# Design and Pendulum Testing of a Frangible Guardrail Post for use in End Terminals

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**Abstract**

*Road safety guardrails are potential hazards, and often need to be modified to avoid subjecting a colliding vehicle's occupants to excessive deceleration forces. Current timber guardrail posts give satisfactory performance but have maintenance and quality issues. Steel posts were thus designed to replicate the failure characteristics of the existing posts. The prototype posts were impact-tested using a 2.5 tonne pendulum, with tests photographed at 500 frames per second.*

## 1.0 Introduction

**Fig. 1 – Guardrail spearing incident**

Road safety guardrails are useful in protecting errant motorists by preventing them from colliding with roadside hazards. However, the guardrails themselves are potential hazards, and are used only where the consequence of a guardrail collision is deemed less severe than one with the unprotected object or unshielded situation (Woon, 2003).

The unprotected ends of guardrails are especially hazardous in "end-on" collisions, where the vehicle impacts the barrier while travelling in a direction parallel to the road. The guardrail can often act as a spear and penetrate the occupant compartment of the vehicle (Fig. 1). To overcome this problem, the end sections of the guardrails are modified in certain ways. These modifications are known as "end terminals" or "end treatments" (see Fig. 2), and are crash-tested to verify their performance. (Woon, 2003)

**Fig. 2 – WAMELT End terminal**

The posts used in these end terminals must perform two main functions. They must be strong enough so that the main guardrail section can safely redirect vehicles which collide with the face of the barrier downstream of the end terminal. However, they must be weak enough in end-on collisions that they do not subject the vehicle's occupants to excessive deceleration forces. In order to satisfy these criteria, several of the leading posts are weakened by the addition of holes orientated parallel to the road direction (see Fig. 3). These "frangible" posts will then break off in an end-on collision, thereby reducing both the stiffness of the end treatment and the deceleration forces acting on the vehicle's occupants.

The current standard end treatment used by MRWA, (the *WAMELT*) uses timber posts, which have a number of advantages. Firstly, they have passed crash-tests and have been extensively used in Australia and overseas. Secondly, they are non-proprietary products, and hence can be manufactured by anyone.

However the timber used in these posts presents a number of problems. Firstly, it requires ongoing maintenance. Furthermore, as an organic material it has a low durability and is susceptible to rotting, fire damage and possible insect attack. It is also difficult to obtain quality timber in the sizes necessary for these posts, and this problem is only expected to increase with time. Finally, it is hard to guarantee the homogeneity and physical properties of the material, given that a certain specimen may include defects such as knots or splits.

The aim of this project was to develop steel posts that have comparable failure characteristics to the tested timber posts.

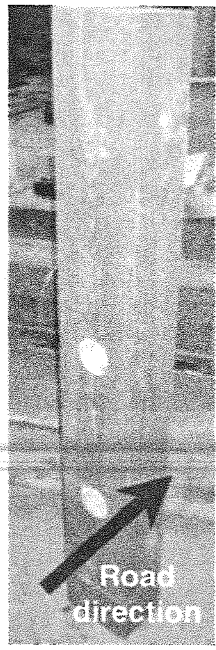


**Fig. 3 – Timber (CRT) post**

## 2.0 Background

The WAMELT uses *Controlled Release Terminal (CRT) Posts* and *Breakaway (BAW) Posts*, which were tested by Mak et al. (1998). These tests provided some reasonable data for use in this project. However, only two tests were conducted for each axis of each post, hence the sample was small compared to the observed variation in the data. The posts were also tested in a soil foundation, hence the failure characteristics of the posts could not be analysed independent of the soil characteristics. It therefore would have been beneficial to test more timber posts before designing the new posts, however time constraints prevented this.

