUCKLING STRESS FORMULAS
605-4 (Volume 4 of 5)	D. L. Ivey C. E. Buth R. M. Olson T. J. Hirsch	TESTING PROGRAM
605-5 (Volume 5 of 5)	A. J. Stocker	FABRICATION AND CONSTRUCTION

The interested reader can find a more detailed description of the studies by consulting the five volumes. This supplementary report (Volume 6) also contains a detailed account of work completed following the publication of Volumes 1 through 5. The study was conducted under Research Project HPR-2(107), entitled "Safety Provisions for Support Structures on Overhead Sign Bridges", which was sponsored jointly by twenty-two highway departments and the U.S. Department of Transportation, Federal Highway Administration.

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ACKNOWLEDGMENTS

The research, development, and evaluation studies presented in this study were sponsored by the highway departments of Alabama, Arkansas, Connecticut, Florida, Georgia, Hawaii, Kentucky, Louisiana, Maryland, Michigan, Mississippi, Montana, Nebraska, New Hampshire, New Mexico, Rhode Island, South Dakota, Tennessee, Texas, West Virginia, Wyoming, and the District of Columbia. The contract was administered by the Department of Transportation, Federal Highway Administration, under Contract No. FH-11-7032. Representatives of each of these agencies met as a Project Policy Committee and consulted with and advised the researchers during the course of this study. The Project Policy Committee appointed a Technical Subcommittee which provided guidance on structural and testing details.

At an early meeting, the deliberations of these engineers, administrators and the research engineers led to the 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 to the original design details became apparent and were incorporated during the testing program.

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

The opinions, findings, and conclusions expressed herein are those of the authors and not necessarily those of the Federal Highway Administration and/or those of the highway departments.

CHAPTER 1. REVIEW OF PROJECT

INTRODUCTION

High-speed highways require the placement of roadside and overhead directional signs for efficient control of traffic. Fixed supports of sign structures constitute a hazardous condition to the occupants of an errant vehicle. Accident information compiled by the California Division of Highways' Traffic Department during the years of 1965-7 indicated that approximately 7 percent of 640 single vehicle fixed-object freeway fatal accidents involved steel sign supports (1)*. Eliminating fixed sign supports from gore areas has proven effective in reducing accident frequency and severity. Operational experience has further shown that, wherever practical, signs should be mounted on overcrossing bridge structures or that the supports of signs should be: (a) located 20 to 30 feet from the roadway shoulder, or (b) placed behind guardrail, or (c) provided with breakaway devices.

The field performance of breakaway *roadside* sign supports, conceived and designed by Hawkins (2) and developed and tested by the Texas Transportation Institute (3), led Hawkins to begin an investigation to extend the breakaway concept to the larger supports of overhead sign bridge structures (OSB). A preliminary design by Hawkins of an OSB with four breakaway supports showed that the concept warranted further consideration. Subsequently a prototype design was prepared, as described in the following paragraphs.

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*Underlined numbers in parentheses refer to items listed under References.

GENERAL DESIGN CONSIDERATIONS

The prototype structure having four breakaway support columns, on which full-scale head-on and angle tests were conducted, shown in Figure 1, is essentially the same as the preliminary design of Hawkins.

The prototype structure was selected to represent a typical large structure which might be constructed on the Interstate Highway System. The prototype OSB has an overall length of 140 feet. The truss is 6 feet wide and 6 feet deep. The 100 foot central portion of the truss is long enough to span a four-lane divided highway. 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 temporarily displaced by a colliding vehicle, the OSB is structurally adequate to resist dead loads and a wind load of 50 mph.

The prototype breakaway columns, shown in Figure 1, are approximately 26-1/2 feet long. To reduce the mass and inertial effects of the breakaway columns during a collision incident and, hence, minimize the vehicle damage and decelerations, the columns were: (a) fabricated from a 100,000 psi Heat-Treated Constructional Alloy Steel (ASTM 514), and (b) tapered in both flanges and web. Each wedge tapered column is pleasing in appearance, and is designed to clear a colliding vehicle as the column rotates about a 1-7/16 inch diameter stainless steel pin connected to lower chord truss members. This upward rotation occurs subsequent to the release of the breakaway base connection and the fracturing of four 1/2 inch A307 bolts in the upper connection.

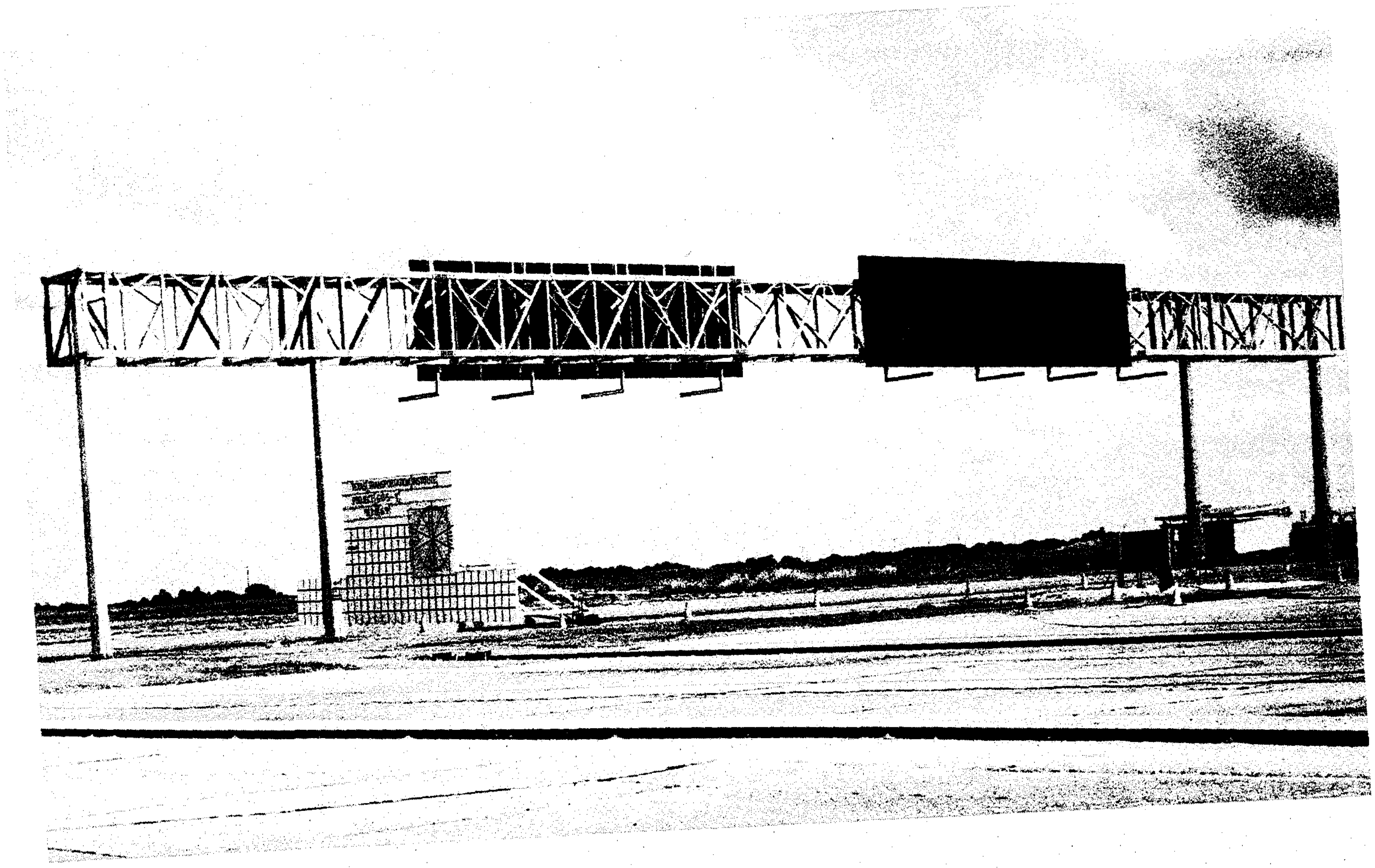


FIGURE 1. PROTOTYPE OVERHEAD SIGN BRIDGE WITH FOUR BREAK-AWAY SUPPORTS

The prototype OSB was designed in accordance with 1968 AASHO Specifications for the Design and Construction of Structural Supports for Highway Signs (4) with the exceptions of: (a) the breakaway column devices and (b) the lateral buckling requirements of sections 6:a(3) and 6:a(7). Sign supports are essentially cantilevers and were analyzed as such. The tapered breakaway wedge columns were designed on the basis of information from research studies performed at Columbia University by Krefeld (5).

In addition to being strong enough to withstand static loading conditions, the OSB columns under dynamic loading conditions must: (a) have breakaway connections weak enough to produce tolerable decelerations on the colliding errant vehicle and (b) have a strong enough pin connection to assure that the breakaway connections will actuate and the column will rotate clear of the vehicle.

Three other important design features evolved during this study: (a) steel pipe sections were fastened to the lower chord members of the truss to distribute the impact forces of a column which, following a collision incident, strikes the truss; (b) horizontal angles were fastened at approximately middepth of the truss to guide the column during an angle collision so that the column will not snag on and damage the vertical truss members; (c) a thin sheet metal "keeper plate" was placed between the slip base plates of the column and the stub post to eliminate the possibility of the breakaway columns *walking* off their foundation stub posts under vibrations set up by wind and vehicle traffic. Details of these features are contained in Volume 1 of this study published in September 1970.

MATHEMATICAL SIMULATION

Mathematical simulation of the behavior of a colliding vehicle and the prototype support was a major objective of this study, and a brief discussion of the technique follows.

The model assumes the supporting column to be a rigid body having only an angular degree of freedom and being hinged at the lower chord truss connection and idealizes 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 are presented in Volume 2 of this study published in September 1970.

A parameter study was conducted using the mathematical model to determine the dynamic response of a vehicle and breakaway support for a variety of conditions. The general conclusions obtained from the parameter study and observations of full-scale crash tests are summarized as follows:

1. The application of the breakaway concept to the supports of an overhead sign bridge is feasible.
2. The prototype truss is structurally adequate to withstand the torsional loads imparted to it by the rotating breakaway support, and the OSB structure as a whole remained stable under the impact forces.
3. Vehicle velocity changes and deceleration increase as the breakaway base and upper shear connection resistances increase.
4. Vehicle velocity changes, deceleration, and damage increase as the column support weight increases.

5. Small size passenger vehicles are subjected to higher velocity changes, deceleration, and damage than are larger size passenger vehicles.

The results obtained from mathematical simulation compared very well with data acquired from full-scale crash tests, as shown in Figure 10. The comparison is remarkable when one considers the simplicity of the model and the difficulties involved in acquiring and reducing data obtained from crash tests. For the angle collisions, a portion of the difference between the model and test data can be explained because the model was developed for head-on impacts only.

BUCKLING STRESS FORMULAS

As mentioned previously, the requirements of sections 6:a(3) and 6:a(7) of the AASHO Specifications were considered to be inapplicable to supports for the prototype design on the basis that supports of overhead sign bridges are essentially cantilever beams. The 1968 AASHO Specifications (4) require, however, that the critical lateral buckling stress be limited by formulas based on theoretical and experimental investigations of a simple beam subjected to loads which produce pure bending. As a consequence, during the course of this project an examination of the AASHO requirements was undertaken and an alternate formula was proposed which more closely approximates the conditions for the overhead sign bridge. The results of this study are presented in Volume 3 published in September 1970, to which the reader is referred for details.

TESTING PROGRAM

A testing program, consisting of several laboratory static tests and full-scale crash tests, was conducted to determine: (a) the feasibility of the prototype structure, (b) the advantages in terms of safety of the prototype structure compared to those in current production, and (c) the validity of the mathematical simulation technique described earlier.

The first laboratory test was performed to obtain some insight into the behavior of the breakaway connections, and to ascertain the strength of a bolt keeper plate installed between the upper and lower plates at the breakaway base connection. Other laboratory tests were conducted later in the program to examine the parameters which affect the resistance of the breakaway base connection. Data obtained from these laboratory tests are used as input for the mathematical simulation.

Two full-scale crash tests were conducted in September 1969 at low impact speeds. Possible parameters to be considered in designing the remaining testing program were thoroughly discussed at Project Policy Committee Meeting No. 2 in September 1969. The minutes of this meeting contain the range of parameters considered. Concern was expressed by the several participating members with regard to the details of the remaining tests to be conducted. It was suggested that an attempt be made to prepare a statistical design for the crash testing program. A series of tests was proposed and conducted as shown in Table 1. The purpose of the statistical design was to permit more meaningful analyses of the primary influences of certain variables as well as the interactions of these variables.

At the conclusion of testing, it was determined that the test input parameters varied considerably from the statistical design values. Because of variations in the vehicle speed at contact, there was considerable variation in the vehicle kinetic energy, one of the primary input parameters. Since several different vehicles were used, the crushing characteristics of the front ends were considerably different and resulted in an unknown variation. Another variation was noted in the OSB itself when a static load test was run at the conclusion of the project. The deformation-force characteristic of the OSB had changed to a remarkable degree during the testing program. Thus, the vagaries in testing, changes in the prototype structure caused by the several collisions, and variability of vehicle characteristics led to the conclusion that statistical interpretation of the testing program was not meaningful.

However, another more productive method of extrapolating the testing program was available; the use of the empirical results for validation of the mathematical simulation technique discussed earler. By using the crash tests to verify the gross response of the vehicle and OSB during a collision, the computer program was applied to a parametric study of a wide range of variables. This study has been shown to be valid over the range of variables explored in the testing phase.

A comparison of the results obtained from a high-speed film analysis with results obtained from a mathematical model simulation is presented in Table 10. The good comparison clearly indicates that the mathematical model can be used with a high degree of confidence to analyze other proposed OSB structures with breakaway supports.

It should be noted that crash test H (as originally labeled -- see Table 1) was not conducted. Two additional tests were recommended by the

TABLE 1. SUMMARY OF CRASH TESTS

ENERGY OF VEHICLE AT IMPACT WITH SUPPORT (See Note 1)		82 K-FT	162 K-FT	356 K-FT	605 K-FT
ENERGY OF SUPPORT WHEN SUPPORT CONTACTS TRUSS (See Note 2)		0 K-FT	27 K-FT	54 K-FT	80 K-FT
OUTSIDE LEG	IMPACT ANGLE: 0° (Head-On)	(A) 3950 lbs at 25.7 mph Tested: 09-23-69			(D) 4880 lbs at 54.0 mph Tested: 02-03-70
	IMPACT ANGLE: 15°		(F) 2350 lbs at 52.0 mph Tested: 02-17-70	(G) 3950 lbs at 50.1 mph Tested: 04-07-70	
INSIDE LEG	IMPACT ANGLE: 0°		(B) 2100 lbs at 44.0 mph Tested: 12-11-69	(C) 4090 lbs at 46.5 mph Tested: 12-18-69	
	IMPACT ANGLE: 15°	(E) 3920 lbs at 28.6 mph Tested: 02-09-70			(H) 5000 lbs at 60.0 mph (Not Tested)

Note 1 -- Statistical design is based on three variables: (1) four levels of vehicle and/or support energies, (2) two impact angles, and (3) two support positions.

Note 2 -- Estimated by mathematical simulation for 0° angle of impact. Energies shown are approximate for 15° angle of impact.

Note 3 -- Tests were conducted in alphabetical order as designated by letters in parentheses.

Project Policy Committee at its third and final meeting in September 1970. These tests, conducted at speeds in excess of 70 mph, were designated crash tests "H" and "I" and are discussed in detail in the following pages.

The work reported in the following pages was completed under Modification No. 3 to Contract No. FH-11-7032, which added (a) two additional tests for verification and evaluation of the breakaway design by full-scale crash testing, (b) static laboratory tests on breakaway bases and other structural components, (c) full-scale torsion tests of the overhead sign bridge truss, and (d) parameter studies by mathematical simulation.

CHAPTER 2. ADDITIONAL PARAMETER STUDIES

The Project Policy Committee (6) recommended that the preliminary studies conducted by mathematical simulation and validated by full-scale crash tests (7) be extended to include:

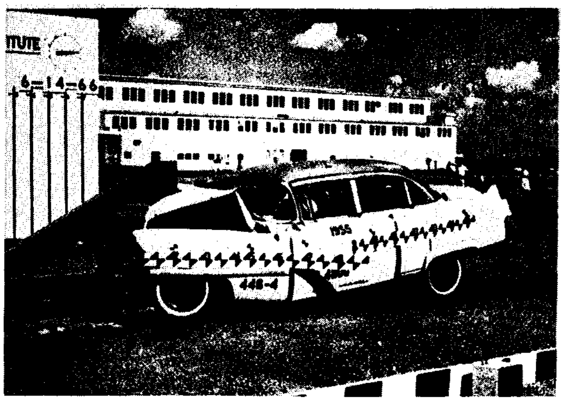
(a) parametric studies to predict the behavior of columns smaller and larger than those supporting the prototype structure and

(b) simulation of two additional full-scale crash tests using a 5,000 pound vehicle traveling 70 mph.

