Security Barrier Design

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Abstract: After a brief introduction on vehicle barriers in general, the writers present a rational basis of determining a design force on security barriers. The design force is derived from rigid barrier impact deceleration values culled from published literature on vehicles with similar kinetic energy. The Appendix provide a summary of references for further study.

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Introduction

General

Vehicle barriers are used to restrict vehicles from entering areas where the vehicles might endanger people or damage property. Light (usually movable or removable) barriers are used to limit incidental access. Their purpose is to inform drivers that vehicles are not permitted beyond certain points. The effectiveness of these barriers is based on the general public's desire not to cause damage (even minor damage) to their vehicles. Such barriers may have decorative plastic, metal, or cement covers making them blend in with the surrounding architectural style or making them look more substantial and sturdy than they actually are. Typically these barriers are small-diameter, movable, closely spaced posts and are not designed for specific forces. But they may be designed for a 26.7 kN (6,000 lb) lateral load in accordance with Paragraph 4.4.2(c) of *SEI/ASCE 7-02*, "Minimum design loads for buildings and other structures" (SEI/ASCE 2002). Although an effective hindrance to normal traffic, they are easily deformed and will not stop large errant vehicles or drivers who are 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.

On the other hand, highway barriers have received detailed study and testing. The U.S. Department of Transportation uses standard crash tests to evaluate barrier systems (usually for vehicles impacting at an angle). These barriers effectively limit the travel of errant vehicles but, even when linked together, barrier elements can move many feet.

Unfortunately, another class of vehicle barrier is becoming more common, the security barrier. Here 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 barrier materials. Flexible security barriers such as planters can move as much as 9 m (30 ft) and Jersey barriers can move 6 m (20 ft) or more.

The latter type of barrier, the fixed/rigid barrier, is of particular interest because it must withstand very large forces. Rigid barriers must be sufficiently stiff to provide a durable physical impediment that a vehicle cannot run over or push out of the way. In many cases, the barrier must not move or move only slightly when hit. The forces imparted to the rigid barrier must be immediately transferred to other more massive elements (usually the ground or a foundation structure).

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 before it reaches its intended objective.

Kinetic Energy

A moving vehicle has KE

$$\text{vehicle KE} = \tfrac{1}{2}mv^2 \tag{1}$$

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 184 kJ (135,700 ft-lb). The same vehicle traveling at twice the speed has four times the kinetic energy.

If a barrier is permitted to move when it is hit, much of the energy from the impact is expended in friction of the barrier being dragged along the ground or in deformation of the vehicle, barrier, and support/restraining elements. Typically, flexible barriers

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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 or deformed. For a flexible barrier, energy transfer usually occurs over a period of several seconds but deceleration rates are still much greater than during normal braking.

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

Determining Equivalent Static Design Force

Introduction

For rigid barrier design, the KE of the vehicle must be converted into an equivalent static design force. Structural engineers may not be accustomed to 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. All of these are important criteria that must be defined according to the anticipated threat and the physical layout of the site.

Example Vehicle Criteria

A design vehicle impact threat may be expressed as follows:

1. Weight: 20 kN (4,500 lb);
2. Speed: 50 km/h (30 mi/h or 44 ft/s);
3. Angle to barrier: 90°;
4. Width (out-to-out): 1,778 mm (70 in.) (similar to a passenger vehicle or a full-size truck);
5. Track (tire centerlines): 1,524 mm (60 in.);
6. Average impact height off roadway surface: 610 mm (24 in.) (this is also assumed to be the center of gravity of the design vehicle); and
7. Acceleration of gravity: 9.80665 $\mathrm{m/s^2}$ ($1g$, 32.167 $\mathrm{ft/s^2}$).

Using Eq. (1), the design vehicle presented above has a kinetic energy of 183.6 kJ (135,420 ft-lb).

