Energy absorption and performance of a vehicle impact protection system

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Abstract

The occurrence of animal strikes with vehicles travelling on outback Australian roads has necessitated the need for mounting a Vehicle Frontal Protection System, or VFPS, to the front of the vehicle structure. Such a device acts to minimise damage to the engine bay and other essential components of the vehicle in the event of an animal strike and during minor collisions. The clearance between the VFPS and the vehicle provides a zone over which impact energy can be absorbed, thus reducing peak damaging forces from being transmitted to the vehicle and occupants during the impact event. A device is being developed, termed the Vehicle Impact Protection (VIP) system, which utilizes this space to absorb impact energy and enhance the overall performance of the VFPS in providing safety to the vehicle and its occupants. The VIP will be mounted between the VFPS and the chassis rails of the vehicle, thus providing a load path along which impact forces can travel from the VFPS to the vehicle. Current developments include initial review and selection of suitable Energy Absorbing (EA) mechanisms for use in the VIP. Physical testing is being used to assess the energy absorbing capacity of the EA mechanisms under quasi-static and dynamic loading. Finite Element (FE) simulations are being used to validate such tests and compare the behaviour of these mechanisms in a frontal impact. Future work in the project will involve developing concepts for the VIP based on selected EA mechanisms. This paper will present the research carried out thus far and discuss the findings.
1 Introduction

Reduction of damage to the essential engine bay components of a vehicle during a frontal animal strike or other minor collision has been initially achieved by mounting a vehicle Frontal Protection System (VFPS), to the front of the vehicle. The clearance between the VFPS and the vehicle provides a “crush zone” over which impact energy can be absorbed, thus reducing peak damaging forces from being transmitted to the vehicle and occupants during the impact event. As such, a device which utilizes this space for absorbing the impact energy would enhance the overall capabilities of the VFPS in providing protection for the vehicle and its occupants.

In this project research is being carried out towards the development of a device known as a VIP, or Vehicle Impact Protection system, which will use this space to absorb kinetic energy during a frontal impact. Consisting of what the open literature terms as an Energy Absorbing (EA) mechanism as its principal component, the VIP will be attached to the ends of the chassis rails, thus providing a load path along which the impact forces can travel from the VFPS to the vehicle. Figure 1 shows how the VIP will be attached between the VFPS and the vehicle.

This paper presents the recent research carried out towards the development of the VIP device. With particular attention to the mode of operation of the VIP, this research involves physical testing and Finite Element (FE) modelling and analysis of EA mechanisms which could find potential use in the VIP. Research is continuing and involves the analysis of further EA mechanisms, leading to development of concepts for the VIP based on selected EA mechanisms.

![Figure 1: Attachment of the VIP between the VFPS and the vehicle.](image)

2 Background

2.1 Vehicle frontal protection systems

A VFPS (Fig. 2) is primarily designed to ensure the essential components, such as engine and radiator, of a vehicle involved in a frontal animal strike or minor
collision, are left in an operable state after the collision. The VFPS is essentially a frame made from welded tubing, plate and channel section. This frame is bolted to a mounting system, which in turn is bolted to the chassis rail of the vehicle. Such attachment allows direct flow of the impact force from the VFPS, through the mount, and to the load-bearing structure of the vehicle. Conventional construction materials for the VFPS are steel or aluminium alloy. The installation of a VIP, which is being treated herein, will further improve the performance of the VFPS and thereby enhance the safety of the vehicle and its occupants.

2.2 Selection of energy absorbing mechanisms

Review of the EA mechanisms covered in the open literature resulted in three types being considered suitable for use in the VIP: frusta, which are tapered thin-walled tubing, honeycomb structures and recoverable (semi-rigid) foams. For information on these mechanisms, refer to Reid [1], Harrigan [2] and Gibson and Ashby [3]. The EA mechanism will absorb impact energy primarily by axial deformation and failure. The VIP is being developed such that it will also be capable of absorbing impact energy effectively under oblique loading. This capability will ensure the VIP will provide sufficient protection in impacts such as animal strikes where the animal approaches at an angle offset from the centreline of the vehicle.