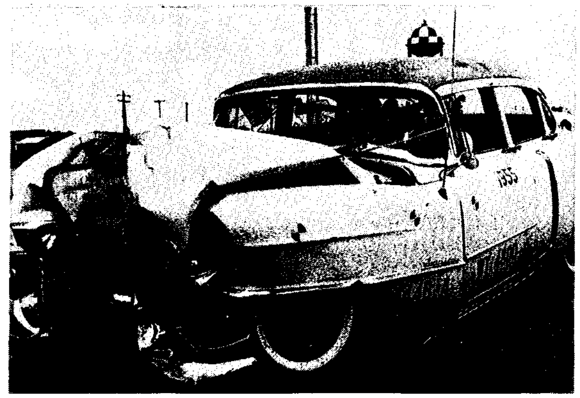
REVIEW OF EARLIER STUDY

Initial findings indicated the feasibility of the application of the breakaway concept to supports for overhead sign bridges (8). Further, they showed that for a given vehicle weight and impact speed, deceleration forces and vehicular damage increase as base plate and upper plate connection strengths increase. And moreover, vehicle damage resulting from a collision with a breakaway overhead sign bridge support is minor when compared with a similar fixed barrier collision (see Figure 2).

Furthermore, evaluation of the simulation of collisions with supports possessing various connection resistances revealed that the major portion of the vehicular deceleration could be attributed to the weight of the supporting column. However, no studies were made to determine the precise influence of this effect.



a) 1954 Cadillac, weighing 4,800 lbs., after collision with fixed post at 44.1 mph (10)



b) View showing damage to 1954 Cadillac, maximum post penetration was 4.50 feet (10)

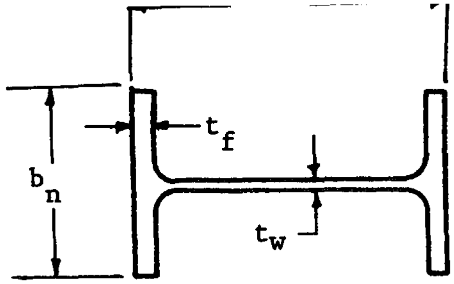
c) 1962 Cadillac weighing 4,880 lbs., following 54.0 mph collision with prototype breakaway support, maximum post penetration was 1.50 feet, vehicle was driven to garage (8)

FIGURE 2. COMPARISON OF VEHICLE DAMAGE

DISCUSSION OF ADDITIONAL PARAMETER STUDIES

Additional parameter studies were conducted to determine (a) behavior of selected vehicles and (b) structural response when support conditions are varied. Overhead sign bridge breakaway column dimensions and corresponding weights selected for these studies are shown in Table 2. Three columns selected for these studies and the prototype column are shown for comparison. The selected columns represent an increase of 22% and decreases of 25% and 50% in the weight of the prototype column for which the crash test data and parameter studies were reported earlier (8). The flange and web tapers of the prototype were maintained in the first two columns and the dimensions of the tapered column weighing 50% less than the prototype were arbitrarily selected. For comparison purposes, two commercially available prismatic rolled shapes were included.

Vehicles weighing 2,000 lbs, 3,500 lbs, and 5,000 lbs having impact speeds varying from 15 mph to 60 mph were simulated. The resistance at the upper connection was taken to be 22 kips and the base shear resistance was taken to be 10 kips.



WHERE:

Subscript n = 0, Describes Base Connection Dimensions

Subscript n = 1, Describes Pin Connection Dimensions

Subscript n = 2, Describes Upper Connection Dimensions

Column Dimensions (in.)								Column Weight* (lbs)	Critical Buckling Stress** (ksi)	Comments
t_w	t_f	$*b_o$	d_o	b_1	d_1	b_2	d_2			
PROTOTYPE TAPERED COLUMN:										
1/2	5/8	10	17-1/2	6-1/2	10-1/2	5-9/16	8-11/16	1412	115	100 mph wind load resisted by two interior columns (9)
SELECTED TAPERED COLUMNS:										
5/8	3/4	10	17-3/4	6-1/2	10-3/4	5-9/16	8-15/16	1722 (+22%)	>115	100 mph wind load resisted by all four columns (9)
3/8	1/2	10	14-1/2	6-1/2	7-1/2	5-9/16	5-11/16	1059 (-25%)	100	
5/16	1/2	8	10	4-7/8	5-1/4	4	4	712 (-50%)	133	
SELECTED ROLLED SHAPES:										
10 WF 29								768 (-46%)	122	These shapes may not be available in 100 ksi steel.
12 WF 27								716 (-50%)	124	

*Weight of base and upper plates not included. The length was 26.5 ft for each support.
**S_{cr} > 100 ksi (steel). Failure predicted to occur by support yielding. (5)
S_{cr} < 100 ksi (steel). Failure predicted to occur by elastic buckling. (5)

TABLE 2. OVERHEAD SIGN BRIDGE COLUMNS USED IN STUDY

RESULTS OF ADDITIONAL PARAMETER STUDIES

The results of the additional studies are presented in Tables 3 through 6, in which the behavior of selected vehicles in simulated collisions with posts weighing 712, 1,059, 1,412, and 1,722 lbs is compared. Graphical presentations of these results are contained in Figures 3 through 8.

The study in general revealed that, for a given vehicle and velocity, the lighter supports produced lower vehicle speed and momentum changes, lower average decelerations, and caused less energy to be imparted to the truss by the support as it swings following impact. The variation in vehicular deformation was not as significant. This may be due to the fact that the spring constant of the vehicle is assumed to be 10 times the vehicular weight and the vehicle is taken to have a single degree of freedom, whereas in reality it is a highly complex multi-degree-of-freedom system. It should be mentioned that the mathematical simulation of the vehicle may appear to be oversimplified; correlation with numerous crash tests has shown that this type of representation produces very satisfactory results (7).

From this study it is apparent that the support weight cannot be significantly increased if the vehicle velocity and momentum change are to remain below the currently recommended values of 11 mph (11) and 1,100 lb-sec (12). In fact, even with the prototype support, all collisions by 2,000 lb vehicles and medium and high-speed collisions by medium weight vehicles may be interpreted as hazardous if the above mentioned criteria are used. However, it should be borne in mind that the prototype structure represents one of the largest OSB structures currently installed (9).

Vehicle Weight (lbs)	Impact Speed (mph)	Change in Speed (mph)	Momentum Change (lbs-sec)	Average g's	Contact Time (sec)	Maximum Vehicle Deformation (in.)	Comments
2000	15	13.8	1258	5.8	0.108	12.1	Post hits top of car
2000	30	11.5	1048	4.4	0.120	19.2	Post hits truss E_k = 3.222 ft-k
2000	60	15.7	1432	6.9	0.104	29.2	Post hits truss E_k = 43.170 ft-k
2000	80	19.0	1734	8.6	0.131	36.0	Post hits truss E_k = 79.5 ft-k
3500	15	6.7	1069	4.0	0.076	9.2	Post clears vehicle Max. post rot = 81°
3500	30	5.9	941	3.3	0.082	13.1	Post hits truss E_k = 7.983 ft-k
3500	60	9.1	1452	5.3	0.078	21.8	Post hits truss E_k = 53.958 ft-k
3500	80	11.9	1892	7.3	0.074	27.6	Post hits truss E_k = 107.1 ft-k
5000	15	3.9	888	2.9	0.061	7.0	Post hits truss E_k = 0.456 ft-k
5000	30	4.1	934	2.8	0.064	10.5	Post hits truss E_k = 10.513 ft-k
5000	60	6.8	1549	5.5	0.057	18.2	Post hits truss E_k = 67.003 ft-k
5000	80	8.5	1944	6.5	0.060	22.8	Post hits truss E_k = 117.2 ft-k

TABLE 3. RESULTS FOR POST MASS OF 712 LBS.

Vehicle Weight (lbs)	Impact Speed (mph)	Change in Speed (mph)	Momentum Change (lbs-sec)	Average g's	Contact Time (sec)	Maximum Vehicle Deformation (in.)	Comments
2000	15	14.3	1304	5.7	0.114	12.3	Post hits hood of car
2000	30	12.7	1158	4.5	0.129	19.7	Post hits truss E_k = 1.831 ft-k
2000	60	17.9	1632	6.3	0.129	31.2	Post hits truss E_k = 44.601 ft-k
2000	80	22.6	2061	7.5	0.138	39.6	Post hits truss E_k = 90.011 ft-k
3500	15	6.9	1100	3.7	0.084	9.6	Post hits top of car
3500	30	6.8	1085	3.3	0.095	14.0	Post hits truss E_k = 7.268 ft-k
3500	60	10.8	1723	5.1	0.097	23.3	Post hits truss E_k = 59.082 ft-k
3500	80	14.1	2253	7.1	0.091	30.0	Post hits truss E_k = 120.041 ft-k
5000	15	4.1	934	2.7	0.068	7.3	Post hits car Max. rot = 67.6°
5000	30	4.8	1094	3.0	0.072	11.4	Post hits truss E_k = 10.928 ft-k
5000	60	7.9	1801	4.9	0.073	20.1	Post hits truss E_k = 69.956 ft-k
5000	80	10.4	2368	6.8	0.070	30.0	Post hits truss E_k = 137.672 ft-k

TABLE 4. RESULTS FOR POST MASS OF 1059 LBS.

Vehicle Weight (lbs)	Impact Speed (mph)	Change in Speed (mph)	Momentum Change (lbs-sec)	Average g's	Contact Time (sec)	Maximum Vehicle Deformation (in.)	Comments
2000	15	15.0	1368	8.2	0.084	12.4	Car was stopped
2000	30	14.0	1276	4.4	0.146	20.4	Post clears car Max. rot = 78.4°
2000	60	21.1	1924	6.1	0.157	33.8	Post hits truss E_k = 46.570 ft-k
2000	80	26.7	2437	8.1	0.151	43.2	Post hits truss E_k = 95.862 ft-k
3500	15	7.1	1132	3.4	0.096	9.8	Post hits top of car
3500	30	7.8	1243	3.1	0.113	14.5	Post hits truss E_k = 5.820 ft-k
3500	60	13.2	2106	5.5	0.110	26.4	Post hits truss E_k = 68.810 ft-k
3500	80	17.3	2767	7.3	0.109	33.6	Post hits truss E_k = 138.801
5000	15	4.5	1026	2.5	0.078	7.7	Post clears car Max. rot = 56.4°
5000	30	5.7	1300	3.1	0.084	11.9	Post hits truss E_k = 10.680 ft-k
5000	60	9.9	2256	5.7	0.080	21.6	Post hits truss E_k = 86.280 ft-k
5000	80	12.6	2861	6.2	0.092	28.8	Post hits truss E_k = 154.901 ft-k

TABLE 5. RESULTS FOR POST MASS OF 1412 LBS.

Vehicle Weight (lbs)	Impact Speed (mph)	Change in Speed (mph)	Momentum Change (lbs-sec)	Average g's	Contact Time (sec)	Maximum Vehicle Deformation (in.)	Comments
2000	15	15.0	1368	7.4	0.092	13.0	Car was stopped
2000	30	14.9	1358	4.2	0.162	20.9	Post clears car
2000	60	23.5	2143	6.5	0.165	35.4	Post hits truss E_k = 48.962 ft-k
2000	80	29.9	2726	8.6	0.159	45.6	Post hits truss E_k = 101.542 ft-k
3500	15	7.4	1180	3.1	0.107	10.1	Post hits top of car
3500	30	8.9	1420	3.4	0.118	15.8	Post hits truss E_k = 5.916 ft-k
3500	60	15.1	2409	6.0	0.115	27.8	Post hits truss E_k = 76.918 ft-k
3500	80	19.3	3077	6.6	0.133	36.0	Post hits truss E_k = 143.958 ft-k
5000	15	4.7	1071	2.4	0.091	8.1	Post clears car Max. rot = 51.4°
5000	30	6.3	1436	3.0	0.095	12.0	Post hits truss E_k = 10.410 ft-k
5000	60	11.1	2530	5.3	0.095	23.7	Post hits truss E_k = 91.268 ft-k
5000	80	14.7	3345	7.0	0.095	30.0	Post hits truss E_k = 180.026 ft-k

TABLE 6. RESULTS FOR POST MASS OF 1722 LBS.

