DEVELOPMENT OF PERFORMANCE SPECIFICATIONS FOR TRUCK MOUNTED ATTENUATORS (TMA's)

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INTRODUCTION

In June of 1989, the Texas Department of Transportation (TxDOT) contracted with the Texas Transportation Institute (TTI) to develop a set of performance specifications for truck mounted attenuators (TMA's). The objectives of this project were to (1) assess the performance of several truck mounted attenuators and then (2) develop and propose the criteria that define an "acceptable" TMA. These criteria will be used by the Equipment and Procurement Division (D-4) in setting minimum performance requirements for TMA's purchased by the TxDOT.

The findings from this study are detailed in a final TTI report which is composed of three volumes:

- *An Evaluation of Selected Truck Mounted Attenuators with Recommended Performance Specifications* by L.I. Griffin, R. Zimmer, W.L. Campise and K.K. Mak
- *Comparative Crash Tests Conducted on Seven Different Makes and Models of Truck Mounted Attenuators (TMA's)*, by Wanda L. Campise
- *Procedures and Equipment for Conducting Vibration and Moisture Tests on Truck Mounted Attenuators (TMA's)*, by Richard A. Zimmer

This paper provides an overview of the work performed during this project, and the conclusions and recommendations drawn from that work.

PROCEDURE

At the outset of this study a decision was made by TxDOT and TTI to evaluate a candidate set of TMA's currently on the market (or under development) on three basic performance criteria. Although other criteria might have been considered in evaluating the performance of TMA's (e.g., flammability), the three criteria listed below were thought to be of primary importance:

- Crashworthiness: (a) How much protection is afforded drivers of vehicles that impact TMA's? (b) To a lesser extent, how much protection is afforded drivers of the dump trucks to which TMA's are attached?
- Fatigue: How well do TMA's "hold up" in real-world operations? How well do TMA's withstand vibrations typical of in-service usage over protracted periods?
- Moisture Resistance: How susceptible are TMA's to collecting moisture during inclement weather – particularly if the collection of moisture might be expected to denigrate the crashworthiness of the TMA?

To conduct the crash, vibration and moisture tests, TTI was provided with seven different makes and models of TMA's (three units per make/model). The specific makes and models provided are listed below.

- Energy Absorption Alpha Model TMA
- Energy Absorption Hexfoam Model TMA
- Hexcel Current Model TMA
- Hexcel Developmental Prototype TMA
- Renco TMA
- Markings and Equipment Corporation TMA
- Connecticut DOT TMA

Crash Testing

During this study, 21 different crash tests were conducted. These tests served (1) to assess the overall benefit of TMA's (relative to similar tests in which no TMA's were used) and (2) to compare the performance of individual makes and models of TMA's with respect to one another.

The TMA's evaluated were mounted on a 24,000-lb (GVWR) dump truck that had been ballasted to 14,000 pounds before the attachment of the TMA. Each test was conducted in general accordance with guidelines presented in NCHRP Report 230.*(1)* The 21 crash tests were divided into four test series:

- Test Series 1: Eight tests were conducted using a 4,500-lb passenger car impacting the TMA head-on at 45 mph with the dump truck in a free-standing position in second gear with the parking brake on. For comparison, an additional (ninth) test was conducted under the same impact conditions without a TMA.
- Test Series 2: Seven tests were conducted using an 1,800-lb passenger car impacting the TMA head-on at 45 mph with the dump truck in a fixed position with its front bumper against a rigid wall. For comparison, an additional (eighth) test was conducted under the same impact conditions without a TMA.
- Test Series 3: Three tests were conducted using a 3,500-lb passenger car impacting the TMA head-on at 55 mph with the dump truck in a free-standing position in second gear with the parking brake on.

- Test Series 4: One test was conducted in this series. The conditions for this test were equivalent to the conditions in Test Series 1, except that the striking vehicle was a 4,500-lb pickup truck instead of a 4,500-lb passenger car.

The results of these four series of crash tests are summarized in three figures: Figure 1 (Test Series 1 and 4); Figure 2, Test Series 2; and Figure 3, Test Series 3.

