Validation of a Surrogate Vehicle for Luminaire Support Certification Testing

ALLEN G. HANSEN, MARTIN W. HARGRAVE, AND CHARLES R. HOTT

This paper describes the validation of a surrogate vehicle for luminaire-support testing. The history of surrogate vehicle development is briefly recounted, and a proposed validation process is discussed in detail. Four levels of validation are described. Level 1 relates force-deflection characteristics between the surrogate and an actual automobile, while level 2 considers velocity-change comparisons. Level 3 focuses on crush-length comparisons, where the concept of normalized crush is introduced. Finally, level 4, the highest level of validation, is based on physical-modeling comparisons. For the purposes of evaluation of luminaire supports and sign posts, it is suggested that validation of a surrogate at levels 1 and 2 only is sufficient to meet the requirements of the American Association of State Highway and Transportation Officials (AASHTO) specifications. Test results are then presented for the new surrogate vehicle, being used by the Federal Highway Administration (FHWA), when impacting luminaire supports mounted on different types of bases. The FHWA surrogate is shown to be validated for evaluation of the breakaway performance of luminaire supports mounted on either transformer bases or couplings. Not only is validation achieved for levels 1 and 2, but also partially for level 3 and level 4. It is recommended that the proposed validation technique be reviewed by the highway research community and considered for future validation of surrogate vehicles. Further, it is recommended that the breakaway bogie, developed under research sponsored by the FHWA, be accepted by the roadside safety community for use in evaluating breakaway luminaire supports.

A new surrogate vehicle (or bogie) has been developed by the Federal Highway Administration (FHWA) for evaluating the performance of breakaway luminaire supports when impacted by lightweight vehicles. This paper describes a proposed validation technique and the use of this technique to validate the new bogie for luminaire supports mounted on transformer bases and frangible couplings.

HISTORY OF SURROGATE DEVELOPMENT

Rationale for Surrogates

For many decades crash testing has used actual automobiles impacting into roadside hardware. These tests can be quite costly, particularly when devices must be re-evaluated due to changing, more stringent criteria. In addition, using actual automobiles can bias test results due to the widely different frontal crush characteristics of various makes and models of vehicles and even the differences within a particular make and model. Because of the cost of full-scale testing and attendant test-result repeatability problems, recognition of the need to develop lower-cost, controlled laboratory methods, including the use of surrogate vehicles, gradually evolved.

Pendulum Devices

In 1970, the FHWA published a notice that permitted the use of a newly developed rigid-nose pendulum as a substitute for full-scale testing. In 1973, the FHWA determined that there was only a weak relationship between the rigid-nose pendulum test and full-scale testing. This was due in part to the lack of vehicle-crush simulation on this pendulum. As a result, the FHWA conducted additional studies, and a crushable-nose pendulum was developed. The final version of this pendulum contained a new nose assembly consisting of two parallel members between which crushable aluminum honeycomb elements were collapsed. Aluminum honeycomb material was also placed on the frontal, or impact, surface of the lead sliding member (Figure 1). This design, which removed the dependency on object shape, was intended to emulate the crush performance of a 2,250-lb (1022-kg) 1973 Chevrolet Vega, and was widely used to certify luminaire-support breakaway performance under the 1975 American Association of State Highway and Transportation Officials (AASHTO) criteria.

Bogie Vehicles

Satisfactory results were obtained with the pendulum when testing single luminaire supports, but testing of large dual-legged signs presented additional problems. These problems were primarily associated with the snagging of the support cables on the sign blank. In 1978, to overcome these problems, a low-speed bogie vehicle was developed. This vehicle incorporated the pendulum nose and weight assembly mounted on a simple frame with four wheels, with no capability to adjust or model additional vehicle properties such as the weight distribution (center of gravity and inertia), the wheel base, or the track width. This bogie proved to be a reasonable surrogate for low-speed testing of sign posts.

The next step in the evolution of surrogate vehicles was the development of the high-speed breakaway bogie, currently

A. G. Hansen, Scientex Corporation, 1750 New York Avenue, N.W., Washington, D.C. 20006. M. W. Hargrave, Safety Design Division, Federal Highway Administration, 6300 Georgetown Pike, McLean, Va. 22101. C. R. Hott, Scientex Corporation, 6300 Georgetown Pike, McLean, Va. 22101.

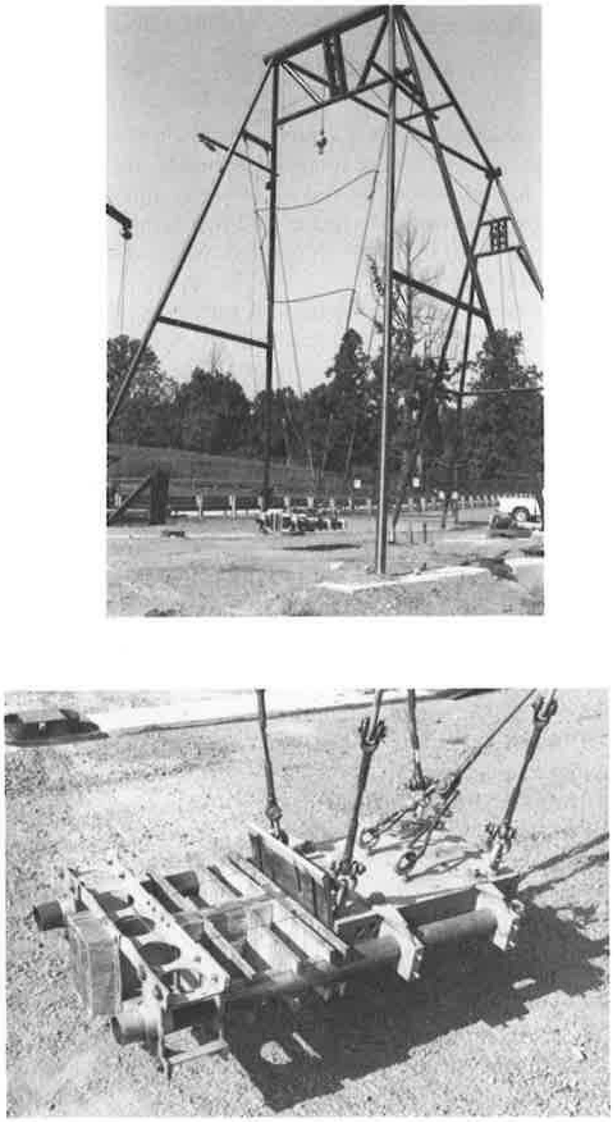

FIGURE 1 FHWA pendulum test system.