Determining Equivalent Static Design Force on Barrier

The average deceleration rate can be determined by comparing the KE of the design vehicle with the KE of physical impact tests culled from a literature search. The Appendix lists several sources of information and a brief explanation of the usefulness of the information for estimating deceleration rates. An average deceleration rate (rather than maximum rate) should be used to account for crushing of the design vehicle. Once the deceleration rate is established, the basic equation for the design force on the barrier is

$$F = ma \tag{2}$$

where m=mass of vehicle and a=deceleration rate of vehicle.

Conclusions

Summary of Design Vehicle Collision Information

For the design vehicle KE presented above, a review of the literature referenced in the Appendix shows the following:

1. Lower bound deceleration values are in the range of 156.9 $\mathrm{m/s^2}$ (16 g) to 215.7 $\mathrm{m/s^2}$ (22 g).
2. Maximum deceleration values are in the range of 608 $\mathrm{m/s^2}$ (62 g) to 980.5 $\mathrm{m/s^2}$ (100 g). This peak deceleration occurs for a very short period of time.
3. Average deceleration values are in the range of 245–304 $\mathrm{m/s^2}$ (25–31 g). An average of these values is 274.5 $\mathrm{m/s^2}$ (28 g).
4. There is considerable variation in acceleration and force test data and in computed results, even for similar vehicles. Thus, when using vehicle crush test results for design, it is wise to examine the testing and measuring methods and locations. Also, it is best to compare the results and use average values from several tests.
5. 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). Some of these sources of energy loss may be taken into account through the use of test results, rather than purely mathematical models.

Design Force on a Rigid Barrier

Based on an average deceleration of 274.5 $\mathrm{m/s^2}$ (28 g) and the design vehicle above, the design force is 561 N (126,000 lb).

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 impact forces will make it necessary to replace the barrier and maybe parts of the supporting structure when hit. It may be more practical to treat the impact force as a factored load and assume 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. Also, security vehicle barriers are not crashworthy so vehicle occupants could be severely injured.

The shape of the front (impacted) surface of the barrier may cause the front of the vehicle to rise during impact. If the front of the vehicle rises, energy and force calculations become more complicated such as:

1. A rise will increase the moment arm (as measured from the base) of the force. With a constant lateral force, this would increase the overturning moment on the barrier.
2. A portion of the weight of the vehicle will have a vertical component onto the barrier (increasing the “weight” of the barrier) thus tending to resist overturning.
3. Energy will be dissipated by friction on the surface thereby tending to reduce the applied force. Since the amount of lifting and loss of energy were not identified in any of the test data, vehicle rise should not be considered unless the vehicle will rise due to the shape of the barrier surface.

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:

1. The barriers are considered rigid and deflections are intended to be negligible. Assuming that the barriers are rigid means

that the designer will have to make it rigid compared to the vehicle. This is most likely accomplished by anchoring the barrier to rigid supports structures or foundations.

2. 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.

Appendix. Summary of Vehicle Barrier Literature

Supporting data were obtained from various published literature. For each document, there is a brief summary of the contents and conclusions as they applied to security barrier design:

Crash Test Reports by U.S. Department of Transportation Federal Highway Administration (USDOT FHA Various Years)

Summary of Contents

The letters are reports on tests on Jersey-type concrete barrier products for acceptance under *NCHRP Rep. 350 Test 3-11* [2000 kg vehicle at 100 km/h (4,400 lb at 60 mi/h) with impact angle of 25°]. The kinetic energy of this test vehicle is 137.8 kJ (101,670 ft-lb) in the lateral direction. Thus, the lateral kinetic energy of this test impact was only a portion of the KE for a head-on impact.

The typical barrier cross section was approximately 55–60 kg/m (400–430 lb/ft) but tests also included heavy barriers estimated at 139 kg/m (1,000 lb/ft).

Barriers were tested as temporary barricades and not anchored to the pavement. Barriers were not tested singly. Barriers were treated as barrier systems with sections linked together. From sketches on some of the reports, it appeared that the vehicle displaced six barricades, meaning that at least six barricades contributed to stopping the vehicle. These reports indicated barrier deflections of 240–2,290 mm (9.6 in.–7.5 ft) and lateral decelerations of approximately 69–157 m/s^2 (7–16 g).

