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SUMMARY OF LUMINAIRE SUPPORT CAPABILITY TESTING

U.S. Department of Transportation
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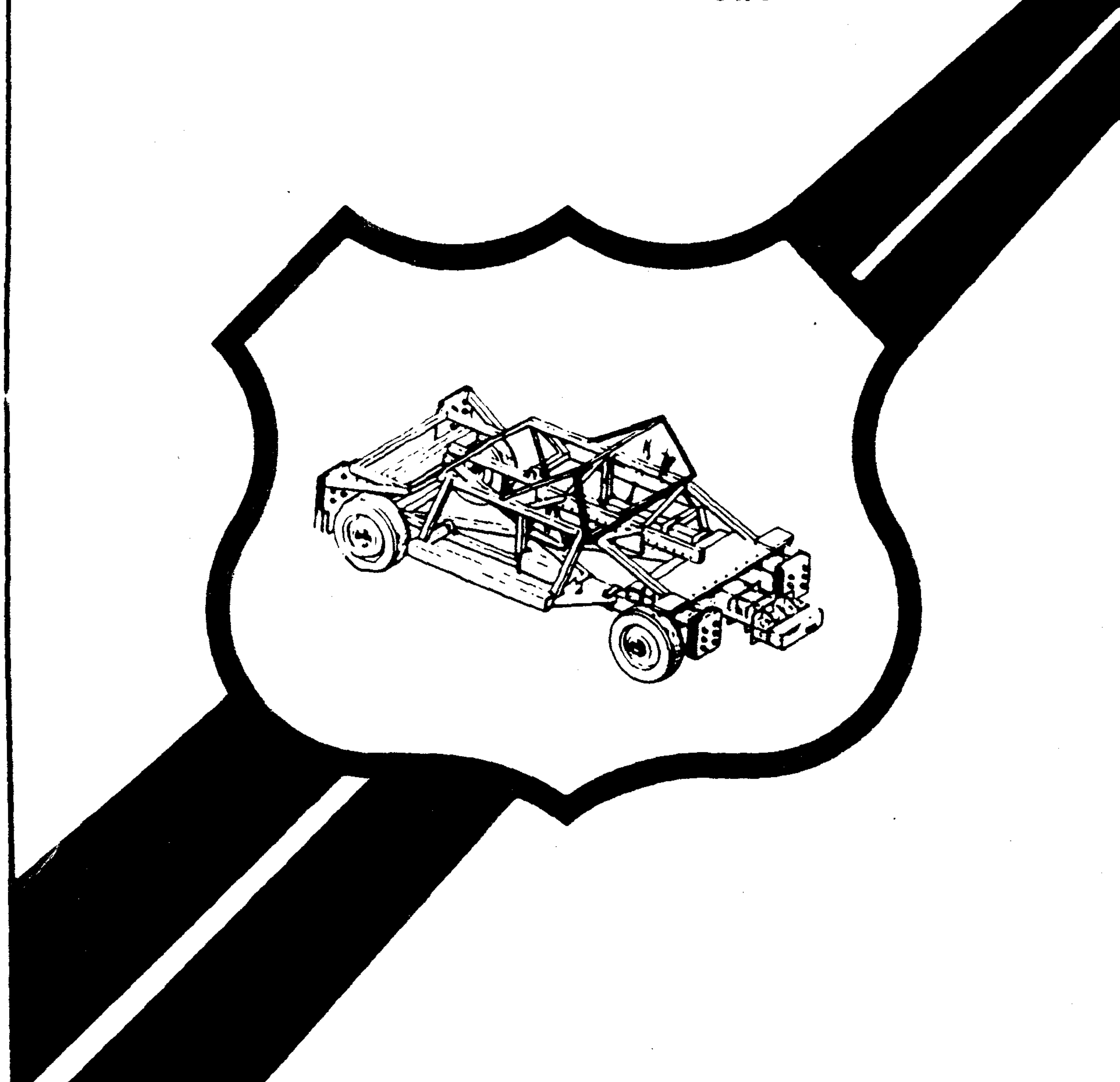
FEDERAL OUTDOOR IMPACT LABORATORY



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16. Abstract

A series of tests has recently been completed at the Federal Outdoor Impact Laboratory (FOIL) to determine the capability of currently accepted luminaire support devices to pass the new (1985) American Association of State Highway and Transportation Officials (AASHTO) breakaway criteria for luminaire supports. This report summarizes the results of those tests. Ten of the 44 devices tested passed the new velocity change criteria. It was found that the performance of transformer bases is dependent on mounting bolt torque and, in addition, may be dependent on bolt circle diameter. However, only 5 devices passed both the velocity change criteria and the stub height criteria.

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INTRODUCTION

A series of tests has recently been completed at the Federal Outdoor Impact Laboratory (FOIL) to determine the capability of currently accepted luminaire support devices to pass the new (1985) American Association of State Highway and Transportation Officials (AASHTO) breakaway criteria for luminaire supports. This report summarizes the results of those tests, and includes the results from a series of tests conducted on direct burial fiberglass luminaire supports. In addition, the old and new AASHTO specifications for luminaire supports are presented. A discussion of the impact of the test results is given, together with data showing the sensitivity of breakaway luminaire support performance to mounting bolt torque and bolt circle diameter. The report closes with recommendations for improving the luminaire support test and certification process, which would lead to an enhancement of the safety of our nation's highways.

