Vehicle Barrier Design

Determining Degrees of Effectiveness

By Philip Terry, P.E., and Mike Tholen, P.E.

Vehicle barriers are used to restrict vehicles from entering areas where they might endanger people or damage property. Light (usually movable or removable) barriers inform drivers that vehicles are not permitted beyond certain points. The effectiveness of these barriers is predicated on the public's desire not to cause even minor damage to their vehicles. Typically these barriers are small-diameter, movable, closely spaced posts and are not designed, but they may be designed for a 6,000-pound lateral load in accordance with ASCE 7-02, *Minimum Design Loads for Buildings and Other Structures*. Although effective at hindering normal traffic, they are easily deformed and will not stop drivers intent on driving over them.

Heavier barriers are used for more positive protection against heavy and/or rapidly moving vehicles. Examples of these barriers are posts at truck access doors or at the corners of buildings, and Jersey or proprietary barriers in construction zones. Typically, protective bollards or posts are not designed for project-specific loads. Rather, standard architectural or civil engineer details, developed many years ago, are used.

The U.S. Department of Transportation uses standard crash tests to evaluate highway barrier systems. These barriers effectively limit the travel of errant vehicles but, even when linked together, can move many feet.

Another class of vehicle barrier is becoming more common, the security barrier. There are two types: Flexible/movable barriers that gradually slow a vehicle, and rigid barriers that take the impact with little or no movement. Flexible barriers include cables, posts, guard rails, buried tires, planters, fences and gates that encapsulate or disable vehicles. Both the flexible and rigid barriers dissipate energy through elastic and inelastic deformation of the vehicle and barrier materials. Flexible/movable barriers can move 20 feet or more.

The fixed/rigid barrier is of particular interest because it must withstand very large forces. Rigid barriers must be stiff enough to provide an impediment that a vehicle can not run over or push out of the way.

The force that a vehicle barrier must resist is largely dependent on the mass and velocity of the vehicle. The force required to stop a large vehicle at a relatively low speed may be the same as that required to stop a much smaller vehicle traveling at a higher speed. This concept is expressed in terms of the kinetic energy (KE) of the moving vehicle. The key to an effective vehicle security barrier is to determine a way to dissipate/absorb the kinetic energy of the vehicle.

Kinetic Energy

A moving vehicle has kinetic energy (KE) = $\frac{1}{2}mv^2$, where "m" = mass of the vehicle and "v" = velocity of the vehicle. A medium-weight automobile or light truck, traveling at city speeds, could easily have a KE of 135,500 foot-pounds.

If a barrier is permitted to move when hit, much of the energy from the impact is expended in friction from the barrier being dragged along the ground. Typically, flexible barriers are linked or tied together to form a barrier system. When one element is hit other parts of the barrier system are engaged, thus adding to the mass that is dragged along the ground and deformed. For a flexible barrier, energy transfer usually occurs over a period of several seconds.

For rigid barriers deceleration rates are very high. Numerous instrumented tests show that most energy transfer in a head-on vehicle impact with a rigid barrier occurs within 0.2 seconds and can be as short as 0.07 to 0.12 seconds.

Equivalent Static Design Force

Structural engineers may not be accustomed to calculating and considering kinetic energy. Design criteria for a vehicle impact would include such items as: vehicle weight (which can be converted to mass), approach speed, direction and approach angle, vehicle width, vehicle track (tire centerlines), and height of impact.

Two methods can be used to determine the design force for the barrier: 1) determination of

For more information on this subject please send an email to the following addresses:
Philip Terry <techbriefs@burnsmcd.com>
Mike Tholen <techbriefs@burnsmcd.com>

average deceleration rate and 2) direct calculation of force value based on vehicle crush data. The average deceleration rate is determined by comparing the KE of the design vehicle with KE of test data culled from published literature. Thus, the basic equation for the design force on the barrier is: F = ma, where "F" = force on barrier and "a" = deceleration rate of the vehicle. In the direct calculation method, crushing characteristics of tested vehicles are used. The force required to stop a design vehicle can be determined by equating the KE of the design vehicle to the work energy required to crush a similar vehicle.

