Dynamic Tests of Five Breakaway Lighting Standard Base Designs

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A study to determine the effectiveness of five breakaway lighting standard base designs in reducing the severity of vehicle impacts is reported. Ten head-on full scale dynamic tests were conducted on 30-ft lighting standards mounted on the various frangible or slip base designs. All of the standards were steel except for one aluminum design. The tests were conducted on a 6-in. high cast aluminum insert base, a notched bolt insert design, a multi-directional steel slip base design developed by Texas Transportation Institute, a 20-in. high aluminum transformer base, and an aluminum standard fitted and epoxy-cemented to an 18-in. high cast aluminum sleeve type base.

All of the base designs tested at moderate (40 mph) impact speeds broke away with tolerable impact resistance. The Texas slip base and the notched bolt insert designs offered the least resistance at this speed. The impact resistance of the notched bolt insert showed a marked increase when the impact speed was reduced to 15 mph. Similar resistance was experienced in the 15-mph test on the 20-in. high aluminum transformer base. However, the impact resistance of the multidirectional slip base was essentially the same when impacted at 15 mph as at 40 mph, supplementing and substantiating the findings of T. T. I. that this is one of the most effective designs for reducing the severity of vehicle impacts into lighting standards at all speeds and angles.

•CALIFORNIA's increased emphasis on highway safety has included a concentrated effort to minimize the potential hazard of fixed objects on the roadside. The 1967 accident statistics for "ran-off-the-road, hit-fixed-object" fatal accidents in California show an improvement over those for 1966. However, this type of accident continues to be the most prevalent on California freeways, with impacts into lighting standards accounting for 15 fatalities in 1967. At the present time, more than 30,000 rigidly mounted lighting standards are located along California's highways and present potential hazards of varying degrees to the motoring public.

The primary purpose of the research project reported herein was to determine or develop, through full-scale dynamic impact testing, the most effective breakaway device that can be used in a traffic-vulnerable lighting standard installation to reduce the severity of vehicle impacts at highway operating speeds. Data from other researchers (1, 2) were thoroughly analyzed and considered fully in deciding which breakaway base designs to test.

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After reviewing the data from the initial six 40-mph tests of this series, there were some reservations regarding low-speed impact performance. The first low-speed test at 15 mph confirmed our suspicions that a base design that breaks away effectively when impacted at 40 mph can, in fact, be an almost immovable object when subjected to low-speed impacts approaching a static loading condition. A review of resulting damage in low-speed tests reveals severe vehicular front end deformations, which we consider to be relatable to the damage often sustained by a broad-sliding vehicle impacting a fixed object within the limits of the passenger compartment (see Plate 3, Appendix). After reviewing the data films from the low-speed tests, consideration was given to continuing the research project by simulating side impacts. However, no matter how conclusive the results would be for a given vehicle, they would be representative only of the damage that could be expected from side impacts on that particular vehicle. Furthermore, in the final analysis it appears that the most effective breakaway base simply offers the least resistance to vehicle impact at all angles yet is capable of resisting the operational loads imposed upon it.

It was significant to note that with an 18-ft setback from the edge of pavement, just one of the three standards tested at low speeds would have fallen into the traveled way (Plate 4, Appendix). In general, the pole reactions in this test series correlate well with work by other researchers with mathematical models, dynamic tests, and field performance (2, 3, 4). Of particular significance is the post-impact position of the lighting standard supported on the slip base design for the 15-mph impact.

Discussion of the data reported herein is limited to the most significant findings. Sequence photos, damage photos, and dynamic data derived from high-speed photography are presented as evidence of the relative efficiency of the five devices tested.

DESIGN AND PERFORMANCE

Common to all tests was the 28-ft 6-in. high lighting standard with 12-ft mast arm and 30-ft luminaire mounting height. For all tests except 193, the lighting standards and mast arms were steel (California Type XV). For Test 193, the lighting standard and mast arm were aluminum. All luminaires were 400-watt mercury vapor units that weighed 25 lb with aluminum shell. Radio-controlled vehicles were impacted head-on into the standards with the planned point of contact near the midpoint of the bumper. The path of the impacting vehicles was parallel to the simulated edge of a highway pavement in the direction of travel. The test vehicles were 1966 sedans weighing 4,540 lb gross, including all test equipment and the dummy, with a bumper height of 22 in. This 22-in. height is to the leading edge near the top of the bumper where it makes initial contact with the pole. Crash vehicles for the 40-mph tests were under power through impact. For the 15-mph tests, the ignition was turned off 10 ft before contact and the vehicle was permitted to coast through impact. The anthropometric dummy was unrestrained for all tests.

Table 1 gives the dynamic data from all ten tests, and Plates 1 and 2 (Appendix) show sequence photos of each dynamic test.

It is important to note that load transfer from the vehicle to the lighting standard occurs at a point approximately 22 in. above the ground. In all tests conducted during this series, local deformation of the pole at this 22-in. height is coincident with the bumper height of the typical 1966 and later vehicles. Breakaway lighting standards impacted with older test vehicles with lower bumper heights would likely indicate more effective breakaway performance than is warranted under current operating conditions. In other words, the lower the impact point, the more effectively the load will be transmitted into any base-type breakaway device before the pole collapses. Therefore, when comparing results of other researchers with the results of this series, correlation as to the effectiveness of any particular device may not, in all cases, be evident.