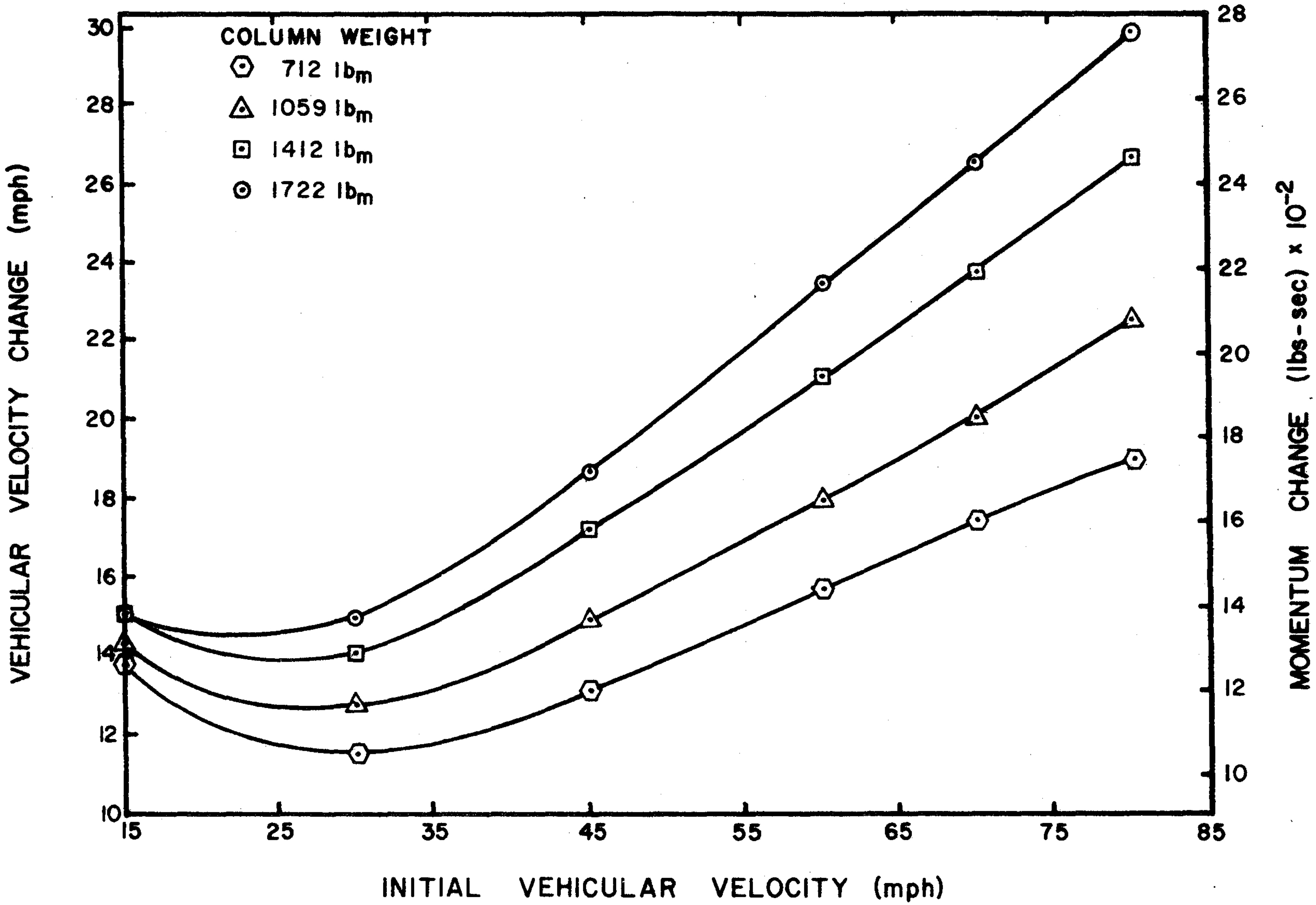


FIGURE 3 VEHICULAR VELOCITY AND MOMENTUM CHANGES FOR 2000 lb_m VEHICLE

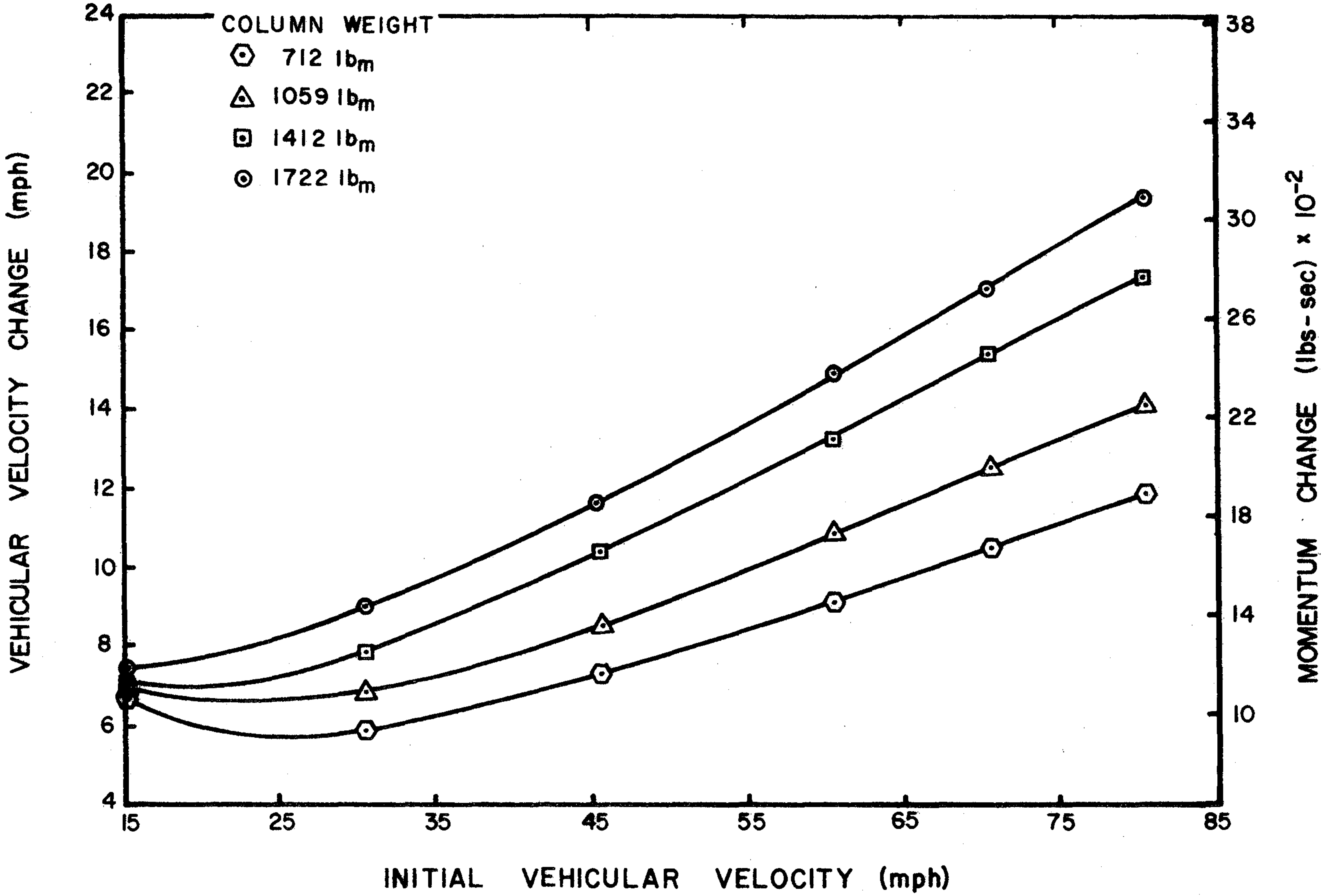


FIGURE 4 VEHICULAR VELOCITY AND MOMENTUM CHANGES FOR 3500 lb_m VEHICLE

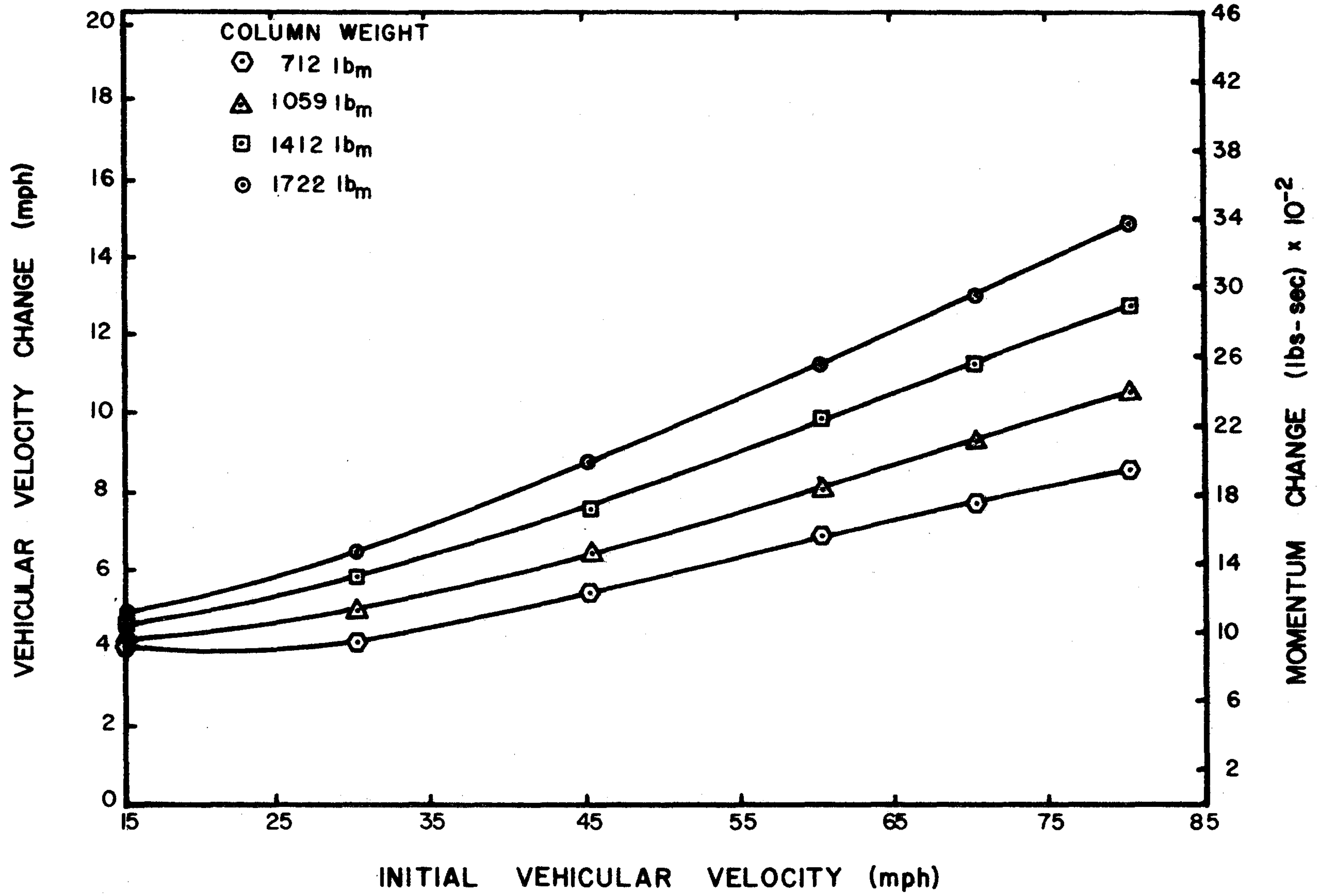


FIGURE 5 VEHICULAR VELOCITY AND MOMENTUM CHANGES FOR 5000 lb_m VEHICLE

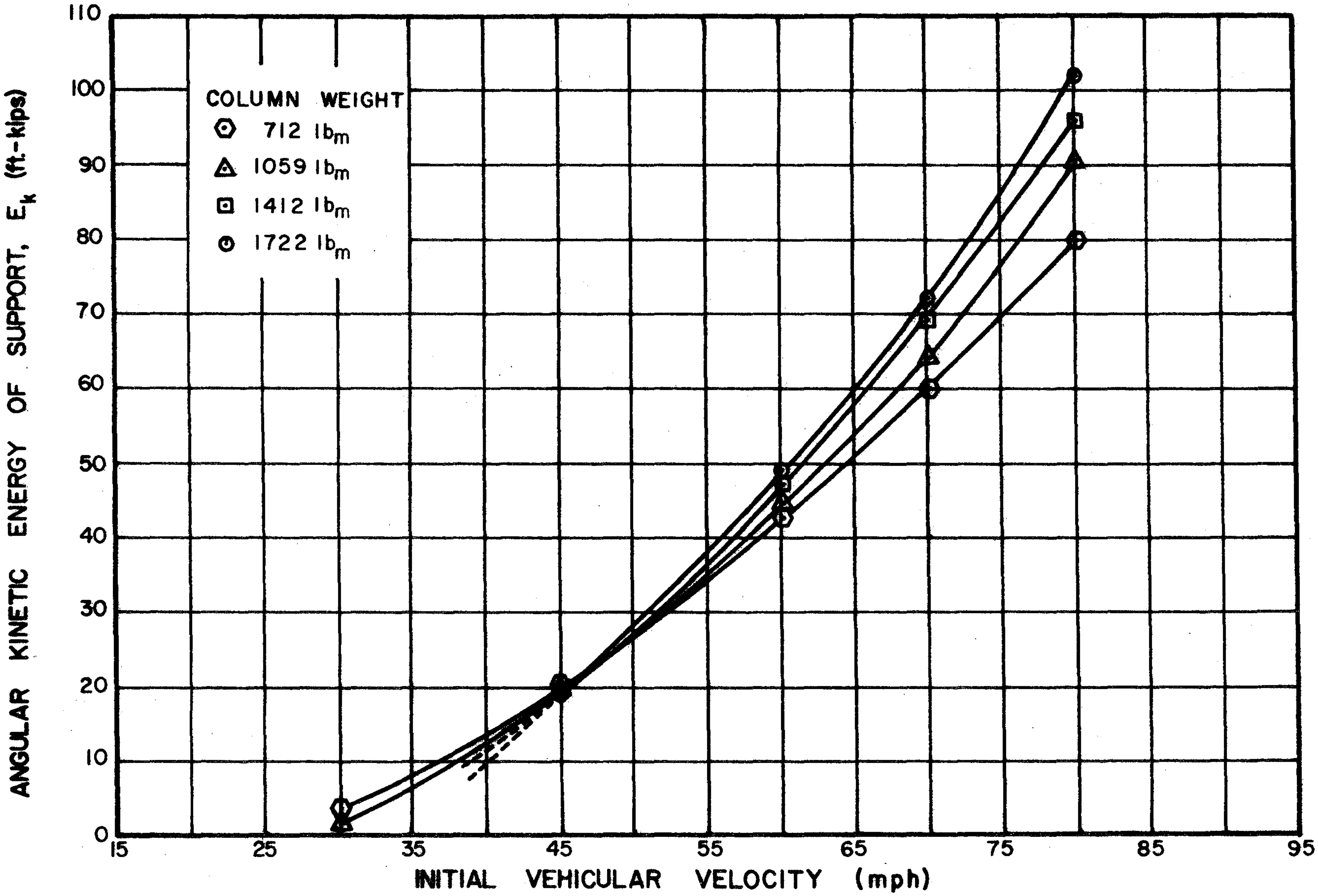


FIGURE 6 KINETIC ENERGY RESULTS FOR 2000 lb_m VEHICLE

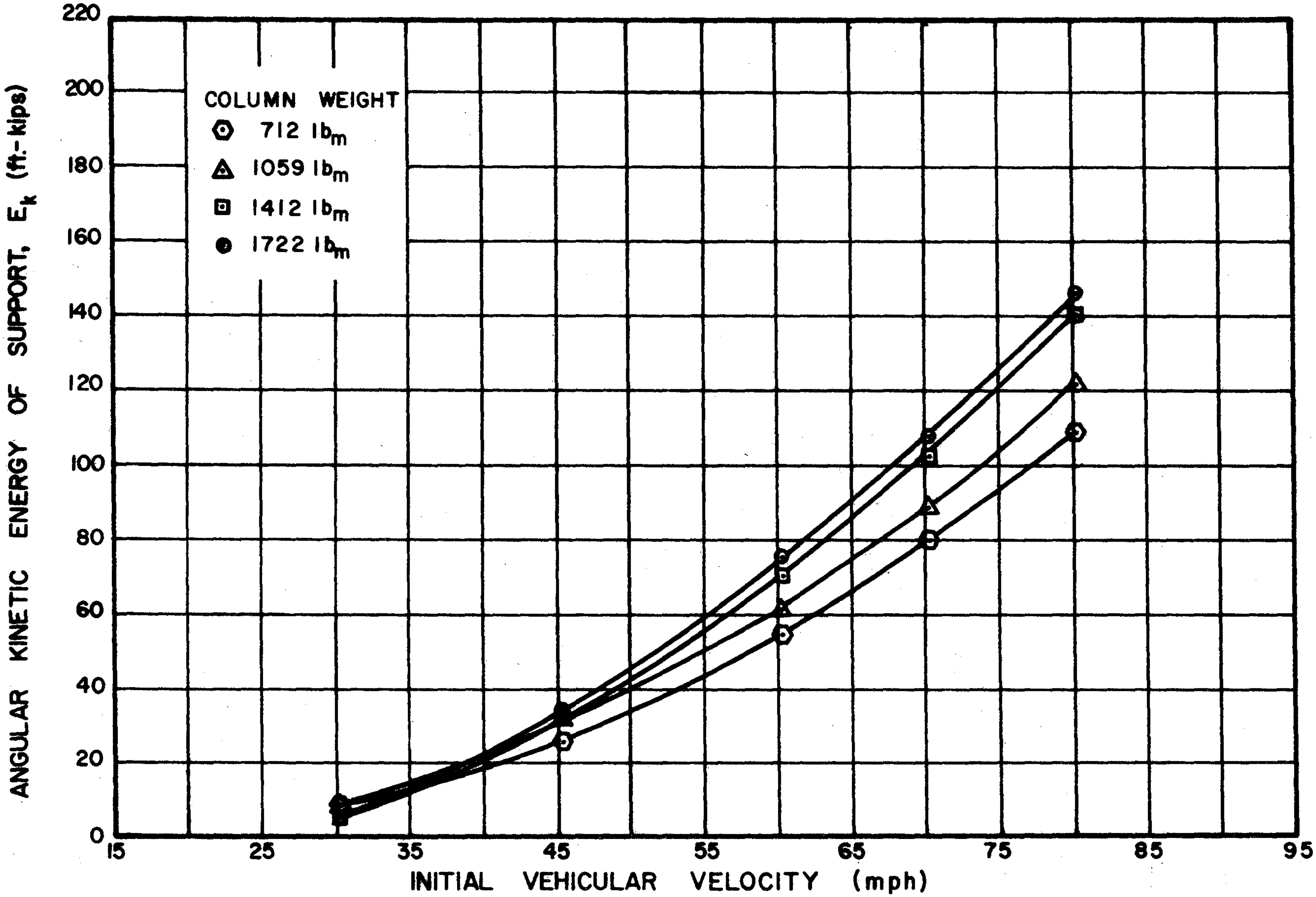


FIGURE 7 KINETIC ENERGY RESULTS FOR 3500 lb_m VEHICLE

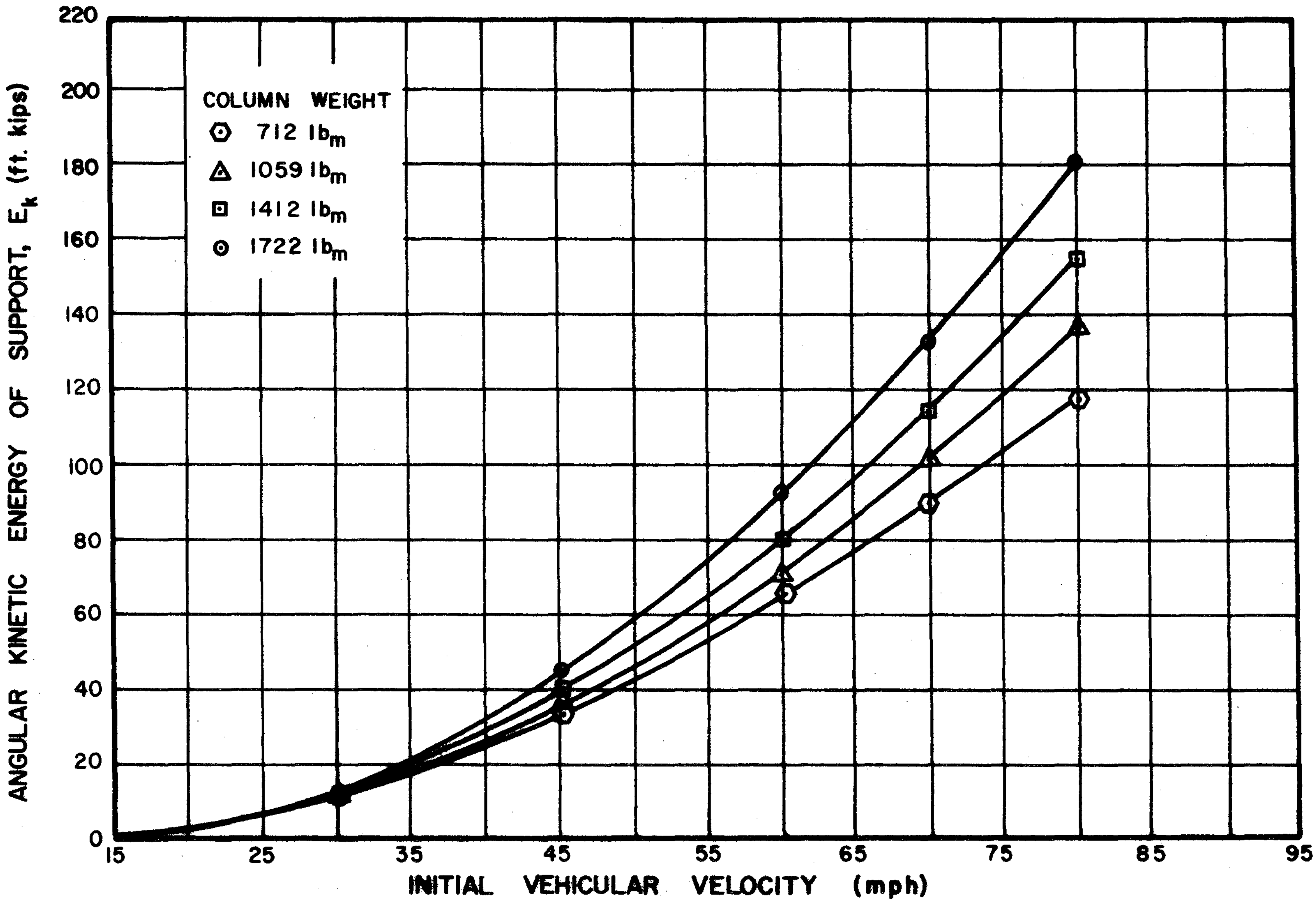


FIGURE 8 KINETIC ENERGY RESULTS FOR 5000 lb_m VEHICLE

Figure 4 and a comparison of Tables 4 and 5 reveal that a 25% reduction in the weight of the existing support reduces the speed changes of the medium weight vehicles below the recommended maximum. Table 3 and Figure 3 reveal that a 50% reduction in the post weight does not produce speed and momentum changes of lightweight impacting vehicles within the currently recommended limits.

