

VEHICLE TO SAFETY BARRIER IMPACTS STUDY

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Introduction

Safety barriers on roads are used to direct an out-of-control vehicle along a safe path, irrespective of driver input. Design of barriers is based on a combination of impact tests under controlled conditions and experience of performance in service. There are two possible methods of checking the performance of barriers when struck by different vehicles under a variety of conditions. One is to carry out tests for each variation of every parameter such a vehicle size, mass, direction of impact. Such a study will prove economically prohibitive if it is to cover a sufficient number of accident situations. The other method is to use theoretical simulation where computer programs can be developed to predict the result of a vehicle barrier impact.

The theoretical background for such a simulation is not sufficiently developed to be used in dynamic situations for accurate predictions. The most effective way is to carry out a limited number of tests to aid the development of mathematical models which can then be used to study the effect of changes in any of the significant parameters. A computer program based on a mathematical model of impact and its consequences will allow safety barrier design to be modified by studying the effects of various parameters, and possibly allow comparisons between different types of barriers.

The Transport and Road Research Laboratory has funded the Cranfield Impact Centre to develop a set of computer programs to model the performance of safety barriers. This was to be suitable for representing at least two types of barrier, the high containment steel safety barrier (HCSF) and the high containment concrete barrier (HCP). The HCSF covers a number of geometric changes to the barrier configuration. The programs should be suitable for modelling the impacts into these barriers if a rigid chassis truck an articulated truck and passenger car. The rigid chassis truck was selected for a detailed comparison between test and simulation. To aid the increase in the accuracy of the rigid chassis simulation, truck tests were carried out to obtain the truck's moment of inertia as well as the non-linear properties of the barrier rail.

Modelling Concept

In accordance with the objective of the project to provide a suitable tool to simulate vehicle to safety barrier impacts, a number of computer programs were considered. It was concluded that no single existing computer program could simulate all the events of a vehicle to safety barrier impact.

The major events in such a crash are:

- a. Vehicle barrier contact. A vehicle, particularly an articulated truck, may have many contact points with the barrier at different times during a crash.
- b. Barrier deformation. As a result from each contact, linear and non-linear deformation barrier may occur. At a point during impact the

vehicle may contact the barrier at a section already collapsed due to a previous contact.

- c. Vehicle deformation.
- d. Interaction between various vehicle segments or vehicle contents during the crash, and their effects on the vehicle trajectory.
- e. Occupant behavior throughout the crash.
- f. Vehicle path during and after contact with the barrier.

A number of computer programs were considered to cover the above requirements.

Since the project at hand was to cover a variety of vehicle types as well as barrier types with the minimum vehicle data available, a combination of CRASH-D (Ref 1), KRASH (Ref 2) and CVS (Ref 3) programs were considered to be the most cost effective tool for vehicle safety barrier impact.

The analysis was carried out in three stages:

- a. Collapse steel analysis of the barrier. For this part of the analysis the barrier was modelled as a single beam supported by a number of posts at regular intervals. The collapse analyses carried out using CRASH-D enabled the load carrying capability curve of the barrier to be determined.
- b. Structural and rigid analysis of the vehicle. The vehicle was modelled as a number of masses interconnected by a number of beam elements idealizing the vehicle structure. The tire and suspension were idealized by a set of external springs capable of acting in compression only. The vehicle to barrier contact was simulated by an external spring with the collapse properties obtained from the analysis carried out to the barrier. The computer program used to carry out this simulation was KRASH. The external spring representing a parapet was assumed to be several magnitudes stiffer than the vehicle model.
- c. Simulation of vehicle occupant motion using Calspan CVS.

Collapse Analysis of the Steel Safety Barrier

The simulation of the collapse behavior of the barrier was conducted using CRASH-D. The simulation was quasi-static, and took into account:

- a. Bending failures in the barrier beam (horizontal rails).
- b. Bending failures in the barrier posts (vertical members).
- c. Shearing of the connection between the post and the rail.

The purposes of the analysis were two-fold. In the first instance the barrier used in the impact tests was analyzed in order to provide data for the KRASH dynamic model. Secondly, a number of runs were conducted to assess the effects of certain parameter changes in the barrier performance.

Ideally the effects of the parameter changes would be assessed by their effects on the KRASH dynamic simulation. Within the time and cost constraints of the present contract a simpler criteria for barrier performance was employed.

If a vehicle impacts a barrier from an oblique angle, and is successfully redirected parallel to the barrier than the kinetic energy associated with vehicle motion perpendicular to the barrier must be dissipated. It is either dissipated by deformation of the barrier, or by deformation of the vehicle. For instance, in the case of a concrete barrier, all the energy is dissipated by deforming the vehicle, and the contact forces are correspondingly high.

Where possible the CRASH-D simulations were continued until tension in the barrier rail exceed 960kN, the failure load. The higher the energy absorbed by the barrier in that loading, the more severe an impact the barrier will be able to withstand without being breached. Similarly, the higher the force the barrier can withstand, the greater its resistance to impact.