AASHTO SPECIFICATIONS

1. Background: AASHTO promulgates standard specifications for structural supports for highway signs, luminaires and traffic signals. Currently accepted luminaire supports were qualified under the 1975 specifications, and in general were evaluated using a pendulum device for tests at 20 mi/h (8.9 m/s) and an analytical expression to extrapolate those results to 60 mi/h (26.8 m/s).

In 1985, AASHTO published updated specifications. These new specifications are more stringent than the 1975 version and currently accepted devices had to be reevaluated to determine if they met the new criteria.

2. 1975 Specifications: The 1975 AASHTO specification for sign and luminaire supports stipulates that the performance of devices must be evaluated utilizing a standard 2250 lb (1020 kg) vehicle, or its equivalent, striking the breakaway support at speeds from 20 to 60 mi/h (8.9 to 26.8 m/s). Satisfactory dynamic performance is indicated when the maximum momentum change does not exceed 1100 lb-s (4893 N-s), but desirably does not exceed 750 lb-s (3336 N-s). This equates to a maximum velocity change of 15.7 ft/s (10.7 mi/h or 4.80 m/s) with the 2250 lb (1020 kg) vehicle, but is equivalent to a velocity change of 19.7 ft/s (6.00 m/s) with the newer 1800 lb (816.5 kg) vehicle discussed below. Device stub height after impact is not specified, though the Federal Highway Administration (FHWA) used 6 in (0.15 m) for acceptance.

3. 1985 Specifications: The 1985 AASHTO specification contains many changes from the previous edition. The allowable momentum change has been replaced with a velocity change criteria and has also been reduced, the vehicle weight

has been reduced, and the stub height has been defined. For sign and luminaire supports, the specification stipulates that the performance of devices must be evaluated utilizing a standard 1800 lb (816.5 kg) vehicle, or its equivalent, striking a breakaway support at speeds from 20 to 60 mi/h (8.9 to 26.8 m/s). Satisfactory dynamic performance is indicated when the maximum change in velocity does not exceed 15 ft/s (10.2 mi/h or 4.57 m/s), but preferably does not exceed 10 ft/s (6.8 mi/h or 3.05 m/s).

This specification goes on to state: "To avoid vehicle undercarriage snagging, any substantial remains of a breakaway support, when it is broken away, should not project more than 4 in (0.102 m) above a 60 inch (1.524 m) chord aligned radially to the centerline of the highway and connecting any point, within the length of the chord, on the ground surface on one side of the support to a point on the ground surface on the other side."

4. Discussion: The following table compares the two AASHTO specifications:

Table 1.

Changes to AASHTO sign and luminaire support specifications.

Performance Criteria	1975 Spec. 2250 lb Vehicle	1975 Spec. Equivalent 1800 lb Vehicle	1985 Spec. 1800 lb Vehicle
Momentum Change (lb-s)	1100 (maximum) 750 (preferred)	---- ----	---- ----
Velocity Change (ft/s)	15.7 (maximum) 10.7 (preferred)	19.7 (maximum) 13.4 (preferred)	15.0 (maximum) 10.0 (preferred)
Stub Height (inches)	Not specified[1]	----	4.0 (maximum)

[1] FHWA used 6 inches maximum for acceptance

Metric Equivalents: 1 lb = 0.454 kg, 1 inch = 0.0254 m, 1 ft = 0.305 m

The last two columns of this table show the equivalent velocity change for the 1975 and the 1985 specifications when an 1800 lb (816.5 kg) vehicle is used. The table reveals that the maximum velocity change criteria has been reduced from 19.7 ft/s (6.00 m/s) to 15.0 ft/s (4.57 m/s), a 24 percent decrease for an 1800 lb (816.5 kg) vehicle.

SUMMARY OF TEST RESULTS

1. Test Program: A series of tests was recently completed to determine the capability of currently accepted luminaire support devices to pass the new (1985) AASHTO proposed criteria. These criteria is currently under consideration by FHWA for use on Federal-aid highways. A total of 44 devices were evaluated, 41 at the FOIL in McLean, Virginia and 3 in Mira Loma, California. The FOIL test program included 63 experiments, all utilizing the bogie vehicle. The luminaire supports were all provided by the manufacturers at no cost to the government, and the tests were performed at no cost to the manufacturers. This cooperative arrangement was negotiated to provide the necessary database to determine the adequacy of the new proposed AASHTO criteria. The tests at the FOIL included 45 at 20 mi/h (8.9 m/s) and 18 at 60 mi/h (26.8 m/s). Fewer high-speed tests were conducted because many of the devices had a very high change in velocity at low speed, and could possibly have caused damage to the bogie at high speed.

The remaining three additional devices were evaluated using full-scale automobiles (the FOIL is not currently configured to test direct burial devices). Five tests were conducted, three at 20 mi/h (8.9 m/s) and two at 60 mi/h (26.8 m/s). The devices tested, by generic type, were:

Table 2.

Devices tested.

Type	Number Tested
Progressive Shear	4
Anchor Base (with aluminum support)	5
Anchor Base (with fiberglass support)	4
Transformer Base	23
Coupling	3
Slip Base	2
Direct Burial Fiberglass Support	3

A separate test report was prepared for each device evaluated at the FOIL, providing details of each experiment. In addition to the FOIL report, another report was prepared summarizing the results of the five tests (3 devices) conducted on direct burial luminaire supports. In each case, the reported change in velocity and the device stub height were presented. Movies and photographs were also taken of each test, and were used for data analysis. Manufacturers were given copies of the reports on the devices which they provided for testing.