All seven of the TMA's evaluated in Test Series 1 were acceptable. That is, during the collision, all seven cushions displayed occupant impact velocities of less than 40 ft/sec and longitudinal ridedown accelerations between 0 and -20 g's. The one test conducted in Test Series 4 was also found to be acceptable.

In Test Series 2, two of the seven cushions that were tested had occupant impact velocities greater than 40 ft/sec. Two others had longitudinal ridedown accelerations below -20 g's.

In Test Series 3, all three TMA's had acceptable occupant impact velocities, but unacceptable longitudinal occupant ridedown accelerations.

Vibration Testing

In the TTI vibration test, TMA cushions are mounted to a vertical, 0.5 inch steel plate. The plate is sinusoidally oscillated up and down at 7 Hz through a total displacement of 0.6 inch for approximately 1,000,000 cycles (40 hrs). The 40-hour vibration test typically takes place over 4 or 5 days of testing, 8 to 10 hours per day.

When TMA's are tested on the TTI fixture, they are in a horizontal position. TxDOT has an established policy that TMA's should be in the "down" or "horizontal" whenever they are operating in traffic, regardless of whether or not they are shadowing (i.e., protecting) a maintenance operation. After the TMA is attached to the test fixture, it is vibrated for a few minutes to ensure that any slack in the system (i.e., in the TMA or in the connection between the TMA and the test fixture) has settled out. Then a reference point is marked on the left and right rear corners of the TMA cushion. The heights of these points are measured, relative to the ground. At periodic intervals the heights of the reference points are remeasured to determine if the unit is "sagging" due to fatigue or structural failure. An evaluation form is completed each time the reference points are remeasured. In addition, any cracks, fractures, popped rivets, broken bolts or pins, etc. that appear during testing are noted and photographed.

Those TMA's that sagged more than 0.5 inch during a 40-hour test were tentatively defined as unacceptable. Of the five TMA's subjected to the TTI vibration test procedure, three were judged acceptable by this criterion (Energy Absorption Alpha, Hexcel Current Model, and Markings and Equipment Corporation) and two were judged unacceptable (Energy Absorption Hexfoam Model and Renco).

Moisture Testing

The three TMA's that were judged acceptable in the vibration test were next subjected to a standard moisture test. Of the three TMA's that were tested for moisture retention, only one was judged acceptable (Energy Absorption Alpha).

TTI's moisture test facility consists of a water-filled reservoir (12 ft. wide by 12 ft. long by 12 in. high) surrounded by clear plastic curtains. A steel "bed" or platform standing in the reservoir was used to support the TMA cushion being tested in a horizontal position, approximately 17 in. above ground level. The water in the reservoir is recirculated through 8 nozzles (2 on each side of the reservoir) plumbed in series at a rate of flow to simulate a 6 in. per hour rain. The nozzles are positioned 64 inches above ground level (approximately 2 ft. above the top of the TMA being tested) and oriented to deliver cone-shaped sprays covering the top and sides of the test cushion.

In the moisture test, the TMA cushion is first weighed. Then it is placed on the "bed" (i.e., the support structure) inside the test chamber and sprayed with water non-stop for 24 hours. At the end of 24 hours, the spray is turned off and the TMA is allowed to drain for one hour. The TMA is then reweighed. The weight gain recorded for the TMA serves to define "moisture retention." The criterion for an acceptable weight gain during this test was set at 5 percent of the initial weight of the cushion.