Conclusions Related to Security Barrier Design

These reports provide interesting background information but because the barriers were connected and were permitted to deflect, the lateral decelerations are expected to be too low. Thus, they indicate a lower bound for lateral deceleration of approximately 157 m/s^2 (16 g) for the tested vehicle.

Safety Performance Evaluation Roadside Hardware Using Finite Element Simulation (Marzougui et al. 2000)

Summary of Contents

1. This report stated: "An impact event for a vehicle/rigid barrier full frontal crash typically last less than 0.2 s."
2. Pin-and-loop connected precast concrete barriers displaced as much as 1.6 m (5.25 ft) at 0.2 s.
3. Connection modifications reduced displacements to 1.0 m (3.28 ft).

Conclusions Related to Security Barrier Design

This report provides some background information only. Other literature indicates that head-on collisions are shorter than 0.2 s (0.07–0.12 s). A project's design criteria may prevent directly connecting barriers.

"Evaluation of Multipurpose Pickup Truck Model Using Full Scale Crash Data with Application to Highway Barrier Impacts" (Zaouk et al. 1996b) and "Development and Evaluation of a C-1500 Pickup Truck Model for Roadside Hardware Impact Simulation" (Zaouk et al. 1996a)

Summary of Contents

Both reports contained a chart showing the maximum deceleration for a truck engine of approximately 981 m/s^2 (100 g) for a 58 km/h (35 mi/h) head-on collision with a rigid barrier. The time of the maximum deceleration occurred 0.045 s after collision. Based on the reported internal energy of 202.8 kJ (149,578 ft-lb), the vehicle weight was approximately 1,820 kg [4,000 lb (as determined from other sources)].

Conclusions Related to Security Barrier Design

These reports show that for a KE of 202.8 kJ (149,578 ft-lb) a maximum deceleration of 981 m/s^2 (100 g) could be expected. But the maximum deceleration occurred over a very short period of time and was measured on the engine (supported by flexible mountings). From the graph, an average deceleration appears to be 294 m/s^2 (30 g).

MIL—HDBK-1013/14, Selection and Application of Vehicle Barriers (US DOD 1999)

Summary of Contents

This military handbook recommends casting a Jersey barrier in a foundation [with a 150 mm (6 in.) key and embedded steel reinforcing bars] where the impact angle is greater than 30°.

A concrete planter from this military handbook has a weight of approximately 222 kg/m^2 (1,600 lb/ft) (concrete and soil). When subjected to a KE of 1,464 kJ (1,080,000 ft-lb) the penetration of the vehicle was 9.5 m (31.2 ft).

When subjected to a KE of 453.4 kJ (334,400 ft-lb) a concrete Jersey barrier allowed the vehicle to penetrate 6.1 m (20 ft). Deceleration values were not provided in the report.

Conclusions Related to Security Barrier Design

This military handbook provides some background information. The shear capacity of such a barrier is estimated to be 66.7–111.2 kN/m (15,000–25,000 lb/ft). Due to the head-on collision (which may be applied at an off-center location that could cause the barrier to rotate), it will be necessary for many designs to include barrier anchorage.

This military handbook provides only background information because the planter and Jersey barrier were permitted to deflect. It indicates that for a design without appreciable deflection, the barrier will require anchoring.

Barrier Impacts, (Datentechnik undated)

Summary of Contents

This report contains a head-on crash test where the maximum deceleration for a small car [estimated weight of 818 kg (1,800 lb)] was 500 m/s^2 (51 g) at 0.06 s from a speed of 95 km/h (57 mi/h) [KE=287.4 kJ (211,997 ft-lb)]. With a speed of 52 km/h (31.2 mi/h) [KE=86.1 kJ (63,506 ft-lb)] the maximum deceleration at 0.035 s was 310 m/s^2 (31.6 *g*). At a speed of 38 km/h (22.8 mi/h) [KE=46 kJ (33,914 ft-lb)] the maximum deceleration was 319.7 m/s^2 (32.6 *g*) at 0.05 s.