2. Summary of Results: The following table summarizes the results of the capability test program. Included in the table are the test number, the speed of impact, the reported change in velocity, the stub height, the luminaire support weight and mounting height, and the luminaire offset, presented for each of the seven types of bases tested.

The histogram which follows (figure 1) shows the distribution of the change in velocity data for four velocity change ranges. Of the 44 devices tested, only 10 passed the 1985 AASHTO specification's velocity change criteria. In addition, only 5 additional devices would pass if the 1975 specification of approximately 20 ft/s (6.10 m/s) velocity change with an 1800 lb (816.5 kg) vehicle] remained in effect. Also note the large number (25) of devices that have a velocity change greater than 25 ft/s (7.62 m/s). In many of these cases, the vehicle actually bounced back after impact, leaving the breakaway device intact.

A similar histogram follows for stub height (figure 2). Of the 44 devices tested, only 9 passed the 1985 AASHTO specification's stub height criteria (there was no specification in 1975). If the stub height limit was increased to 6 inches (0.152 m), only 3 additional devices would pass. Note also the large number of devices with a stub height in excess of 8 inches (0.203 m), this includes the devices that remained standing.

Table 3. Summary of capability test results.

TEST NUMBER	SPEED (mi/h)	DELTA-V (ft/sec)	STUB[1] HEIGHT (inches)	TOTAL WEIGHT (lb)	NOMINAL MOUNTING HEIGHT (ft)	NOMINAL LUMINAIRE OFFSET (ft)
			TRANSFORMER BASE			
86F075	20	22.5	9.0	429	47	15
86F079	60	12.9	6.5	429	47	15
86F077	20	35.6	NA	586	55	15
86F080	20	33.3	NA	813	53	17
86F081	20	13.4	9.5	525	50	15
86F082	60	15.0	9.5	525	50	15
86F083	20	12.0	5.0	844	40	15
86F084	60	17.5	4.5	844	40	15
86F085	20	25.2	9.5	853	40	15
86F086	60	22.7	5.9	853	40	15
86F087	20	29.8	10.5	1048	55	16
86F088	20	30.1	17.0	809	53	17
86F089	20	23.0	7.5	319	28	4
86F090	60	12.6	7.0	319	28	4
86F091	20	35.0	NA	584	55	15
87F004	20	34.6	NA	528	51	15

NA = Not applicable (device did not break away and it stopped the test vehicle abruptly)
NF = Not fractured (device yielded gradually stopping the test vehicle)
Metric Equivalents: 1 mi/h = 1.61 km/h, 1 ft/sec = 0.305 m/s,
1 ft = 0.305 m, 1 in = 0.025 m, 1 lb = 0.45 kg

[1] The 1985 AASHTO Sign and Luminaire Support Specification specifies a maximum stub height of 4 in or less. The remains must be substantial enough to cause significant snagging of the undercarriage of the automobile. The stub height measurements listed are the height of the actual remains after the test. No attempt was made to determine if the the remains were "substantial".

Table 3. Summary of capability test results (continued).

TEST NUMBER	SPEED (mi/h)	DELTA-V (ft/sec)	STUB[1] HEIGHT (inches)	TOTAL WEIGHT (lb)	NOMINAL MOUNTING HEIGHT (ft)	NOMINAL LUMINAIRE OFFSET (ft)
			TRANSFORMER BASE, continued			
87F012	20	35.7	NA	522	51	15
87F013	20	35.5	NA	518	51	15
87F014	20	34.2	NA	520	51	15
87F020	20	35.7	NA	520	51	15
87F021	20	34.2	NA	667	56	15
87F051	20	35.8	NA	398	40	15
87F052	20	18.3	3.0	558	50	15
87F053	20	35.6	NA	558	50	15
87F072	60	13.9	3.0	558	50	15
87F111	20	10.8	10.5	869	45	22
87F118	20	24.3	5.5	869	45	22
87F113	60	13.6	9.4	869	45	22
87F112	20	30.1	10.0	869	45	22
87F114	20	30.6	9.5	869	45	22
87F115	20	34.3	NA	651	47	15
87F116	20	34.4	NA	588	50	15
87F117	20	35.3	NA	799	49	15
			FIBERGLAS SUPPORT/ALUMINUM ANCHOR BASE			
87F001	20	29.3	15.0	266	40	9
87F002	20	10.3	9.0	149	24	7
87F003	60	4.7	9.0	149	24	7
87F068	20	10.2	8.0	208	35	8
87F070	60	4.1	8.0	208	35	8
87F069	20	10.4	8.0	237	35	8
87F071	60	5.8	8.0	237	35	8

Table 3. Summary of capability test results (continued).

TEST NUMBER	SPEED (mi/h)	DELTA-V (ft/sec)	STUB[1] HEIGHT (inches)	TOTAL WEIGHT (lb)	NOMINAL MOUNTING HEIGHT (ft)	NOMINAL LUMINAIRE OFFSET (ft)
			ALUMINUM SUPPORT/ALUMINUM ANCHOR BASE			
87F022	20	35.4	NA	530	51	15
87F023	20	35.5	NA	530	51	15
86F072	20	36.1	12.5	285	40	15
86F073	20	34.6	NA	285	40	15
86F074	20	31.9	NA	188	25	15
86F076	20	23.2	4.5	213	35	6
86F078	60	11.2	4.5	213	35	6
			COUPLINGS			
87F054	20	17.5	5.0	995	55	16
87F055	60	13.8	5.0	995	55	16
87F073	20	11.2	2.5	523	53	15
87F074	60	8.8	2.5	523	53	15
87F075	20	16.7	2.5	523	45	10
87F076	60	11.7	2.5	523	45	10
			PROGRESSIVE SHEAR			
86F066	20	34.2	NA	745	51	6
86F067	20	9.7	1.8	390	51	6
86F068	60	10.2	1.8	390	51	6
86F069	20	6.1	2.8	300	40	7
86F070	60	8.8	2.8	300	40	7
86F071	20	30.3	1.8	467	40	7

Table 3. Summary of capability test results (continued).

