# AUTOMOBILES AND HIGHWAY CRASH ATTENUATORS: SYSTEM DESIGN CONSIDERATIONS

Charles Y. Warner, Brigham Young University; and
Donald Friedman, Minicars, Inc., Goleta, California

## ABRIDGMENT

Present fixed-object casualties and scheduled future vehicle crashworthiness performance, when compared with trends toward smaller automobiles, allow rough estimation of future requirements for highway crash attenuators. Smaller, stiffer attenuators will be appropriate. They should provide protection for frontal crashes between 40 and 70 mph (64 and 113 km/h). Resulting savings in attenuator costs should allow protection of 2 to 3 times as many hazard sites.

•ALTHOUGH IMPLEMENTATION proceeds slowly and maintenance problems persist, highway crash attenuation devices (HCAD) have proved themselves technically in laboratory tests (1, 2, 3) and both technically and economically in real-world accidents (6).

It is reasonable to predict significant shifts in vehicle factors that have direct bearing on the efficacy and efficiency of the HCAD. Fuel costs will accentuate the already well-established trend toward smaller, lighter vehicles and will temporarily reduce the average traveling speed. More than 40 percent of U. S. cars in 1985 will be subcompacts (15). Lower traveling speeds may reduce the average severity of fixed-object collisions. The trend to smaller, lighter automobiles will very likely increase the average injury level in those crashes that do occur. Federal motor vehicle safety standards and state laws requiring installation and use of effective occupant restraints will significantly improve the built-in crashworthiness of passenger cars. If these measures are effective, vehicle deceleration from a frontal crash can be more than twice the 12-g guideline now used for attenuator design. This will allow installation of attenuators at 2 to 3 times as many hazard sites without cost increases. Occupant restraints planned for the late 1970s will further increase the survivable crash intensity. The structural stiffness of the subcompact will probably increase by that time, in response to federal standards requiring 40-mph (64-km/h) frontal barrier crash survivability and structural compatibility among cars of different mass (7, 8, 9).

### ATTENUATORS AND THE FIXED-OBJECT PROBLEM

Analysis of available crash statistics indicates that fixed-object crashes produce between 6,000 and 13,000 fatalities and between 270,000 and 530,000 injuries annually. It is not unreasonable to assume that 6,000 deaths, 300,000 reversible injuries, and 30,000 permanently disabling injuries occur annually in this type of accident. The total annual societal cost is probably in excess of $5 billion (17-22).

It has been shown, however, that crash attenuation systems can provide effective, economical alternatives to this loss (6). Attenuators that are dynamically matched to vehicle crashworthiness levels can provide an even more economical and equally effective crash protection system. Fewer than 10 percent of the automobiles traveling our roadways in 1985 will lack appropriate occupant restraints. Thus the design conditions now in use for crash attenuators will not be cost-effective for that period.

Early attempts to establish attenuator design criteria were hampered by a lack of biomechanical data and the absence of viable automotive occupant restraints. Hence, a 12-g, 40-msec vehicle deceleration limit was established for 60-mph (97-km/h), ±25-deg impacts of 2,000- to 4,000-lbm (907- to 1814-kg) automobiles. It served as a starting point for attenuator design and allowed appropriate comparisons of prototype systems. It was also employed in the development program initiated in the mid-1960s, under federal sponsorship. The program resulted in the development of several crash attenuators having acceptable crash performance (10, 11).

The attenuator systems that evolved in response to the initial performance criteria have some common characteristics. They range in depth from about 12 to 24 ft (2.7 to 7.4 m), depending on the force-velocity-deflection characteristics, and thus require 70 to 150 $ft^2$ (6.5 to 14 $m^2$) of roadside area. Their cost ranges from about $2,000 to about $5,000 for first-installation hardware, but cost per impact varies because some systems are wholly or partially reusable (6).

Thus three very important trends need to be understood for rational prediction of future attenuator needs (16, 17):

1. The total U.S. vehicle population will reach about 150 million by 1985, increasing traffic and accidents by over 50 percent.
2. Emissions, fuel costs, parking, and other economic factors of increasingly urbanized living will drive many purchasers toward smaller automobiles. The subcompact will account for more than 40 percent of all passenger cars by 1985.
3. Enforced active restraint use, factory-installed passive restraints, structural changes, and other vehicle crashworthiness features will greatly reduce the need for crash attenuation along the roadside. This will allow a much more effective implementation of attenuators at those sites where they are needed.