COMPARISON OF SIMULATION PREDICTIONS WITH CRASH TESTS 605-H AND 605-I

Table 7 shows a comparison of model and crash test results for crash test 605-H. This test employed a 1961 Cadillac sedan weighing 5,150 lbs, having an impact speed of 75.3 mph, and striking the outer support of the overhead sign bridge head-on. A detailed discussion of this test and of test 605-I is presented in another chapter of this report and only the model simulation will be briefly discussed in this section.

Two computer runs were made; one employed a base resistance of 10 kips and the other a resistance of 20 kips. Both cases considered the prototype support which was assumed to have a base shear force of 10 kips for the crash test. The 20 kip resistance is encountered when the structure is subjected to wind loads of approximately 20 mph and a bolt torque of 300 ft-lbs (9). It is felt that a base resistance of 10 kips is realistic.

The results indicate that the effects of the base shear resistance are insignificant for representative values reported in Reference 7.

The agreement between model prediction and prototype test data is very satisfactory. Besides the values reported in Table 7, the model predicted an angular kinetic energy value of 142 ft-kips at the instant the support contacts the truss structure of the sign bridge. A value of 144.8 ft-kips had been reported in Reference 8 as the value necessary to produce failure of the four upper bolted connections at the top of each of the four column supports. Failure occurred at the four upper shear connections in crash test H. The greatest discrepancy occurred for the related values of average vehicle deceleration and contact time. Part of this discrepancy can possibly be attributed to the assumed loss of contact between vehicle and support from the data reduction and part due to the vehicle being assumed to be a single degree-of-freedom spring-mass system possessing a spring constant equal to 10 times its weight.

In order to better evaluate this effect, test 605-F was compared to model results using different values of the vehicular spring constant as input information. This test was selected because it had shown a rather large discrepancy for the deceleration and contact time. The comparison of the study is shown in Table 8. The results presented in Table 8 indicate that an assumed value of 10 times the vehicle weight for the vehicular spring constant was low. The 1959 Borgward sedan weighing 2,350 lbs employed for this case was observed to have a strong front end, and thus increasing the model's value for the spring constant brings the model results closer to the test data. However, for the heavier vehicles, the current approach of assuming the spring constant to be 10 times the vehicular weight appears realistic.

Table 9 shows a comparison of model and crash test 605-I results. The test employed a 1962 Cadillac sedan weighing 5170 lbs, having an impact speed of 72 mph, and striking an inner support of the overhead sign bridge at an approach angle of 15°. The model employed a base shear resistance value of 10 kips and assumed the vehicle spring constant to be 10 times the weight of the vehicle. Further, the model assumed a head-on collision.

The results presented in Table 9 indicate good agreement and illustrate that, even though the effects of an angular collision are precluded by the model, satisfactory results for the column and vehicle response are obtained. In addition to the values presented in Table 9, the model predicted a value of 128 ft-kips for the rotational kinetic energy of the support. This value, according to data presented in Reference 7, should be sufficient to fracture two adjacent upper shear connections under a head-on impact. The crash test results revealed that only the support that was impacted by the vehicle suffered a shear connection failure. However, it was observed that the support encountered one of the horizontal angles of the truss and sliced a piece of metal from it. Thus, it appears that, even though satisfactory simulation is obtained for the rigid body dynamics of the support by neglecting the effects of the angular collision, error may be introduced in predicting the magnitude of the forces to which the upper shear connections are subjected.

CONCLUSIONS

The following conclusions are offered:

1. Supports heavier than the prototype are undesirable, but this is not a critical condition since most structures are smaller than the prototype.
2. Supports having 75% of the weight of the prototype permit medium weight vehicles to satisfy the current criteria (11,12).
3. Supports having 50% of the prototype weight produce lightweight vehicle speed and momentum changes in excess of the current hazard limits (11,12).
4. Varying the base connection resistance up to a value of 20 kips does not significantly affect vehicle behavior nor response of the sign bridge.
5. Some lightweight vehicles may have a front end that is stronger and stiffer than the assumed value of 10 times the vehicle weight.

It is felt that adequate research has been done on the rigid body dynamic behavior of the overhead sign bridge support. An area that requires investigation concerns the calculation of the reactive forces that are experienced by the truss during a collision.

	Crash Test Data	Model	Model
Vehicle Weight (lbs)	5150	5150	5150
Impact Speed (mph)	75.3	75.3	75.3
Change in Speed (mph)	11.5	11.7	12.1
Momentum Change (lbs-sec)	2700	2747	2841
Average g's = $\left(\frac{\text{Speed change, fps}}{\text{Contact time, sec}}\right) \times \frac{1}{32.2}$	8.1	6.4	6.0
Contact Time (sec)	0.066	0.083	0.091
Maximum Vehicle Deformation (in.)	25.2	26.9	28.0
Base Shear Force (kips)	10	10	20

TABLE 7. COMPARISON OF MODEL AND CRASH TEST 605-H

	Crash Test	Model	Model	Model	Model
Vehicle Weight (lbs)	2350	2350	2350	2350	2350
Vehicle Spring Constant (lbs/ft)	----	23,500	28,000	33,000	50,000
Impact Speed (mph)	52.0	52.0	52.0	52.0	52.0
Change in Speed (mph)	14.3	16.7	16.6	16.1	16.3
Momentum Change (lbs-sec)	1531	1789	1772	1730	1750
Average g's = $\left(\frac{\text{Speed change, fps}}{\text{Contact time, sec}}\right) \times \frac{1}{32.2}$	10.7	5.8	6.8	7.0	10.1
Contact Time (sec)	0.062	0.130	0.111	0.106	0.074
Max. Vehicle Deformation (in.)	1.5	2.3	2.1	1.9	1.5
Base Shear Force (kips)	10	10	10	10	10

TABLE 8. COMPARISON OF MODEL AND CRASH TEST 605-F

	Crash Test	Model
Vehicle Weight (lbs)	5170	5170
Impact Speed (mph)	72.0	72.0
Change in Speed (mph)	11.20	11.25
Momentum Change (lbs-sec)	2639	2652
Average g's = $\left(\frac{\text{Speed change, fps}}{\text{Contact time, sec}}\right) \times \frac{1}{32.2}$	7.7	6.2
Contact Time (sec)	0.068	0.083
Maximum Vehicle Deformation (in.)	32.4	26.4

TABLE 9. COMPARISON OF MODEL AND CRASH TEST 605-I

CHAPTER 3. ADDITIONAL CRASH TESTS

The Project Policy Committee (6) recommended that two tests be conducted using 5000 pound vehicles traveling at 70 mph, the first car to strike an outside support head-on, and the second to strike an inside support at 15 degrees. These tests were scheduled and the results are reported in the following paragraphs.

TEST 605-H

On December 10, 1970, Column A was struck head-on by a 5,150 pound Cadillac traveling at 75.3 mph, as shown in Figure 9. The upward rotating support ripped the hood from the car, came into contact with the load distributors (0.211 sec), deformed them and caused the truss to rotate about the pin connections. After the vehicle had moved clear the support swung downward (1.001 sec), past the lower stub (1.441 sec) then upward again (2.043 sec and 3.014 sec). During the time this swinging was occurring the upper connection bolts at Columns B, C, and D fractured and the truss rotated over against supports B, C, and D and came to rest in the position shown in Figure 10.

The structure was not damaged as a result of this test, but it should be observed that the catwalk and lighting supports for the sign restricted clearance to about 12 feet.

Damage to the vehicle is shown in Figure 11. The automobile was slowed 11.5 mph by the force of the collision. The average and peak decelerations are shown in Table 10. The high-speed film data from Test H is given in Table 12.

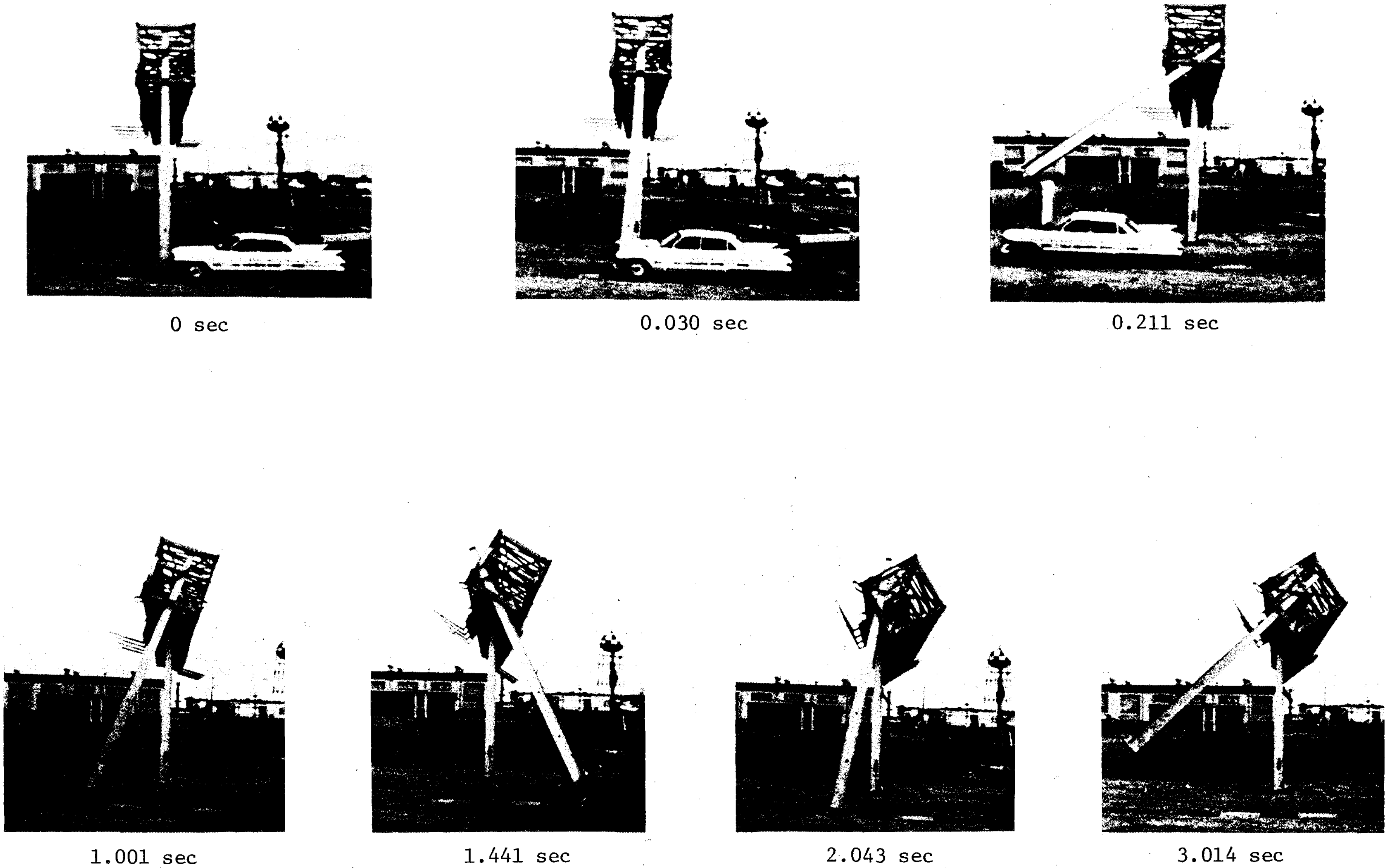


FIGURE 9. Sequential Photographs of Test H

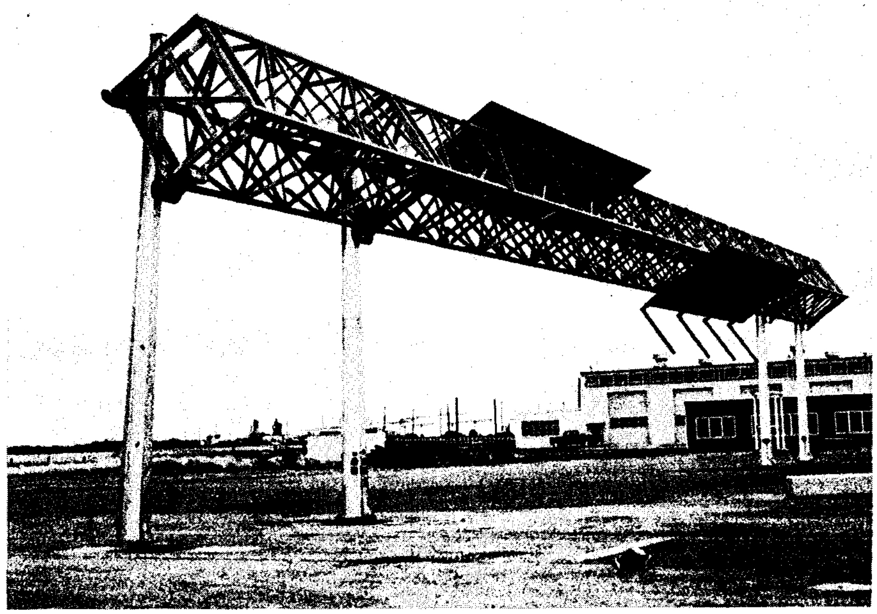


FIGURE 10. Condition of Structure After Test H

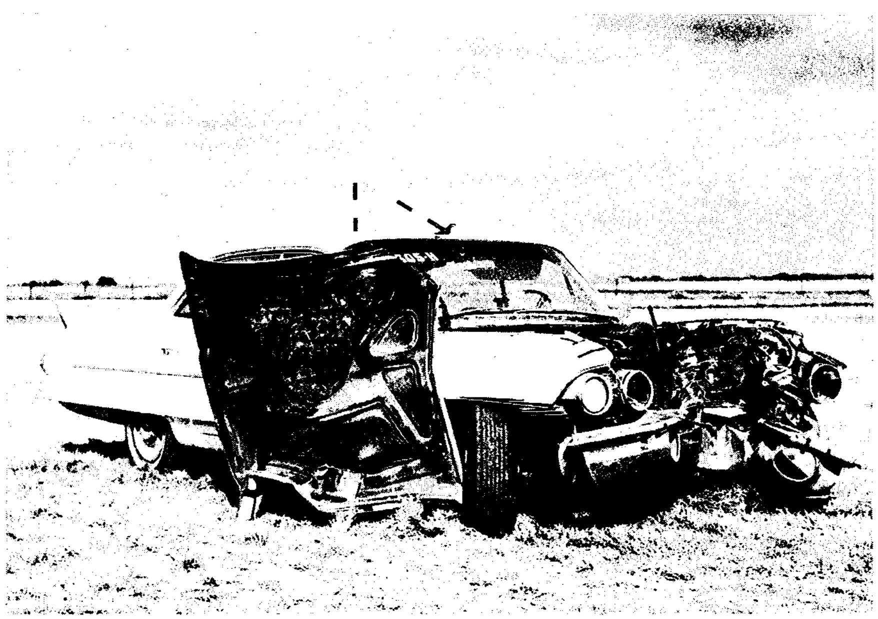


FIGURE 11. Crash vehicle after Test H

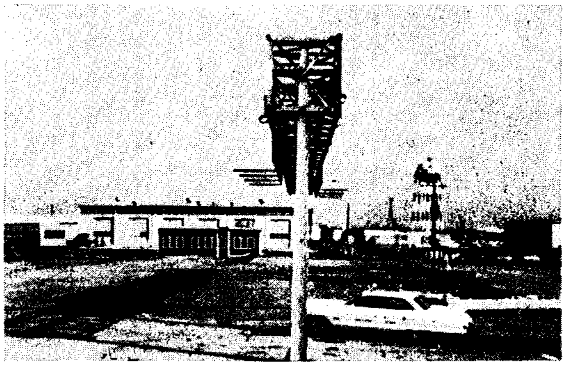
TEST 605-1

This final crash test was conducted on January 28, 1971. A 5,170 pound 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 12, in which it can be observed that the truss rotation caused by the force of the upward moving support is minimal by examination of the high-speed film which indicated that the maximum rotation was 1.6 degrees. The support rotated to a maximum angle of 70 degrees from the original upright position, and the height of the lower end of the support at the peak of its swing was 13.5 feet above the ground. The average and peak decelerations from accelerometer data are listed in Table 10. The high-speed film data is given in Table 13.