Idealization and Analysis

The section of barrier used in the tests was idealized as shown in figure 1a. The model consisted of 48 vertical members (posts) and 49 horizontal members (beams). Thus the complete rail assembly (4 interconnected open box sections) was idealized as a single continuous rail. The properties of this single rail accurately represent the elastic and plastic properties of the array of box section beams, with due consideration given to the way these beams are interconnected. Figure 1b shows the results of collapse analysis of the barrier when a single point load is applied.

Results from the collapse analysis are shown in figure 1b giving the component of load perpendicular to the barrier, energy absorbed and rail tension as functions of displacement perpendicular to the barrier. Several of the post/rail connections sheared, the first such failure being the cause of the large drop in the applied load at a deflection of 300mm.

Structural and Rigid Analysis of Vehicle and Simulations of Barrier Impacts

The vehicle to barrier simulations were carried out using the KRASH computer program. This program monitors the interaction of a vehicle with two plane surfaces set at a given angle. In the case of this project one plane defines the road surface, while the other defines the support for the barrier. The planes are unyielding and react on the vehicle via non-linear inelastic springs representing the structural behavior of tires and the barrier.

The vehicle is modelled as a collection of masses interconnected by beam elements. The masses represent the major inertias of the structure i.e., engine, ballast, etc. Any mass can be connected to a massless node (a beam end) through a massless rigid link.

The impact parametric studies were carried out for the following impact simulations:

- a. 16 tonne rigid chassis truck to barrier impact (model 1).
- b. Articulated truck to barrier impact (model 2).
- c. Passenger car to barrier impact (model 3).

Each model was impacted to both a steel safety barrier and a concrete barrier at a variety of impact angles; this paper reports only the results for the steel safety barrier.

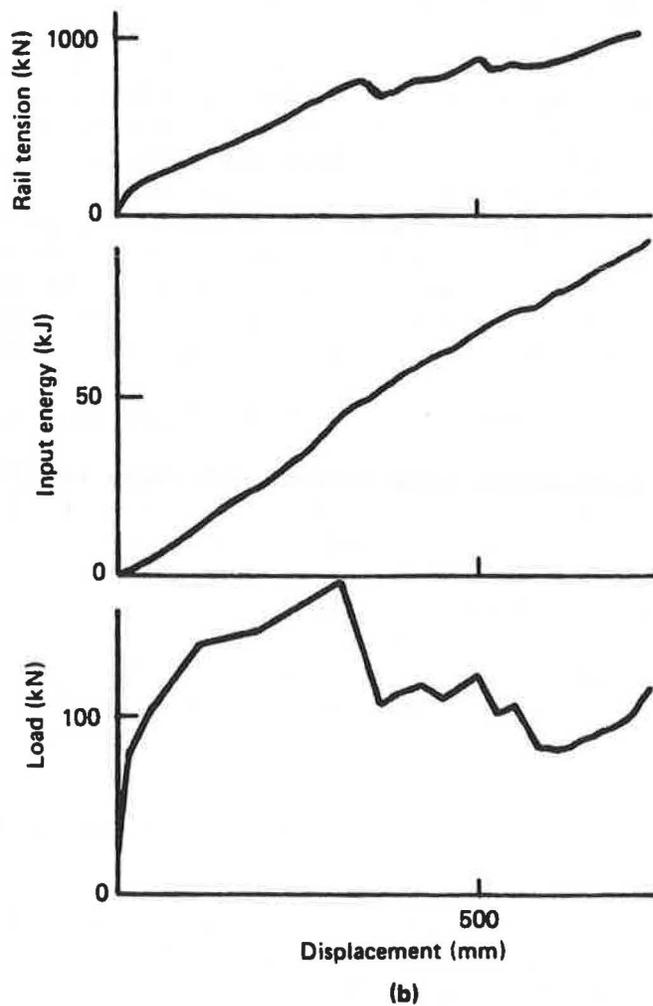
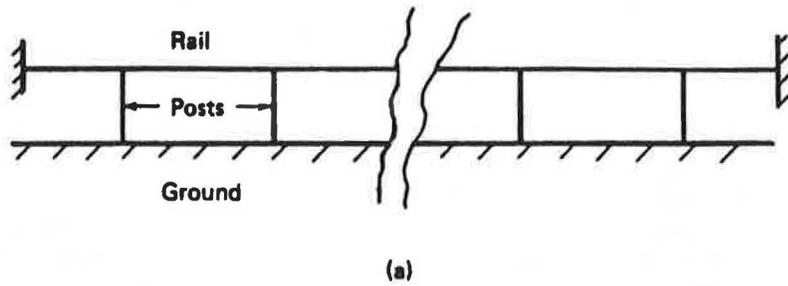


FIGURE 1 - HCSF CRASH-D analysis

Idealization

The basic data required to carry out KRASH analyses are as follows:

- a. External springs representing the barrier. The load deflection

curve resulting from CRASH-D analysis of the base line steel safety barrier is used for this purpose. In accordance with KRASH requirements this curve is idealized by a number of straight lines (figure 2a). At 760mm of lateral deformation the barrier contacts the ground resulting in a very much higher barrier reactive force. This phenomenon is simulated by the last idealized slope of the external spring representing the barrier. This slope is also used to simulate the concrete barrier stiffness when impacts to the concrete barrier are modelled.