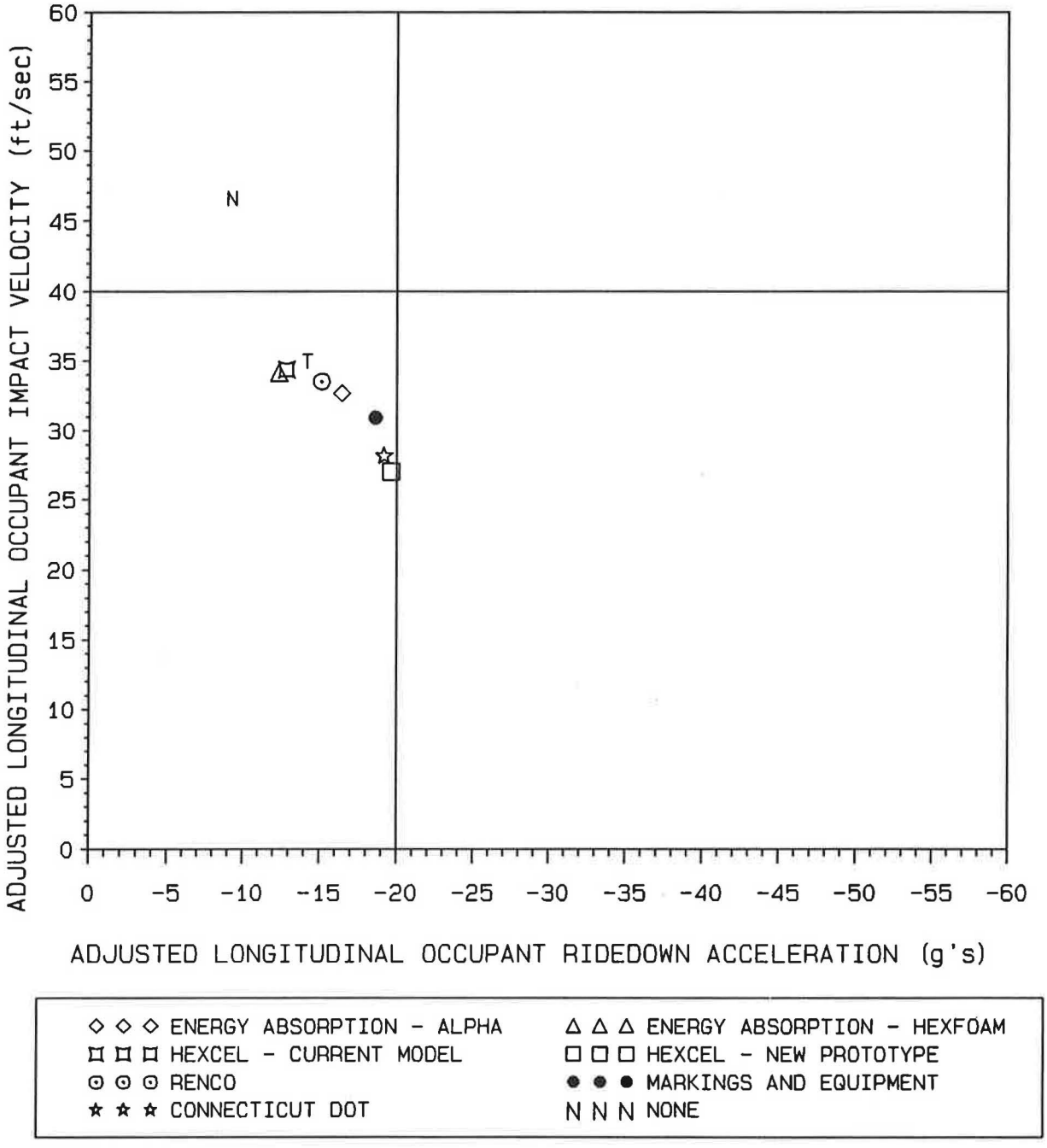
PROPOSED TMA PERFORMANCE SPECIFICATIONS

Based upon the work done during this study, future performance standards for TMA's were proposed in three areas: crash testing, vibration testing and moisture testing.

Crash Testing

A minimum of two crash tests were proposed for qualifying TMA's for purchase by TxDOT in the future:

- Test 1: An eccentric (off-center) test with a 4,500-lb pickup truck or utility vehicle traveling at 45 mph. The centerline of the impacting vehicle would be aligned with a point half way between the centerline of the TMA and the left (or right) side of the TMA.