Conclusions Related to Security Barrier Design

This report provides very useful information when the design KE is compared to the tested KEs. The maximum deceleration of 500 m/s^2 (51 *g*) for the 95 km/h (57 mi/h) impact occurs only over a short period of time (0.015 s). The maximum deceleration for the 52 and 38 km/h (31.2 and 22.8 mi/h) impacts occur over longer time periods. An average deceleration would be approximately 245 m/s^2 (25 *g*). Using Eq. (1) with the data from the three cases, the design forces on the barrier would be 333.8, 356, or 522 kN (75,000, 80,000, or 117,400 lb). The variation in the computed design force could be due to many factors (such as nonlinear crushing stiffnesses and location of the accelerometer), but the calculated values show a range consistent with other data.

Guide for Selecting, Locating, and Designing Traffic Barriers (AASHTO 1977)

Summary of Contents

This *AASHTO guide* provides crash test information for concrete median barriers. This document also recommends a maximum deceleration of 117.7 m/s^2 (12 *g*) for life safety of the vehicle occupants.

Conclusions Related to Security Barrier Design

The average lateral deceleration values for tested vehicles varied from 17.7 to 135.4 m/s^2 (1.8–13.8 *g*). Using Eq. (1) with the test data, the design forces on the barriers vary from 69.4 to 1,206 kN (15,600–271,000 lb). The higher values occur for large tractor-trailer trucks. If the largest and smallest values are removed from further consideration, the range becomes 138–392 kN (31,000–88,000 lb). The average lateral deceleration results and calculated design forces from this report vary considerably for similar values of KE. These results are for sideswipe type of vehicle impacts on connected but movable Jersey barriers. Based on other literature, decelerations for head-on impacts are higher than computed here. The report provided some background information and some information for indirect comparisons.

SAE Technical Paper 1999-01-0083, Reverse Engineering Method for Developing Passenger Vehicle Finite Element Models (Gupta et al. 1999)

Summary of Contents

This SAE technical paper contains test data for two vehicles impacting a rigid barrier at 35 mi/h. The frontal impact for a Chevrolet Lumina [KE=175 kJ (129,096 ft-lb)] shows a maximum deceleration at the engine bottom of 608 m/s^2 (62 *g*) at 0.045 s. The frontal impact for a Dodge Intrepid [KE=184 kJ (135,766 ft-lb)] shows a maximum deceleration at the engine top of 1,492 m/s^2 (152 *g*) at 0.028 s.

Conclusions Related to Security Barrier Design

This technical paper provides useful background information and partial verification. The reported maximum decelerations were measured at the top and bottom of the engines (rather than for the overall vehicle frame). Since engines are supported on flexible mountings, deceleration at the top of the engine is expected to be higher than deceleration of the frame. Deceleration at the bottom of the engine is expected to be similar to but higher that the deceleration of the frame. The maximum value for the top of the engine is significantly different than for the bottom of the engine. The average deceleration of the frame should be approximately half of the maximum deceleration of the engine bottom 245 m/s^2 (25 *g*).

FHWA-TS-89-036, Work Zone Traffic Management Synthesis: Tiedown Methods for Precast Concrete Safety Shaped Barriers (USDOT FHA 1989)

Summary of Contents

This publication contains some impact test results. A table shows several peak impact forces, durations, and displacements for a 2,273 kg (5,000 lb) vehicle at 33.33 km/h (20 mi/h) at 90° [KE=90.6 kJ (66,805 ft-lb)]. Displacements were caused when some portion of the anchorage system failed.

Conclusions Related to Security Barrier Design

The peak impact forces listed in this report varied from 183.8 to 309.3 kN (41,300–69,500 lb) (a variation of almost 70% for essentially the same vehicle but not inconsistent with variations in accelerations and forces reported or calculated from other literature). Using an average time of 0.055 s for decelerating from 33.33 km/h (20 mi/h), a constant deceleration rate would be 162.4 m/s^2 (16.56 *g*). This report only provides some background information because the barriers were permitted to deflect/rotate.