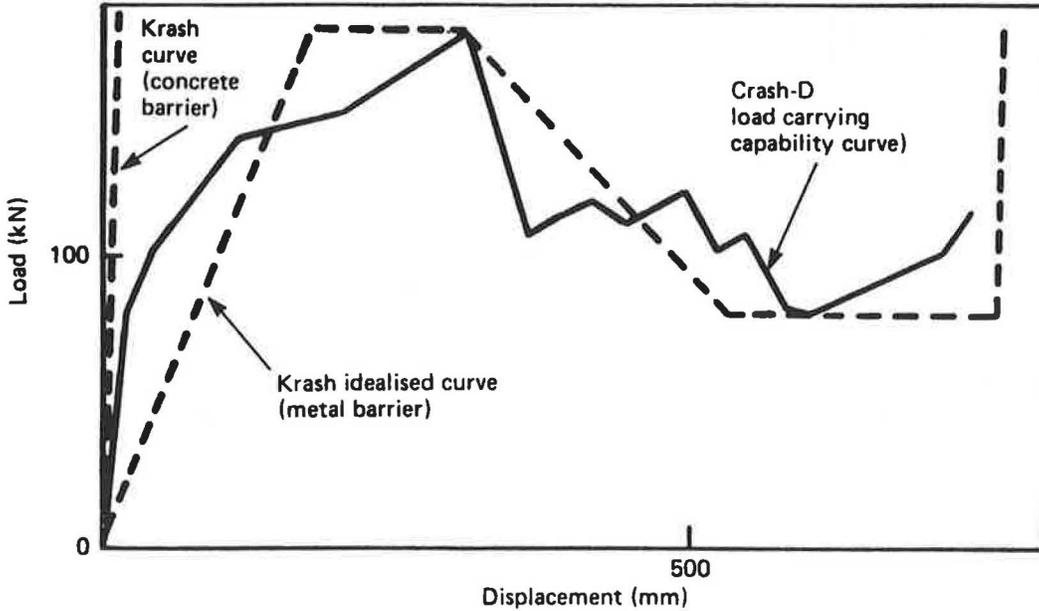


Fig. 2(a) Barrier/external spring load carrying capability curve

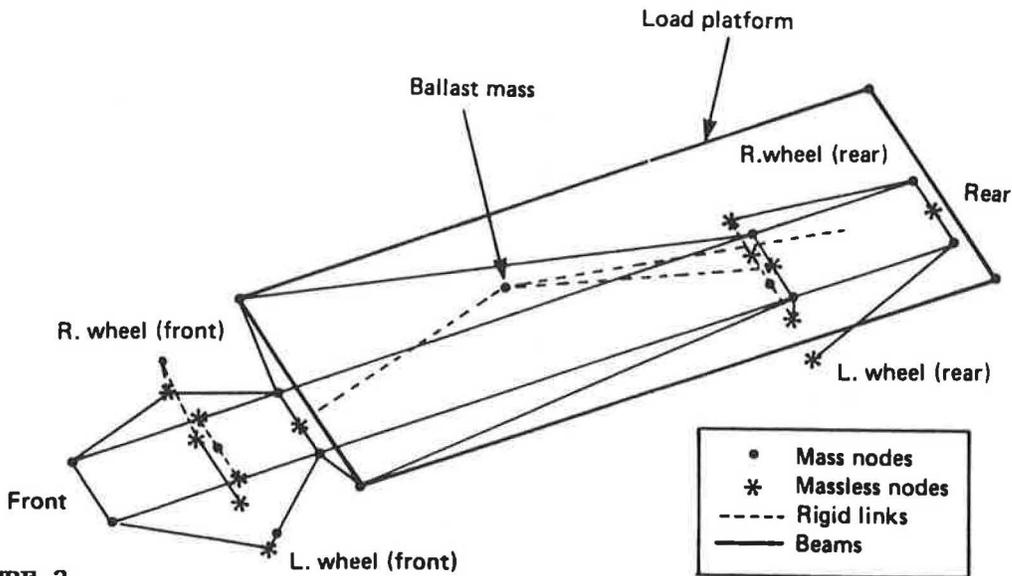


FIGURE 2

Fig. 2(b) Rigid chassis lorry model

- b. Vehicle data. The required data which includes beam properties for the vehicle idealization as well as dynamic data (masses, mass moments of inertia, tire and suspension data etc.) were not readily available. In the case of the 16 tonne truck where the comparison with dynamic tests were to be carried out, significant effort was put into obtaining as much data as possible. Moment of inertia figures were obtained by testing a very similar vehicle (an identical vehicle could not be found).

The 16 tonne rigid truck model incorporated 15 masses, 18 massless nodes, 28 beams and 12 external springs (figure 2b). Information on the test vehicle was limited to mass, location of center of gravity and general vehicle dimensions.

Dynamic Analysis

For the base line run, the 16 tonne rigid truck model (figure 2b) was impacted into the steel safety barrier at a 15 degree angle with a speed of 50 mph. The simulation of this impact was singled out for detailed correlation with the dynamic test.