used at the Federal Outdoor Impact Laboratory (FOIL). This vehicle, shown in Figure 2, models many vehicle properties not included in the earlier low-speed bogie. In addition, this vehicle can be used at test speeds up to 60-mph (26.8 m/s). This vehicle can emulate the actual impact and post-impact (runout) performance of many of the smaller real-world vehicles. Any automobile weighing from 1,400-lb (636-kg) to 2,250-lb (1022-kg) can be modeled by adjusting the weight, weight distribution, wheelbase, and track width of the bogie. Testing at FHWA's FOIL has indicated that reductions in test costs of up to 75 percent are achievable using this surrogate instead of an actual automobile. The validation of this bogie, in an 1,800-lb (817-kg) configuration, for evaluating the breakaway performance of luminaire supports mounted on transformer bases and frangible couplings is the subject of this paper.

THE VALIDATION PROCESS

Before a surrogate can be accepted for use in evaluating the performance of roadside hardware, its performance must be

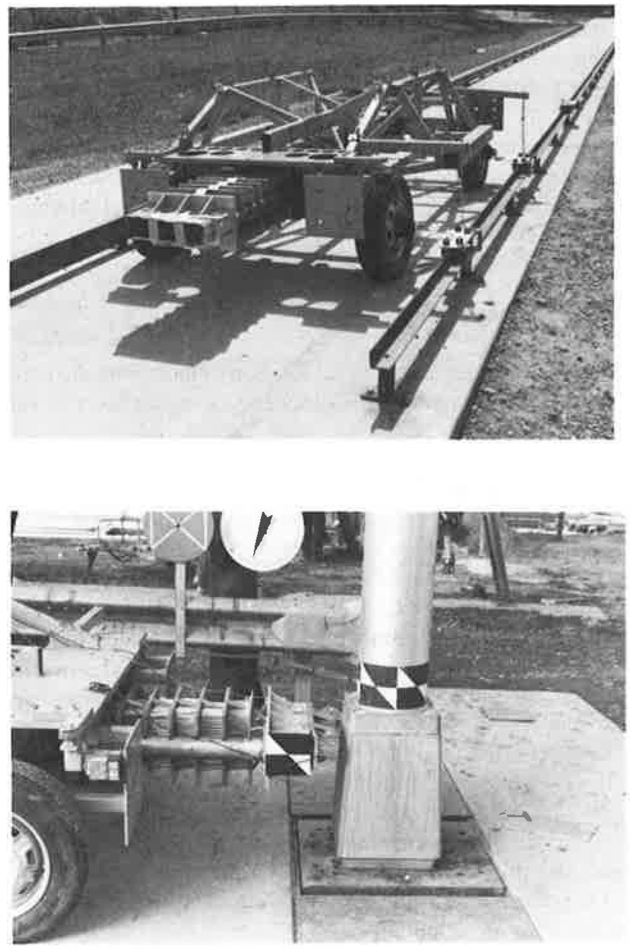

FIGURE 2 FOIL Breakaway bogie test vehicle.

validated against actual automobile test results. It is proposed that this validation be segregated into four distinct (though not independent) levels:

1. Force-deflection curve comparisons,
2. Velocity-change comparisons,
3. Crush-length comparisons, and
4. Physical modeling comparisons.

For each level of validation obtained, a higher overall level of validation is achieved. While it is desirable to obtain validation at all four levels, validation to a lesser level should be appropriate for specific purposes, as discussed later.

Force-Deflection Comparisons

The first level of validation is force-deflection curve comparisons. The bogie can be considered a reasonable loading device (as determined, for example, with low-speed rigid instrumented pole experiments) if the force-deflection curve of the bogie is similar to an automobile. That is, the force exerted by the bogie on the rigid instrumented pole (when plotted versus aluminum honeycomb crush) is equivalent to an automobile's loading pattern (when plotted against the automobile's actual frontal crush).

These comparison experiments, to be strictly accurate, must be conducted with a rigid pole whose impact face is similar in shape to that of the luminaire support being evaluated. This is particularly true when testing with an automobile to properly account for any force-deflection differences due to device geometry. This is not as great a concern with the breakaway bogie because it has been designed with parallel sliding surfaces between layers of crushable honeycomb to minimize any geometric effects due to luminaire support shape.

Velocity-Change Comparisons

A second level of validation is based on velocity-change comparisons. When combined with level 1, a higher level of validation is obtained. The bogie can be considered a reasonable predictor of velocity change when a series of tests (into actual luminaire supports, for example) indicates that the velocity-change values of the bogie are similar to the automobile values at both low (20-mph or 8.9 m/s) and high (60-mph or 26.8-m/s) speeds. This would show that the areas under the respective acceleration-time traces are essentially equivalent for both the bogie and the automobile. It does not, however, indicate that the shapes of the two traces are necessarily identical or even similar, merely that the velocity changes obtained are equivalent.

To be conservative, the bogie should either predict closely or over-estimate the velocity change, making it a reasonable worst-case predictor. This assures that no devices will be certified by the bogie that would fail tests using automobiles. A bogie also provides very repeatable controlled test results, so that variations among different makes and models of full-scale automobiles are eliminated (*1*).

Crush-Length Comparisons

A third, and even higher, level of validation couples the first two levels with crush-length comparisons (which are important only from a research and not a certification standpoint). A bogie can be used to predict the crush of a vehicle if the crush-length measurements (as determined from tests into actual luminaire supports) of the bogie and automobiles agree at both low and high speeds. That is, predictions of intrusion into the engine compartment of a vehicle can be made with a bogie which satisfies this criterion.