SAE Technical Paper 2000-01-0878, Systems Modeling of Frontal Crash Compatibility (Gabler et al. 2000)

Summary of Contents

This SAE technical paper contains frontal barrier crash test data for a Taurus [estimated vehicle weight 1,711 kg (3,722 lb)]. The vehicle was tested at 47.2 km/h (29.32 mi/h) and at 56.3 km/h (34.98 mi/h). The maximum occupant compartment deceleration was approximately 265 m/s^2 (27*g*) and 235 m/s^2 (24 *g*), respectively.

Conclusions Related to Security Barrier Design

The paper reported decelerations of the occupant compartment rather than of the vehicle frame. The deceleration graphs indicate that the compartment deceleration curves are smoother (the values have less variations) than the curves reported for engine mount decelerations. The compartment values are not within the crushing zone and therefore provide more average values of the entire vehicle than the irregular engine mount values.

Updated Review of Potential Test Procedures for FMVSS No. 208 (Hollowell et al. 1999)

Summary of Contents

A figure in this report shows average deceleration values and pulse duration times. For the tested vehicles, the average pulse duration is 110 ms and the average acceleration is 157–167 m/s^2 (16 or 17 *g*). Another figure shows that “for a given vehicle weight, vehicles display a substantial variation in the amount of crush” (front-end crumpling). Another figure compares the front-end stiffness of a 1996 Ford Taurus with a 1995 Ford Ranger pickup truck. Both vehicles were certified to the FMVSS No. 208

barrier test and both are approximately the same mass [approximately 1,760 kg (3,871 lb)]. However, the Ranger is substantially stiffer than the Taurus. At 250 mm (9.84 in.) of crush the Taurus exerted 250 kN (56,000 lb) and the Ranger exerted 720 kN (161,800 lb) of force. Thus, for the same deflection, the Ranger exerted approximately 2.9 times the force of the Taurus. The maximum deflection of the Ranger was approximately 550 mm (21.7 in.) and for the Taurus was 750 mm (29.5 in.).

Conclusions Related to Security Barrier Design

This report points out the extent of variations in data and results, even for similarly tested vehicles. Front-end crushing ability (i.e., energy absorbing ability) varies considerably and directly affects deceleration rates and forces. The variation in the maximum forces of 720 and 498 kN (161,800 and 111,900 lb) are consistent with other sources.

FMVSS 208 Frontal Crash Test Data Sheets (USDOT NHTSA various years)

Summary of Contents

The NHTSA FMVSS 208 frontal crash test data sheets for various years provide data on chest decelerations of restrained dummy occupants. Chest decelerations varied from 245 to 628 $\mathrm{m/s^2}$ (25–64 g).

Conclusions Related to Security Barrier Design

The reported chest decelerations of restrained dummy occupants covered a large range 245–628 $\mathrm{m/s^2}$ (25–64 g). It is assumed that the reported values were maximum or near maximum values, not average values. This variability is due to many factors including crushing stiffnesses of the vehicles and the various forms of occupant restraint. Restrained chest deceleration (especially when air bags were used) is not identical to deceleration of the vehicle. However, these values indicate that an average value of 196–294 $\mathrm{m/s^2}$ (20–30 g) could be expected for the vehicle itself.

From Test Collisions to Stiffness Coefficients (Neades Undated) and SAE Technical Paper 960897, Updating the Vehicle Class Categories (Siddall and Day 1996)

Summary of Contents

These reports describe an alternate way (using average front-end crushing values) to determine the design force on a fixed barrier.

