Numerical Analysis Of Steel Traffic Barriers

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Abstract

"AS5100 2004 Bridge design Part 1: Scope and general principles" acceptance criteria requires that all Bridge Traffic Barriers undergo full-scale crash testing if a geometrically and structurally equivalent barrier has not previously been shown to adhere. As a precursor to crash testing this paper explores Finite Element simulations of the MRWA "2 rail barrier" and type RP2 road traffic barrier under vehicle impact, assesses their performance level as defined in AS5100 Clause 10.5, and subsequently analyses the performance with the inclusion of a roadside kerb. Crash testing requirements as defined in TRB-NCHRP 350 are deemed acceptable provisions and it is from this report that the conclusions on safety performance are based. The simulations show that both barriers are able to meet Low Performance levels yet Regular Performance levels could not be determined as sufficient results at the time of writing were not available. Vehicle and Kerb interaction was not shown to be an important factor in the performance of the Traffic Barrier.

1.0 Introduction

Guardrails such as the MRWA "2 Rail Barrier" are a critical bridge safety feature and have been used extensively in Western Australia for the last 20 years. With the introduction of the Type RP2 barrier (The new standard in Western Australia, modelled on the NYS 3 Rail Barrier) there exist many bridges that still have the 2 Rail Barrier system in place. During an accident on a bridge it is imperative that the performance of the guardrail under vehicle impact assists in minimising the occurrence and severity of injury to the occupants and other motorists.

Clause 10.4 of AS5100.1 "Acceptance criteria for bridge traffic barriers" (released in 2004) requires that all testing requirements, including safety provisions for all Barrier performance levels are in accordance with the requirements of Report 350 (TRB-NCHRP 350) produced by the National Coopoerative Highway Program in 1993, which "outlines uniform guidelines for the crash testing of both permanent and temporary highway safety features and recommends evaluation criteria to assess test results."(1)

To comply with AS5100, guardrails must undergo full scale crash test as outlined in Table 1 (2). As a precursor to actual crash tests, Finite Element simulations are carried out to improve the base understanding of the system behaviour and to obtain preliminary results for the crash tests. For the two barriers under investigation Low and Regular Performance Levels are the designated level of performance.

Table 1: Crash test criteria for the two barriers under investigation

Barrier Performance	Vehicles	Design Speed	Impact Angle	TRB-NCHRB Report 350 test

level		(km/h)	(degrees)	level
Low	0.8t small car	70	20	TL2
	2.0t Utility	70	25	
Regular	0.8t small car	100	20	TL3
	2.0t Utility	100	25	
	8.0t rigid truck	80	15	

2.0 Review of Previous Work

"Finite Element Analysis" (FEA) was first developed in 1943 by R. Courant, who utilised the Ritz method of numerical analysis and minimisation of variational calculus to obtain approximate solutions to vibrational systems."(3) A major breakthrough in Finite Element Analysis of roadside safety hardware occurred in the 1960's at Cornell Aeronautical Laboritories with the creation of the Simulation Model of Automobile Collisions for the New York Department of Public Works. 1991 saw the dawn of a new age in Finite Element analysis for roadside safety design when the Federal Highway Administration (FHWA) sponsored three projects to recommend a plan for developing improved capabilities for analytical simulations of roadside hardware collisions.(4) The otcome of these projects was that the general-purpose non-linear finite element program DYNA3D (and LS-DYNA3D) became the new standard for simulating these cllisions.

It is not economically feesable to perform full-scale field testing on a wide range of parameters. Impact simulation utilising non-linear Fininte Element analysis is thus rapidly becoming an effective tool in the design and evaluation of these systems.(5) "Crash tests, despite their considerable costs, furnish relatively little information. A computer simulation based on the non-linear finite element model of the crash vehicle and/or its immobile target typically supplies far more information".(6)

In their "Roadmap for crashworthiness" Tabiei and Wu (5) describe several of the key issues when modelling roadside safety structures. They specifically highlight the inadequacies of merging the nodes of the rail and the post. Although they determined that the use of a non linear spring to simulate the connection between the rail and posts was the most accurate way to simulate the actual behaviour of the physical system, Atahan and Cansiz (8) through their work with W-Beam guardrails "observed in crash tests that none of the W-Beam to post attachments were separated, thus utilisation of non-failing rigid links was judged to be reasonable approximation in representing the connection between W-Beams and offset blocks. For the RP2 barrier the contact between guard rail and posts has been modelled by merging the nodes between the parts (A rigid, non failing link).