TEST NUMBER	SPEED (mi/h)	DELTA-V (ft/sec)	STUB[1] HEIGHT (inches)	TOTAL WEIGHT (lb)	NOMINAL MOUNTING HEIGHT (ft)	NOMINAL LUMINAIRE OFFSET (ft)
			SLIP BASE			
87F033	20	15.0	3.5	964	56	16
87F034	60	12.7	3.5	964	56	16
87F119	20	15.4	3.8	626	50	15
87f120	60	9.7	3.8	626	50	15
		SOIL MOUNTED FIBERGLAS SUPPORT[2]				
2	60	10.3	0.0	193	30	6
6	20	(14.4)[3]	NF	193	30	6
3	20	(13.6)[3,4]	0.0	157	24	6
4	60	11.0	0.0	193	26	8
5	20	(20.9)	NF	193	26	8

[2] Tests conducted by Mobility Systems and Equipment Company through an FHWA contract. The poles were buried in a strong soil type. The test vehicles were 1979 Volkswagen Rabbits.

[3] In most cases, because the impact event is of short duration, the reported value represents both the vehicular change in velocity or the longitudinal occupant impact velocity. the measure of occupant risk cited in National Cooperative Highway Research Program Report 230. However, for crash tests where the vehicle/pole impact was of relatively long duration, the measured vehicle change in velocity was typically higher than the longitudinal occupant impact velocity. In these cases, only the longitudinal occupant impact velocity is given.

[4] Only 20 mi/h data available. The 60 mi/h test is planned for a later date. For purposes of the discussion in the text it is assumed this support will produce a change in velocity under 15 ft/sec in a 60 mi/h test.

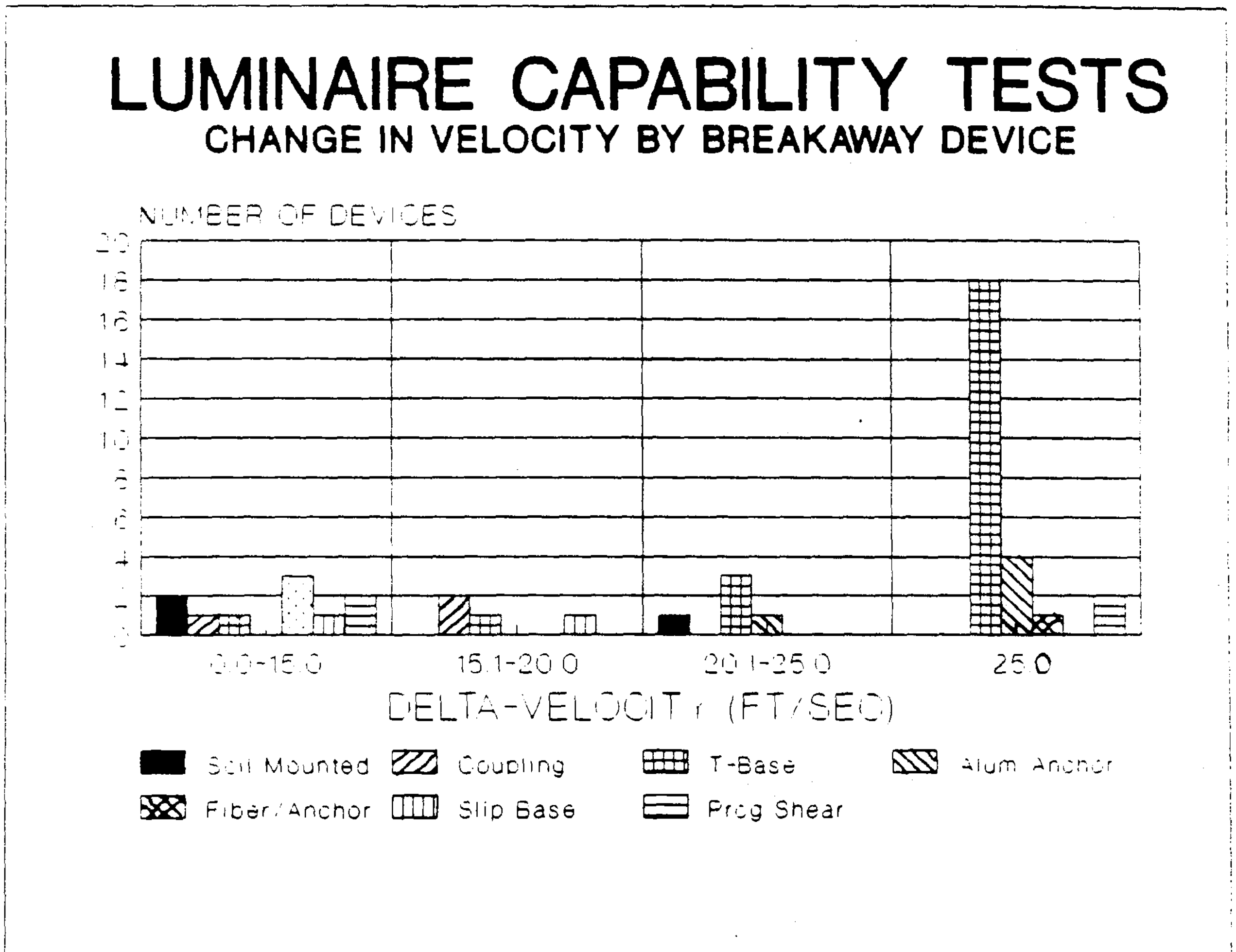

Figure 1. Distribution of highest change in velocity by breakaway device.