Cast Aluminum Insert Base (Tests 182, 183, and 191)

The 6-in. high frangible aluminum insert bases used for these three tests were cast from material conforming to the requirements of ASTM Designation B-108, alloy

TABLE 1

BREAKAWAY LIGHTING STANDARDS
(Vehicle: 1966 Sedan – Weight 4,540 lbs. w/ instrumentation and dummy)

TEST NO.		181	182	183	191	192	193	194	195	196	197
SHAFT TYPE AND HEIGHT		Steel 28'-6"	Steel 28'-6"	Steel 28'-6"	Steel 28'-6"	Steel 28'-6"	Alum. 28'-6"	Steel 28'-6"	Steel 28'-6"	Steel 28'-6"	Steel 28'-6"
BASE TYPE		Notch bolts H-950°F	6" Frang Alum. Insert	6" Frang Al. Insert (Modif.#1)	6" Frang Al. Insert (Modif.#2)	Notch bolts H-1050°F	Cast Al. Sleeve Base	Notch bolts H 1050°F	Texas Slip base	Texas Slip base	Alum. Trans base
INITIAL (MPH)* VELOCITY		40±	39.7	41.2	47.7	39.9	38.2	14.8	40.4	15.8	15.8
FINAL (MPH)** VELOCITY		NO DATA	35.6	37.6	45.2	38.0	34.6	0	39.0	14.8	0
Δ VELOCITY (MPH)			4.1	3.6	2.5	1.9	3.6	14.8	1.4	1.0	15.8
Δ MOMENTUM (LB SEC)			850	750	510	390	740	3040	290	210	3270
TIME IN POLE CONTACT (SEC)			0.170	0.212	0.136	0.107	0.197	2.54	0.114	0.130	3.76
TIME TO POLE RELEASE (SEC)			0.024	0.025	0.018	0.009	0.027	0.115	0.009	0.010	0.470
DEFORMATION OF POLE		Minor	30° Bend	25° Bend	5° Bend	10° Bend	90° Bend	Minor	None	None	None
MAXIMUM VEHICLE DEFORM.	HOOD	12"	12.5"	12"	12"	2"	9"	21"	9"	1.5"	21"
	BUMPER	18"	24"	20.5"	19"	2"	19"	21"	9"	3"	21"

* Initial Velocity — average velocity calculated over 1' interval prior to impact.
** Final Velocity — average velocity calculated over 1' interval after pole lost contact with test vehicle.

SG70A, heat-treated ot a T-6 temper. The side wall thickness of the casting was ¼ in.

Test 182 was conducted at 40 mph on an unmodified cast aluminum insert with the hand hole facing away from the traveled way. Figure 1A and Plate 5 show design details. As the base failed on impact, the standard was kicked up and ahead of the test vehicle (Figure 1B). The lower portion of the pole shaft hit the roof as the test vehicle progressed under it. The top of the pole shaft came to rest about 30 ft beyond the foundation. The force of impact not only collapsed the front end of the test vehicle about 24 in. but the pole shaft was damaged beyond repair with a 30-deg bend at the point of contact. In addition, the foundation anchor bolts were bent approximately 30 deg away from the direction of impact.

Test 183 was conducted at 40 mph on a cast aluminum insert base modified by drilling a series of four 1-in. diameter holes at 2½-in. centers in each of the three side walls (modification 1) and the hand hole was oriented toward impact. Figure 2A and Plate 5 show design details. It was anticipated that the base would fracture through this weakened cross section, thus reducing the impact resistance. However, upon

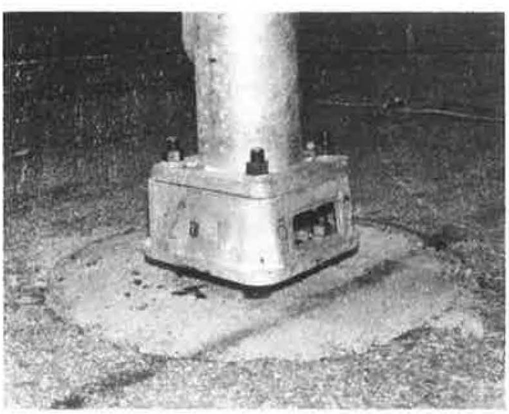

Figure 1A.

Figure 1B.

Figure 2A.

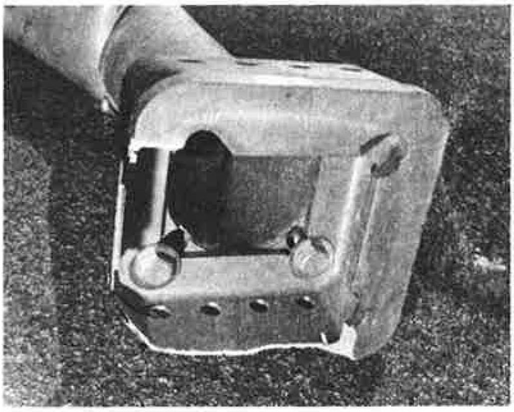

Figure 2B.

impact, the base failed through the base flange in much the same manner as in Test 182. There was no evidence of fracture through the weakened plane of the drilled holes (Fig. 2B). The lighting standard was kicked ahead and up, clearing the vehicle by 3 ft as it passed through the impact zone. It settled to the pavement with the top approximately 35 ft beyond the anchorage. The shaft was bent to approximately 25 deg at the point of first contact and was damaged beyond repair. The anchor bolts were bent approximately 30 deg. Vehicle damage was much the same as sustained during Test 182, with a 20-in. deformation to the front end.