AS 5100.2 clause 11.2.4 states that a load factor of 1.05 shall apply to the design of anchor bolts and anchorage reinforcement. As such it will be assumed that the posts will not break away from the base as the posts will fail before the anchor bolts fail. This is modelled in LS-DYNA by constraining the movement of the base nodes of the posts in all directions.

A previous report by Wu (9) outlines the initial Finite Element simulations of the MRWA two-rail barrier that were carried out in late 2003. The presence of a roadside kerb was omitted as the performance of the guardrail was specifically tested. The current project will extend Wu's work by adding the presence of a standard roadside kerb to futher increase the accuracy of the similation. MRWA believes that the presence of a kerb will help to improve the performance by providing a small restoring force to the vehicle, reducing the angle of impact and subsequently reducing the impact force on the guardrail system

To construct a suitable mesh, convergence tests must be carried out in an attempt to reach a desired accuracy with the proviso of maintaining an acceptable computation time. Both Wu and Miller (10) determined that a convergence to 5% accuracy was acceptable. This convergence criteria was used during the construction of the RP2 barrier.

3.0 Convergence Tests

In previous work on the MRWA 2 rail barrier Wu et al conducted two convergence tests on the numerical model, with a similar method being used in these simulations. In finite element modelling, a finer mesh typically results in a more accurate solution and when modelling guardrails the number of spans required to accurately represent a barrier of a length, which can be considered infinite must also be determined. Two independent convergence tests were carried out to determine these two important parameters.

3.1 Convergence tests in LS-DYNA

The convergence tests involved the impact of a 1 tonne solid cube with side lengths of 1 meter at an impact velocity of 10m/sec perpendicular to the guardrail. This body was chosen, as the impact force is the same order of magnitude as the forces during vehicle impact. The cube utilised the *MAT_RIGID card in LS-DYNA with the default options selected, which is a cost efficient modelling technique as the elements are bypassed in the element processing and no storage is allocated for storing history variables

3.2 Span Convergence

Modelling a large or infinite section of guardrail is impractical due to computational limitations therefore the number of spans required for the behaviour of the model to accurately represent the global behaviour of an infinite length rail must be determined whilst also being computationally viable. The convergence criteria used for these test was 5% which is considered by Miller to be an acceptable convergence limit to achieve accurate results yet limit computation time. Finite Element Models were created with the number of posts varying from two to eleven. As the presence of the kerb does not play any part in the convergent behaviour of the guardrail it was omitted to reduce computation time. Report 350 requires that impact at both the post and mid-span must be carried out, this required that convergence of both collision types be determined. 6 nodes were chosen at critical locations along the guardrails and the displacement history (with respect to time) of each node was compared for guardrails with 3,5,7,9,11 posts (post collision) and 2,4,6,8,10 posts (mid-span collision).

Convergence for Mid-Span collisions was achieved with 8 posts and for post collisions 9 posts were required. Figure 1 shows the displacement time history for a target node in the midspan collisions. As can be seen the results converge to 5% for a guardrail with 8 posts.

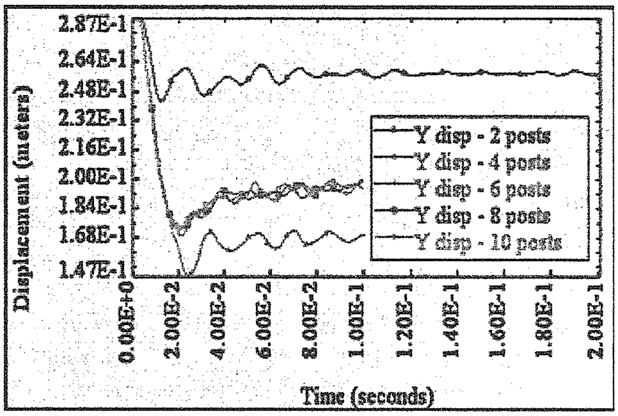


Figure 1: Target 1 (y displacement)

3.3 Mesh Convergence

To determine the required mesh size for convergence, Models were created with element sizes ranging from approximately 75mm to 20mm. These element sizes could not be obtained exactly due to the irregular dimensions of the NYS barrier. 6 target nodes were chosen again and their displacement in the X, Y, and Z directions were compared. A convergence criterion of 5% was again used, with convergence obtained with a mesh size of approximately 20mm. similar graphical results were obtained as in Figure 1.