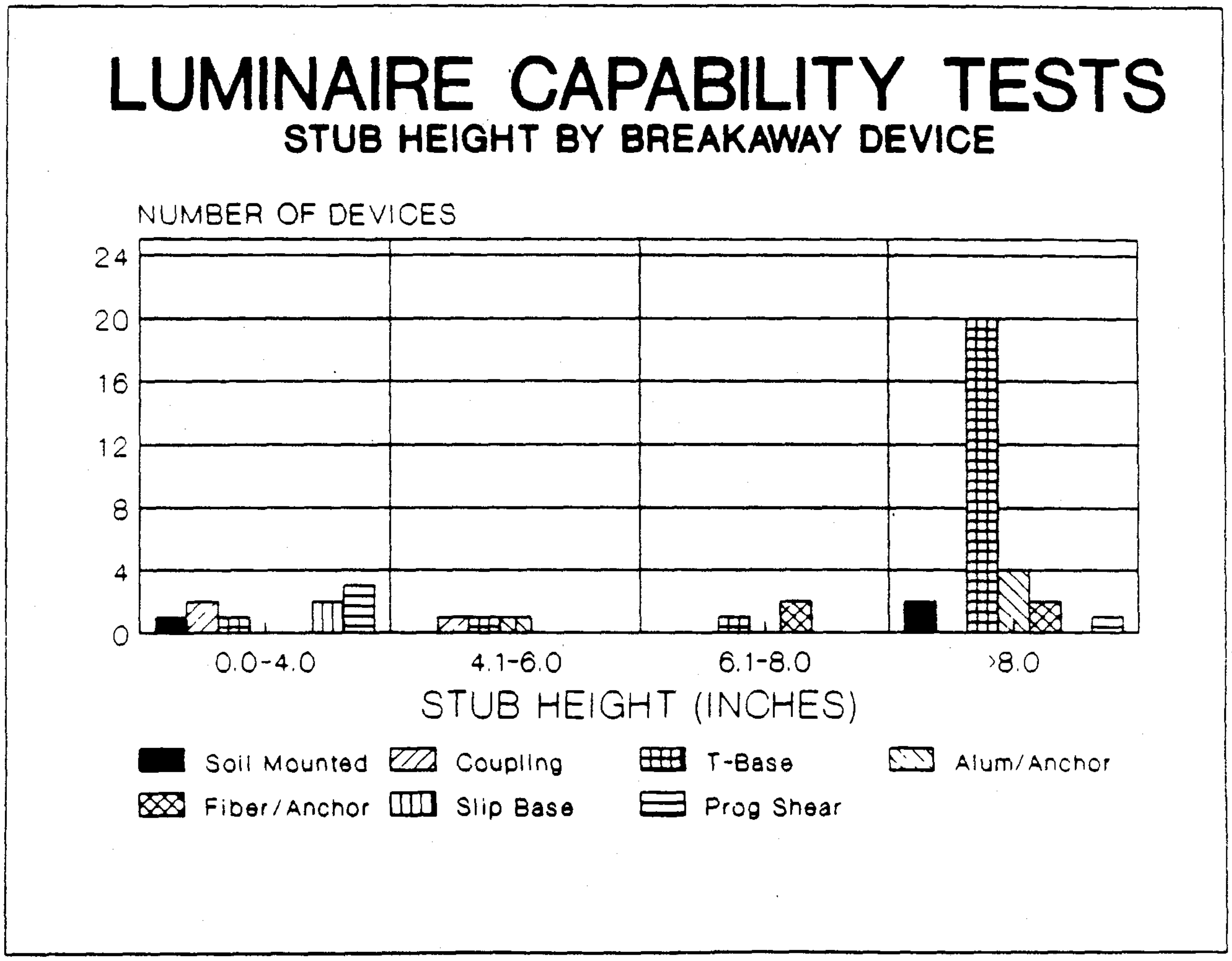

Figure 2. Distribution of stub height by breakaway device.

Figure 3 shows the distribution of change in velocity for the five devices that passed both the velocity change and the stub height criteria. Note that no anchor bases (either fiberglass or aluminum) and no transformer bases passed both criteria.