2.3 Physical testing

Several EA mechanisms were tested, the most recent being a honeycomb structure made of Ethylene Vinyl Acetate (EVA), an injection moulded polymer (Fig. 3). The load-deflection profile of the structure is shown in Figure 4. The honeycomb was observed to have suitable energy absorbing capacity for minor impacts, since due to the small depth of the cells (35 mm) only a limited amount of energy could be absorbed. It was observed that increasing the wall height would enable the honeycomb mechanism to absorb greater energy associated with major impacts.
3 Finite element simulation

3.1 Frusta models

Several FE models of EA mechanisms have been analysed. One such mechanism was a rectangular frusta, of which various geometries were modelled to compare...
their energy absorbing capacities. In this section the results of three of the geometries are presented, as shown in Figures 5, 6 and 7. The FE code ABAQUS/Explicit version 6.2 was used, which is suited for modelling unstable buckling of structures under impact loads, where complex contact interactions occur within the structure.

Each model was configured such that the EA mechanism was attached at its base to a rigid body simulating a fully fixed rigid surface. A second rigid body was then positioned 10 mm above the EA mechanism at the start of the simulation and was allowed only translation along the vertical axis. A mass element and initial velocity, which specify momentum, were assigned to the reference node of the top rigid body, such that it moved vertically downwards to impact the stationary EA mechanism.

The first two frusta mechanisms modelled (Figs. 5 and 6) had a taper on only one and two sides, respectively. Base dimensions measured 80 mm by 50 mm, and top dimensions 50 mm by 50 mm. The third frusta (Fig. 7) had a taper on three sides, with base dimensions measuring 80 mm by 80 mm, and top dimensions 50 mm by 50 mm. The height of all specimens was 100 mm. For all simulations an impact mass of 1800 kg was used, which is a typical mass for a medium-sized commercial four wheel drive vehicle.

All models were run for a simulated impact duration of 60 to 100 ms, a realistic range for a frontal vehicle impact. A relatively low impact velocity of 1700 mm/s (approx. 6.12 km/hr) was used for all simulations, since only comparative results were sought at this stage. All the computer models were of steel with Young’s Modulus of 207 GPa, Poisson’s Ratio of 0.3, and density of 7700 kg/m³. Plasticity was defined using true stress-strain data. A section thickness of 2 mm was used for all models.

Figure 5: Undeformed and final deformed profile for the straight, single taper frusta.
Figure 6: Undeformed and final deformed profile for the straight, double taper frusta.

Figure 7: Undeformed and final deformed profile for the truncated, double taper frusta.
3.2 Results and discussion

Each load-deflection profile obtained is characteristic for thin-walled rectangular frusta crushing axially under an impact load, and these profiles are shown in Figures 8, 9 and 10. The initial sharp rise in load is evident in each graph as the upper rigid body initially contacts the top edge of the frusta. Once the elastic limit of the frusta is reached, the load rapidly drops to enter a range where it levels out and fluctuates about a mean value. This range corresponds to the progressive crushing of the EA mechanism as it deforms to absorb energy. The load then rises dramatically as each EA mechanism ceases to absorb energy via gross plastic deformation and compacts onto the bottom rigid body.

The crushing force is only relatively stable for the straight, single taper frusta, while it ranges around 30 to 35 kN for all three frusta. The initial peak force for each frusta is relatively the same, being 55 kN for the truncated, single taper frusta, and 59 kN for the two straight frusta. The Specific Energy Absorption (SEA) is a parameter commonly used to assess the energy absorbing capacity of a particular EA mechanism. Calculated as the total energy absorbed per unit deformed mass, the SEA is essentially a measure of how efficiently the EA mechanism absorbs energy. The SEA calculated for the three frusta treated in this paper are 30.8 kJ/kg, 18.3 kJ/kg and 17.3 kJ/kg respectively, based on a deflection of 70 mm. These results indicate that the straight, single taper frusta can absorb almost twice the energy as its counterparts for the same given mass.
In terms of energy absorbing capacity, the straight, single taper frusta proves to be the most promising for use in the VIP. This is due to its relatively stable crushing force and high SEA. If the other mechanisms are to be considered for use as well, they will require further analysis to determine how their performance can be improved by modifying such parameters as geometry and material.
properties. The behaviour of each frusta has also been simulated under oblique loads, however space does not permit presentation of these results.

4 Conclusions

This paper has presented the main features of the research carried out to date towards the development of the Vehicle Impact Protection (VIP) system. Potential EA mechanisms for use in the VIP have been selected from the open literature, and are currently being assessed in terms of their energy absorbing capacities, using physical testing and Finite Element (FE) simulations. Representative results have been presented herein, as space does not permit the discussion of the extensive results obtained from the computer modelling. Future work will involve developing concepts for the VIP based on the optimised EA mechanisms. Work is in progress and some of the important findings will be presented at the conference.

References