## ATTENUATOR-AUTOMOBILE COMPATABILITY

Figure 1 shows the estimated distribution of all U. S. accidental frontal crash fatalities as a function of barrier equivalent velocity (BEV). BEV as used here is defined on the basis of vehicle crush: It is the barrier crash velocity needed to produce about the same vehicle crush as that seen in an actual accident and thus serves as a measure of severity. If account is taken of the distribution of about 38,000 passenger car occupant deaths and 2.8 million occupant injuries that occurred in 1971, it is seen that about 19,000 deaths and 1 million injuries occurred in the frontal mode alone, and almost 7,000 deaths occurred in frontal crashes between 20 and 40 mph (32 to 64 km/h) BEV (9). The dashed line in Figure 1 is an estimate of the upper limit of fatality distribution in fixed-object accidents. Such crashes account for an inordinate number of casualties per accident and may have a distribution that is as much as 10 mph (16 km/h) BEV more intense than average. The precise distributions are unknown. Had crashworthiness standards recently announced for the 1976 to 1980 time frame been in effect, as many as 16,000 of the 38,000 deaths that occurred in 1971 could have been avoided. If these standards take effect according to announced schedule, similar savings can be realized by 1985, independent of attenuator implementation (Fig. 2).

Basically, occupant survival depends on proper control of occupant crash forces, which requires prevention of occupant compartment intrusion and use of stopping distance to limit vehicle forces. The occupant only requires (12) that the acceleration be kept below about 50 to 60 g (with 2,000-g/s onset) and that the area of force application be large enough to prevent pressures from exceeding 50 to 100 psia (3.5 to 7 $\times 10^5$ Pa). Experimental crashes (9) have shown that most cars exhibit sufficient structural integrity to prevent serious occupant compartment collapse in frontal barrier crashes up to about 30 to 35 mph (48 to 56 km/h).

Lap-shoulder belts perform quite well in controlling occupant forces at speeds below 25 to 30 mph BEV. Improved restraints are likely to give good performance at speeds up to 40 mph (64 km/h) BEV (12, 13, 14). Future automobiles will probably be built to meet a federal standard frontal crush force of about 80,000 lbf (356 000 N) to provide improved car-to-car crash protection (8, 9, 15, 16).

## DESIGN GUIDELINES

Attenuator design guidelines from the vehicle crashworthiness programs announced by DOT indicate that attenuators should be designed to provide the additional stopping

Figure 1. Estimated distribution of frontal fatalities versus crash severity.

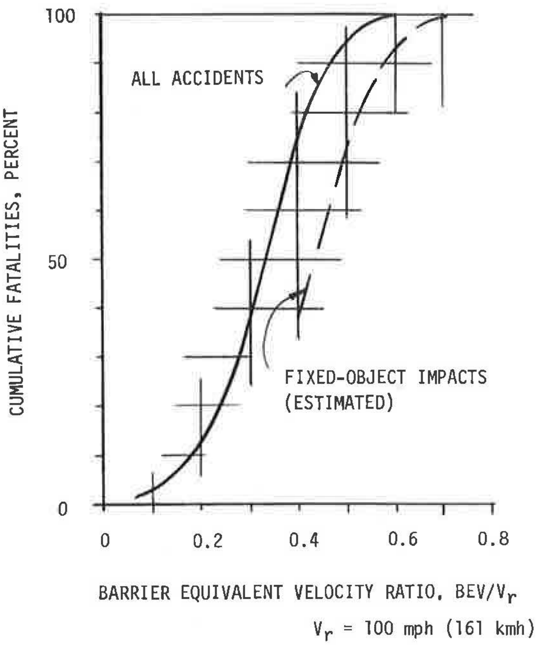



Figure 2. Estimated effectiveness of announced FHWA standards for frontal impacts.

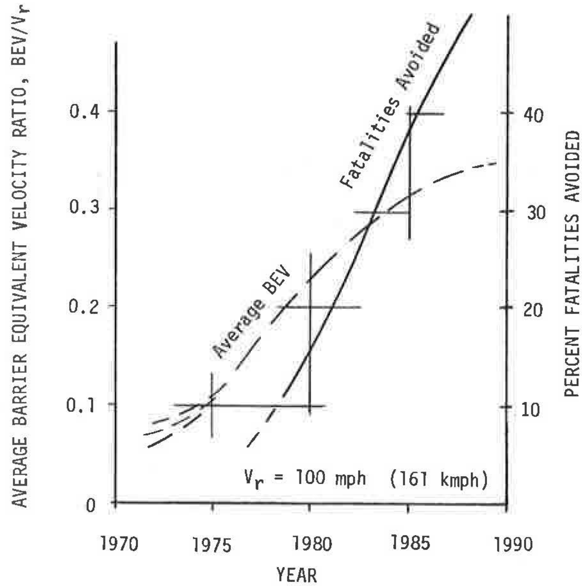



Figure 3. Minimum attenuator stroke versus fixed-object crash velocity ratio.