The vehicle trajectory resulting from this simulation is shown in figure 3. Compared to observations from the tests, from 700ms onwards the simulation shows a slightly higher yaw rate than that in the tests.

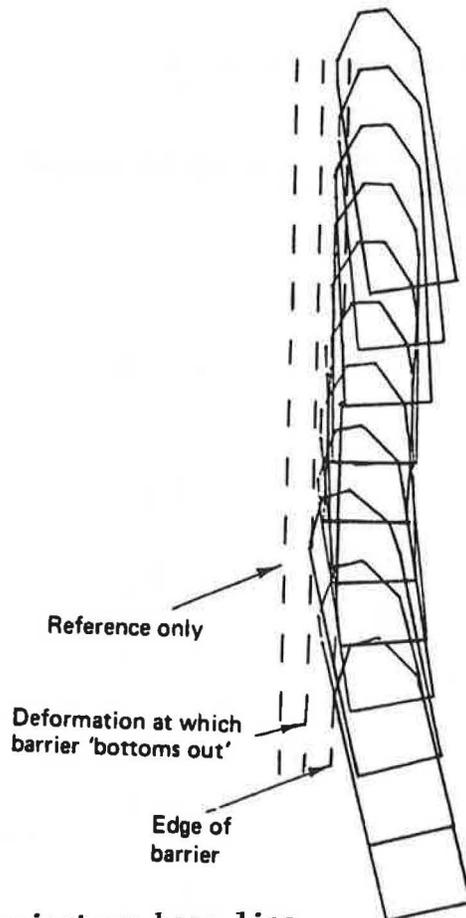
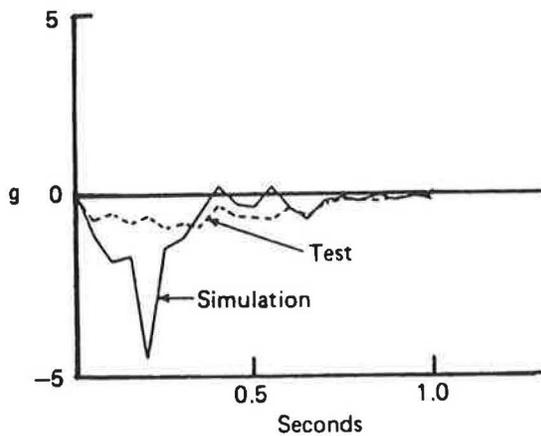
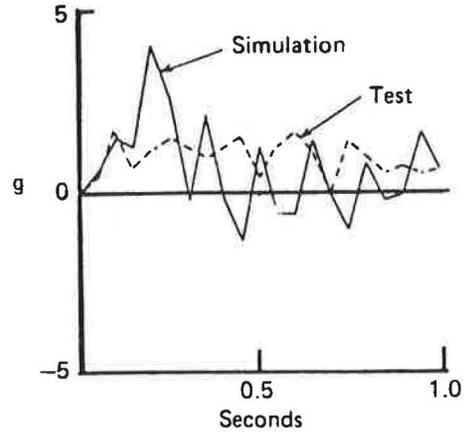


FIGURE 3 - Vehicle trajectory base line

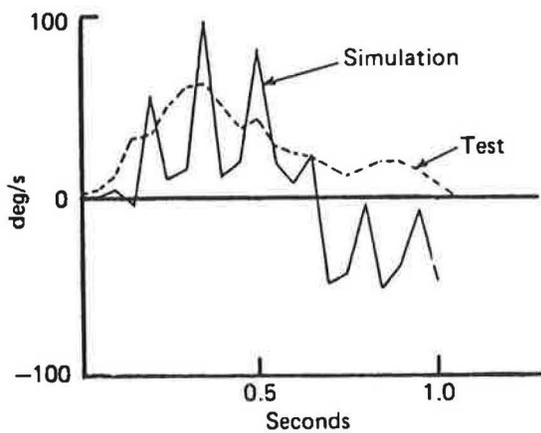
Information from simulation and test are compared in figure 4. For the first 300ms the average value of the fore and aft acceleration from simulation is over twice that obtained from the tests. From 300 to 1000ms however, there is a much better correlation between the two figures. The comparisons between the two lateral accelerations (figure 4) shows that although various peaks do not correlate up to 500ms the average values compare well, while between 500ms to 1000ms the simulated value is below 50 percent of the test value. One reason for the difference between test and simulation may be due to the slack in the beam joints not being included in the model.