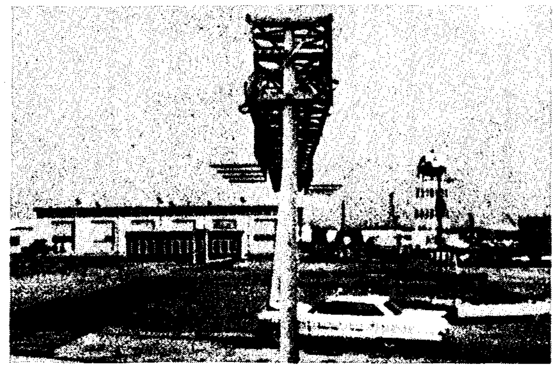
The angle of impact in this test was 15 degrees as can be seen in the sequential photographs in Figure 13. The hood of the vehicle was thrown against the windshield. It was determined following the collision that the post had penetrated the front end of the vehicle 2.67 feet.

Following the crash test the prototype structure was examined carefully and it was observed that several truss members had been slightly bent by the force of impact; also it was observed that the upper plate of the breakaway base at Column C slid 2 inches toward the north (in the direction of the vehicle impact) as is evident in Figure 14. A splinter of steel (Figure 15) peeled from the toe of the guide angle by the portion of the support above the pinned connection was found on the ground near the prototype structure. The structure remained erect and in good condition following this high-speed crash test.

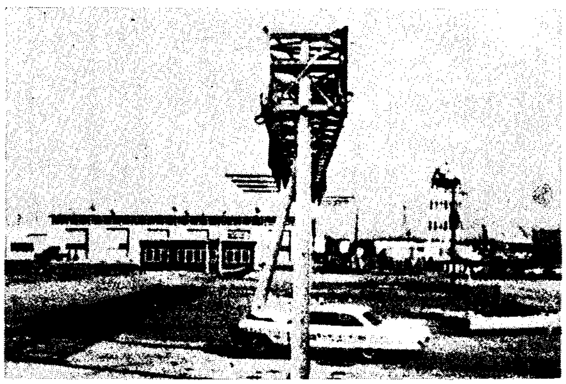
Vehicle damage is shown in Figure 16 in which it can be seen that the major damage was to the bumper and grill of the car.



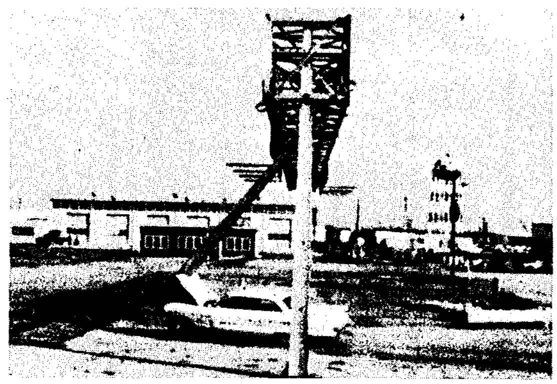
0 sec



.035 sec



.068 sec



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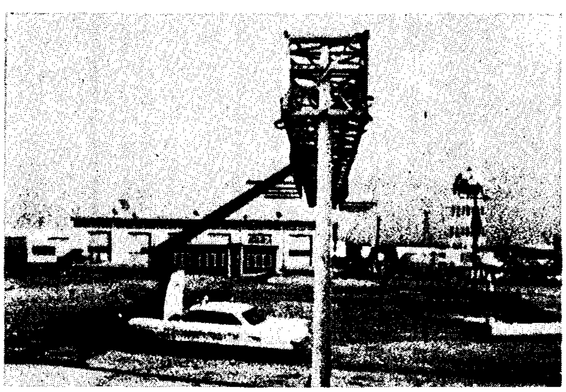
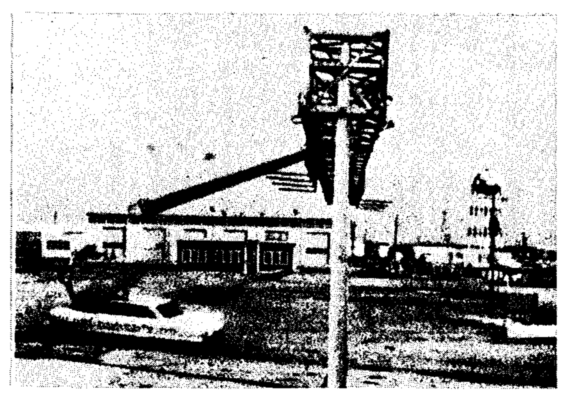
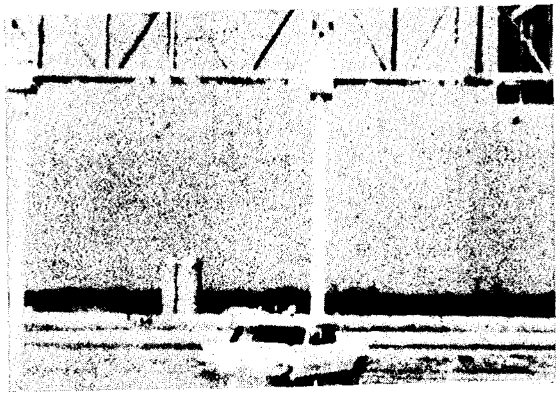


.229 sec



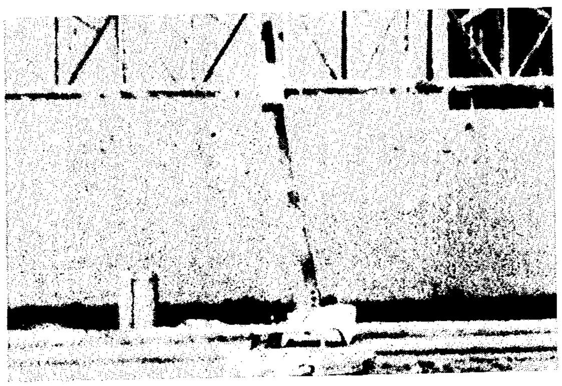
.353 sec

FIGURE 12 . Sequential Photographs of Test I

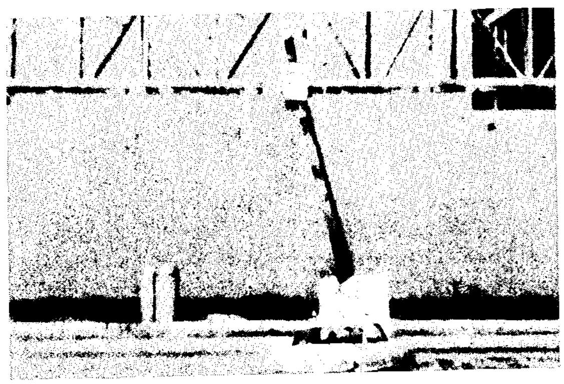


0 sec

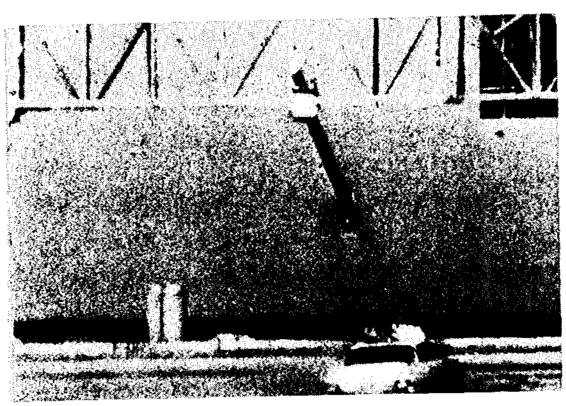
.041 sec



.151 sec



.216 sec



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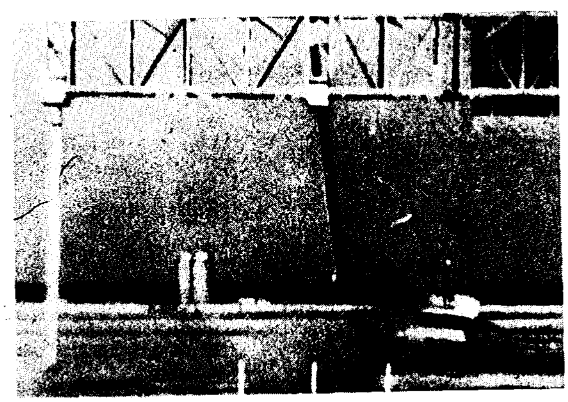


.611 sec

FIGURE 13. Sequential Photographs of Test I

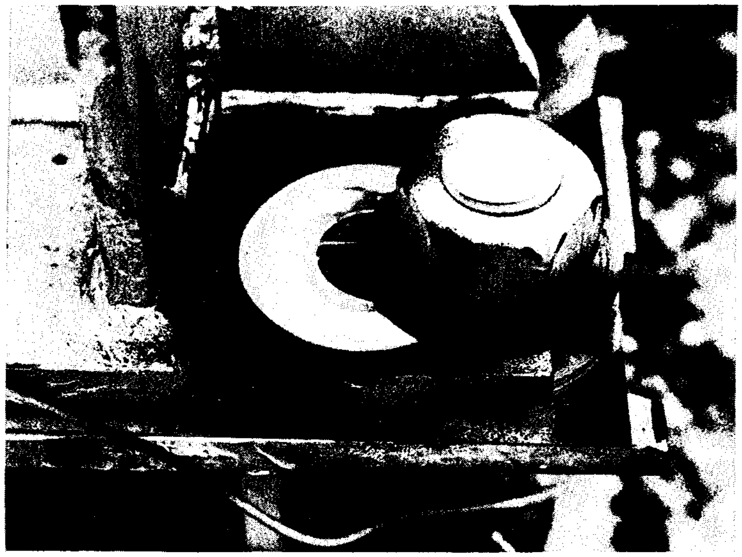


FIGURE 14. Breakaway Base Movement at Column C, Test I

FIGURE 15. Splinter from Guide Angle

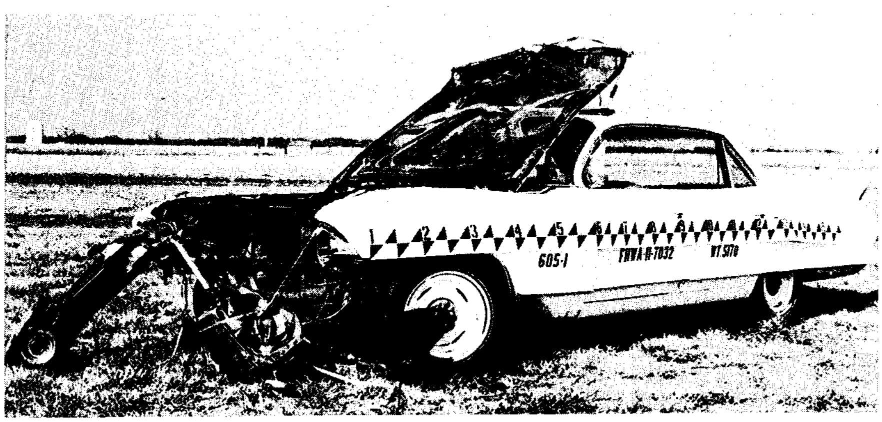


FIGURE 16. Damaged Vehicle, Test I

TABLE 10.

SUMMARY OF VEHICLE CRASH TEST RESULTS

Test No. →	A	B	C	D	E	F	G	H	I
Vehicle, Make Year	Ford 1963	Simca 1959	Ford 1963	Cadillac 1962	Ford 1963	Borgward 1959	Ford 1962	Cadillac 1961	Cadillac 1962
Vehicle Weight, lbs.	3950	2100	4090	4880	3920	2350	3950	5150	5170
Impact Angle, degrees	0	0	0	0	15	15	15	0	15
Initial Speed -- mph*	25.7	44.0	46.5	54.0	28.6	52.0	50.1	75.3	72.0
Change in Speed -- mph*	5.4	14.7**	8.9	9.0	7.2	13.6	10.2	11.5	11.2
Avg. Decel., g's (long.) (trans.)	3.1 ---	9.6 ---	6.7 ---	7.8 ---	3.7 0.1	12.2 1.3	5.8 0.6	6.9 ---	8.8 0.4
Peak Decel., g's (long.) g's (trans.)	7.4 ---	22.4 ---	19.1 ---	15.1 ---	8.8 3.4	30.8 8.7	15.3 3.6	17.6 ---	22.4 4.7
Target Support****	A	B	B	A	B	A	A	A	B
Max. Rotation of Support, degrees*	83	65***	63	68	65	59	65	77	70
Height of lower end of support at peak of swing, ft*	19.5	12.1	11.5	13.1	12.1	10.2	12.1	16.3	13.5
Approximate Rotation of Truss*, degrees	2	3	1	9	1	4	8	60	1.6

*From film data.
**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.
***Impact load distributors were installed in this and all following tests.
****Support A is an exterior column and support B is an interior column.

TABLE 11

COMPARISON OF COMPUTER SIMULATION WITH CRASH TEST

TEST CONDITIONS AND COMPUTER INPUT*				COMPARISON OF RESULTS*							
Test	Vehicle Weight (lbs)	Vehicle Approach Angle (deg)	Impact Velocity (mph)	Change in Vehicle Velocity (mph)		Time Post and Vehicle Were in Contact (sec)		Average Deceleration (g's)		Maximum Post Penetration (ft)	
				Test	Model	Test	Model	Test	Model	Test	Model
A	3950	0	25.7	5.4	5.9	0.091	0.082	2.9	2.9	0.96	0.97
B	2100	0	44.0	14.7	16.2	0.080†	0.139	8.9	5.3	1.75	2.15
C	4090	0	46.5	8.9	9.3	0.080	0.099	5.5	4.3	1.25	1.63
D	4880	0	54.0	9.0	9.1	0.080	0.087	4.2	4.7	1.50	1.60
E	3920	15	28.6	7.2	7.0	0.085	0.095	4.1	3.4	0.83	1.13
F	2350	15	52.0	14.3	16.3	0.062	0.074	10.7	10.1	1.42	1.50
G	3950	15	50.1	10.2	10.4	0.059	0.093	7.9	5.1	1.60	1.76
H	5150	0	75.3	11.5	11.7	0.066	0.083	8.1	6.4	2.08	2.24
I	5170	15	72.0	11.2	11.2	0.068	0.083	7.7	6.2	2.67	2.20

* "Mathematical Simulation and Correlation", Technical Memorandum 605-2 (7).

† 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.

TABLE 12

TEST 605-H

High-Speed Film Data
Vehicle Displacement versus Time

Time (milliseconds)		Displacement (feet)	Time (milliseconds)	Displacement (feet)
-38.9		-4.3	(continued)	
-31.1		-3.4	77.8	7.7
-23.3		-2.6	85.6	8.4
-15.6		-1.7	93.4	9.1
-7.8		-0.9	101.2	9.9
0	Impact	0	108.9	10.6
7.8		0.9	116.7	11.3
15.6		1.7	124.5	12.1
23.3		2.5	132.3	12.8
31.1		3.3	140.1	13.5
38.9		4.1	147.9	14.3
46.7		4.8	155.6	15.0
54.5		5.5	163.4	15.8
62.3	Loss of Contact	6.2	171.2	16.5
70.0		6.9	179.0	17.2

TABLE 13

TEST 605-I

High-Speed Film Data
Vehicle Displacement versus Time

Time (milliseconds)		Displacement (feet)	Time (milliseconds)	Displacement (feet)
-39.9		-4.2	(continued)	
-31.9		-3.4	79.8	7.5
-24.0		-2.5	89.8	8.4
-16.0		-1.7	99.8	9.3
-7.9		-0.9	109.8	10.2
0	Impact	0	119.8	11.1
10.0		1.0	129.7	12.0
20.0		2.0	139.7	12.9
29.9		3.0	149.7	13.8
39.9		4.0	159.7	14.7
49.9		4.9	169.7	15.5
59.9	Loss of	5.8	179.6	16.4
69.9	Contact	6.6	189.6	17.3

ACCELEROMETER DATA

The locations of the accelerometers with respect to the center of gravity (CG) of the vehicle are shown in Figure 17. Figures 18, 19, and 20 contain traces obtained from accelerometers mounted on the crash vehicles in Tests H and I.