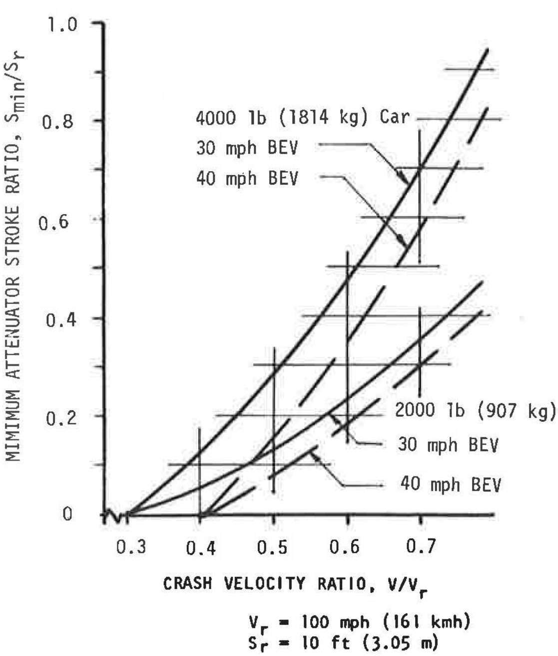
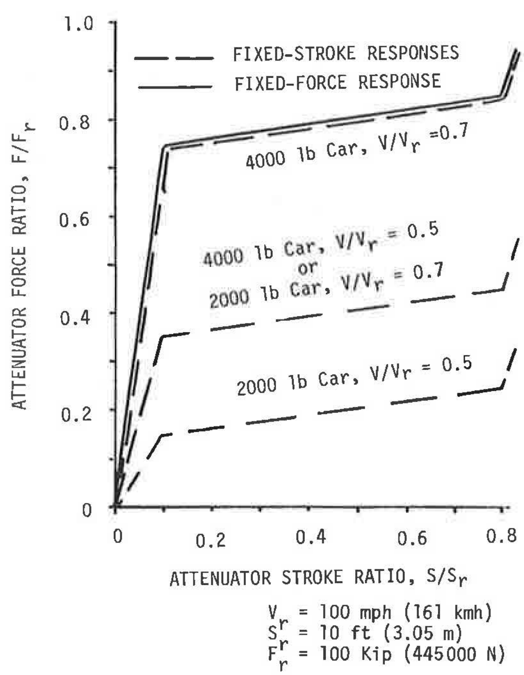



Figure 4. Recommended stiffness profiles for 40-mph BEV car crash attenuators.



distance needed for crashes above 35 to 40 mph (56 to 64 km/h) and should provide a stopping force near, but slightly less than, the design frontal crush force on the vehicle. Hence, the majority of the crush provided by a crash attenuator should be near but less than 80,000 lbf for maximum total occupant stroke efficiency.

As shown in Figure 1, the fatality benefits achievable above 40 mph (64 km/h) BEV are essentially all contained below 70 mph (113 km/h) and most of these are below 60 mph (97 km/h) BEV. Figure 3 is a plot of required attenuator depth versus BEV performance, assuming a 75,000 lbf (334 000 N) crush force and 30- or 40-mph (48- or 60-km/h) BEV frontal crashworthiness of all cars between 2,000 and 5,000 lbm (907 and 2260 kg).

As may be seen from Figure 3, about 5 ft (1.52 m) of properly designed attenuator may be expected to give acceptable 60-mph performance for all 40-mph crashworthy passenger vehicles. Even when nonideal conditions encountered in practice are considered, a depth of 8 ft (2.44 m) would be adequate. A device this short can be much less expensive than present attenuators, for not only less space is needed but less complexity, less concern about buckling, redirection hardware, and the like.

Although these estimates were derived on the basis of constant attenuator forces, the ideal attenuator would probably include a moderate "ramp" force characteristic over the first foot of deflection and should exhibit constant-stroke behavior if this can be achieved at low cost (2, 3). These features would reduce losses in low-speed collisions and skidding side impacts. Suggested force-deflection characteristics are given in Figure 4. For a fixed-force attenuator, the upper curve would hold for all car weights and impact velocities.

Hence, the realization of 40-mph (64-km/h) automobile frontal crashworthiness could allow a reduction in HCAD length to one-third the present values, without compromise of effectiveness. This should make costs more reasonable inasmuch as attenuator complexity will be greatly reduced. Far greater overall safety can result without increased highway cost.

## CONCLUSIONS

Significant changes in highway safety will result from automobile improvements that are now being introduced into public use. Appropriate crashworthiness measures scheduled for implementation in all new cars by 1980 will provide built-in safety for most fixed-object crashes at speeds between 30 and 40 mph. Attenuators designed for fixed-object impacts with those vehicles should concentrate on high-velocity impacts and may therefore be more compact. An attenuator depth of 8 ft (2.4 m) will be adequate for survival of frontal crashes at speeds up to 70 mph (113 km/h) in 1980+ vehicles, and will improve crashworthiness of lower speed impacts, if appropriately designed. Whereas a constant-stroke attenuator is preferable for the same space constraints, a fixed-force system having a gradually increasing force can also provide good performance. Attenuator force for the 70-mph impact should be 75,000 to 85,000 lbf (334 000 to 378 000 N). The highway crash attenuator will thus fill an important gap in the future safety problem; it will provide a means to prevent casualties that vehicle systems are not able to prevent economically.

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