4.0 Final Model

The final model (shown deformed in Figure 3) contained 9 posts and was constructed from a 20mm mesh. The material card *MAT_ISOTROPIC_ELASTIC_PLASTIC was used as it is a low cost isotropic plasticity model for three dimensional solids, with the material properties obtained from the BHP steel catalogue. The utility and truck model were downloaded from the NCAC Finite Element model archive (7) and contain approximately 10500 and 25000 elements respectively, with the kerb and guardrail contributing another 15000 elements to the final model. Contact was defined by a penalty method algorithm with the *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE card.. LS-DYNA was used to control the timestep with a minimum time-step not being allocated to ensure stability and prevent mass-scaling.

In their simulations Wu et al used a simplified car model with a large mass element to represent the utility. There are obvious flaws in this method as vehicle behaviour is highly dependent on not just mass but also mass distribution and geometry. By using the NCAC model it is expected that results will be a more accurate representation of a real world crash test as it is a far more detailed model (larger number of elements) and has the correct mass distribution and geometry.

In comparison to the MWRA two-rail barrier the RP2 barrier is a far more rigid model, deforming significantly less under impact from the utility. This is a favourable characteristic as it may be able to withstand further impacts and continue to perform at the desired regular performance level. However, because it does not deform sigificantly, its ability to absorb impact energy is not good. Therefore, it may cause severe damage to the vehicle and injury to passengers. In stark contrast to the MRWA 2 rail barrier which deforms significantly and would not be able to withstand further collisions and would infact pose a hazard to motorists if they collided with it.

The simulations were run on an ASUS M6000 Lap-Top runinng an Intel Centrino 1.7GHz processor, 1GB of RAM and a Mobility Radeon 9100 IGP. Each simulation took approximately 72 hours to solve to 0.5sec where at this time there was no obvious change in the dynamics of the system.

5.0 Results & Conclusions

To date results have been obtained with both guarrail systems under impact from the 2.0 tonne utility at 100 km/h and a 25° impact angle for both a mid-span and post collisions, as shown in Table 2. The inclusion of a kerb in the guardrail system was shown to have negligible influence over the initial behaviour of the utility and subsequent performance of the guardrail as can be seen in Figure 2 where a plot of the bumper velocity shows no significant change until impact with the railing.

Preliminary results from the 8.0 tonne truck collisions show that the RP2 barrier is able to contain the vehicle and redirect it safely, which is defined in report 350 evaluation criteria M as redirecting the vehicle at no more than 60% of the impact angle. The truck collision is shown in Table 3.

Figure 3 shows the displacment contours of the guardrail post impact (utility), with the Von Mises stress plotted in Figure 4. It is important to note that the base of the posts are subjected to the highest stress levels, highlighting that the rails simply act as a guidance mechanism for the vehicle whilst the posts provide structural integrity and are the critical component when large transverse loads are applied to the guardrail.