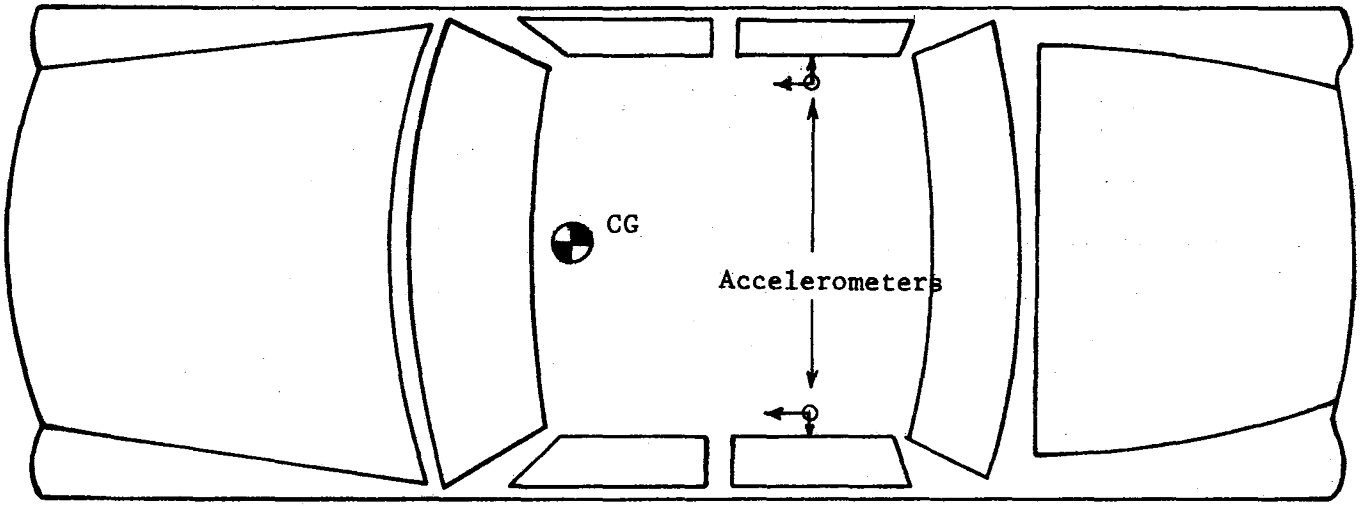
SUMMARY

A summary of crash test results is contained in Table 10, and a comparison of computer simulation predictions with crash test results is presented in Table 11. These tables include information for all tests conducted during the course of the study. Details of Tests A through G were reported in Technical Memoranda (8).

CONCLUSIONS

At the outset, this study was primarily concerned with the behavior of an automobile colliding with a breakaway column supporting an overhead sign bridge at low speed and high speed. Damage to the colliding vehicle, decelerative forces and change in speed, were of primary concern. As the study developed, it became clear that behavior of the prototype structure, 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 degrees; load distributors and guide angles were developed and incorporated into the prototype structure. The following conclusions are drawn from the study:

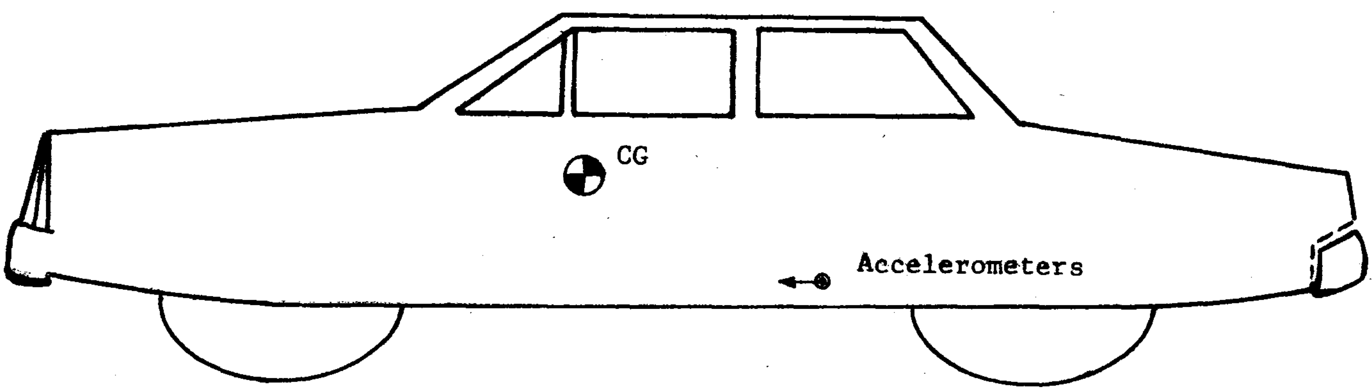
1. The breakaway safety features of this truss will reduce the collision forces on a standard size vehicle to a level which is considered survivable for restrained passengers.
2. The prototype structure remained erect, and suffered only localized damages during the series of tests reported herein.
3. Computer simulation techniques have been satisfactorily compared with crash test data and vehicle and support behavior are predictable using the computer simulation.



Plan View

Statham Accelerometers (strain gage type)

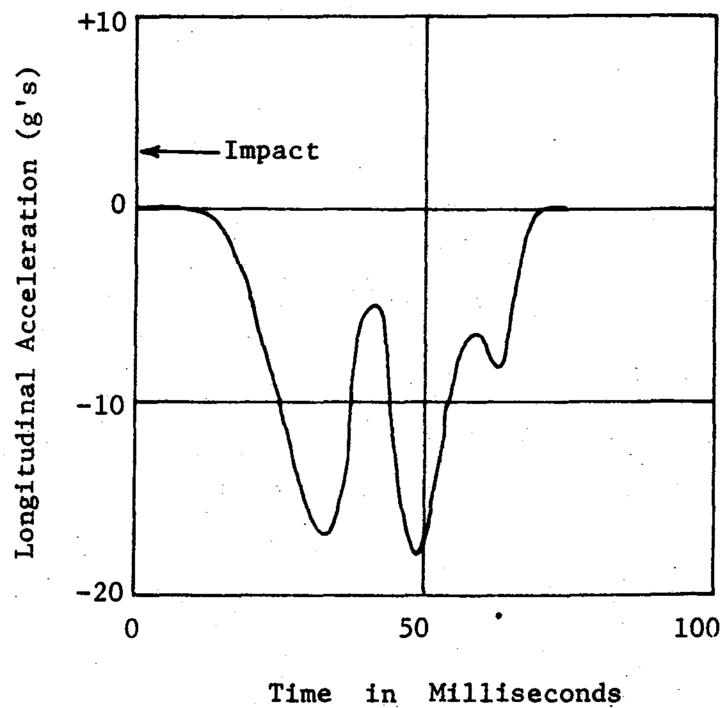
80 HZ Low-Pass Filter (active analog)



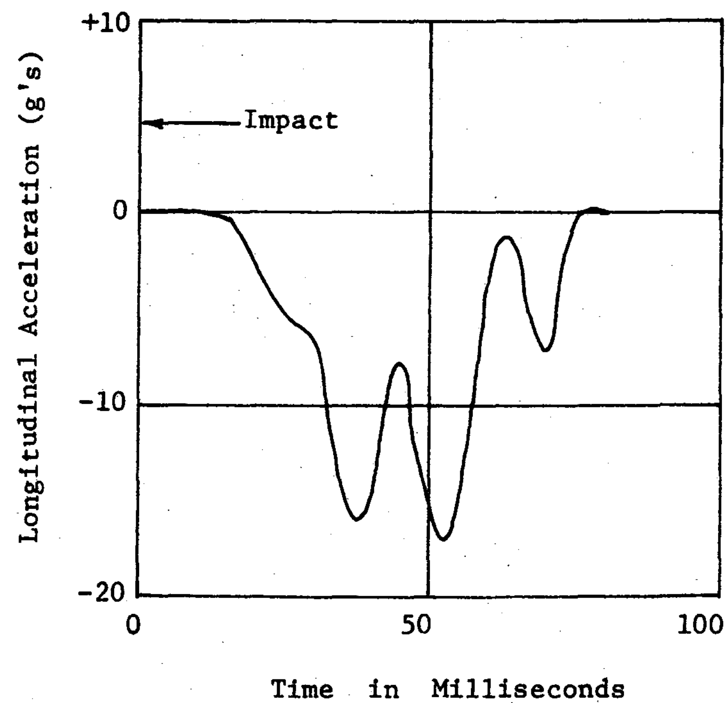
Side View

Figure 17. Location of Accelerometers With Respect to Vehicle CG.

Test 605-H



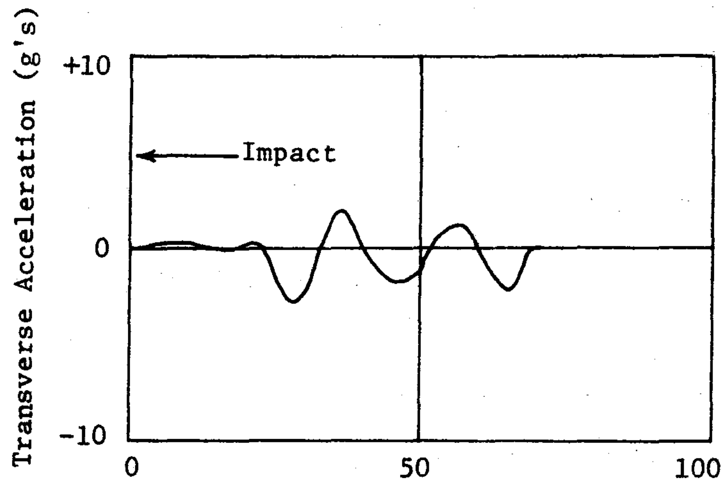
Statham 11081 (Left)
80 HZ Filter
Average = 7.3 g's
Peak =17.8 g's
Δ t = 70 msec.



Statham 12186 (Right)
80 HZ Filter
Average = 6.5 g's
Peak =17.4 g's
Δ t = 75 msec.

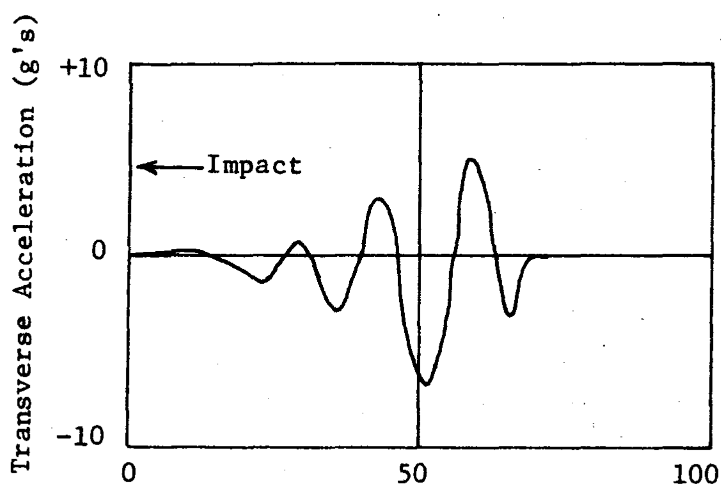
FIGURE 18. Longitudinal Accelerometer Data

Test 605-I



Time in Milliseconds

Statham 20 (Left)
80 HZ Filter
Average = 0.4 g's
Peak = 2.6 g's
Δ t = 69 msec.

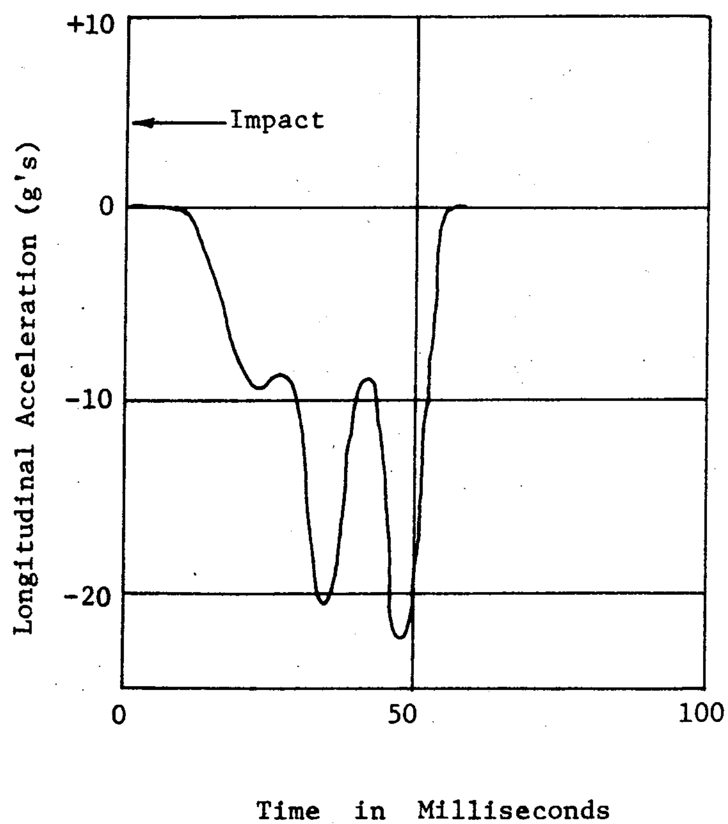


Time in Milliseconds

Statham 511 (Right)
80 HZ Filter
Average = 0.4 g's
Peak = 6.8 g's
Δ t = 69 msec.

FIGURE 19. Transverse Accelerometer Data

Test 605-I



Statham 11081 (Left)
80 HZ Filter
Average = 8.8 g's
Peak=22.4 g's
Δ t = 55 msec.

FIGURE 20. Longitudinal Accelerometer Data

LOWER CONNECTION TESTS

Nine additional laboratory tests were conducted using the previously fabricated column stub and base. Parameters incorporated in this series of tests were (1) the angle at which the load was applied, (2) new bolts, nuts, and washers and (3) the condition of bolts, nuts, and washers. Load and base slip data were recorded.

It was concluded that: (1) variables associated with bolts, nuts, and washers caused as much as 100% variation in the peak force required to slip the base and (2) the angle at which the load was applied has a very small influence on the value of peak force.

ADDITIONAL TORSION TEST - STATIC TEST 605-S3

Two cranes were used to return the truss to its original position following crash test 605-H. Following re-erection of the truss a 50 ton crane was used to apply a torque to the truss as had been done previously (13). Results of this torsion test of the truss are shown in Figure 21. During this test the wind was gusting to 25 mph from a southerly direction.

Examination of the plotted data reveals that fracture of the upper connection bolts at Column B occurred at a higher load and at a greater rotation than in the previous test.

A remarkable and unexpected incident occurred when one of the 1-3/4 inch diameter 4130 high strength base bolts at Column B fractured in tension at or about the time the upper connection bolts fractured. The nut and part of the base bolt were catapulted upward through the truss and above it about three to five feet. The load dropped from 16 kips to 9 kips as shown in Figure 21.

After examining the structure, the broken bolt was replaced and loading continued. It was apparent that the truss was much less stiff than in the previous test conducted in 1969. The 1970 torsion test was conducted on the structure after the entire full-scale impact test program had been completed and the slip in the various bolted joint connections and plastic working of some of the members would be expected to influence the torque-rotation behavior of the structure. The principal investigator decided to discontinue the test before additional unexpected incidents occurred. The reduction in torsional stiffness is attributed to movement of the truss section bolted connections which appeared to have some relative movement. That such movement occurred was verified when Column A was lowered, and it was observed that the base plates had approximately one inch clearance.

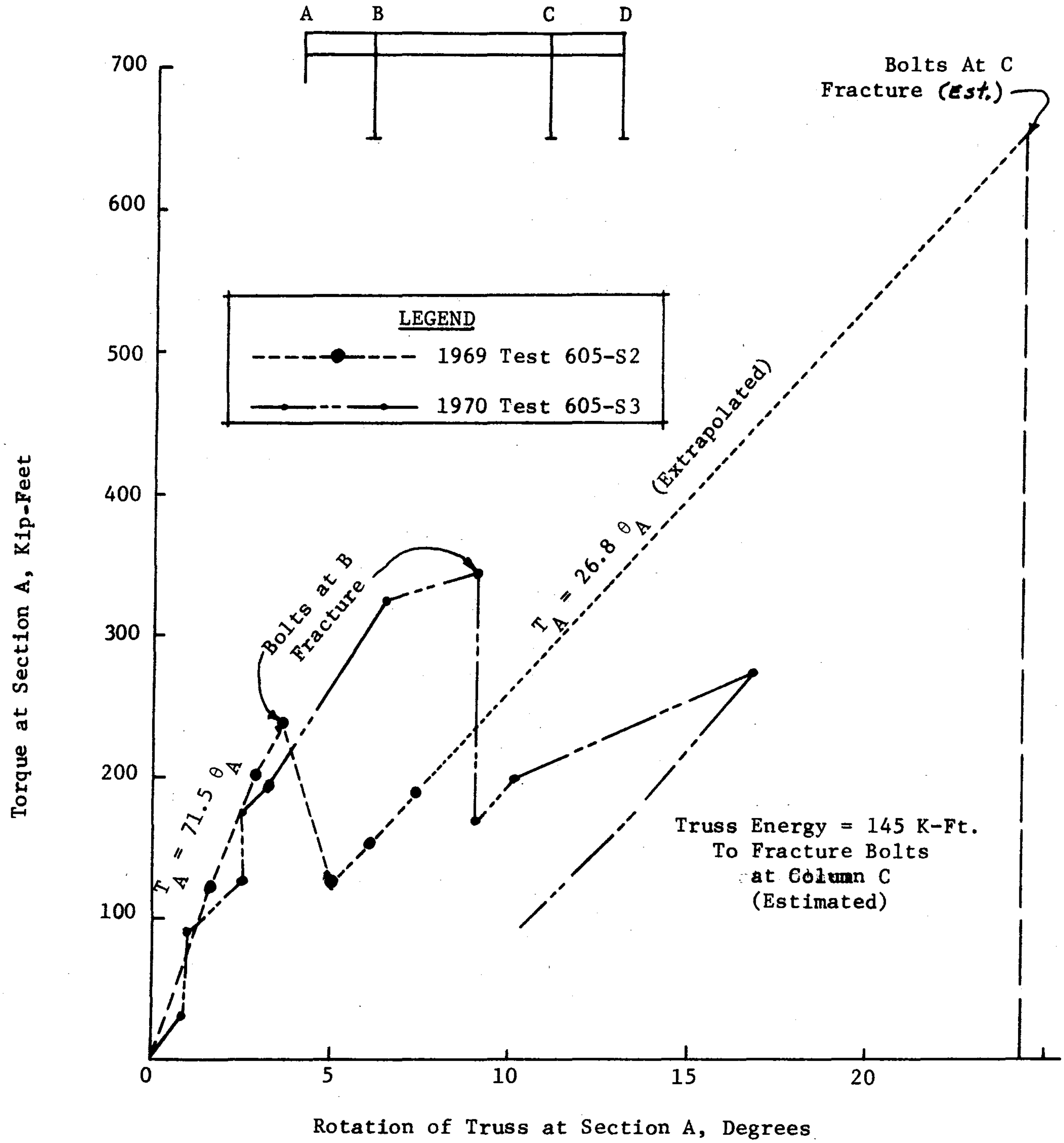


FIGURE 21. Torque-Rotation Relationship

APPENDIX

ALTERNATE CONCEPTS

Several interesting alternate design concepts were suggested during the course of this study. These alternate concepts were considered at Project Policy Meetings and Technical Subcommittee Meetings, and are presented here with brief comments about each concept.