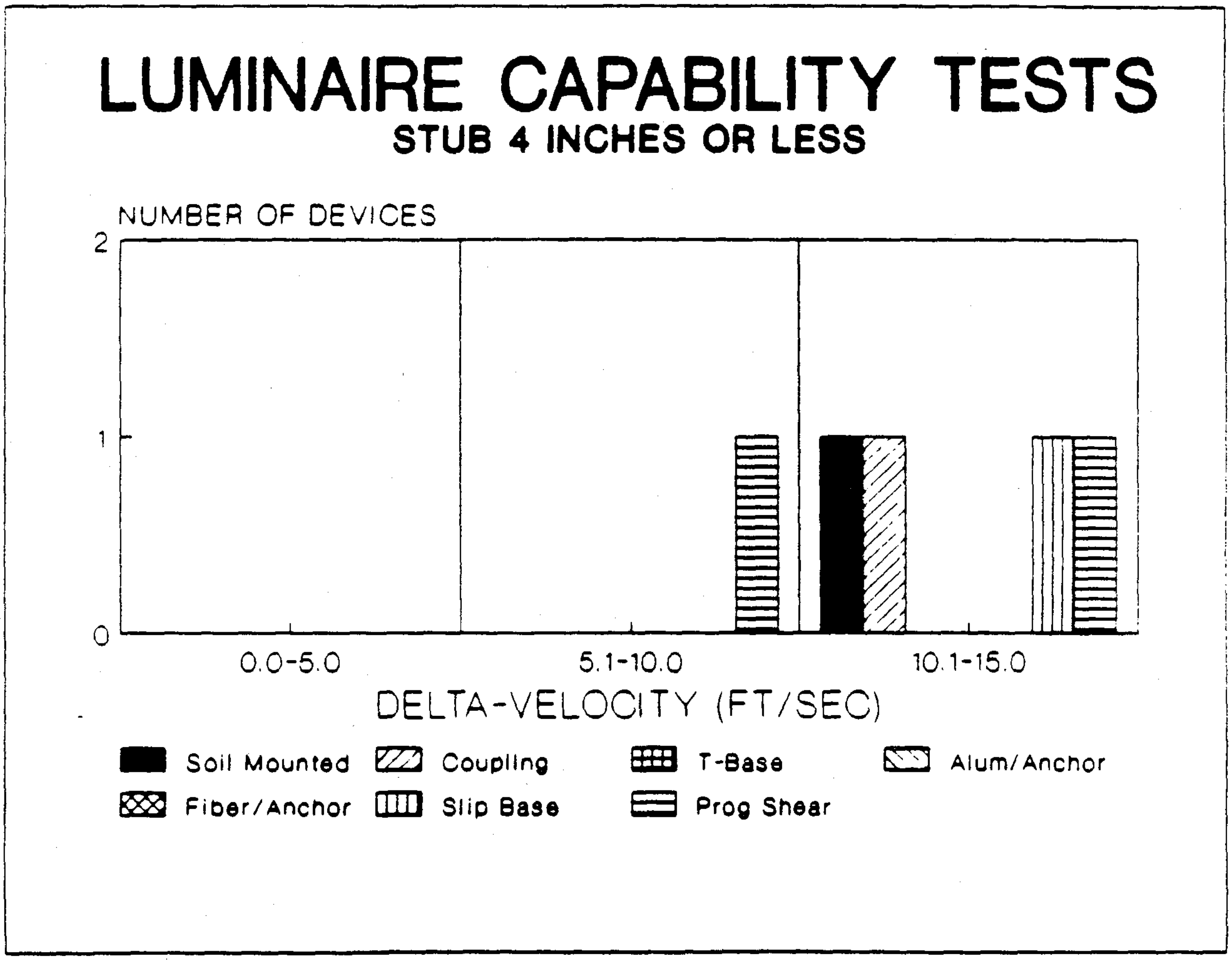

Figure 3. Velocity change distribution for stub heights less 4 inches when the change in velocity is not greater than 15 ft/s.

ADDITIONAL RESULTS AND DISCUSSION

1. Pendulum Versus Bogie Testing: The data presented in the previous section indicates a large number of devices not only do not pass the new 1985 AASHTO specification, but also do not pass the comparable 1975 specification [1800 lb (816.5 kg) vehicle, 19.7 ft/s (6.01 m/s)]. This result is significant because data from pendulum tests using a 2250 lb (1020 kg) vehicle equivalent indicated these devices passed the 1975 specification.

This conflict between past test data and current test data resulted in an assessment of the pendulum originally used to qualify these devices. The pendulum was equipped with a crushable nose system which **bottomed out** for velocity changes greater than about 15 ft/s (4.57 m/s). Upon **bottoming out**, the pendulum transmitted a high impulsive force level to the device under test which may have caused many of the devices tested to break away prematurely. This situation does not normally occur with an actual vehicle because the crush length is continuous. It also does not normally occur with the FOIL bogie which closely models the crush of an actual automobile due to its longer crush length. It is apparent the data collected during this test program more accurately reflect expected field experience with 1800 lb (816.5 kg) automobiles.

2. Mounting Bolt Torque Sensitivity: During preliminary tests of transformer bases used to qualify the FOIL bogie, a potential problem with mounting bolt torque was identified. The mounting torque for transformer bases is not normally specified by the manufacturer, and tests at different torque levels indicated that torque could have a substantial effect on vehicle velocity change. Thus, several additional tests were conducted to evaluate this

effect. The hardware used for torque sensitivity testing were Union Metal Model 2849 transformer bases with 40 ft (12.2 m) steel poles. The transformer bases were identical to those used during earlier FOIL validation testing, but were from a different manufacturing lot. Each pole-base combination had an approximate weight of 450 lb (204.3 kg).

Five tests were conducted with the FOIL bogie configured to represent a 1979 Volkswagen Rabbit weighing 1850 lb (839.9 kg). Each test was controlled so that the only variable was the transformer base mounting torque. Table 4 provides a summary of all tests, while a graph of change in velocity versus mounting torque is presented in figure 4.

Table 4.

Torque sensitivity test results.

Torque (ft-lb)	Vehicle	Speed(mi/h)	Change in Velocity ft/s (m/s)	Test #
100	bogie	20	22.2 (6.77)	86F048
200	bogie	20	21.6 (6.59)	86F050
300	bogie	20	21.7 (6.62)	86F049
400	bogie	20	25.6 (7.81)	86F051
450	bogie	20	29.2 (8.91)*	86F054

1 ft-lb = 1.342 N-m   1 mi/h = .447 m/s

* This is equivalent to a change in velocity of 20 mi/h. That is, the support did not break away.