Design Vehicle Collision Information

The following items summarize some of the published literature available on flexible and rigid barriers and vehicle crushing:

a. There is considerable variation in acceleration, force test data and computed results, even for similar vehicles and similar tests. Following are the reasons for these variations:

- Approach angle and size of barrier affect deceleration values because different portions of the vehicle frame are involved in the crash
- Differences in vehicle construction (automobiles versus trucks and vans)
- Readings from accelerometers at various locations (engine tops, engine bottoms, dummy occupants, within crushing zone) vary considerably due to restraint, damping and spring action of the support.

b. Despite the large variation in data and testing methods, it is possible to deduce that an average automobile or light truck impacting a rigid barrier at city speeds would have a lower-bound deceleration in the range of 16 to 22g. The maximum/peak deceleration value is in the range of 62 to 100g. This peak deceleration occurs for a very short period of time (0.01 second). The average deceleration value is in the range of 25 to 31g. For barrier design, the average deceleration rate (rather than the maximum rate) should be used to account for crushing of the design vehicle.

c. Figure 1 shows typical variations in acceleration with respect to time in a head-on impact. This graph is from Society of Automotive Engineers (SAE) Technical Paper 930899.

d. Other sources of energy dissipation are not considered directly (such as rotations of the vehicle or barrier, plastic and elastic deformation of the barrier, elongation of the anchor rods, and damage to the barrier).

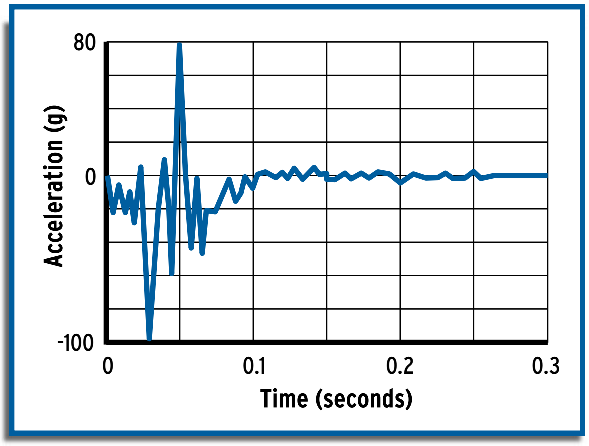

Figure 1
Vehicle Acceleration vs. Time (from SAE Technical Paper 930899)

Design Force on Rigid Barrier

The design force could occur at any point on the barrier, so it must be assumed that it will occur at the points that cause the most overturning, shear, axial compression or tension, bending or rotation of the barrier, and to the supporting structure. For barrier design, several simplifying assumptions are used:

a. The barriers are considered rigid and deflections are intended to be negligible. Assuming rigid barriers means that the designer will have to make it rigid compared to the vehicle.

b. Some kinetic energy will be converted to elastic deformation of the vehicle (rebound), elastic and inelastic deformation of the barrier, damage to the barrier, sound, light, and heat, but most kinetic energy will be converted to permanent deformation (crushing) of the vehicle. Based on an average deceleration of 28g, an average vehicle at city speeds would produce a design force of approximately 130,000 pounds.

Additional Design Assumptions

For security barrier design, it may not be necessary or practical to treat the impact force as a live load or to apply live load factors. The typically large forces will make it necessary to replace the barrier and maybe parts of the supporting structure if it is hit. It may be more practical to treat the impact force as already factored, thereby assuming that the full ultimate/inelastic capacity of the barrier will be used.

Material strength reduction factors should be applied for the materials because they relate to construction tolerances and variations in material properties. If the design vehicle impact occurs, local damage to the existing supporting structure and to the barrier is expected. These vehicle barriers are not crash-worthy and vehicle occupants could be severely injured.

Philip Terry, P.E., S.E., is an associate structural engineer with the Aviation & Architecture division of Burns & McDonnell, and has 25 years of experience specializing in the design of industrial, government and aircraft facilities.

Mike Tholen, Ph.D., P.E., is a structural engineer with the Aviation & Architecture division of Burns & McDonnell and has six years of experience in the design of government and industrial facilities.