CONCEPT A

An overhead sign bridge support with a lower breakaway base and a truss roller assembly is shown in Figure A. Subsequent to the actuation of the breakaway base, the support will clear the colliding vehicle as it rotates around the outside of the truss. The rollers are attached to the truss and guide a circular ring attached to the breakaway support.

A lighter truss can be used in this type of design because the truss does not need to reduce the forces induced by the rotating support when it strikes the truss as in the case of the present prototype OSB in this study.

CONCEPT B

An overhead sign bridge with a lower breakaway base and an upper hinged fuse plate is shown in Figure B. Subsequent to the actuation of the breakaway base and the fracturing of the bolts on the near side of the fuse plate, the rotating support will clear the colliding vehicle as it pivots about the fuse plate on the far side which forms a plastic hinge. In this type of design, the truss and remaining supports must expend a portion of the kinetic energy of the rotating column; however, the support must rotate about 90 degrees in order to strike the truss as compared to about 60 degrees for the prototype OSB tested in this study.

CONCEPT C

An overhead sign bridge with a lower breakaway base and an upper frangible plate and arresting cable is shown in Figure C. Subsequent to the actuation of the breakaway base and the fracturing of the upper frangible fuse plates the rotating support will clear the colliding vehicle as the support pivots at the end of a short length of an arresting cable. As evident in Figure C, the support can rotate about 180 degrees before striking the truss.

CONCEPT D

An overhead sign bridge with tubular frangible supports and cable suspension system is shown in Figure D. Subsequent to one frangible support being temporarily removed by a colliding vehicle, the overhead sign bridge truss will function as a cantilever beam. Also, the outside anchor cables are fastened to breakaway supports.

CONCEPT E

An overhead sign bridge with two breakaway supports and two breakaway cable anchors is shown in Figure E. Subsequent to the actuation of the support breakaway base and the fracturing of the bolts on the near side of the fuse plate, the rotating support will clear the colliding vehicle as it pivots about the fuse plate on the far side which forms a plastic hinge, and, the overhead sign bridge will function as a cantilever beam. The fuse plate detail is similar to that of Concept B. This concept requires less distance between the support breakaway base and the cable breakaway anchor location than that of Concept D.

CONCEPT F

An overhead sign bridge with three breakaway supports and two breakaway cable anchors is shown in Figure F. Subsequent to the actuation of a support breakaway base and the fracturing of the bolts on the near side of the fuse plate, the rotating support will clear the colliding vehicle as it pivots about the fuse plate on the far side which forms a plastic hinge and, the overhead sign bridge will function as a cantilever beam. The fuse plate detail is similar to that of Concept B. This concept requires less distance between the support breakaway base and the cable breakaway anchor location than that of Concept D.

CONCEPT G

An overhead sign bridge with a lower breakaway base and an upper hinged fuse plate is shown in Figure G. Subsequent to the actuation of the breakaway base and the fracturing of the bolts on the near side of the fuse plate, the rotating support will clear the colliding vehicle as it pivots about the fuse plate on the far side which forms a plastic hinge. In this type of design, the truss and remaining supports must expend a portion of the kinetic energy of the rotating column; however, the support must rotate about 180 degrees in order to strike the truss as compared to about 60 degrees for the prototype OSB tested in this study. This is a modification of Concept B; making the width of the column connection (w) the same width as the truss allows the support significantly greater freedom to rotate. The additional rotation could be important especially in cases of impact by trucks.

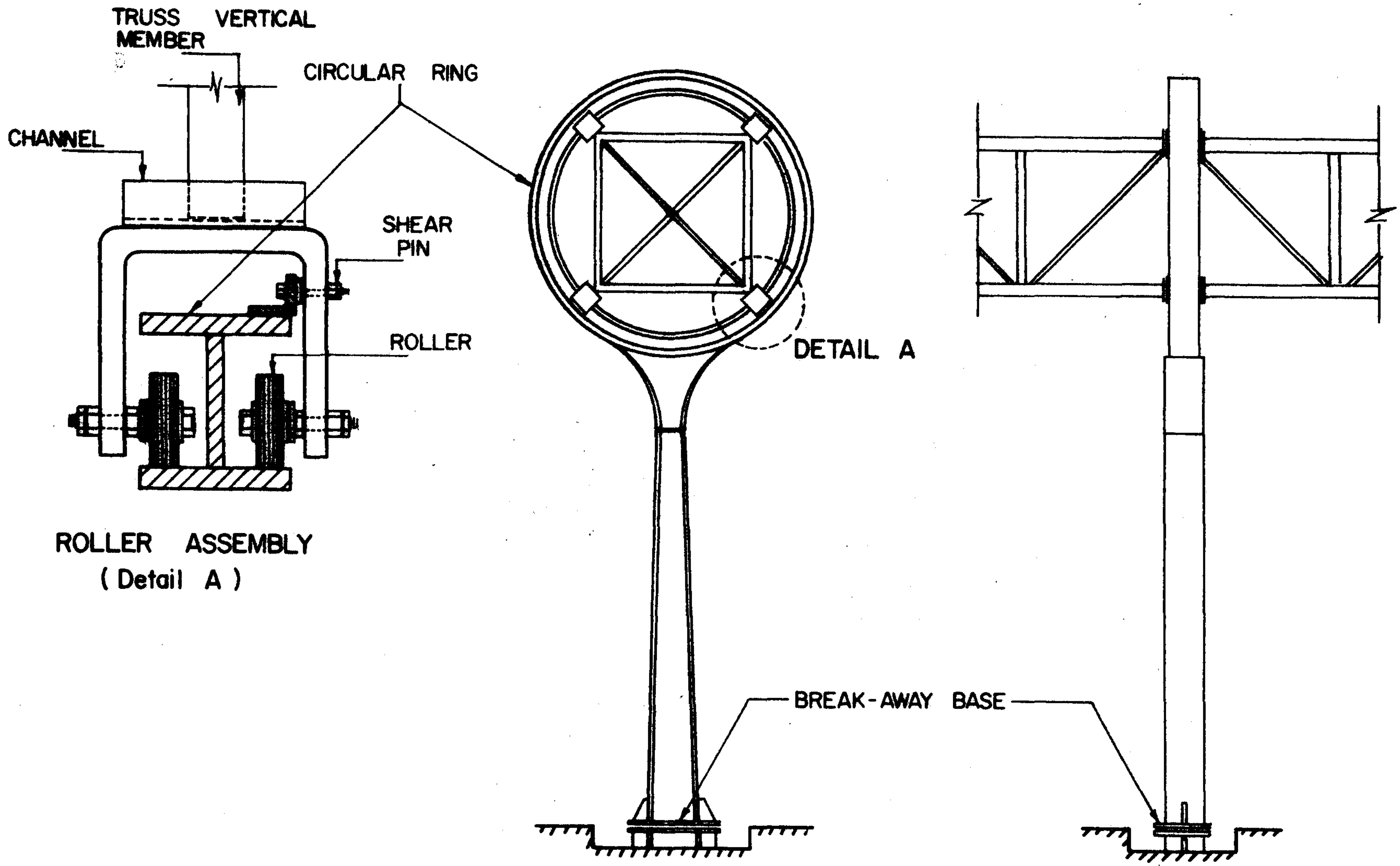


FIGURE A. OVERHEAD SIGN BRIDGE WITH BREAK-AWAY BASE AND CIRCULAR RING UPPER CONNECTION (AFTER HOBRLA)

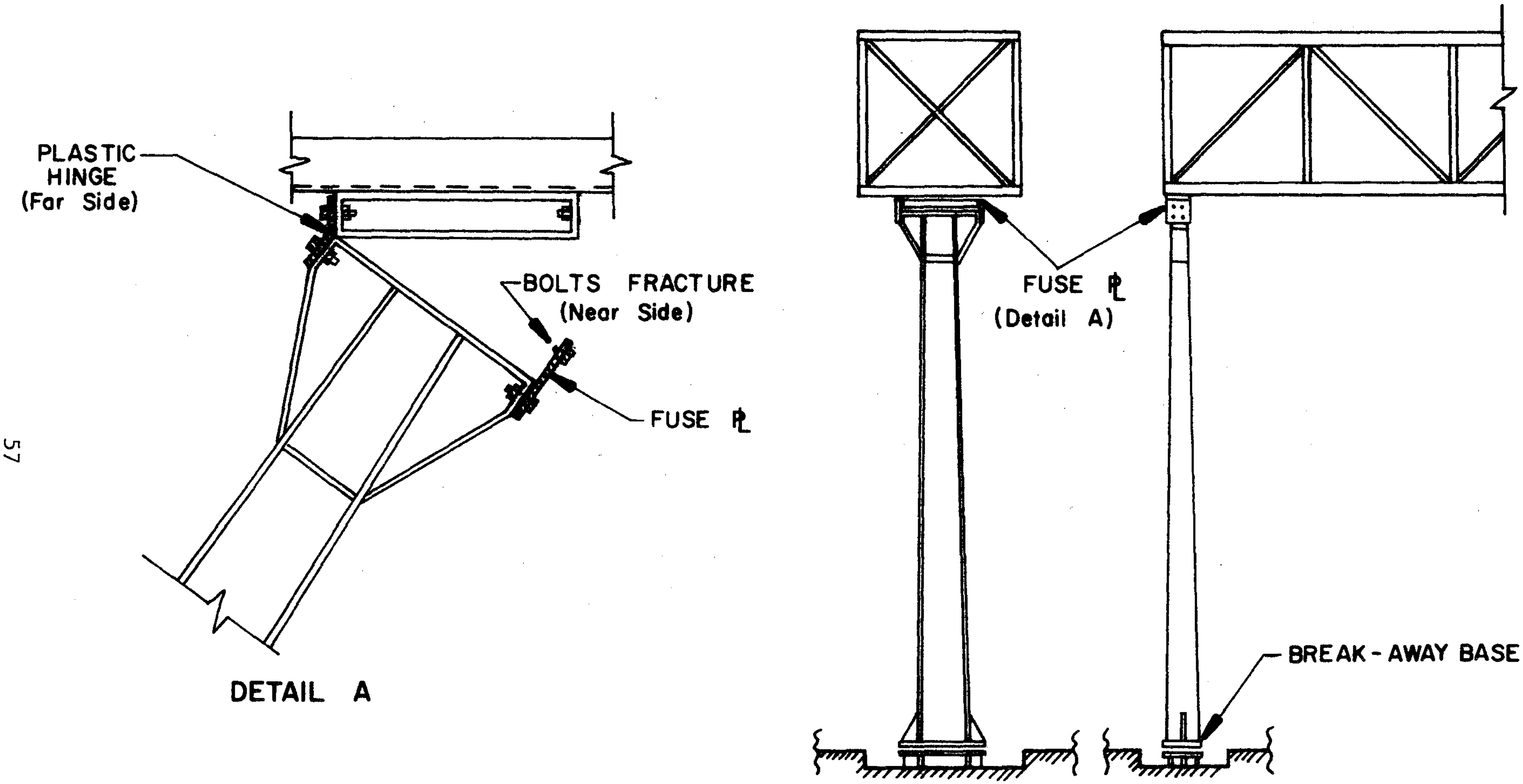


FIGURE B OVERHEAD SIGN BRIDGE WITH BREAK-AWAY BASE AND PLASTIC HINGE UPPER CONNECTION (AFTER SCHEFFEY)