Test 191 was conducted at 48 mph on the cast aluminum insert base mounted on the same anchorage as was used for Test 182 (the previously damaged bolts were repaired by straightening and welding on new studs). In a further effort to reduce the impact resistance noted in Tests 182 and 183, two 1-in. by 3¼-in. slots were milled through the three side walls near the base flange (modification 2) where the fracture occurred in the insert bases in the preceding two tests. Figure 3A and Plate 5 show design details. The hand hole was oriented facing away from the traveled way. Upon impact, the aluminum insert again failed in a combination of shear and tension with the fracture taking place through the milled slots as anticipated (Fig. 3B). The two right-hand bolts were bent 30 deg and the two left-hand bolts were sheared off at the surface of the concrete foundation. The lighting standard was kicked ahead and up, clearing the vehicle by 7 ft as it passed through the impact zone. The top of the pole settled to

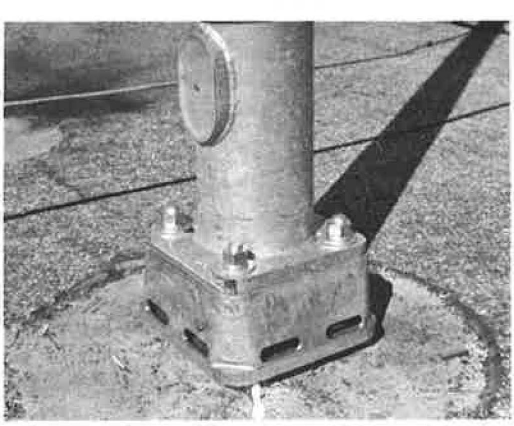

Figure 3A.

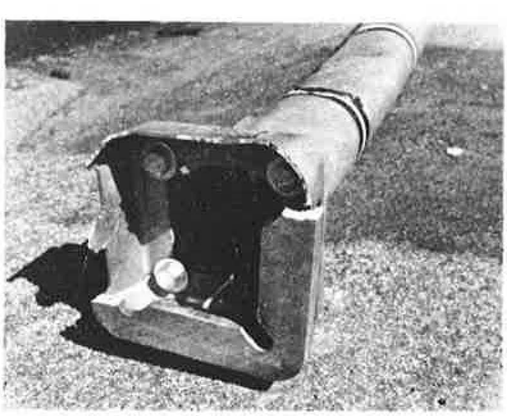

Figure 3B.

the pavement 25 ft beyond the anchorage. The shaft was dented 2 in. and was not considered salvageable. The vehicle sustained the least front end deformation (19 in.) observed in the three frangible aluminum insert tests.

The performance of the 6-in. cast aluminum insert with the second modification as in Test 191 under moderate impact was satisfactory. However, due to concern over the loss of side-wall cross section induced by the slots, it was concluded that this device should not be adopted as a design standard unless subsequent cyclic vibration tests are performed to insure that wind loads would not cause premature operational fatigue failure. Such tests were not within the scope of this research study.

Notched Bolt Inserts (Tests 181, 192, and 194)

A notched bolt insert concept designed to provide structural support equivalent to that provided by the conventional ASTM A-307 anchor bolt but with a notch machined in it to induce instantaneous shear failure under lateral impact was proposed as a breakaway device. Three impact tests were performed on installations incorporating the notched bolt inserts, two at 40 mph and one at 15 mph. The notched bolts were fabricated from 17-4 PH stainless steel, which is a martensitic precipitation hardening stainless steel of high tensile strength and low impact resistance. Although maximum strength and hardness are achieved by hardening at 850 F, in this condition, the material is brittle and the fatigue characteristics are questionable for this application. As the hardening temperature is increased, the material has better fatigue characteristics, better corrosion resistance, and is less susceptible to stress corrosion cracking. However, as the heat-treating temperature is increased, the impact resistance is also increased.

Test 181 was conducted on bolts heat-treated at 950 F and Tests 192 and 194 used bolts heat-treated at 1050 F. Prior to heat-treating, a notch is machined in the bolt insert to reduce its diameter from the standard 1 in. to 7/16 in., as shown in Plate 5. The notched inserts are threaded into 3-in. long sleeve nuts, which in turn are threaded onto the regular anchor bolt.

Test 181 was conducted at 40 mph on the assembly shown in Figure 4. Upon impact the lighting standard was kicked ahead and up and cleared the vehicle by 6 ft as it passed through the impact zone. The top of the pole came to rest 16 ft beyond the anchorage. Damage to the lighting standard consisted of a minor dent at the point of contact with the vehicle. Although the A-307 anchor bolts bent 30 deg, they were successfully straightened for use in a succeeding test. Vehicle deformation (18 in.) was less than sustained during any of the frangible aluminum insert tests. From the standpoint of impact resistance at 40 mph, the notched bolts performed efficiently and dummy driver decelerations were almost negligible. However, there is some concern as to the possibility of stress corrosion cracking occurring in this material in a 950 deg heat-treatment condition after extended exposure to wind loading and accompanying vibration. It was therefore agreed that the heat-treatment temperature should be increased to improve the fatigue characteristics. However, since an increase in treatment temperature also increases the impact resistance, another proof test was conducted using the revised heat treatment.


Figure 4.

Test 192 was conducted at 40 mph on the same notched bolt insert design as was used for Test 181 with the following modifications: (a) heat treatment was increased from 950 deg to 1050 deg and (b) a 3-in. high grout pad was cast around the sleeve nuts and epoxy-bonded to the con-

crete foundation (Fig. 5). Upon impact the notched bolts failed as before and the standard was kicked ahead and up 4 ft over the vehicle as it passed through the impact zone. The standard came to rest with the top approximately 12 ft beyond the anchorage. The point of impact was off-center on the vehicle bumper and close to the supporting brackets. Consequently, the vehicle sustained only very minor damage, consisting of a $1\frac{1}{2}$-in. dent in the bumper and a slight dent in the grill and hood. The light standard was bent 10 deg and the steel pole base plate was deformed. The grout pad was damaged and broken out around the right sleeve nut. No discernible decelerations were recorded in the unrestrained dummy. Because of the off-center point of impact by the vehicle on the reinforced section of the bumper, no valid correlation could be made between the results of Tests 181 and 192 concerning the increase in impact resistance presented by the notched studs with the higher temperature treatment.