The actual crush length (L_{crush}) reported here is normalized by the change in kinetic energy (ΔKE) of the vehicle. The normalized crush length takes into account the different force levels resulting from variations in the impact velocity and velocity change observed in the tests, and allows for a straightforward comparison of crush length.

Since most of the work done on the vehicle at low speed results in vehicle crush, the work done can be approximated by the integral of the force (F_{impact}) acting on the vehicle from the luminaire support times its crush length, if the tire and aerodynamic forces are neglected. Also, because at low speed the work done is approximately equal to the change in the kinetic energy of the vehicle, this normalization is essentially a measure of the reciprocal of the average force (F_{avg}) acting on the vehicle. That is,

$$\Delta KE = \int F_{impact}\, dL_{crush}$$

$$= F_{avg}\, L_{crush}$$

$$L_{crush,\ normalized} = L_{crush} / \Delta KE$$

$$= 1 / F_{avg}$$

Thus, normalized crush is equivalent to the reciprocal of the average force when all units of measure are correctly accounted for. However, in the following comparisons, the crush length is expressed in inches and the change in kinetic energy is expressed in ft-kips, consistent with common usage and convention for each.

At high speed, the crush energy is only a portion of the ΔKE of the vehicle due to a significant energy exchange between the vehicle and the luminaire support. Thus, this normalization technique is not strictly accurate from an analytical standpoint. However, the trend of increased ΔKE leading to increased crush length is still valid and provides for a comparative assessment of vehicle crush with less dependence on variations in impact velocity and velocity change.

Physical Modeling Comparisons

The final and most complete level of validation (level 4) includes physical modeling. Here three interrelated phenomena must all agree between bogie and automobile:

1. Impact dynamics,
2. Chronology of breakaway, and
3. Fracture patterns of the device.

In addition, the lower levels of validation must also be achieved.

For the impact dynamics to be validated, the acceleration versus time history of the bogie and the automobile must be in agreement. Not only must the areas under the respective curves be reasonably similar but also the shapes of the curves. Because acceleration is proportional to force, this level of validation implies that the force applied to a break-away device over a specific time period is essentially the same for a bogie and the corresponding automobile.

Using high speed film or other methods, the chronology of breakaway is obtained by observing and comparing the breakaway of respective breakaway devices when impacted by a bogie and an automobile. Validation is achieved when the sequence of events initiates breakaway and complete breakaway of each device at approximately the same time for both the bogie and the automobile.

Finally, the resulting fracture patterns of each breakaway device can be obtained and compared after completion of the tests. Validation is achieved when the fracture patterns of bases impacted with the bogie and with automobiles are similar.

Desired Level of Validation

The level to which a bogie surrogate must be validated is determined by the function which the bogie is to perform. Ideally, all levels of validation should be obtained. However, for luminaire-support certification testing, it is proposed that only levels 1 and 2 are necessary. This is because velocity change is the primary criterion for breakaway support acceptance. Therefore, a valid velocity-change comparison (level 2) must be obtained as well as a valid force-deflection comparison (level 1). However, it is not necessary that the shape of the acceleration traces of the bogie and the automobile agree, nor that the breakaway chronology and fracture patterns agree (level 4). In addition, although desirable, it is not essential that the crush lengths closely correlate (level 3).

VALIDATION FOR TRANSFORMER-BASE LUMINAIRE SUPPORTS

Prior Data

Transformer-base luminaire supports were previously tested in the unmodified design at the FHWA pendulum test facility and, if they did not pass the current acceptance criteria, they were modified to provide acceptable breakaway performance (*1*). Table 1 presents the results from the 20-mph (8.9-m/s), 2,250-lb (1022 kg) pendulum impact tests, listed by manufacturer and model number, with the bases in the unmodified and the modified conditions.

TABLE 1 TRANSFORMER BASE HISTORIC TEST DATA

Test No.	Delta V (ft/sec)	Delta V Span (ft/sec)
Unmodified		
HAPCO 45964		
201	29.3	17.2
202	12.1	
203	21.9	
208	12.9	
210	29.1	
Phaff and Kendall TB2A		
206	10.5	7.3
212	12.5	
213	17.8	
Union Metal 2851		
242	14.2	1.0
244	13.2	
Pole-Lite TB20-8		
236	14.6	1.2
237	13.4	
Union Metal 2852		
221	9.1	0.5
225	9.6	
HAPCO 44681		
245	11.3	2.3
246	13.6	
Modified		
HAPCO 45964		
215	9.6	2.5
219	12.1	
Phaff and Kendall TB2A		
(Modification 1)		
207	9.2	2.4
222	11.6	
(Modification 2)		
232	12.6	2.9
233	15.5	
Phaff and Kendall TB4		
265	11.9	2.2
266	14.1	
Union Metal 2850		
239	10.1	7.0
251	13.9	
256	15.3	
258	8.3	

Analysis of these data reveals that transformer bases have a large variation in breakaway performance. The span of change in velocity for each transformer-base model varies from a low of 0.5 ft/sec to a high of 7.0 ft/sec (0.15 to 2.1 m/s) even after the bases were modified to improve their breakaway performance. Thus, a large variation in safety performance exists for each model of a transformer base due to production variables. This variation must be taken into consideration when comparing test results between two different vehicles (such as a bogie and its corresponding automobile) or even when comparing results produced by the same vehicle.

Level 1: Force-Deflection Comparisons

Previous research studied the variation of the force-deflection characteristics of a 1979 Volkswagen Rabbit and other small cars at several impact locations across the front of each vehicle (*2*). The quarter point of the Rabbit was modeled by the bogie because this research indicated that it yielded one of the higher changes in velocity when compared with the other cars and impact locations tested, providing a conservative surrogate.

A comparison of the force-deflection characteristics of the bogie vehicle with the quarter point of a 1979 Volkswagen Rabbit automobile at level 1 validation is shown in Figure 3. These tests were conducted at the FOIL by impacting each vehicle at low speed into a rigid, instrumented pole with a cylindrical shape. Since the pole face should have modeled the shape of a typical transformer-base/luminaire-support system, the results shown in the figure are not strictly applicable. However, the localized crush characteristics of each vehicle are reasonably similar when impacted with a vertically distributed, cylindrical loading pattern having a width of approximately 9 in (0.23 m). This is less than the width of a typical transformer base, which is approximately 15 in (0.38 m). The effect of this difference in shape is not known, but is presumed to be small based on the level 2 validation results discussed below.