(Data point "T" from Test Series 4 is provided for comparison)

Figure 1 Adjusted Occupant Impact Velocity and Ridedown Acceleration by TMA Make/Model Test Series 1, (Griffin 1991).

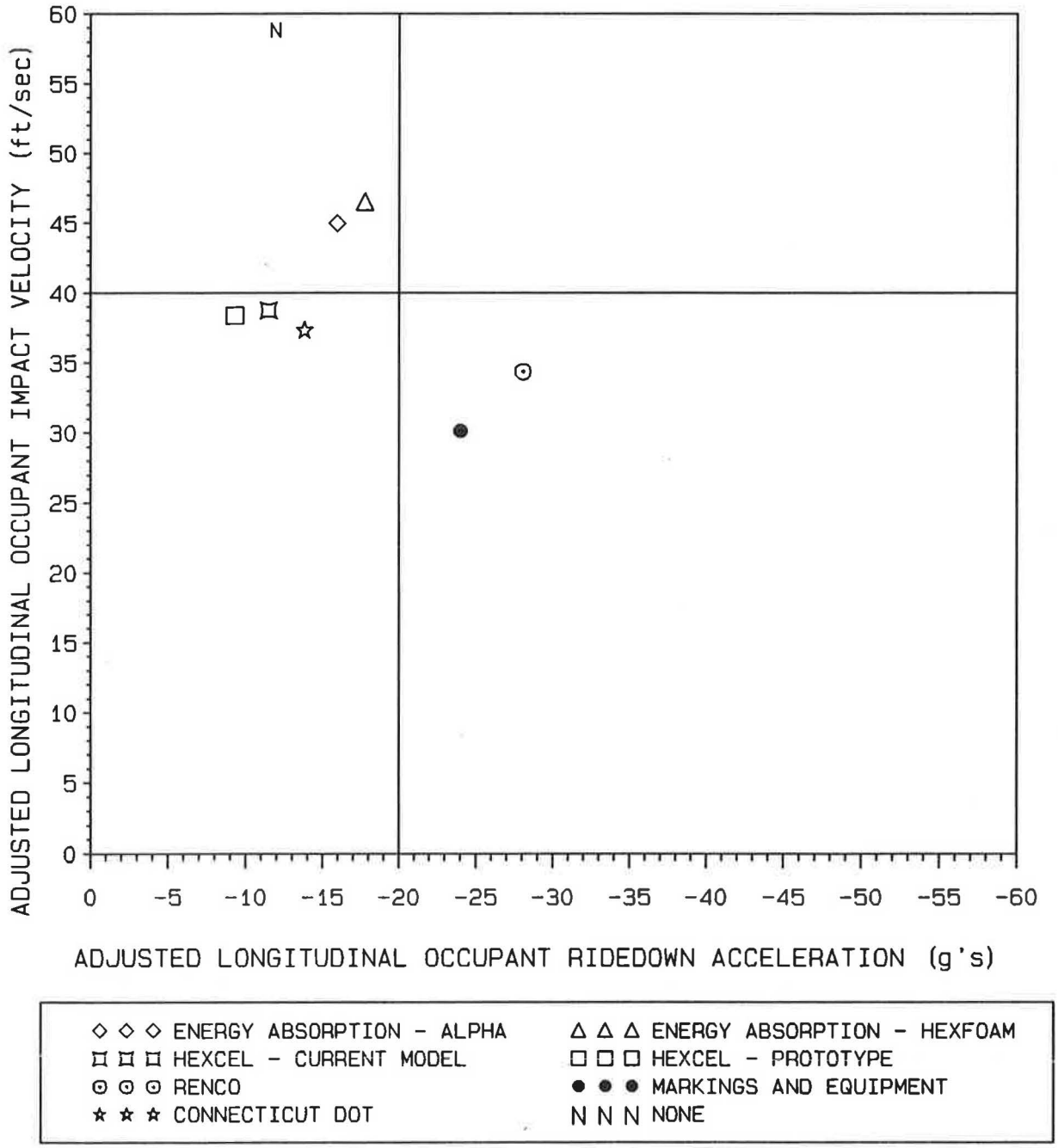


Figure 2 Adjusted Occupant Impact Velocity and Ridedown Acceleration by TMA Make/Model Test Series 2, (Griffin 1991).