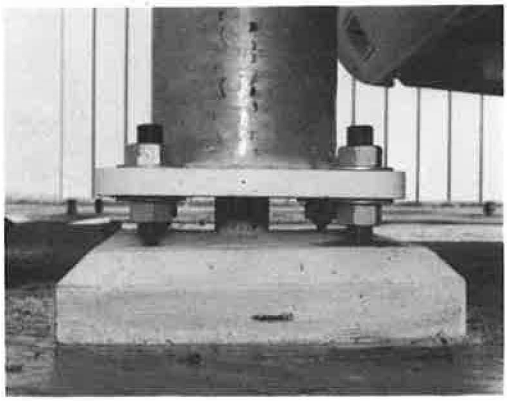

Figure 5.

In the first notched bolt test (181) the vehicle experienced most of the damage, whereas the principal damage in Test 192 was sustained by the pole. Although the performance of this design when impacted at 40 mph was very satisfactory, a third test was considered necessary to determine the impact characteristics of the notched bolts at a lower speed under loading approaching a static condition.

Test 194 was conducted on the same notched bolt design as was used for Test 192 (1050-deg treatment and 3-in. grout pad around sleeve nuts) but with a 15-mph vehicle impact speed and the ignition cut off prior to contact (Fig. 6). Upon impact, the bolts failed primarily in tension and the standard remained vertical and in contact with the car, "walking" for 6 ft before falling forward and to the left. The pole came to rest within 3 ft of the 18-ft offset line used to simulate the edge of pavement. The base of the standard remained under the front bumper, 18 in. from the anchorage. The vehicle sustained extensive damage (21-in. deformation) but the lighting standard was only slightly dented. The test results from this 15-mph test indicate the performance of this device as a breakaway design to be marginal under low-speed impact. Further research into the metallurgical properties of the 17-4 PH steel is necessary before this concept could be accepted as an effective breakaway device for the inevitably wide range of operational impact conditions.

Figure 6.

Cast Aluminum Sleeve Base With Aluminum Pole (Test 193)

In this test the lighting standard consisted of a tapered, welded aluminum pole fitted and epoxy-cemented to an 18-in. high cast aluminum sleeve shoe base (Fig. 7A). The base extends 12 in. inside the aluminum pole. This serves not only as an effective structural connection but also reinforces the pole to resist collapse on impact and to transmit more effectively the impact load into the frangible base. Plate 6 gives design details.

The vehicle impacted the pole head-on at 40 mph. Upon contact, the pole collapsed and bent to an angle of approximately 90 deg at a point

Figure 7A.

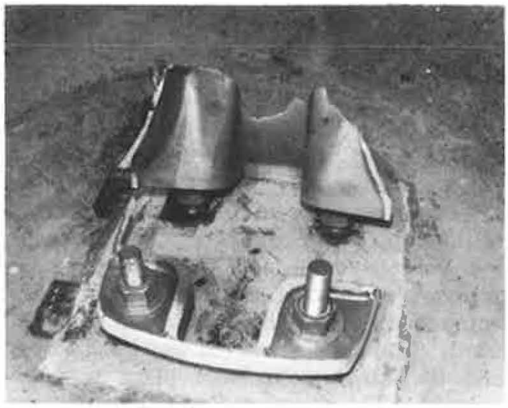

Figure 7B.

35 in. above the concrete foundation. As the cast aluminum base failed (Fig. 7B) the car bumper was deformed 19 in. into and back under the vehicle. The collapse and bending of the pole caused it to hang up under the bumper and remain in contact with the vehicle for a relatively long period of time. However, after releasing from the car, the pole cleared the vehicle by 4 ft and the top of the pole came to rest about 25 ft beyond impact. Vehicle decelerations were low and dummy decelerations were negligible. With the 22-in. bumper height (typical of most American passenger vehicles now in operation and production), the pole was contacted above the reinforced section. Consequently, as the pole collapsed, the load was transmitted to the base primarily in bending rather than in shear. The Texas Transportation Institute reported a more favorable breakaway action in a test on this base design using a 1958 model test vehicle with a 14-in. bumper height.

Cast Aluminum Transformer Base (Test 197)

The 20-in. high tapered cast aluminum alloy transformer base tested conforms to the requirements of ASTM Designation B-108, alloy SG70A, heat treated to a T-6 temper. The top of the base accepts the 11½-in. bolt circle steel lighting standard base and the bottom requires a 15-in. bolt circle. Figure 8A and Plate 6 show design details.

The vehicle impacted near the top of the transformer base at a speed of 15 mph. The impact side of the base fractured but remained hung up on the anchor bolts. The

Figure 8A.

Figure 8B.

remainder of the base (Fig. 8B) and lighting standard remained in contact with the vehicle and was pushed along in the vertical position for about 10 ft before falling ahead and to the left of the vehicle. A portion of the pole and the entire mast arm protruded 16 ft beyond the 18-ft offset simulating the edge of the traveled way. This test illustrates, as did that on the notched bolt insert design, the significant increase in impact resistance that might be expected with any frangible system as the impact velocity is decreased from the 40-mph to the 15-mph range.

Multi-Directional Slip Base (Tests 195 and 196)

Two impact tests were conducted using a multi-directional slip base adapter patterned after (and very similar to) that developed and tested by the Texas Transportation Institute. However, some modifications were necessary to accommodate the California Type XV steel pole base configuration. Details of the design tested are shown in Plate 7.

The two 18¼-in. diameter, 1-in. thick mild steel plates on the slip base were held together with three 1¼-in. black bolts conforming to ASTM Designation A-307 (Figs. 9 and 10). Bolt torque was approximately 50 ft-lb, which is equivalent to about 2000 lb bolt tension. Each of the top washers was pinned to the upper 1-in. plate with two ⅛-in. shear pins to prevent the bolts from walking out of the slots due to wind vibration.

Test 195 was a 40-mph head-on impact. Upon contact, the base parted instantaneously and the pole kicked up and ahead, clearing the vehicle passing underneath by 5 ft. The luminaire broke loose from the mast arm and fell directly over the foundation. While falling, the mast arm rotated 180 deg in the clockwise direction and the pole came to rest approximately on line 25 ft beyond impact. Vehicle damage was mild with only a 9-in. penetration into the hood and bumper.