Analysis of the data reveals a transformer base sensitivity to bolt-mounting torque, when impacted by a vehicle traveling at a low speed. As the test series graphically demonstrated, a torque value of 450 ft-lb (603.9 Nm) would stop a vehicle traveling at 20 mi/h (8.94 m/s) from breaking through the base. At higher speeds, however, the vehicle has sufficient energy to break away a device installed with a very high torque value. The change in velocity, though, may be greatly increased.

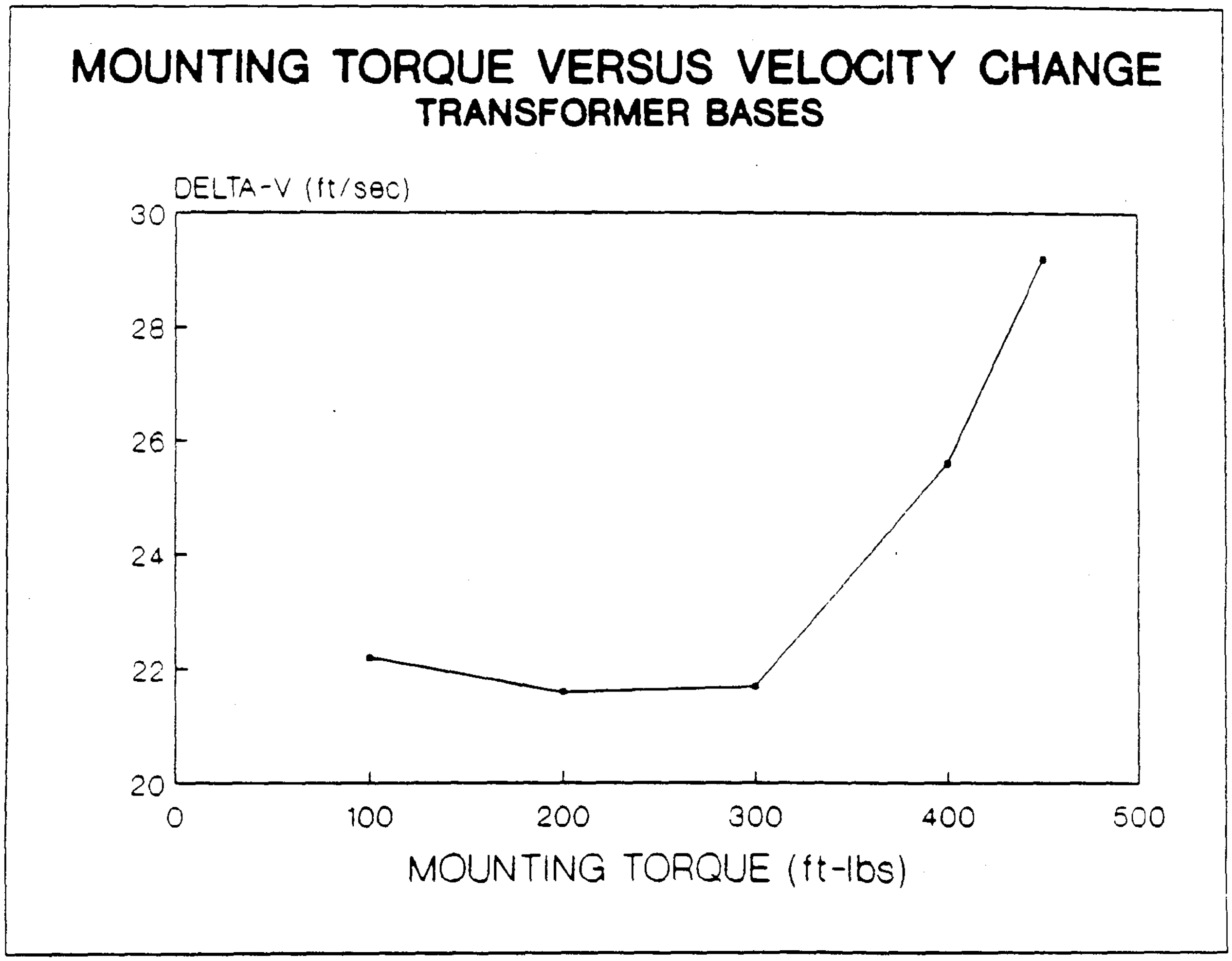

Figure 4. Change in velocity versus mounting torque.

Further analysis of this test sequence reveals that there is also a wide variation in breakaway performance of transformer bases between a given manufacturer's processing lots. With a mounting torque of 200 ft-lbs (268.4 N-m), the bases used for the earlier validation testing (lot #1) broke away with a change of velocity of 13.6 through 15.8 ft/s (4.15 - 4.87 m/s), while the bases used in torque testing (lot #2) broke away at 21.6 ft/s (6.59 m/s). It should also be noted that, when the bases from lot #1 were mounted with 400 ft-lb (536.8 N-m) torque, the bogie vehicle bounced backwards. With the lot #2 bases, the bogie broke the base away, but suffered a very high change in velocity, 25.5 ft/s (17.4 mi/h or 7.78 m/s).