Levels 2 and 3: Velocity-Change and Crush-Length Comparisons at Low Speed

The transformer base selected for this series of tests was a modern, two-piece design composed of two castings welded together. This design is typical of the design practice of many transformer bases currently in use in the United States. In addition, this base was selected and used previously in tests conducted during development of the FOIL and the bogie vehicle. Because this base is typical of current design practice and because it was used in prior development testing, this base was selected and used in the current test series.

Five tests, three with bogies and two with automobiles, were performed with a 20-mph (8.9-m/s) test speed (*3*). Two of these tests (one bogie and one automobile) were conducted with the transformer bases mounted to the test foundation using standard mounting hardware tightened to 400 ft-lb (537 N-m) of torque. These transformer bases did not break away. Three additional tests (two with the bogie and one with an automobile) were conducted with the base-mounting hardware tightened to 200 ft-lb (268 N-m). In these tests, the transformer bases all broke away. All five transformer bases tested were the same model number and from the same manufacturing lot.

Velocity-Change Comparisons

The change in velocity for the five tests are compared in Table 2. In the tests with the base torqued to 400 ft-lb (537 N-m), the change in velocity for the bogie and automobile were essentially the same as the impact speed (bogie impact at 28.2 ft/sec, automobile impact at 29.5 ft/sec). The change of the bogie vehicle was slightly higher because it rebounded with a small negative velocity while the automobile stopped completely without rebounding after hitting the base. In the tests with the base torqued to 200 ft-lbs (268 N-m), the two velocity-change values for the bogie vehicle bracket the value for the automobile.

Crush-Length Comparisons

Normalized crush lengths for this series of tests are compared in Table 2. At a mounting torque of 400 ft-lbs (537 N-m), the normalized crush length of the bogie is identical to the value for the automobile. At a torque of 200 ft-lbs (268 N-m), the normalized crush length of the bogie varies from essentially the same as the car to slightly higher than that of the car. This suggests that the bogie crush length at low speed can be

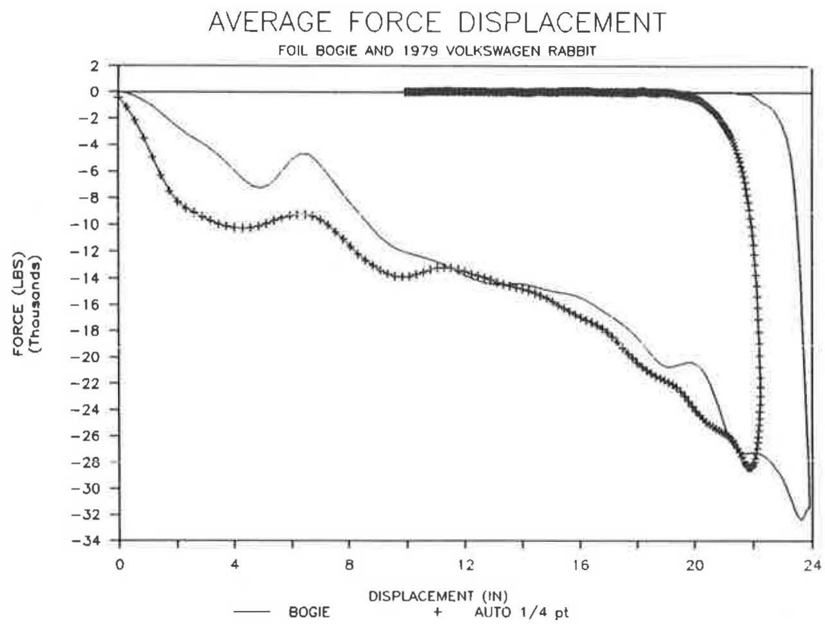

FIGURE 3 Force-deflection characteristics of VW Rabbit and FOIL bogie.

TABLE 2 SUMMARY OF RESULTS FOR TRANSFORMER BASE TESTING

Test Vehicle	Actual Impact Speed (ft/sec)[a]	Delta Velocity (ft/sec)	Actual Crush Length (in.)	Normalized Crush Length (in./ft-kip)	Base Tensile Strength (ksi)	Test No.
20 mph Impact Speed						
(Torque 400 ft-lbs)						
Bogie	28.2	31.8	17.1[b]	0.76	33.0	86F001
Car	29.5	29.5	19.0	0.76	34.4	85F011
(Torque 200 ft-lbs)						
Bogie	27.5	15.8	15.3[b]	0.86	34.6	86F002
Bogie	28.3	13.5	12.7[b]	0.76	33.2	86F003
Car	29.5	14.6	14.0	0.75	30.8	86F004
60 mph Impact Speed						
Bogie	86.5	14.5	19.3[c]	0.29	33.8	86F023
Bogie	88.5	15.5	18.9[c]	0.26	32.2	86F033
Bogie	87.2	13.2	18.5[c]	0.30	28.1	86F038
Car	85.8	13.4	20.5	0.34	33.3	86F019
Car	88.7	12.4	19.3	0.33	33.7	86F031

[a]Average from film and speed trap.
[b]After subtraction of 2 in. for the zero resistance honeycomb cartridge.
[c]After subtraction of 6 in. for the zero resistance honeycomb cartridge.

expected to be a reasonable, though perhaps slightly higher, estimate of the crush of an automobile for similar impact velocities and similar changes in velocity.

Levels 2 and 3: Velocity-Change and Crush-Length Comparisons at High Speed

Five tests were performed with a 60-mph (26.8-m/s) test speed, three with the bogie vehicle and two with an automobile (*3*). All tests were conducted with the transformer bases mounted to the test foundation using standard mounting hardware tightened to 200 ft-lb (268 N-m) of torque. In this test series, all bases broke away.