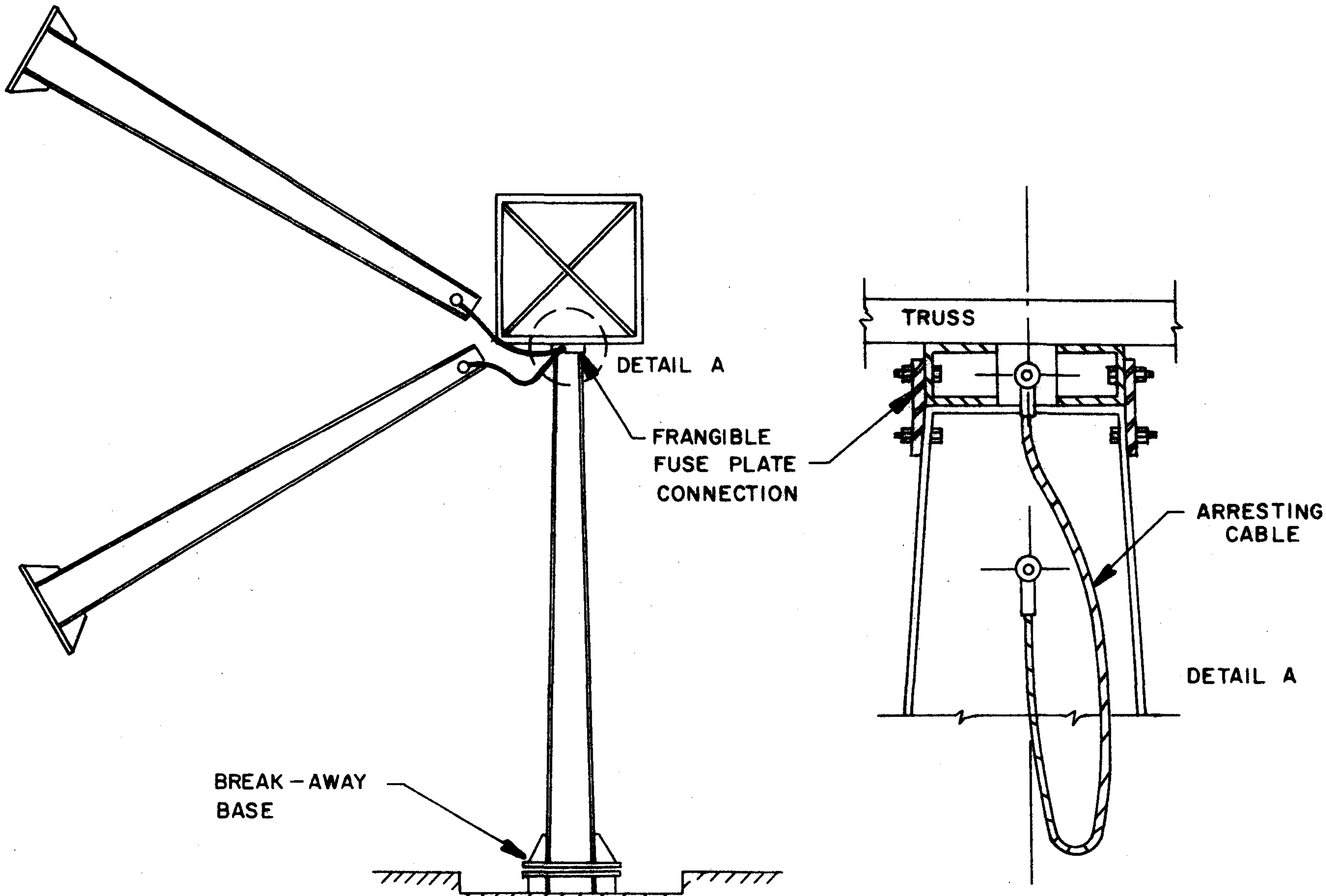


FIGURE C OVERHEAD SIGN BRIDGE WITH BREAK - AWAY BASE AND FRANGIBLE FUSE PLATE UPPER CONNECTION

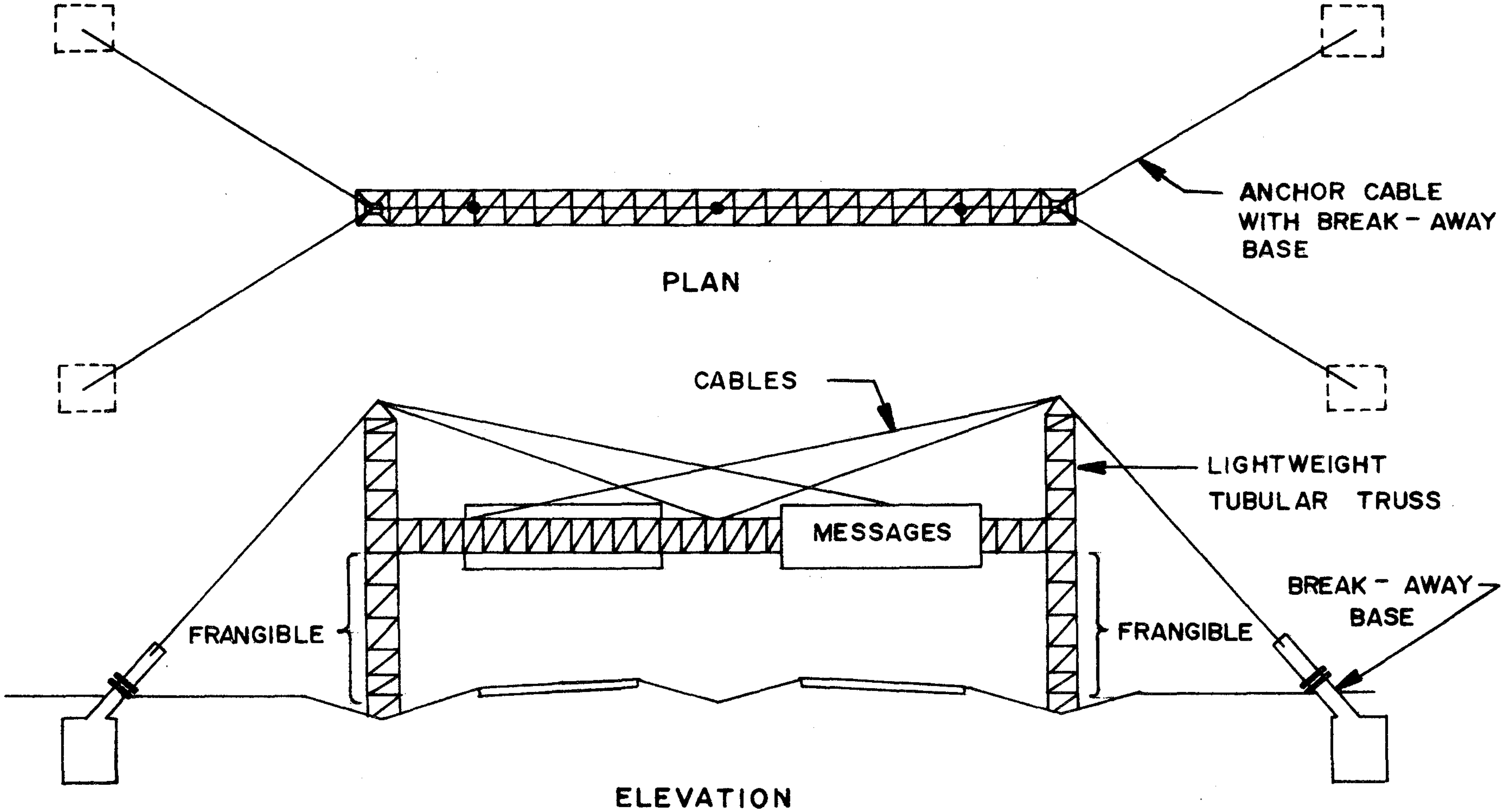


FIGURE D OVERHEAD SIGN BRIDGE WITH FRANGIBLE TUBULAR SUPPORTS AND CABLE SUSPENSION SYSTEM (AFTER IVEY)

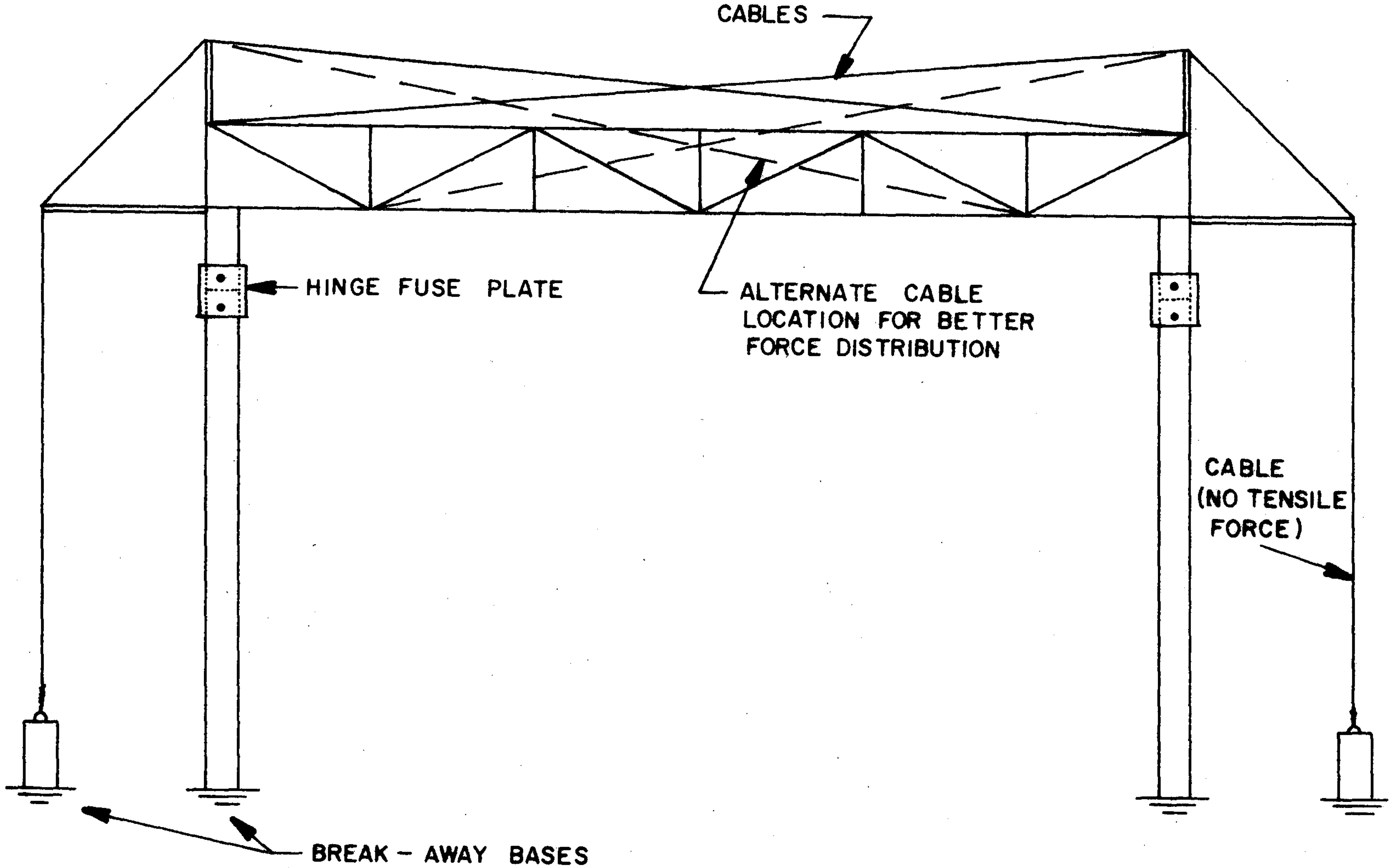


FIGURE E OVERHEAD SIGN BRIDGE WITH BREAK-AWAY SUPPORTS AND BREAK-AWAY CABLE ANCHORS (AFTER CHAPMAN)

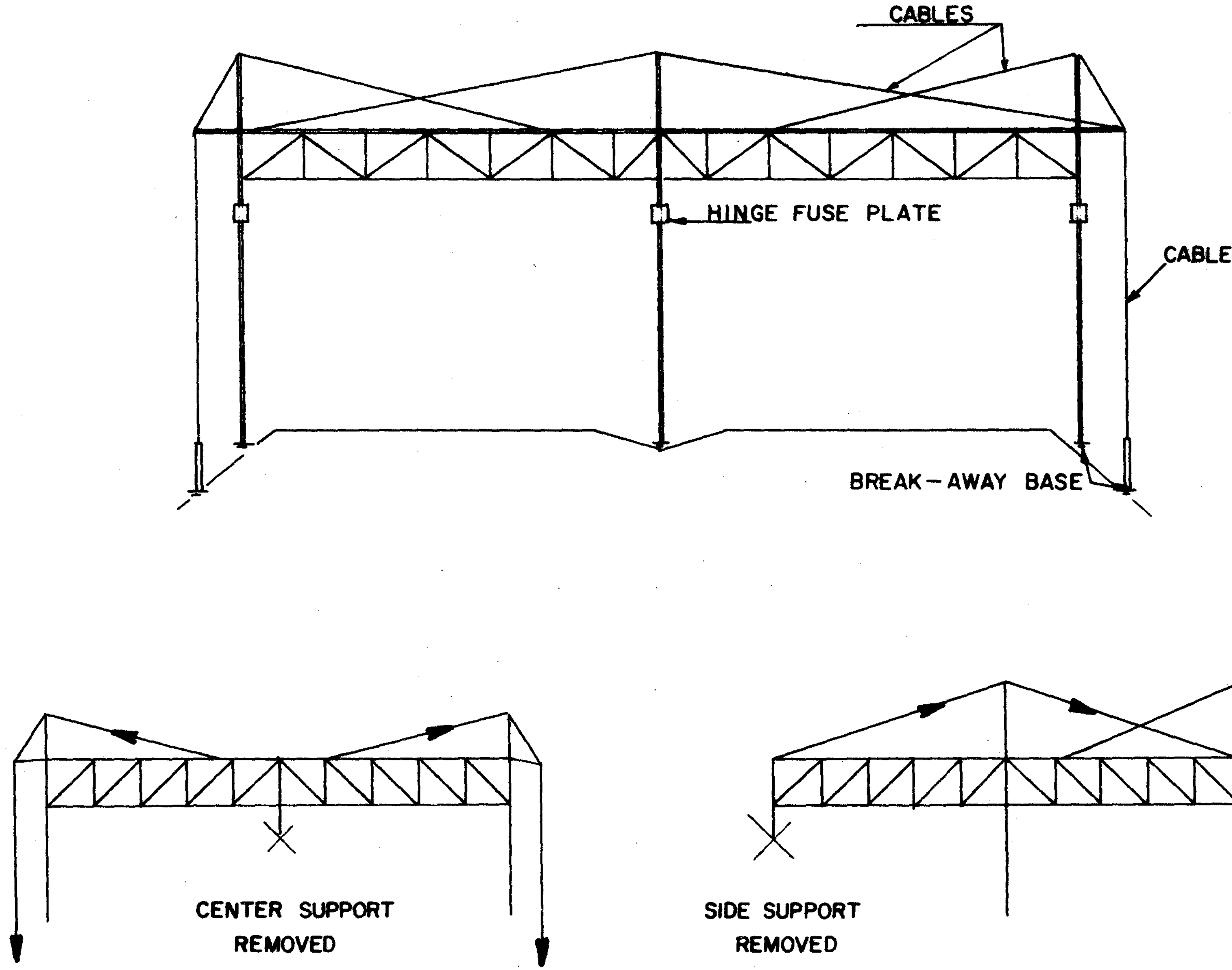
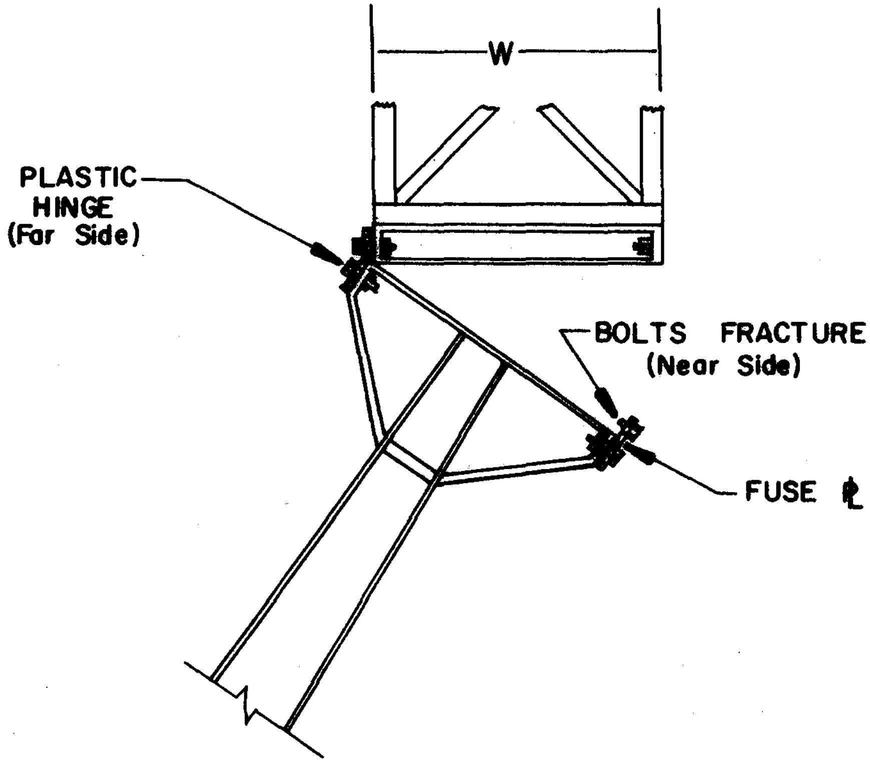
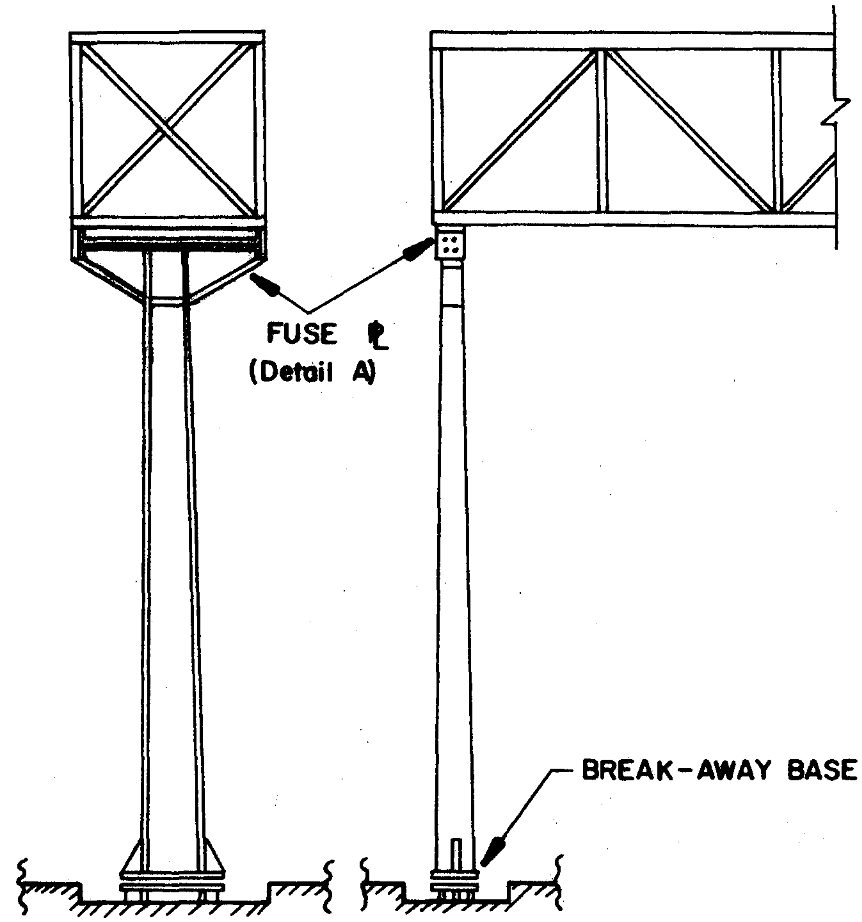


FIGURE F OVERHEAD SIGN BRIDGE WITH BREAK-AWAY SUPPORTS AND BREAK-AWAY CABLE ANCHORS (AFTER CHAPMAN)



DETAIL A



NOTE: THIS IS A MODIFICATION OF CONCEPT B; MAKING THE WIDTH OF THE COLUMN CONNECTION (W) THE SAME WIDTH AS THE TRUSS ALLOWS THE SUPPORT SIGNIFICANTLY GREATER FREEDOM TO ROTATE

FIGURE G OVERHEAD SIGN BRIDGE WITH BREAK-AWAY BASE AND PLASTIC HINGE UPPER CONNECTION (AFTER GUNDERSON)

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