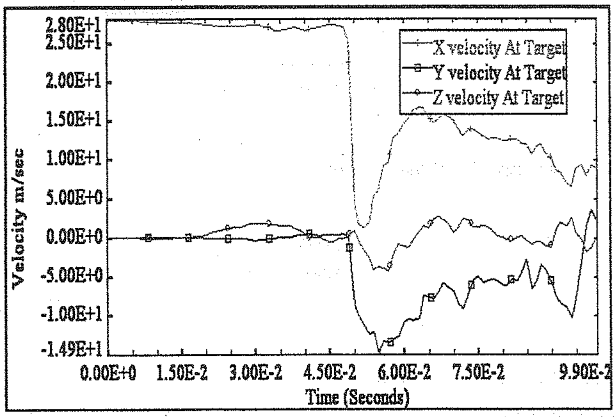


Figure 2: Bumper velocity

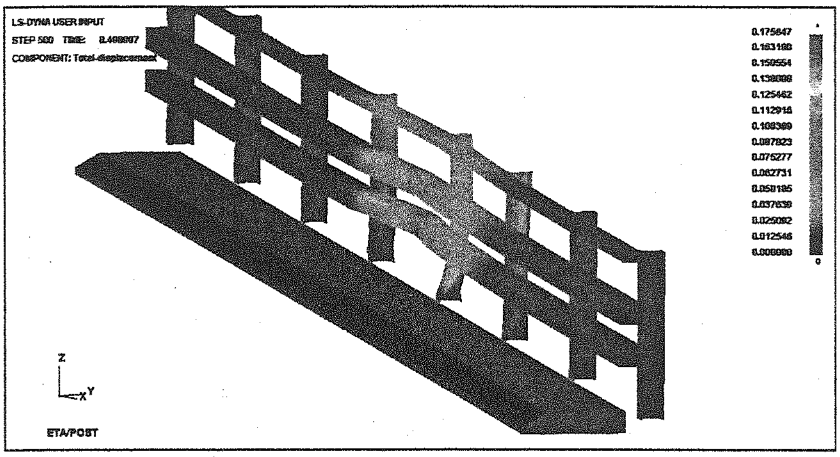


Figure 3: Displacement contours during impact

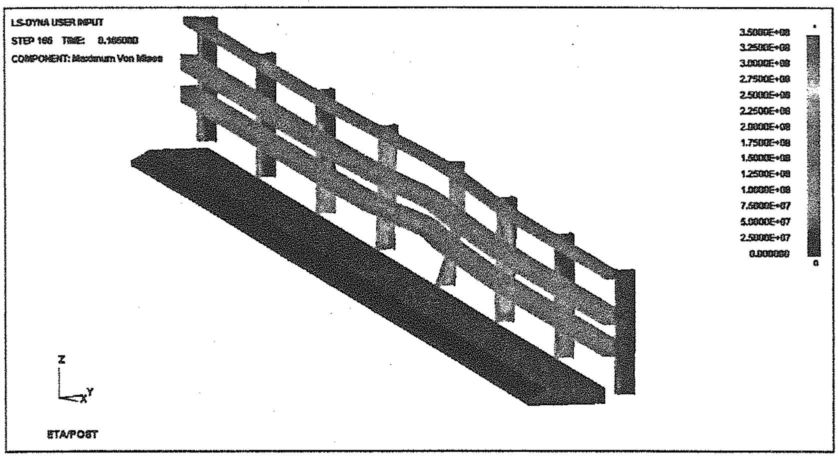


Figure 4: Stress Distribution

6.0 Recommendations for further work

- Detailed analysis of Utility suspension model.
- Detailed analysis/creation of NCAC 8.0 tonne rigid truck model.
- Investigation of a new guardrail model meshed entirely from Shell elements. (To reduce computational time)
- Investigation of post post/ground joint
- Investigation of Contact algorithm
- Investment in a Cluster of high power PC's to decrease computation time for further simulations.

Table 2: Time series for 2.0 tonne utility.