Velocity-Change Comparisons

The changes in velocity of the five tests are compared in Table 2. Although overlap occurs, the range of velocity change for the bogie vehicle is slightly higher than that of the automobile. This may be due to the variation in the transformer base's breakaway performance, though it is also possible that the bogie may be more conservative than the particular automobile tested.

Crush-Length Comparisons

Crush lengths of this series of tests are compared in Table 2. The normalized crush length of the bogie is slightly lower than that of the automobile. This suggests that the bogie crush length at high speed can be expected to be slightly lower than that of an automobile for similar changes in velocity.

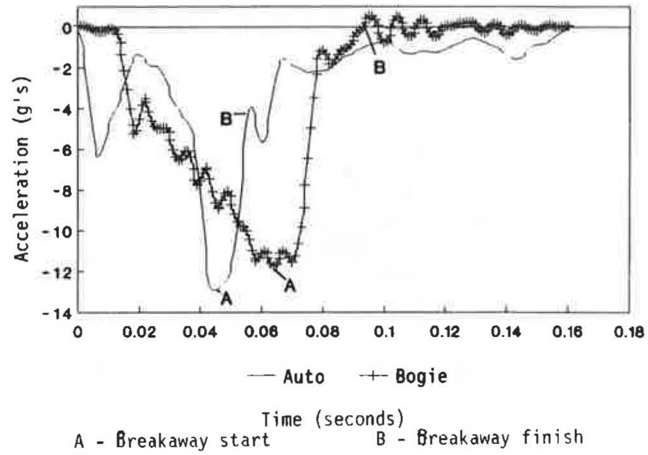

FIGURE 4 Typical acceleration traces, 20 mph, transformer bases.

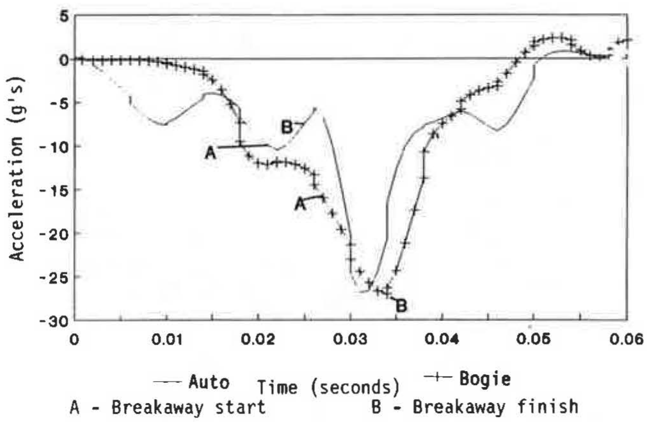

FIGURE 5 Typical acceleration traces, 60 mph, transformer bases.

Level 4: Physical-Modeling Comparisons

This section analyzes both the low- and high-speed tests with respect to level 4 (physical modeling comparisons) validation requirements for transformer-base supports. A plot of typical low-speed longitudinal acceleration versus time (from impact) traces from transducers located at each vehicle's center of gravity is shown in Figure 4. A typical high-speed plot is shown in Figure 5.

Impact Dynamics

The first part of physical modeling is impact dynamics. The acceleration data presented above indicate that the bogie interacts somewhat differently from the automobile when impacting transformer bases at both low and high speed. First, the bogie experiences a delay in sensing deceleration due to the construction of the bogie's crushable front end, while the automobile does not (*3*). Second, the bogie, probably due to its concentrated loading as opposed to the automobile's more distributed loading, causes a lower peak deceleration at low speed and causes the peak to occur later in the impact event at both low and high speed.

Chronology of Breakaway

Another aspect of physical modeling is chronology of breakaway. Here, the bogie does not agree with the automobile. At low speed, initiation of fracture occurs somewhat later in time with the bogie than it does with the automobile, and, at both low and high speeds, the time to complete fracture and initiate separation is somewhat more extended for the bogie than for the automobile.

Fracture Patterns

The final part of physical modeling is a comparison of fracture patterns of bases impacted with the bogie and with an automobile. Figures 6 and 7 are photographs of transformer bases impacted with the bogie and with an automobile. These figures are typical of both low- and high-speed impacts. As can be seen, the patterns are very similar, indicating that the bogie does model the automobile with regard to observed fracture patterns of bases that have broken away.

FIGURE 6 Typical transformer-base fracture pattern, bogie impact.

FIGURE 7 Typical transformer-base fracture pattern, automobile impact.

Base Tensile Strength

Table 2 shows the base tensile strength and the corresponding velocity change for each test. Tensile tests were performed on each test base to determine if the tensile strength of the base was a major variable in its breakaway performance. Based on these data, it is concluded that there is no correlation between tensile strength and velocity change.

VALIDATION FOR COUPLING-MOUNTED LUMINAIRE SUPPORTS

Prior Data

During the developmental testing with the FOIL bogie vehicle, two sets of Alcoa aluminum couplings, model 100-1, wer tested (*4*). Both tests were conducted at low speed using identical luminaire supports. The first test used couplings from the same lot, while the second test used couplings from mixed lots. The results of these two tests, presented in Table 3, show a difference of change in the bogie vehicle's velocity of 4.1 ft/sec (1.3 m/s). It is not known whether or not this difference is the maximum, minimum, or average range of values that can be expected from a series of tests using the same model of coupling. What can be deduced, however, is that some range-of-velocity change values can be expected from such a series of tests.

Level 1: Force-Deflection Comparisons

As discussed previously, the bogie vehicle's reported force-deflection characteristics are in reasonable agreement with the reported characteristics of a 1979 Volkswagen Rabbit automobile when impacting a cylindrically shaped object similar to a luminaire support (see Figure 3).

Levels 2 and 3: Velocity-Change and Crush-Length Comparisons at Low Speed

The Alcoa model 100-1 frangible aluminum coupling is typical of couplings currently in use on highways in the United States and was previously selected and used for tests conducted during the development of the FOIL and the bogie vehicle. Because of the additional fact that reasonably repeatable results can be expected from this model of coupling, it was again selected for this test series.