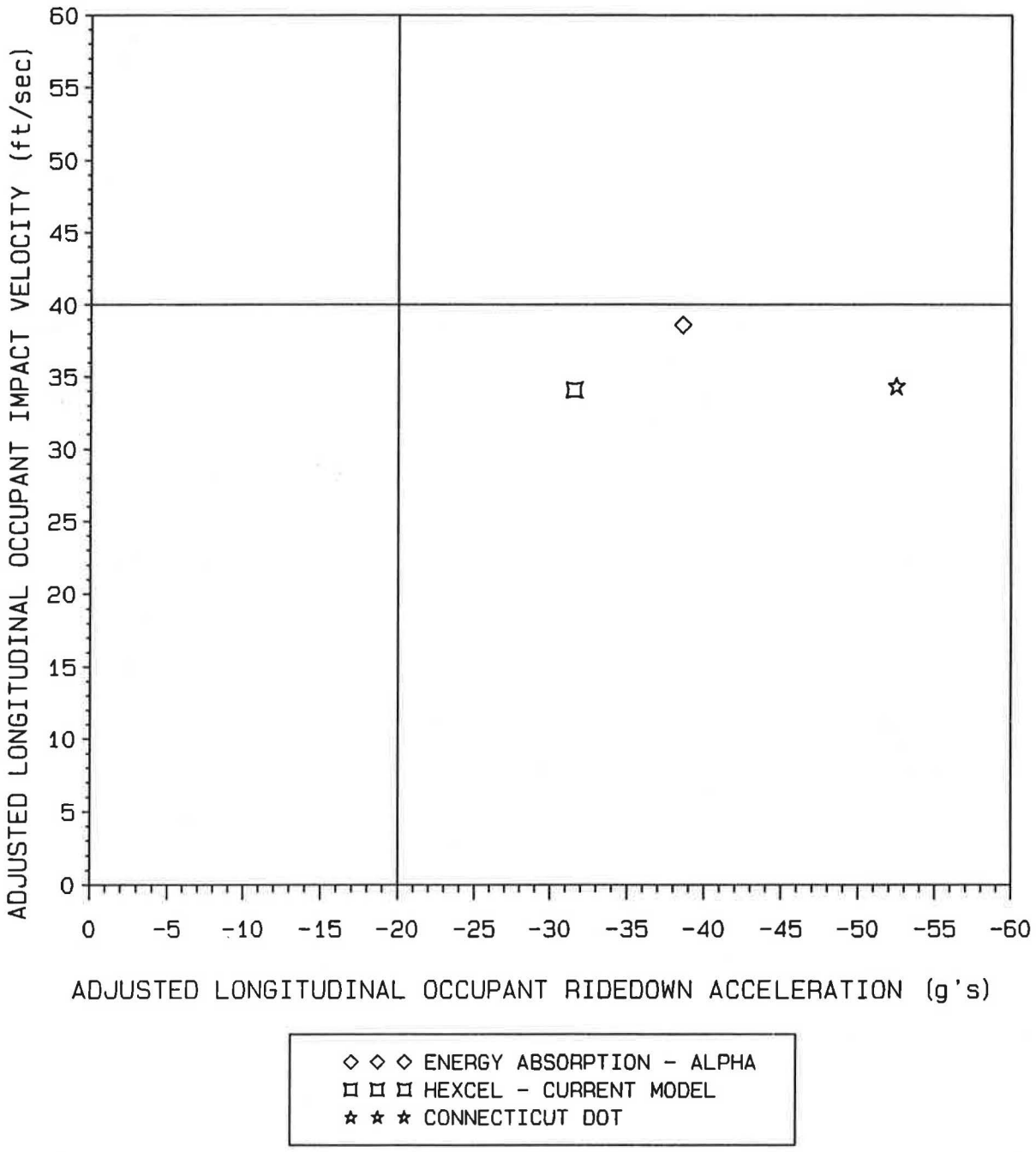


Figure 3 Adjusted Occupant Impact Velocity and Ridedown Acceleration by TMA Make/Model Test Series 3, (Griffin 1991).