Test 196 used the same slip base adapter as in Test 195. In fact, the installation and parameters were identical except that impact speed was reduced to 15 mph and the ignition on the test vehicle was cut off 10 ft prior to impact.

As in the previous test, the base again parted instantaneously on impact with very little damage to the front of the test vehicle (3-in. bumper penetration). However, because of the low impact speed, the pole did not kick up high enough to clear the test vehicle and fell back on top of it as it passed under, denting the roof and cracking the windshield. As the car continued under the pole, the pole base struck the rear part of the roof, shattering the rear window. Judging by the minor extent of roof denting and by the broken glass, injuries to occupants of the vehicle, if any, would likely have been minor. This reaction (the pole falling on the vehicle), although not desirable, will doubtless occur with any breakaway device at certain critical low speeds.

Based on front-end damage, high-speed film analysis, and impactograph intensity readings, this low-speed test was an extremely mild impact. Excluding the secondary

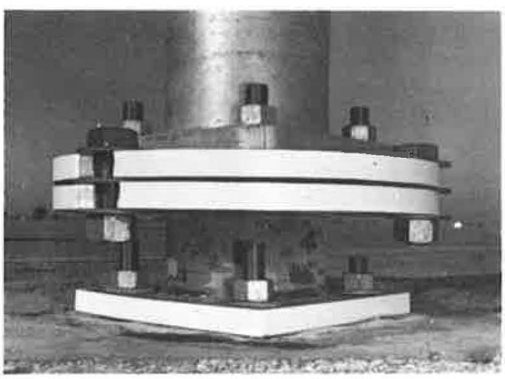

Figure 9.

Figure 10.

impact, there was a momentum change of only 210 lb-sec, as compared with a 290 lb-sec change for the 40-mph impact using this same base. This indicates that the impact resistance of the multi-directional slip base is relatively independent of impact speed, whereas other breakaway concepts, particularly when breakaway requires a frangible metal failure, are highly dependent on the rate of load application.

GENERAL OBSERVATIONS

Vehicle Deformation

Although the depth of the deformation of the bumper and hood of the vehicles used in this test series is subjective and should not be used as the sole criterion for basing the relative effectiveness of the various breakaway base designs, a close examination of the damage indicates that this information generally correlates with the change in speed through impact, and particularly with the reaction of the dummy driver. The difference between 19-, 20-, and 21-in. deformation on the same model vehicle is important when observing the intimacy of adjacent collapsed parts and, particularly, the displacement of the engine and any localized buckling of the frame and body. Measurements indicate that a 20-in. deformation of the hood and bumper of the 1966 sedan is the maximum the vehicle can sustain before engine displacement and frame buckling occurs. For instance, the vehicle in Test 181, with 18-in. maximum deformation after impact, required only a bumper, grill, radiator, and fan to place it back in operating condition. Test vehicle 193, sustaining a 19-in. maximum deformation, required the same repair as 181 plus replacement of the water pump. The 21-in. maximum deformation of both hood and bumper resulting from Tests 194 and 197 displaced the engine and warped the frame, resulting in the total loss of those vehicles. Plate 3 shows relative deformation of the test vehicles for the various tests.

Consideration must also be given to the manner in which the lighting standard separates from the frangible base during impact. When the vehicle overrides the pole, such as experienced in Tests 182 and 193, extensive bumper deformation was noted, yet only moderate hood deformation and subsequent low dummy decelerations were recorded. Critical examination of the damage is therefore important and deformations reported in Table 1 must be interpreted subjectively along with photographs of the actual damage.

Impactograph Recordings

Deceleration recordings traced by triaxial mechanical stylus impact-type instruments located in the chest cavity of the dummy and on the rear floor of the vehicle are shown in Plate 8 (Appendix). Deceleration readings from the impactograph are filtered values due to the low-frequency response (23 cps) of the instrument. In effect, this means that the relatively smooth traces recorded in the dummy cover durations in excess of 40 milliseconds. However, the data are significant for comparison purposes with other tests.

As can be seen from the dummy's impactograph traces, the only tests showing deceleration forces of any significant magnitude were the low-speed impacts using the notched bolt inserts and the 20-in. high cast aluminum transformer base as breakaway devices. This would likely be true of any breakaway system dependent on frangible metal failure.

CONCLUSIONS

All designs tested offer a significant reduction in impact resistance at moderate impact speeds (approximately 40 mph) when compared with conventional rigid base designs. The Texas Transportation Institute multi-directional slip base and the notched bolt designs offer the greatest reductions in impact resistance of those tested at this speed in this test series. However, the commonly used 20-in. high cast aluminum transformer base and the experimental notched bolt insert designs offer little reduction in impact resistance when impacted at lower speeds (15 mph). Based on the data

derived from the ten impact tests, the overall breakaway performance of the T. T. I. multi-directional slip base design at both high- and low-speed impacts is considered to be superior to all other designs tested in this project.

Caution should be used in locating any breakaway lighting standard close to the traveled way. Pole trajectories after impact indicate that the problem of pole encroachment into the traveled way is minimized with the T. T. I. slip base design. Even at a 15-mph impact speed, the slip base was carried approximately 40 ft beyond the foundation and in the direction of impact, resulting in the least encroachment toward the traveled way of the three designs tested at that speed.