To understand the results of these tests, an explanation of the breakaway mechanism of a transformer base must be given. The base fracture starts at the inner radius of the lower foundation bolt slots on the impact side, and continues up the corners adjacent to the impacted side. In order to initiate this fracture, the base must slide a small amount, allowing the foundation bolts to bear against the edges of the bolt slots. This loading initiates a crack in the lower corner which then continues up the edge as the side is peeled off. When the foundation bolts were torqued to very high values, the bolt tension prevented the base from sliding and forced the base to fracture by a different mechanism, that is, tension in the side. Lowering the bolt torque allowed the base to slide the small amount required and thus allowed the preferred breakaway mechanism to function.

3. <u>Bolt Circle Sensitivity:</u> During the testing, two 20 mi/h (8.94 m/s) impact tests were conducted on one transformer base, using different mounting bolt circles, each within the manufacturer's specifications. When a small diameter (15 inch or 0.38 m) bolt circle was used, the device broke away with a change in velocity of 18.3 ft/s (5.58 m/s). However, when the bolt circle

was increased to the maximum allowed by the manufacturer (17 inch or 0.43 m), the bogie bounced off the device, leaving the base and pole standing.

Several rationales can be formulated in an attempt to explain the fundamental failure mechanisms. For example, the moment caused by the impact force resulted in higher stresses to the transformer base when mounted at the minimum bolt circle, causing it to fail. That is, the stress was concentrated near the corner radii of the mounting slots when mounted with the minimum bolt circle, whereas the stress was more evenly distributed over the corner of the transformer base when mounted with the maximum bolt circle. Another rationale is that transformer bases in general exhibit a wide variation in breakaway performance. Identical transformer bases tested under the same conditions have exhibited a large variation in the impacting vehicle's change in velocity. Though these rationales are plausible, there are insufficient data for validation.

Though only two tests were conducted and transformer bases display a wide variation in performance, the dramatic difference in experimental results suggests that mounting bolt circle diameter may have a significant influence on the breakaway characteristics of transformer bases. Thus, the range of mounting bolt circle diameters currently specified may have to be modified to ensure good field performance. A possible physical modification to a base to reduce the change in velocity would be to partially close off the slots for the mounting studs (without strengthening the base) to prevent insertion of bolts in the larger bolt circle diameters.

4. Passenger Compartment Intrusion: During low speed tests, the luminaire support almost always falls on the vehicle. The amount of penetration into

the passenger compartment differs with each test and is dependent on the weight of the assembly and the energy required to activate the base breakaway mechanism. It appears this should be an area of concern with regard to passenger safety, and some consideration should be given to developing a criterion to evaluate this phenomena. During high speed tests, the vehicle usually passes freely under the luminaire support after the impact event, with the pole hitting the ground some distance behind the moving vehicle.

5. Stub Height: The 1985 AASHTO specification stipulates that the **substantial** remains of a breakaway support should not project more than 4 in (0.102 m). However, the snag height and strength of the vehicles' undercarriages were not rigorously studied prior to inclusion of this criteria into the 1985 AASHTO Specifications. Therefore, though stub height was reported both numerically and photographically, no determination as to whether the stub was **substantial** was made during the capability testing. Better definitions of the concepts of substantial and vehicle undercarriage strength should be made so meaningful and consistent results can be determined.

6. Appropriateness of New AASHTO Specification: The results of the capability testing program reveal that most devices currently approved and in use on Federal-aid highways do not meet the new (1985) AASHTO specifications for breakaway luminaire supports. In fact, of the 38 devices evaluated, only four passed both the velocity change and the stub height criteria. In addition, some may not pass the old (1975) specification when tested with an actual vehicle or an improved pendulum. Since field experience does not indicate a major problem exists, velocity change comparable to the 1975 criteria using an 1800 lb (816.5 kg) vehicle may be more appropriate for certification of breakaway luminaire supports. In addition, stub height should not be included until a more definitive criterion developed.

RECOMMENDATIONS

1. Mounting Bolt Torque: On devices such as transformer bases which have been shown to be sensitive to the mounting torque, the manufacturer should be required to label each device and its associated drawing with the correct torque for mounting. This torque should agree with the torque level that was used during certification testing. This procedure will ensure that the installation crew will have the necessary data to properly install each device, enhancing the safety of vehicle occupants during impacts with luminaire supports. The results of the capability test program indicate that 200 ft-lbs (268 N-m) is an appropriate torque level for transformer bases similar to the devices tested at the FOIL.

2. Bolt Circle Specification: Additional tests need to be conducted to quantify the dependence of breakaway performance on bolt circle diameter. Until data are available, devices which may be sensitive to mounting bolt circle diameter should be tested at their maximum bolt circle. This should provide a reasonable worst case for base performance evaluation, consistent with current highway research philosophy.

3. Passenger Compartment Intrusion: The intrusion of a vehicle's roof structure into the vehicle passenger compartment during low speed tests raises two concerns. First, is the denting of the roof sufficient to cause concern with the safety of passengers in small cars? And second, what is the impact of convertible vehicles on passenger compartment intrusion, and are there enough of these vehicles on the highways to justify a concern? These issues should be addressed in future research so they can be included in the luminaire support criteria.

4. Stub Height: As indicated in the discussion in the previous section, the concept of **"substantial"** needs to be quantified. Also, how the vehicle undercarriage should be modeled to provide consistent, reportable results for stub height needs to be addressed prior to inclusion in the criteria.

5. Suitability of New AASHTO Specifications: The decision to adopt the new (1985) AASHTO specifications should be carefully reviewed based on the results of this test program to determine the appropriate velocity change, if stub height criteria should be included in the specification, and if roof intrusion should be added as an acceptance criteria for 20 mi/h (8.94 m/s) test conditions.