Velocity-Change Comparisons

Two tests were performed with an impact speed of 20 mph (8.9 m/s), one with the bogie and one with an automobile (*5*). The changes in velocity for the two tests are compared in Table 4, and indicate that the bogie vehicle produces a slightly higher value than the automobile. However, this value is judged

TABLE 3 PREVIOUS COUPLING TESTS

Test Number	Impact Speed (mph)	Change in Velocity (ft/sec)	Vehicle Crush Length (in.)
502	20	15.5	18.4
505	20	19.6	19.6

TABLE 4 SUMMARY OF RESULTS FOR COUPLING TESTING

Test Vehicle	Actual Impact Speed[a] (ft/sec)	Delta Velocity (ft/sec)	Actual Crush Length (in.)	Normalized Crush Length (in./ft-kip)	Test No.
20 mph Impact Speed					
Bogie	29.5	19.2	16.7[b]	0.76	86F062
Car	29.9	17.2	13.5	0.64	86F056
60 mph Impact Speed					
Bogie	85.7	12.7	19.3[c]	0.33	86F061
Bogie	87.2	12.0	20.9[c]	0.37	86F063
Car	89.4	8.2	16.5	0.41	86F058
Car	87.0	8.3	16.0	0.41	86F060

[a]Average from film and speed trap.
[b]After subtraction of 2 in. for the zero resistance honeycomb cartridge.
[c]After subtraction of 5 in. for the zero resistance honeycomb cartridge.

to be within the range of expected deviation of couplings in general.

Crush-Length Comparisons

Crush lengths for this series of tests are compared in Table 4. The normalized crush length of the bogie is slightly higher than that of the car. This suggests that the bogie crush length at low speed can be expected to be slightly higher than that of an automobile for similar impact velocities and similar changes in velocity.

Levels 2 and 3: Velocity-Change and Crush-Length Comparisons at High Speed

Velocity-Change Comparisons

Four tests were performed at high speed, two with the bogie vehicle and two with an automobile (*5*). The changes in velocity of the four tests are compared in Table 4. The range of velocity change for the bogie vehicle is higher than for the automobile. This may be due, in part, to the variation in the coupling's breakaway performance. However, deformation of the luminaire support is thought to be the probable reason for this discrepancy.

In tests using the bogie vehicle, the impact load is distributed over a small area of the pole centered at a height of 17.5 in (0.445 m). With the impact load concentrated in a small area on the pole, the pole deforms significantly when struck at high speed and, in some cases, tears from the mounting shoe (Figure 8). This causes the breakaway event to be extended, thus consuming more of the vehicle's velocity.

Tests with the Volkswagen Rabbit, however, created a load which initially was at bumper height (18 in or 0.458 m), but which subsequently was distributed over a large area of the pole. With the impact load spread over a larger area, the pole deformed only slightly (Figure 9), and broke away much sooner. The extended breakaway due to bogie impact causes the change in velocity for the bogie vehicle to be greater than for an automobile.

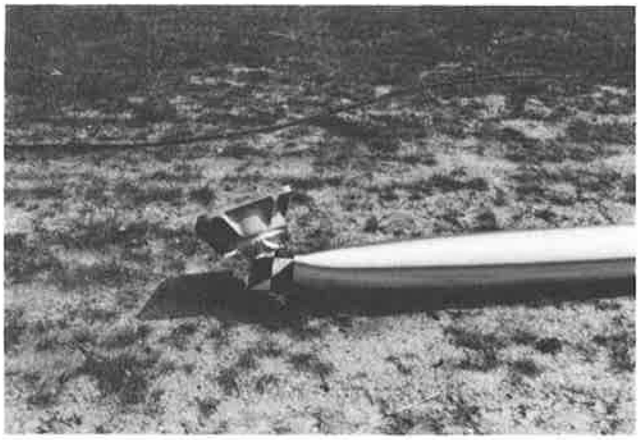

FIGURE 8 Coupling-mounted support impacted by bogie at high speed.

Crush-Length Comparisons

Crush lengths of this series of tests are compared in Table 4. The normalized crush length of the bogie is very close to, but slightly lower than, that of the automobile. This suggests that the bogie crush length can be expected to be very close to (though perhaps slightly lower than) that of an automobile for similar impact velocities.

Level 4: Physical-Modeling Comparisons

This section analyzes both the low- and high-speed tests with respect to level 4 (physical modeling comparisons) validation requirements for coupling-mounted supports. A plot of typical, low-speed longitudinal acceleration versus time (from impact) traces from transducers located at each vehicle's center of gravity is shown in Figure 10. A typical high speed plot is shown in Figure 11.

Impact Dynamics

The acceleration data presented above are similar to those presented for transformer bases, and indicate that the bogie interacts somewhat differently from the automobile when impacting coupling-mounted luminaire supports at both low

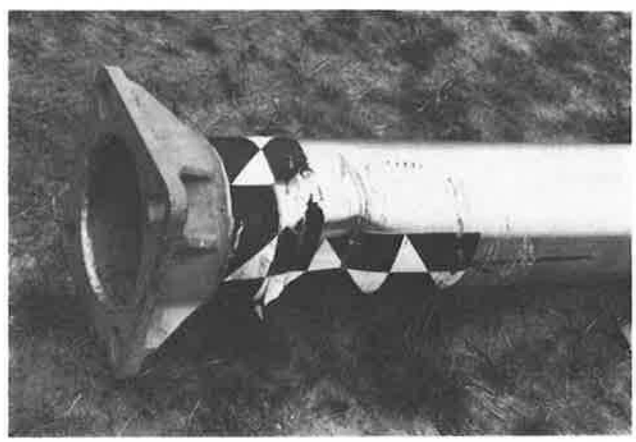

FIGURE 9 Coupling-mounted support impacted by automobile at high speed.