ACKNOWLEDGMENTS

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Appendix

Plate 1. Sequence Photos (Test Nos. 181, 182, 183, 191, 192).
Plate 2. Sequence Photos (Test Nos. 193, 194, 195, 196, 197).
Plate 3. Deformation of Vehicles.
Plate 4. Pole Locations Before and After Impact.
Plate 5. Frangible Aluminum Base Insert (Unmodified) (Test 182).
Frangible Aluminum Base Insert (Modification 1) (Test 183).
Frangible Aluminum Base Insert (Modification 2) (Test 191).
Notched Bolt Insert Detail (Tests 181, 192, 194).
Plate 6. Cast Aluminum Sleeve Base (Test 193).
Cast Aluminum Transformer Base (Test 197).
Plate 7. Texas Slip Base (Tests 195, 196).
Plate 8. Impactograph Data.

PLATE 1

TEST 181 IMPACT + 0.17 SEC | I + 0.38 SEC | I + 0.59 SEC

TEST 182 IMPACT + 0.20 SEC | I + 0.45 SEC | I + 0.70 SEC

TEST 183 IMPACT + 0.25 SEC | I + 0.40 SEC | I + 0.75 SEC

TEST 191 IMPACT + 0.05 SEC | I + 0.35 SEC | I + 0.55 SEC

TEST 192 IMPACT + 0.10 SEC | I + 0.20 SEC | I + 0.75 SEC

TEST SEQUENCE PHOTOS

PLATE 2

TEST 193 IMPACT + 0.25 SEC

I + 0.50 SEC

I + 0.95 SEC

TEST 194 IMPACT + 1.25 SEC

I + 2.35 SEC

I + 2.65 SEC

TEST 195 IMPACT + 0.07 SEC

I + 0.19 SEC

I + 0.34 SEC

TEST 196 IMPACT + 0.25 SEC

I + 0.95 SEC

I + 1.80 SEC

TEST 197 IMPACT + 1.75 SEC

I + 2.75 SEC

I + 3.55 SEC

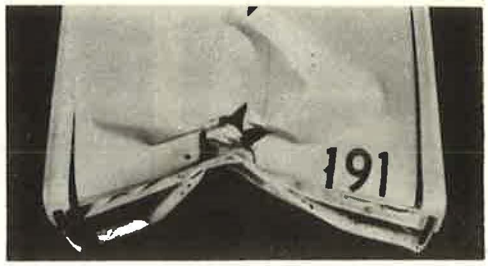
TEST SEQUENCE PHOTOS

PLATE 3

18" Def.

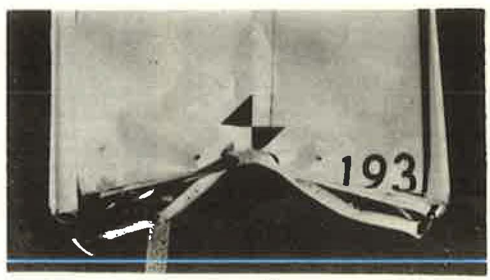
24" Def.

20" Def.



19" Def.

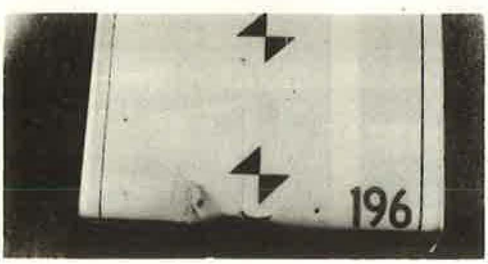
2" Def.



19" Def.

21" Def.

9" Def.

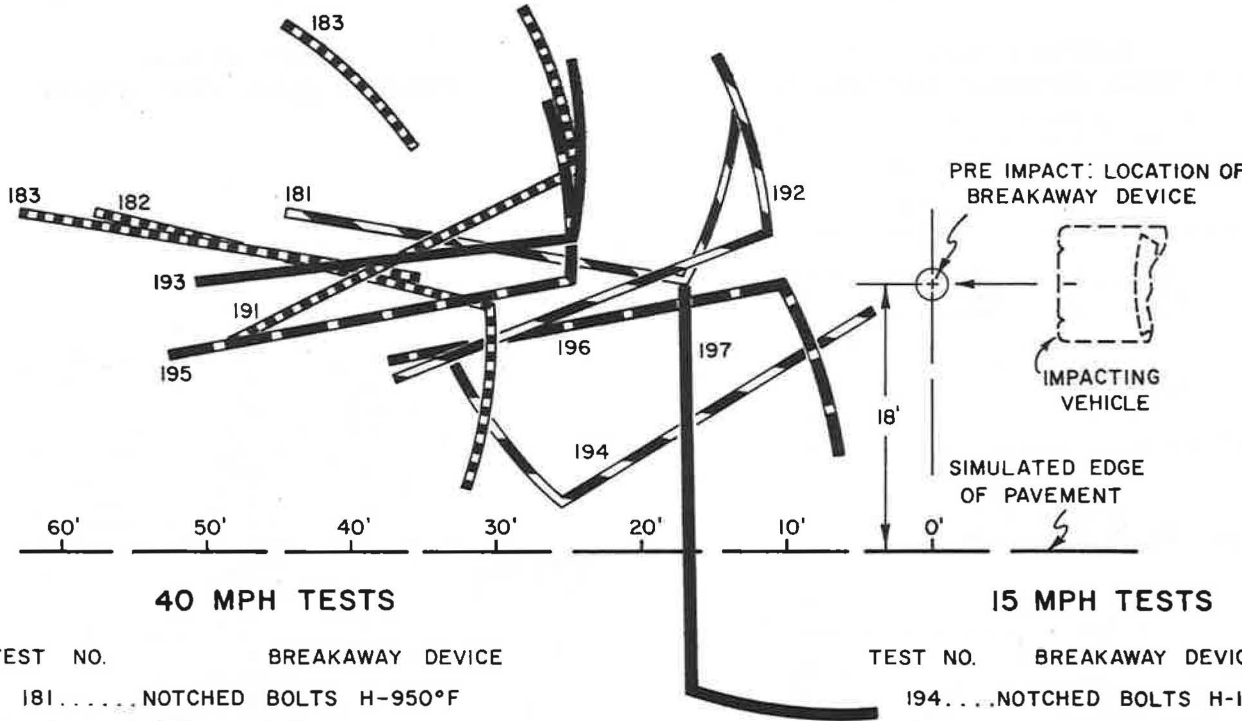


3" Def.