Conclusions Related to Security Barrier Design

When used together, these reports provide a method of calculating the design force on a fixed barrier. The method is based on the design vehicle KE and considers the front-end crushing ability of different types of vehicles. Using this method for various vehicle types (cars, vans, and pickup trucks) similar to the design vehicle, calculated design forces ranged from 534 to 790 kN (119,900–177,500 lb). The average force was 630 kN (141,600 lb). This value correlates well with other methods. Again, the range of values is large (but consistent with other methods) and demonstrates the variability in the crushing process.

SAE Technical Paper 2000-02-0850, Vehicle Impact Response Analysis through Use of Accelerometer Data (Varat and Husher 2000)

Summary of Contents

This SAE technical paper shows that accelerometer crash data are very dependent on the location of the accelerometer. Various locations on the tested vehicle have unique kinematic time histories. "A significant factor for rigidly mounted accelerometers is whether the instrument is mounted in or out of the crush zone." A figure in the report shows accelerometer output for a 58 km/h (35 mi/h) frontal barrier impact test of a 1982 Chevrolet Citation. The peak acceleration appears to be approximately 245 $\mathrm{m/s^2}$ (33 g) with an average acceleration of approximately 245 $\mathrm{m/s^2}$ (25 g). Another figure shows results for a rigidly mounted accelerometer in a 1998 Toyota Camry. For the Camry, the peak accelerations were approximately 461 $\mathrm{m/s^2}$ (47 g) with an average acceleration of approximately 196 $\mathrm{m/s^2}$ (20 g). Another figure shows a peak force (measured by load cells for the frontal barrier impact) of 579 kN (130,000 lb) for a 1980 Chevrolet Citation. The paper develops $\sin^2$ curves to approximate acceleration versus time.

Conclusions Related to Security Barrier Design

The paper does not provide weights or velocities of the tested vehicles. However, the paper shows force and acceleration consistent with forces and accelerations for other tests. The paper makes the following conclusions which are important for use of accelerometer-based test data:

1. Sensor mounting location is important to consider when analyzing test data.
2. Barrier load cell data has been shown to over-represent the amount of absorbed energy in a frontal barrier collision.
3. For the vehicles studied, some vehicle structural rebound takes place after separation from the barrier. This phenomenon prevents the structural rebound from being directly measured by either load cell or accelerometer instrumentation.
4. Acceleration pulse models can be scaled to different impact velocities for the same vehicle but care must be used in the application.
5. Different crash modes with the same vehicle can exhibit different collision pulse shapes.

Although load-cell data may over-represent the amount of absorbed energy, it may be accurate for barrier force information.

SAE Technical Paper 930899, an Investigation into Vehicle Frontal Impact Stiffness, BEV and Repeated Testing for Reconstruction (Kerkhoff et al. 1993)

Summary of Contents

This SAE technical paper provides information on rigid barrier impact tests at 25, 33.3, 67, and 83.3 km/h (15, 20, 40, and 50 mi/h) for vehicles of almost identical weight. Vehicle weights, velocities, and deceleration rates are reported.

Conclusions Related to Security Barrier Design

Using information from the four reported tests, kinetic energy for the tested vehicles can be calculated and compared to a design KE. A figure in the report indicates that as the barrier impact speeds increase from 16.7 to 50 km/h (10–30 mi/h), the magnitude of the average deceleration increases approximately linearly from 68.7 to approximately 196.1 $\mathrm{m/s^2}$ (7 to ~20 g). At higher impact velocities, the progressive yield of the vehicle structure results in leveling off of the average decelerations at approximately 167 $\mathrm{m/s^2}$ (17 g). Considering information from tests in other reports, these average decelerations and forces appear to be lower bounds.

SAE Technical Paper 940914, an Analysis of Trends of Vehicle Frontal Impact Stiffness (Varat et al. 1994)

Summary of Contents

This SAE technical paper discusses the concept of energy of approach factor (EAF) as it relates to amount of front-end crushing. EAF is a function of velocity (square root of energy).

Conclusions Related to Security Barrier Design

The paper provided only background information.