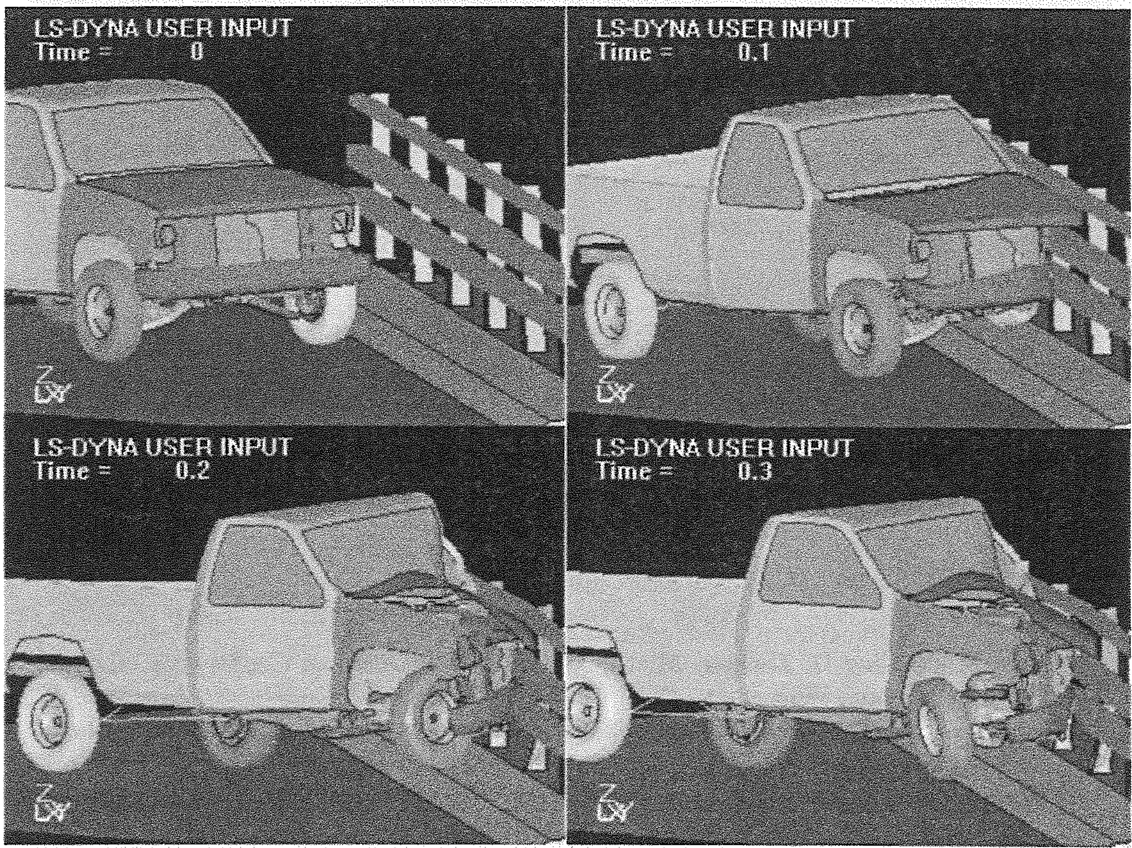
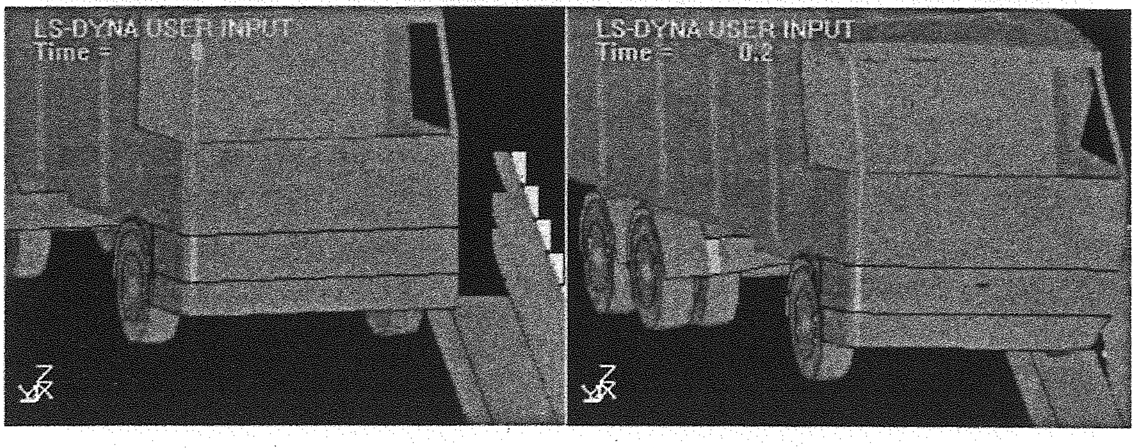
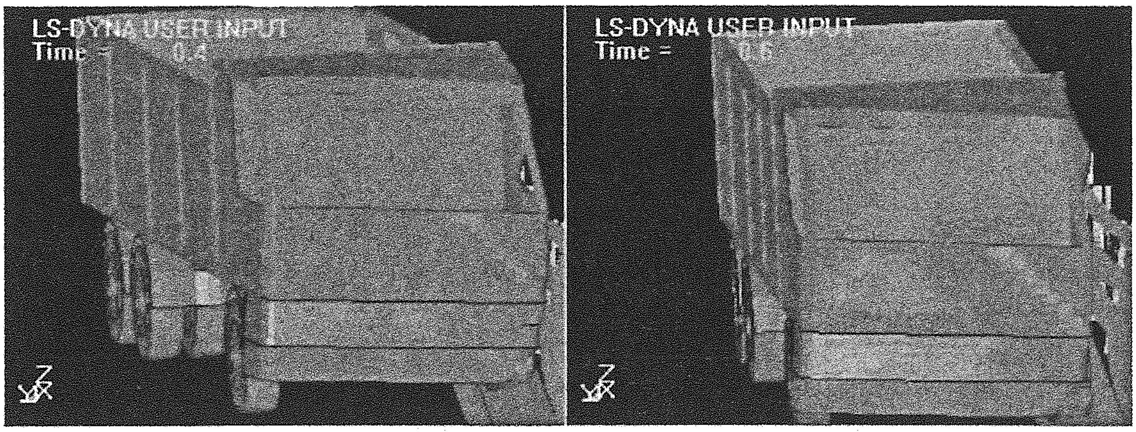


Table 3: Time series for 8.0 tonne truck model.





7.0 References

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