21" Def.

DEFORMATION OF VEHICLES

Plate 4



40 MPH TESTS

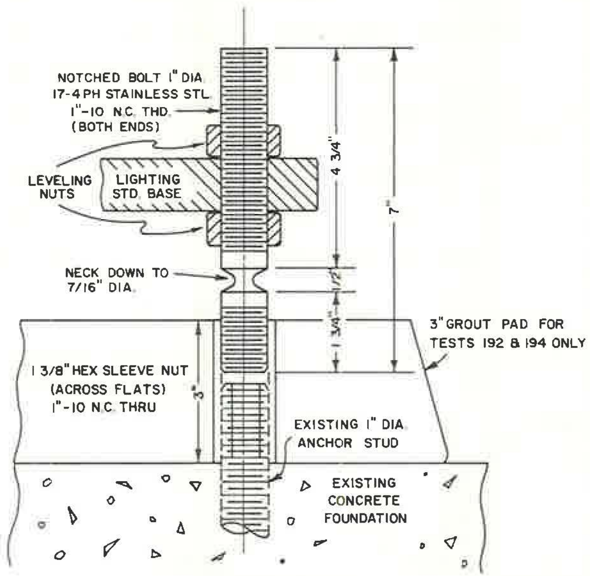
TEST NO.	BREAKAWAY DEVICE
181	NOTCHED BOLTS H-950°F
182	6" FRANGIBLE AL. INSERT
183	6" FRANGIBLE AL. INSERT (MODIF. #1)
191	6" FRANGIBLE AL. INSERT (MODIF. #2)
192	NOTCHED BOLTS H-1050°F
193	AL. SLEEVE BASE WITH AL. POLE
195	TEXAS SLIP BASE

15 MPH TESTS

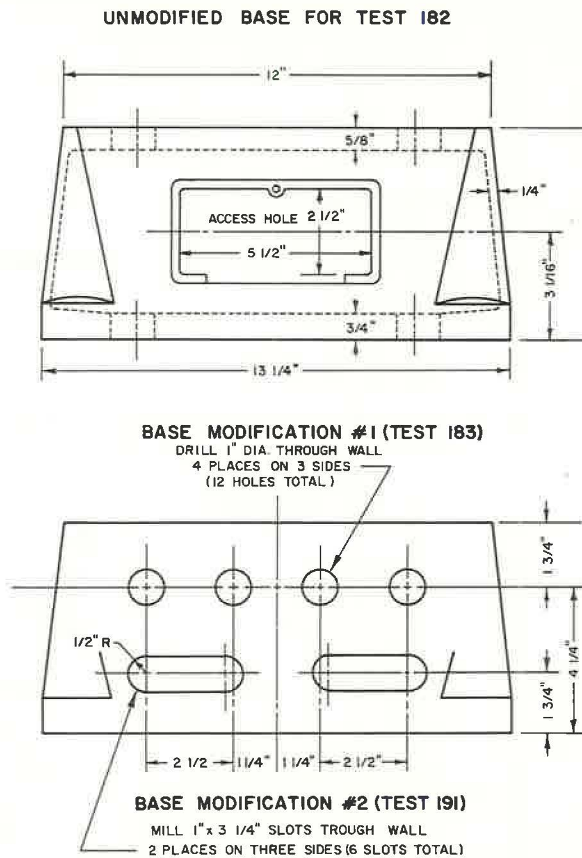
TEST NO.	BREAKAWAY DEVICE
194	NOTCHED BOLTS H-1050°F
196	TEXAS SLIP BASE
197	AL. TRANSFORMER BASE