Development and Validation of High Fidelity Crash Simulation Models (Kirkpatrick et al. 1998)

Summary of Contents

This paper describes developing a finite element model for a 1997 Ford Crown Victoria [mass of 1,705 kg (3,759 lb)]. 56 km/h (37.8 mi/h) full frontal, rigid barrier impact tests and simulations were conducted on a component of the vehicle. The component consisted of the frame, suspension, engine, and drive train [total component mass of 960 kg (2,116 lb)]. The report contains a graph comparing the measured and calculated accelerations at the upper and lower engine in the component impact test. The graph shows the peak engine acceleration of approximately 981 $\mathrm{m/s^2}$ (100 g). The average acceleration appears to be in the range of 245–294 $\mathrm{m/s^2}$ (25–30 g).

Conclusions Related to Security Barrier Design

Because the impact tests were performed only on a component of the vehicle, the information is not directly applicable to a design case. It is expected that the components tested are the more rigid components of the vehicle, however the engine (location of the accelerometers) is attached to the frame using flexible mounts. This appears to be born out in the large peak acceleration that was reported. Again, peak and average engine accelerations reported are consistent with other references.

Methodology Development for Simulating Full Frontal and Offset Frontal Impacts Using Full Vehicle MADYMO Models (Deshpande et al. 1999)

Summary of Contents

This report provides graphs of deceleration versus time for occupants of several vehicles in full frontal 58.3 km/h (35 mi/h) impact tests. A 1995 Chevrolet Lumina, 1992 Ford Taurus, and 1994 Dodge Intrepid were tested. The peak driver chest decelerations were approximately 441, 490, and 540 $\mathrm{m/s^2}$ (45, 50, and 55 g), respectively. The average decelerations were approximately 196.1, 245.2, and 392 $\mathrm{m/s^2}$ (20, 25, and 40 g). A graph of driver chest deceleration for four car-to-car impact velocities for a 1992 Ford Taurus show peak decelerations of 441 $\mathrm{m/s^2}$ (45 g) and average decelerations in the range of 245 to 294 $\mathrm{m/s^2}$ (25–30 g). Seat belt and air bag restraints were used in the testing.

Conclusions Related to Security Barrier Design

Because restraints were used and because measurements were of the occupant torso, the acceleration data cannot be directly applied to the design. However, the values are consistent with other published values and tend to confirm the deceleration values intended for use on this project.

Ford Crown Victoria Crash Simulation and Vehicle Frame Component Test (ARASVO Undated)

Summary of Contents

These brochures provide additional information about the impact tests on a Crown Victoria. A figure shows barrier forces (as measured by load cells) for a 58.3 km/h (35 mi/h) full frontal impact into a rigid wall. The maximum force is approximately 610 kN (137,000 lb). Measured peak deceleration was approximately 735 $\mathrm{m/s^2}$ (75 g) with an average deceleration of approximately in the range of 294–343 $\mathrm{m/s^2}$ (30–35 g). Graphs for a component impact test show a peak barrier force of 508 kN (114,200 lb), a peak engine acceleration of 883 $\mathrm{m/s^2}$ (90 g), average engine deceleration in the range of 196–294 $\mathrm{m/s^2}$ (20–30 g), a peak frame deceleration of approximately 785 $\mathrm{m/s^2}$ (80 g), and average frame deceleration in the range of 245–294 $\mathrm{m/s^2}$ (25–30 g).

Conclusions Related to Security Barrier Design

This brochure provides additional information about testing of a Ford Crown Victoria that confirms the range of acceleration and force values reported in other literature.

TM 5-853 and AFMAN 32-1071, Vol. 2 Security Engineering—Concept Design and Vol. 3 Security Engineering—Final Design (U.S. Department of the Army and Air Force 1994)

Summary of Contents

These military manuals provide graphs of kinetic energy versus vehicle velocity for various vehicle weights.

Conclusions Related to Security Barrier Design

These TMs provide additional background information.

Notation

The following symbols are used in this paper:

a = acceleration/deceleration;
g = acceleration of gravity;
KE = kinetic energy;
m = mass; and
v = velocity.

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