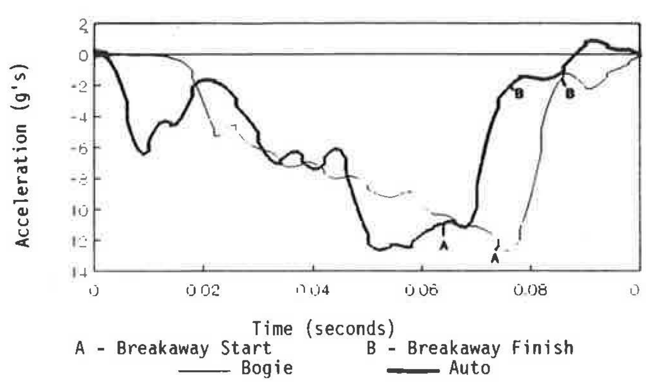

FIGURE 10 Typical acceleration traces, 20 mph, couplings.

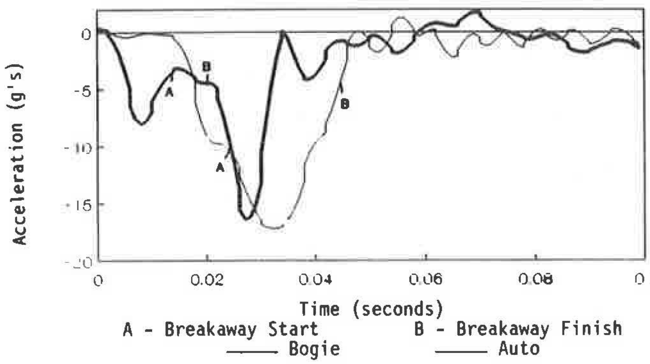

FIGURE 11 **Typical acceleration traces, 60 mph, couplings.**

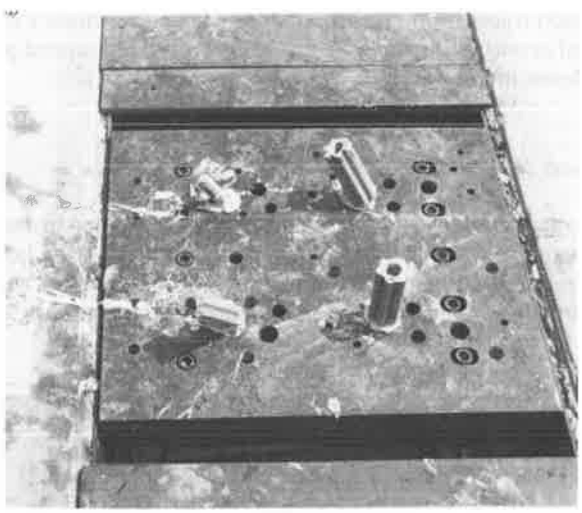

FIGURE 12 **Typical coupling fracture pattern, bogie impact.**

and high speed. First, the bogie experiences a delay in sensing deceleration due to the construction of the bogie's crushable front end, while the automobile does not (*5*). Second, the bogie, due to its concentrated loading, causes the peak to occur later in the impact event at both low and high speed. However, the peak deceleration in both cases is similar.

Chronology of Breakaway

At low speed, initiation of fracture occurs at a slightly later time with the bogie than with the automobile. However, the durations of fracture are very similar. At high speeds, the time to initiate fracture with the bogie is somewhat later than with the automobile. In addition, the duration of fracture with the bogie is longer than with an automobile.

Fracture Patterns

Figures 12 and 13 are photographs of typical couplings after impact by the bogie and an automobile, respectively. These figures indicate that the fracture patterns of the couplings are similar when impacted by either the bogie or an automobile.

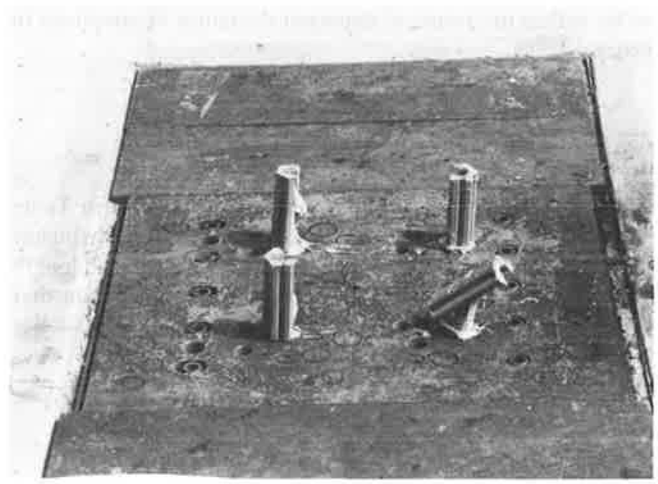

FIGURE 13 **Typical coupling fracture pattern, automobile impact.**

CONCLUSIONS

Transformer Base Validation

Level 1: Force-Deflection Comparisons

The bogie vehicle force-deflection characteristics reasonably model the characteristics of a 1979 Volkswagen Rabbit automobile when both are impacted into a cylindrically shaped, pole-like object. No attempt was made to compare the force-deflection characteristics of each vehicle when impacted into an object shaped like a transformer base. This should be done in the future. It can be stated, however, that the localized crush characteristics of each vehicle are reasonably similar when impacting into a vertically distributed loading pattern having a width of approximately 9 in (0.23 m). This is somewhat less than the width of a typical transformer base, which is approximately 15 in (0.38 m).

Level 2: Velocity-Change Comparisons

Historic data have shown that the repeatability of transformer-base breakaway performance is poor. Therefore, to expect extremely close correlation between tests is unrealistic. Correlation must be found by assessing the results of several tests made with the bogie and with the automobile. If the results are close, with some overlap of scatter, then correlation has probably been obtained.

The results of this study tend to indicate a trend toward slightly higher velocity changes for the bogie during low-speed tests when the base does not break away (due to bounce-back of the bogie), equivalent velocity change values during low-speed tests when the base does break away, and a velocity change slightly higher for the bogie at high speeds than for the automobile. However, because of the expected variation in the performance of transformer bases, these differences are minor. In addition, when the bogie does not agree with the automobile, it is slightly conservative, which is desirable. Therefore, the bogie can be considered a reasonable velocity-change predictor for transformer bases.