POLE LOCATIONS BEFORE & AFTER IMPACT

Plate 5

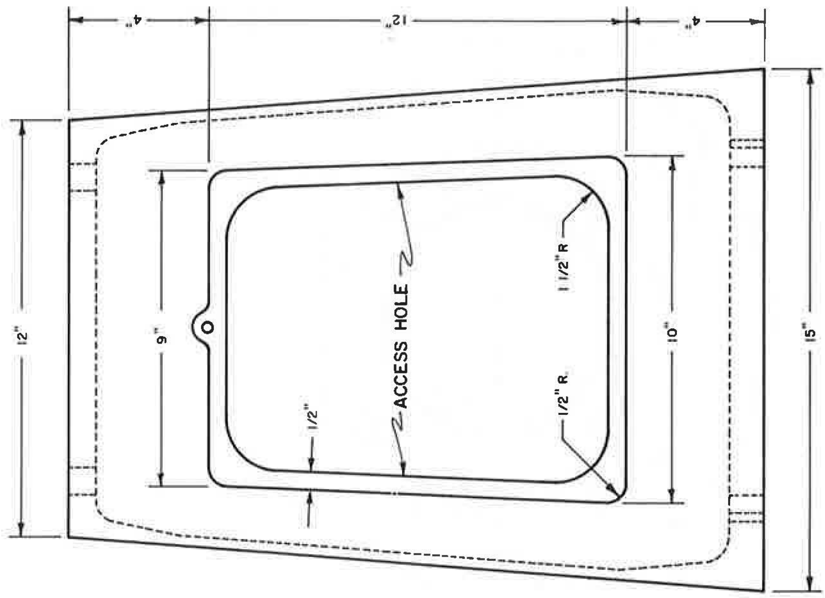


NOTCHED BOLT INSERT ASSEMBLY
TESTS 181-192 & 194

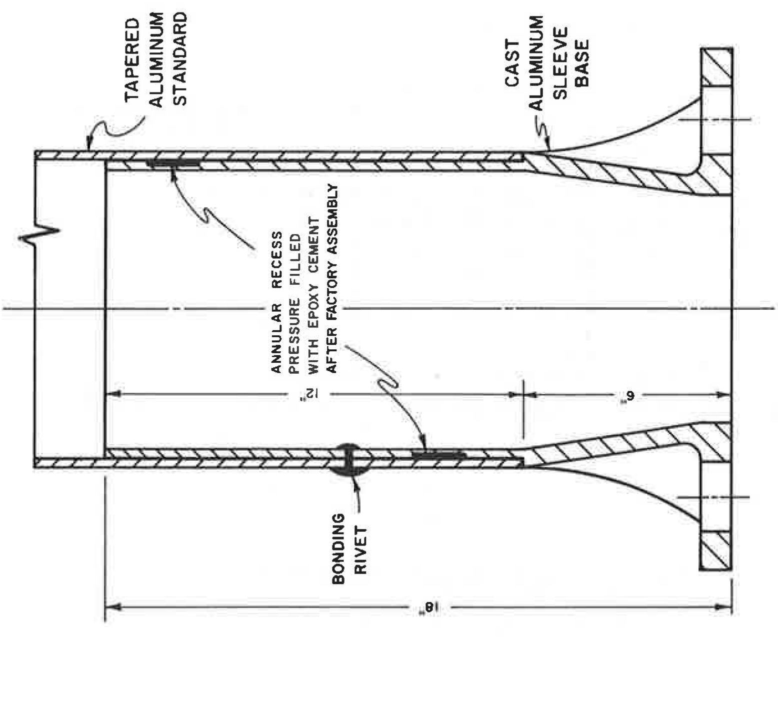


6" FRANGIBLE ALUMINUM INSERT BASE
TESTS 182-183 & 191

Plate 6

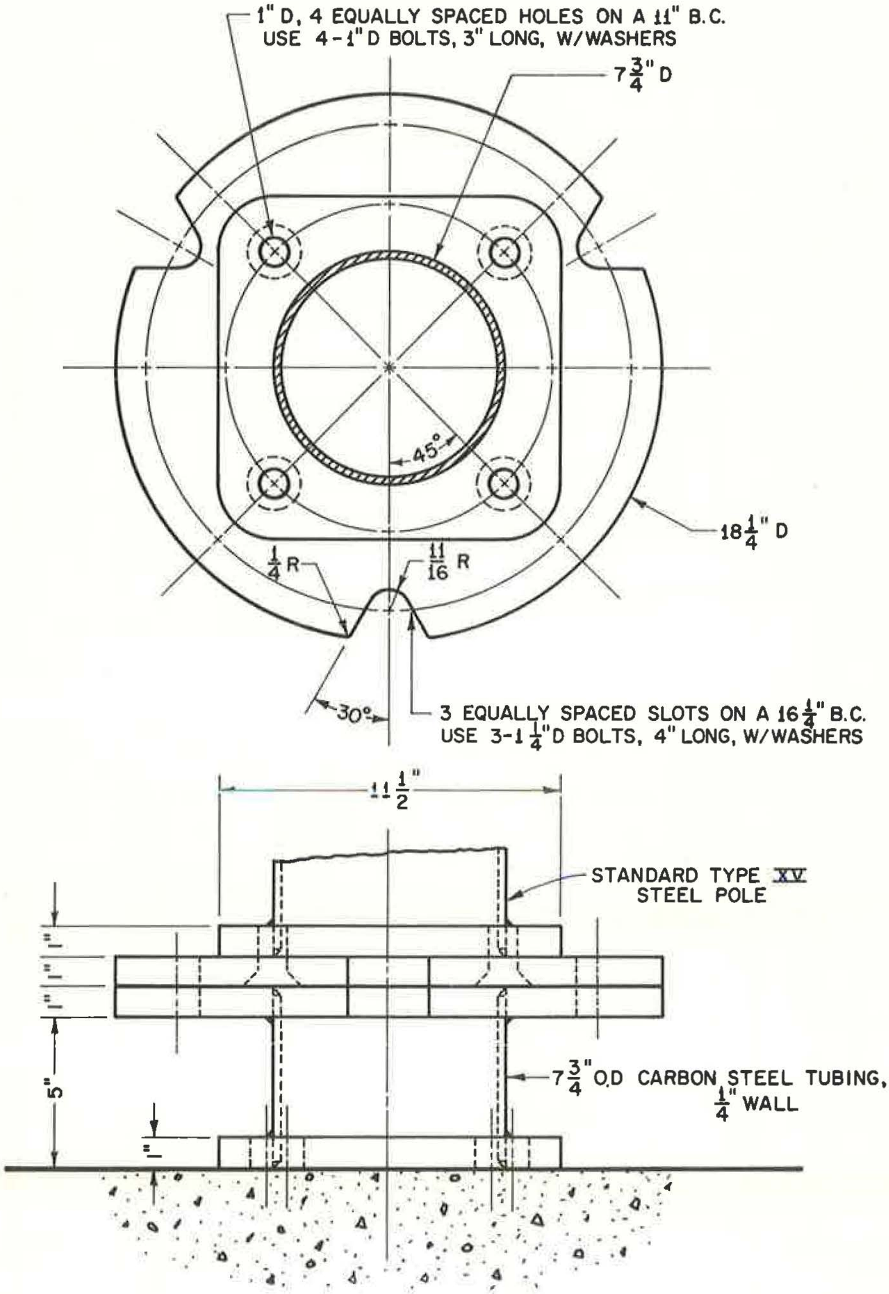


ALUMINUM TRANSFORMER BASE
TEST 197



CAST ALUMINUM SLEEVE BASE
TEST 193

Plate 7



TEXAS SLIP BASE ADAPTER
TESTS 195 AND 196

Plate 8

IMPACTOGRAPH DATA