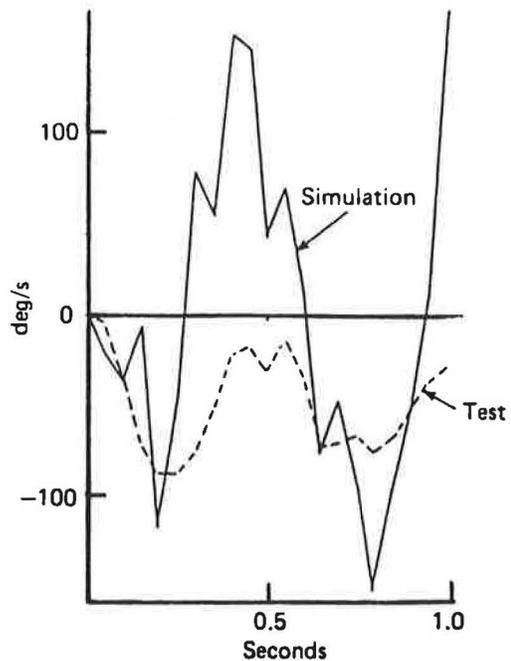
(a) Fore and aft acceleration



(b) Lateral acceleration



(c) Yaw rate



(d) Roll rate

FIGURE 4 - Comparison simulation vs. tests

The tensile load in the barrier rail during the simulated impact was compared with the measurement made at the splices connecting the rail sections during dynamic tests (figure 5). Tension in the complete rail assembly, as given by CRASH-D, was divided by eight of comparison with the measured splice plate load. Reasons for the discrepancy in the maximum load may be found by considering that, for a simulated splice tension of 11.5 tonne, one of the 4.8m rail sections extends only 2.1mm - play in the bolts holes at the splices is certain to be of this order.

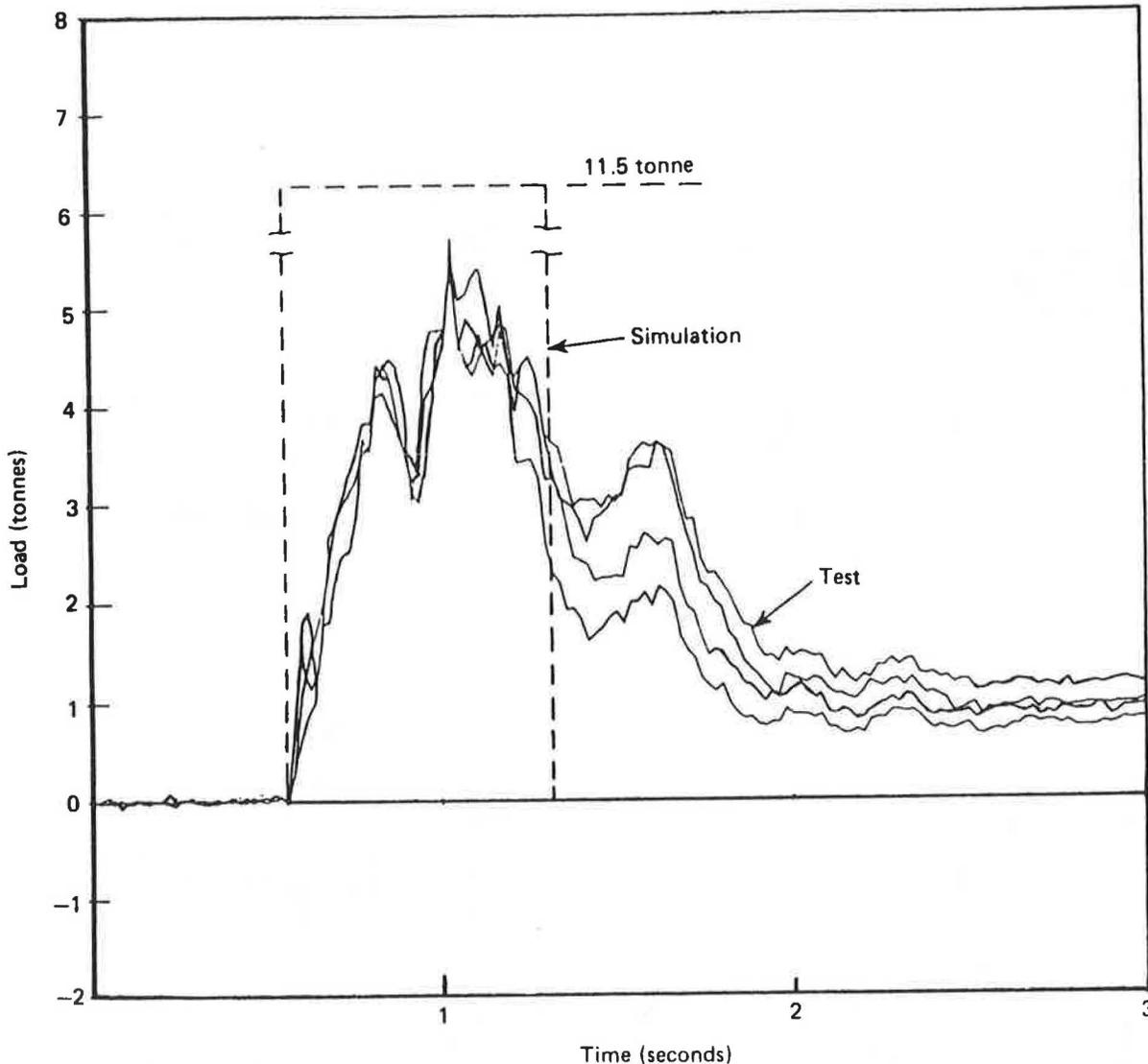
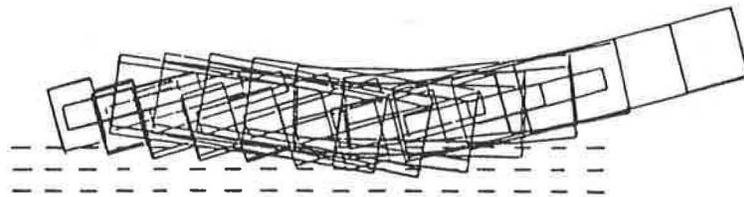
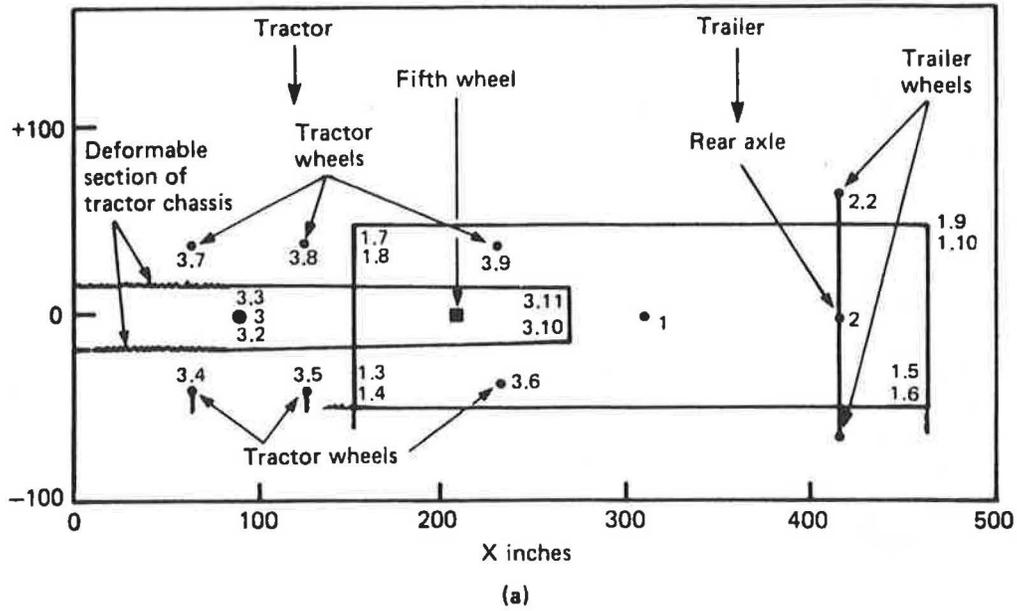