- Test 2: A head-on (centerline-to-centerline) test with an 1,800-lb passenger car traveling at 45 mph.

Test Conditions: In both tests the dump truck should be ballasted to 14,000 lbs before the TMA is attached. The parking brake on the truck should be set and the transmission put in second gear. In addition, the rear wheels on the truck should be prevented from rotating by chaining, or through other means.

In all other respects, both tests should be conducted in accordance with *NCHRP Report 230*.

Acceptance Criteria: Occupant impact velocities and occupant ridedown accelerations in both tests should be within stated quantitative limits as proposed in *NCHRP Report 230*. Other applicable qualitative evaluation criteria cited in *NCHRP Report 230* also should be met.

There is a tendency in the crash test literature to emphasize the quantitative evaluation criteria in *NCHRP Report 230* and to give short shrift to the qualitative criteria when assessing TMA's, and other test articles. From the experience gained in this study, and based on the test reports contained in the literature, it appears that particular attention should be paid to vehicle underride and occupant compartment intrusion in future evaluations of TMA's.

Vibration Testing

The vibration test apparatus, procedures and performance criteria developed during this study appear to provide a reasonable test of how well a TMA will "hold up" in real world operations.

Test Conditions: The cushion portion of a typical TMA is attached to a vertical plate. The plate is then sinusoidally oscillated up and down at 7 Hz through a displacement of 0.6 in (peak to peak). The test is continued for 40 hours, 8 to 10 hours per day over a 4 to 5 day period.

Acceptance Criteria: Quantitatively, a cushion will be judged acceptable if it sags no more than 0.5 in. at the left and right rear corners of the cushion after 40 hours of vibration. Qualitatively, any damage sustained by the unit during testing (e.g., popped rivets, cracks, distortions in sheet metal, etc.) should be minor. If any damage sustained might reasonably be expected to reduce the energy absorbing characteristics of the cushion, the cushion is unacceptable.

Moisture Testing

Test Conditions: The cushion portion of a TMA is placed on a frame inside a 12-ft. by 12-ft. moisture chamber. The cushion is oriented in the normal, horizontal operational position. Through eight nozzles positioned approximately two feet above the cushion, water is sprayed onto the top and sides of the unit at a rate determined to simulate a 6 in. per hour rain. Spraying is continued non-stop for 24 hours.

Acceptance Criteria: The TMA cushion is weighed before it is placed in the moisture chamber and one hour after it is removed from the chamber. If the weight of the unit is increased by more than five percent, this test is unacceptable.

RECOMMENDATIONS

Three recommendations were offered to the TxDOT based upon the work carried out during the course of this study:

- As an interim measure, accept three (3) truck mounted attenuators for purchase by the TxDOT:
  - Energy Absorption Alpha Model TMA
  - Hexcel TMA (current model offered for sale)
  - Connecticut DOT TMA

- In the relatively near future (say, two or three years hence), require all manufacturers who would sell TMA's to the TxDOT (including the three named above) to pass the crash, vibration and moisture tests defined in the previous section. Between now and the time the new purchase requirements go into effect, a TMA would be deemed acceptable for purchase by TxDOT if it was found to pass the new performance requirements (defined in the previous section) or the performance requirements met by the three (3) makes and models of TMA's (named above) during this study.
- TxDOT should serve notice to the industry that TMA's currently manufactured for sale in this country can be significantly improved, and that in the not too distant future (say, within the next four years), it (the Department) intends to be purchasing such TMA's. Realistically, and within the next four years, TxDOT should expect to be able to purchase TMA's that adequately protect occupants of 3,500-lb vehicles striking TMA's at 55 mile per hour.

REFERENCE

1. Michie, J.D. "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," *NCHRP Report 230*, Transportation Research Board, National Research Council, Washington, D.C., March 1981.