Level 3: Crush-Length Comparisons

For low speed tests (when the luminaire support did not break away), the normalized crush length of the bogie was identical to that of the automobile. When breakaway occurred, the bogie crush was slightly higher than the automobile. At high speeds, the normalized bogie crush was slightly less than that of the automobile. Overall, this indicates that the bogie can be expected to yield crush lengths that reasonably approximate automobile values for all tests.

Level 4: Physical-Modeling Comparisons

The bogie vehicle acceleration curves do not agree with the automobile curves because the dynamics of the breakaway (impact dynamics) are not the same. In addition, the chronology of the breakaway is not the same. However, the fracture patterns of bases impacted with the bogie and with an automobile are similar.

Base Tensile Strength

No correlation was found between the tensile strength of each transformer-base casting and the breakaway performance of the base. This is probably due to the breakaway mechanism of the base. Base fracture starts at the bolt slots on the impact side and propagates in a tearing fashion. The tensile strength of the base is not as important as the localized imperfections along the crack path. Charpy impact test results would probably be a better indicator of base performance than tensile strength. However, variations in mounting-bolt placement in the slot can also be an important factor in the breakaway performance of transformer bases. Smaller mounting-bolt circle diameters result in lower velocity change values. In addition, differences caused by the casting process, such as wall-thickness variations, inclusions, and other abnormalities introduced during manufacturing, are also important factors affecting breakaway performance.

Coupling Validation

Level 1: Force-Deflection Comparisons

As previously stated, bogie-vehicle force-deflection characteristics reasonably model the localized crush characteristics of a 1979 Volkswagen Rabbit automobile when both are impacted into a cylindrically shaped, pole-like object.

Level 2: Velocity Change Comparisons

Prior test data obtained during development of the bogie vehicle have shown that the repeatability of the breakaway couplings' performance is also poor. Therefore, extremely close correlation may not be reasonable. If the results are close, then correlation has probably been obtained.

The results of this study indicate a trend toward a higher velocity change for the bogie vehicle, particularly for high-speed tests. The thin-walled aluminum poles used for these tests deformed significantly when impacted at high speed by the concentrated load of the bogie vehicle's nose, increasing the velocity change of the bogie. It is expected that the velocity-change correlation would be better if stiffer and/or heavier poles were tested.

Based on these results, the bogie vehicle is at best a conservative predictor of change in velocity and is more accurate at low speed where most devices fail the change-in-velocity criterion. Only very heavy luminaire supports typically fail during high speed tests, due to their high inertial properties. Therefore, the bogie can be considered to be a reasonable surrogate for the low-speed testing of breakaway luminaire supports when mounted with coupling devices, and a conservative surrogate for high-speed testing particularly with thin-wall, easily deformable poles.

Level 3: Crush Length Comparisons

At low speeds, the normalized crush length of the bogie was slightly more than that of the automobile. For high-speed tests, the normalized crush length of the bogie was practically the same as that of the automobile. Overall, this indicates that the bogie can be expected to yield crush lengths that reasonably approximate automobile values for all tests.

Level 4: Physical Modeling Comparisons

The bogie vehicle acceleration curves do not agree with the automobile curves because the dynamics of the breakaway are not the same. In addition, the chronology of the breakaway is not the same. However, the fracture patterns of couplings impacted with the bogie and with an automobile are similar.

RECOMMENDATIONS

The bogie vehicle developed and evaluated at the FOIL has been shown to provide force-deflection comparison (level 1), velocity change comparison (level 2), and partial crush length comparison (level 3) validation for luminaire supports mounted on transformer bases or frangible couplings. With regard to physical modeling validation (level 4), the bogie produces similar fracture patterns when impacting transformer-base and coupling-mounted devices, but the impact dynamics (the shape of the acceleration curve) and the chronology of breakaway are somewhat different.

Because the bogie vehicle is reasonably valid at both level 1 and level 2, it is recommended that it be utilized as a surrogate vehicle for determining the expected velocity change when a luminaire support mounted on a transformer base or on couplings is impacted with a small, 1,800-lb (817 kg) vehicle. In addition, since it has been partially validated at level 3, it could be used in some cases to estimate intrusion into the engine compartment for research purposes.

If a coupling-mounted luminaire support fails the high speed test when impacted with the bogie vehicle, and if a significant amount of deformation of the pole occurs, then it is recommended that the test be repeated with an automobile to determine if the device is acceptable.

It is further recommended that the validation technique described in this paper be reviewed by the highway research community, refined and improved as appropriate, and subsequently adopted as a standard for validation of future surrogates.

Finally, the concept of normalized crush should be studied further. Perhaps a formulation which better accounts for high speed crush can be found. In addition, an appropriate nondimensional formula would be an improvement.

ACKNOWLEDGMENT

The research described in this paper was sponsored by the Safety Design Division of the Federal Highway Administration, located at the Turner-Fairbank Highway Research Center in McLean, Virginia.

REFERENCES

1. J. Bloom and J. Hinch. *Laboratory Evaluation of Existing Breakaway Structures*. Report FHWA-RD-79-140. FHWA, U.S. Department of Transportation, June 1980.
2. Mobility Systems and Equipment Corporation. *Improved Performance of Small Sign Supports*. Report FHWA-RD-86-072. FHWA, U.S. Department of Transportation, August 1985.
3. C. Hott, C. Brown, N. Totani, and A. Hansen. *Validation of a Surrogate Vehicle for Certification Testing of Transformer Base Luminaire Supports*. Report FHWA-RD-87-034. FHWA, U.S. Department of Transportation, September 1988.
4. J. Hinch, G. Manhard, and R. Owings. *Laboratory Procedures to Determine Breakaway Behavior of Luminaire Supports in Mini-Sized Vehicle Collisions, Test Results Report, Task E*. Ensco, Inc., Springfield, Virginia, March 1986.
5. C. Hott, C. Brown, N. Totani, and A. Hansen. *Validation of a Surrogate Vehicle for Certification Testing of Coupling Mounted Luminaire Supports*. Report FHWA-RD-88-206. FHWA, U.S. Department of Transportation, May 1988.

Publication of this paper sponsored by Committee on Roadside Safety Features.