Abridgment

Laboratory Acceptance Testing of Breakaway Supports for Signs and Luminaires

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Two Federal Highway Administration (FHWA) acceptance standards currently exist for breakaway luminaire supports, and none exist for breakaway sign supports. The first is the acceptance criterion set by FHWA in June 1968 (1) that is based on full-scale vehicle impact tests with a luminaire support. The specified limit on change in vehicle momentum (ΔMV) was set at 4890 N·s (1100 lbf·s). The second set of FHWA acceptance criteria was issued in November 1970 (2) and was based on the use of the simpler rigid pendulum (or drop weight) test. The specified limit on ΔMV in these tests was set at 1780 N·s (400 lbf·s), which was based on test data then available and on some preliminary correlation of these data with previous full-scale test data. Recently, the American Association of State Highway and Transportation Officials (AASHTO) presented specifications covering the performance of breakaway supports for both sign and luminaire supports (3). These specifications were based on full-scale tests and set a maximum limit for ΔMV of 4890 N·s (1100 lbf·s) with a desirable limit of 3340 N·s (750 lbf·s). The AASHTO criteria take into account possible worst case situations by specifying a 1020-kg (2250-lb) test vehicle and requiring satisfactory performance over a speed range of 32.2 km/h (20 mph) to 96.6 km/h (60 mph).

A need still exists for a simple and reliable laboratory test procedure and associated criteria that will ensure safe performance by a breakaway sign or luminaire support. The study recently completed by ENSCO for FHWA has addressed this problem in a comprehensive manner. This study involved

1. Analysis and computer simulation of vehicle impacts with breakaway sign and luminaire supports;
2. Design and construction of a pendulum impact test facility that incorporates simulated vehicle crush and a controlled foundation-soil interface;
3. Impact testing of breakaway supports at this facility;
4. Specification of full-scale vehicle impact tests;
5. Correlation of computer-simulated, laboratory, and full-scale tests;
6. Development of foundation design guidelines and laboratory acceptance test criteria that will ensure satisfactory performance of breakaway supports.

The analytical portion of the study is described by Owings and Cantor in a paper in this Record. In brief, this analysis divided the impact into distinct phases to gain insight into the effect of vehicle stiffness, breakaway force level, base fracture energy, pole inertial properties, and vehicle impact speed on ΔMV. With simplifying assumptions, the results of this analysis were

$$\Delta MV \simeq \frac{a}{V_o} + bV_o \qquad (1)$$

where

- a = constant dependent on vehicle crush and breakaway base characteristics,
- V_o = vehicle impact velocity, and
- b = constant dependent on pole inertial properties.

Computer simulations were performed to gain further understanding of the impact phenomenon and to provide a basis for correlation with subsequent laboratory and full-scale impact tests. The vehicle in the computer model was represented by a single degree-of-freedom, spring-mass system. The spring characteristics, representing the force-deformation characteristics of the vehicle, could be modeled as linear or nonlinear and with partial restitution because vehicle crush is mostly inelastic. The sign or luminaire support was simulated by means of the finite element method for a linear elastic frame. The dynamic response of the foundation in soil was represented by two linear differential equations with constant coefficients—one for translation and one for rotation. The breakaway base was modeled by a specified force-displacement characteristic in which the force (and moment) decays to zero at a given maximum base displacement. When this maximum displacement is

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reached, the support and foundation subsystems are completely decoupled. The interaction of the vehicle with the support was accomplished through an iterative procedure that matched the force levels at each time step. Details of the computer simulation model can be found elsewhere (4).

As part of the study, a pendulum impact test facility was designed and constructed to permit controlled testing of breakaway sign and luminaire supports and to facilitate correlation with computer-simulated and full-scale tests. The facility was designed for a maximum speed of 40.2 km/h (25 mph) because previous analysis had shown that vehicle crush and base breakaway characteristics have the most critical effect on ΔMV at low impact speeds. The pendulum mass can be adjusted between 1020 kg (2250 lb) and 2040 kg (4500 lb), which simulates the range of vehicles from subcompacts to full-sized automobiles. Vehicle crush characteristics can be simulated by a presettable honeycomb assembly attached to the front of the pendulum mass. In addition, the facility contains a soil pit to house the foundation for the breakaway support. This permits evaluation of foundation-soil interaction during impact and its effect on ΔMV. The facility contains independent sets of instrumentation for measuring ΔMV during impact, namely a high-speed camera, accelerometers mounted on the pendulum mass, and electronic transducers that measure the speed of the pendulum mass before and after impact. Details of the facility design can be found elsewhere (5).