FIGURE 5 - Comparison simulation vs. test, base line run, Barrier Tension

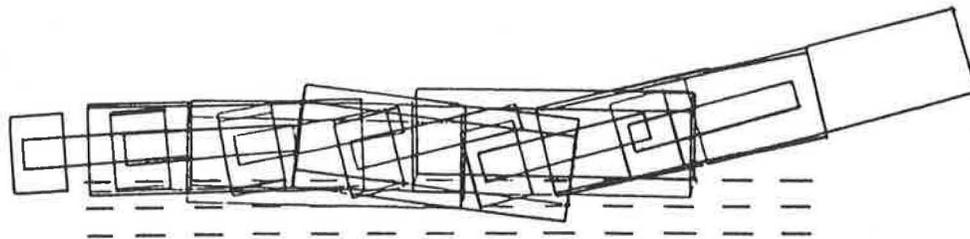
Articulated Truck to Barrier

Idealization

This model was developed to simulate a 38 tonne articulated truck impacting a barrier. As only limited data were available from the test HGV, a similar



(b) 32 tonne lorry



(c) 38 tonne lorry

FIGURE 6 - Articulated lorry to HCSF 15 degree impact

vehicle weighing 32.5 tonnes, from which more data could be measured, forms the basis of this model. The 32 tonne truck has a three axle tractor and a single axle trailer where the trailer is a uniform density box container. In one simulation run the weight was increased to 38 tonnes keeping all other parameters constant.

The vehicle's mathematical representation is shown in figure 6a. It incorporates three masses, 27 massless nodes, four beams and 20 external springs. Out of 20 external springs eight represent wheel to ground contact and the other 12 possible barrier contacts. The coefficient of friction for the barrier and ground were set at 0.57 and 0.5 respectively.

Dynamic Analysis

For the base line run, the 32.5 tonne articulated truck was impacted into the steel safety barrier at an angle of 15 degrees and a speed of 50 mph. The maximum shear load the fifth wheel can withstand is 1MN.

The trajectory computed (figure 6b) show that although the fifth wheel is allowed to shear under excessive load, it stays intact and the vehicle travels on along the barrier and next to it. This simulation run was repeated with a 38-tonne vehicle (figure 6c).

PASSENGER CAR TO BARRIER IMPACT

Idealization

The passenger car's mathematical model was developed to simulate a car to safety barrier crash with particular emphasis on the vehicle trajectory during and immediately after the crash. No attempt was made to compare the acceleration and forces experienced by the car or barrier with the actual test. To improve the detailed comparison between the model and the test it is necessary to model the vehicle structure and masses in great detail which is beyond the scope of this project. However, to simulate the trajectory and pathway of the vehicle, a simple mode (1 mass and 20 massless nodes, see figure 7a) based on the available data proved to be adequate. The vehicle weighed 960kg, had a width of 1.48m and a length of 3.34m. The coefficient of friction between barrier and vehicle was assumed to be 0.3.

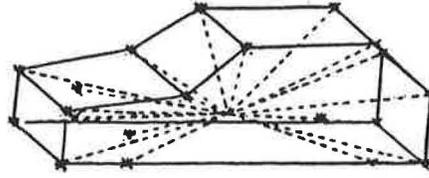
Dynamic Analysis

For the base line run the car was impacted into the baseline steel safety barrier at an angle of 15 degrees. Figure 7b shows the trajectory of the vehicle during the simulation. In this simulation the vehicle stayed in contact with the barrier for a short time before running parallel to it and a few inches from it. A more detailed modelling of the vehicle would have resulted in more lateral energy absorption which would have kept the vehicle in contact with the barrier. The simulated trajectory is very close to the test result.

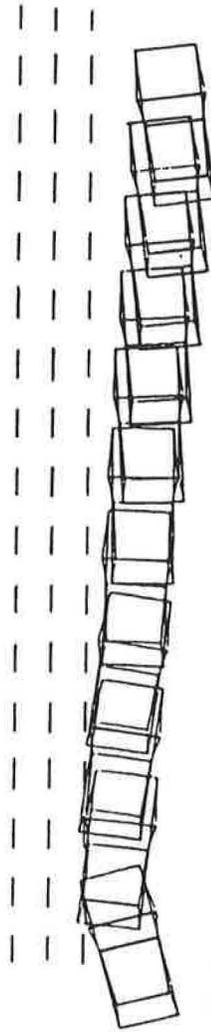
Modelling of Vehicle Occupant Behavior Using Calspan CVS Program

It has been shown that from information on the barrier, vehicle and impact conditions, the program KRASH can provide a simulation of the vehicle motion. It may be required to assess the effect of this motion on the vehicle occupants. The Calspan CVS program provides a means of doing this.

The Calspan CVS (Crash Victim Simulation) program represents the occupants by a series of body segments (having masses and inertias and represented physically by three dimensional ellipses) and joints (having viscous and damping



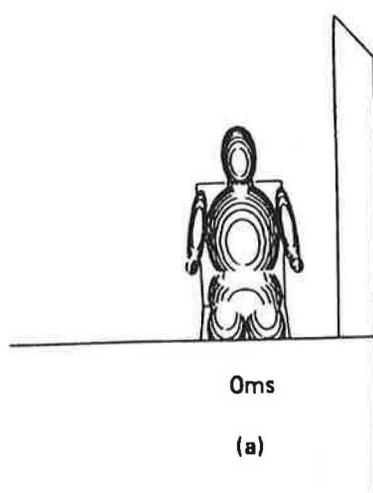
(a)



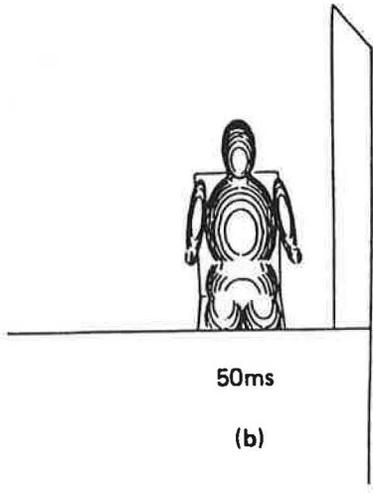
(b)

FIGURE 7 - Passenger car impacts

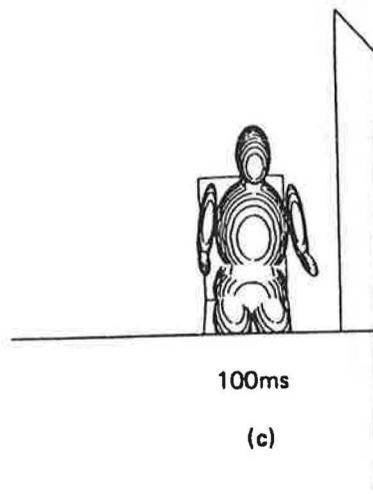
characteristics and ranges of travel similar to those of a human or dummy) which connect together the body segments. Planes that represent interior fittings of a vehicle can be defined such as seats, glass areas and the floor. By allowing contacts between the various body segments and the planes and defining an



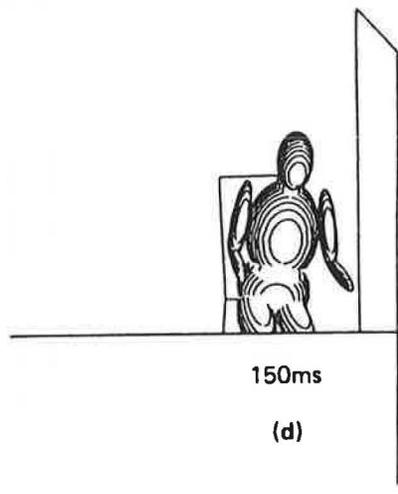
0ms
(a)