A series of 27 tests of breakaway supports was conducted at this impact test facility. All tests were conducted at an impact speed of 32.2 km/h (20 mph). Both rigid-faced and crushable-faced pendulum tests were included in this series. The purpose of the rigid-faced tests was to examine the importance of the inertial characteristics of the impacted structure in determining ΔMV. These characteristics determine the constant b of equation 1. The results were almost exactly as predicted by the analysis. The crushable-faced tests included tests of slip base luminaire supports in which the bolt torque was varied and several tests of "identical" shoe base supports. The slip base tests exhibited low ΔMV that increased with bolt torque as expected. The shoe base test results varied considerably because of the variable modes of failure associated with this base. In general, the laboratory test results confirmed the validity of the analytical and computer simulation models.

Finally, a series of seven full-scale tests were specified by ENSCO and carried out at the Texas Transportation Institute. The tests were conducted with compact and full-sized automobiles at impact speeds from 32.2 km/h (20 mph) to 96.6 km/h (60 mph). The breakaway supports included slip base and shoe base luminaire supports and slip base sign supports. The test results were about as expected, showing moderate ΔMV for the slip base supports and high ΔMV for the shoe base supports. More important, the full-scale test results correlated very well with results of computer-simulated and laboratory tests and with results predicted by the analytic model of equation 1. This correlation is discussed in more detail elsewhere (6).

The foregoing work accomplished two main objectives of the study.

1. An understanding of the entire impact phenomenon was achieved. Specifically, the individual effects of vehicle stiffness, breakaway force level, base fracture energy, pole inertial properties, and vehicle impact speed on ΔMV were determined.
2. Good correlation was obtained between the results of analysis, computer simulation, laboratory testing, and full-scale testing.

This understanding and correlation enabled the development of simple laboratory test procedures and acceptance criteria that would ensure satisfactory performance by a breakaway support under field conditions. The recommended laboratory test procedure involves impact testing of the actual breakaway support at 32.2 km/h (20 mph) with a crushable-faced, 1020-kg (2250-lb) mass. A standard crush characteristic is obtained by use of three stacked, aluminum honeycomb segments of specified crush pressure ratings to achieve a generally linear force-deformation characteristic that extends to 133 450 N (30 000 lbf) at 50.8 cm (20 in). The selected impact speed, mass, and crush characteristic represent a conservative set of impact conditions with respect to their effect on ΔMV.

The low-speed performance of the support is considered satisfactory if either of the following conditions is met:

1. The measured ΔMV in the first test is less than 3340 N·s (750 lbf·s) (only one test would then be required) and
2. The measured ΔMV in the first and second tests of identical supports are both less than 4890 N·s (1100 lbf·s).

When a support has satisfied the low-speed criteria, its high-speed performance at 96.6 km/h (60 mph) would be calculated on the basis of its inertial properties together with its measured low-speed ΔMV (Owings and Cantor, in a paper in this Record, give more information on this). This calculation is considered to be valid because the inertial properties of the pole predominate at high impact speeds and these properties can be quite accurately measured. If the calculated ΔMV for high-speed impact is less than 4890 N·s (1100 lbf·s), the support would be considered acceptable. Thus one or two simple laboratory impact tests, together with an extrapolation to check high-speed performance, are sufficient to qualify a given support over the entire speed range of interest. (An examination of equation 1 will reveal that peak ΔMV can only occur at the minimum or maximum speed in the range of interest.) Further details of the laboratory acceptance test procedures and criteria can be found elsewhere (7).

One final item considered in the study was the effect of foundation size on breakaway support performance. An acceptable support, if mounted on an inadequate foundation, could still produce unacceptable levels of ΔMV during impact because of foundation motion. The computer simulation studies and the testing at the impact test facility revealed that a cylindrical foundation 0.61 m (2 ft) in diameter and 1.83 m (6 ft) long would result in negligible increase in ΔMV. Thus this size is recommended as the minimum foundation for breakaway sign and luminaire supports to be compatible with satisfactory impact performance. Of course, other factors, such as wind loading, may necessitate a larger foundation (3).

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