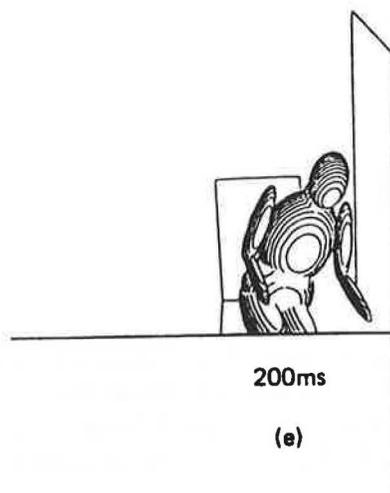
50ms
(b)



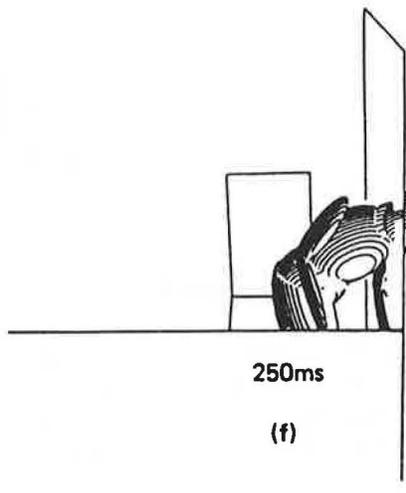
100ms
(c)



150ms
(d)



200ms
(e)



250ms
(f)

FIGURE 8 - Crash victim simulation

acceleration or deceleration characteristic which the vehicle experiences, the behavior of the occupants can be simulated.

Idealization

The occupant characteristics were for an Aprod 81 side impact dummy. Planes were defined to represent the seat, truck floor, side and front (see figures 8a to 8f).

The vehicle motion is that for the 15 degree articulated truck impact into the steel safety barrier.

Results

The occupant motion is shown in figure 8. The occupant would either have a severe impact with the door, or be ejected from the window.

Conclusions

The CRASH-D parametric studies indicate that the post properties are extremely important in determining the strength and energy absorption of the steel safety barrier. However, there are two important reservations:

1. The tensile strength of the rail is of greater importance than the bending properties of the posts.
2. The CRASH-D model does not take into account and "give" in the connections between rail sections. It is necessary to check whether this effect would modify the above conclusion.

Detailed comparison between the simulated and test results for one of the KRASH simulations shows that the basic sequence of events is correct, although broadly speaking events happen more quickly in the simulated impact, and the simulated impact is more severe. Correcting some of the limitations of the current vehicle and barrier models should result in better correlation.

Comparison between simulated and test vehicle trajectories show many of the predictions match practical test results. Suggestions are given as to how to improve the correlation of those predictions which did not match.

A wide range of vehicle trajectories (jack-knifing of articulated trucks, yawing, rolling) may be simulated.

Parametric studies indicate that friction between vehicle and barrier, barrier height and fifth wheel strength in the case of the articulated truck, have been shown to be important parameters.

Simulation of the occupant motion may be carried out using the Calspan CVS program. It is proposed that such predictions may be used to assess the effect of barrier design changes on occupant motion, using either simulated or measured vehicle accelerations. The effect of seat belts may also be studied.

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1. CRASH-D, Cranfield Structural High Deformation program user's manual. Cranfield Impact Centre, Cranfield, Bedford, England.

2. KRASH, Structural Crashworthiness user's manual. National Technical Information Service, Springfield, Virginia 22161, U.S.A.
3. CVS, Crash Victim Simulation program user's manual. National Technical Information Service, Springfield, Virginia 22161, U.S.A.

Acknowledgment

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AN INSTALLATION FOR THE ACCELERATION AND GUIDANCE OF HEAVY TRUCKS FOR CRASH TESTS

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Abstract

To evaluate the performance of roadside barriers and bridge parapets, a facility has been developed for the acceleration and guidance of heavy trucks to high speeds. Motive power is provided remotely by a winch system that is driven by two 500 hp electric induction motors with a 3MVA supply. The characteristics of these motors are controlled during acceleration for most efficient operation and accuracy of final velocity. The vehicle is towed along a guidance rail capable of handling the side and vertical loading imposed.

Recent test programs have included a wide range of impact requirements with vehicle masses ranging from 150 tonnes down to one tonne and speeds ranging from 10 mph to 100 mph. The maximum energy design specification for the system was for a 38-tonne articulated truck at 50 mph.

Introduction

Roadside barrier and bridge parapet designs require practical testing of their performance in containing and redirecting vehicles which impact them. Depending on the specification, the impact vehicle can be drawn from the full range of vehicles used on the roads, that is from the small car weighing less than one tonne to the maximum permissible truck with a weight of about 40 tonne. Impact speeds tend to be high, 50 to 70 mph, as the roadside hardware is normally installed on fast major roads.

Other transportation problems, such as the movement of nuclear materials, also require facilities for large scale impact tests the following features need to be considered.

1. Target Representation. The length of barrier -- its installation in the ground -- end conditions for a tension barrier -- bridge deck simulation for a parapet.
2. Vehicle Selection. Typical of range or extremes of size -- type of load for trucks -- weight distribution.