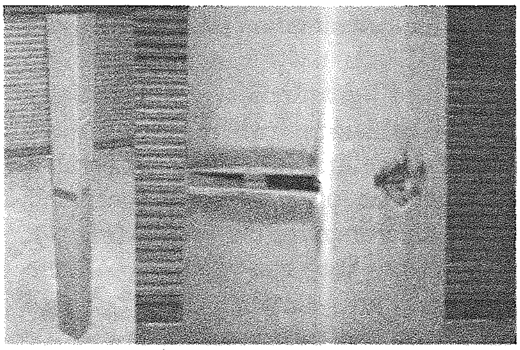

**Fig. 4 – CRT Post steel replacement design**

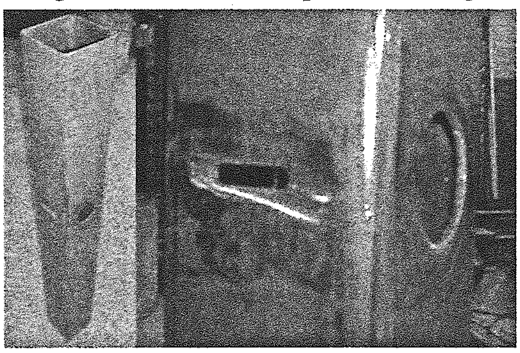

**Fig. 5 – BAW Post steel replacement design**

Michie (1971) indicated that the breaking force of timber posts is directly related to the area moment of inertia of the posts, as predicted by the theory of solid mechanics. However, little information was available on the failure characteristics of steel posts. Therefore the new posts were also designed around moment of inertia criterion.

## 3.0 Design

From the data available, a number of prototypes were designed for both post types. The designs were to be based on standard steel sections for simplicity and economy. C-channel and I-beam sections had already been used in current proprietary designs. Therefore a rectangular hollow section was chosen, which also has the advantage of being torsionally rigid. Slots were cut into the sides of each post to reduce the moment of inertia. The BAW post needed a large cable hole to suit the current end terminal design (See Fig. 4 & 5).

After the initial design, there were several design reviews based on the following additional information:

- Smallest section dimensions would need to be greater than 125mm to provide sufficient soil resistance and torsional rigidity
- Yield strength changed from 350 to 450MPa to reflect the more common availability of the higher grade steel in the relevant section sizes.

Both of these reviews led to stronger sections and the necessity for larger slots in the posts.

Failure dynamics were harder to predict for these thin post sections than for solid sections. Buckling of the section wall would lead to a lower breaking force. Conversely, the yield strength of the material would be higher than the rated value for quality reasons, leading to a higher breaking force. Therefore the overall behaviour of the posts had to be investigated through destructive testing.

## 4.0 Testing

Pendulum testing was the most practical and useful method for testing the new posts, because the energy of the impactor could be easily controlled based its initial height. The option of setting up a local testing rig was investigated. A suitable 1-tonne impactor was sourced from Curtin University (see Fig. 6). An investigation was conducted into the feasibility of setting up a local test-rig inside a MRWA building in Welshpool (See Fig. 7).

However, this option was rejected on cost and practical grounds in favour of using the existing pendulum facility at the Centre for Advanced Structural Engineering, University of Sydney. The author supervised the first two days of testing.

### 4.1 Apparatus

The pendulum used in the testing is shown in Fig. 8. It has a mass of 2.5t and is suspended 5.2m from the floor. An overhead crane (Fig. 12) winched the pendulum until it was almost horizontal. Its speed at impact was 8m/s or 29km/h.

The posts were held in place by a clamp as seen in Fig. 9. The radial and tangential acceleration of the impactor was measured by accelerometers, one of which is shown in Fig. 10.

Two infrared sensors underneath the pendulum were used to

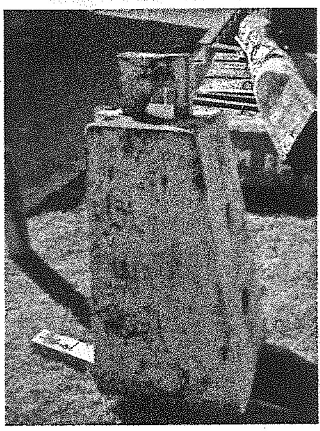

**Fig. 6 – 1 tonne impactor**

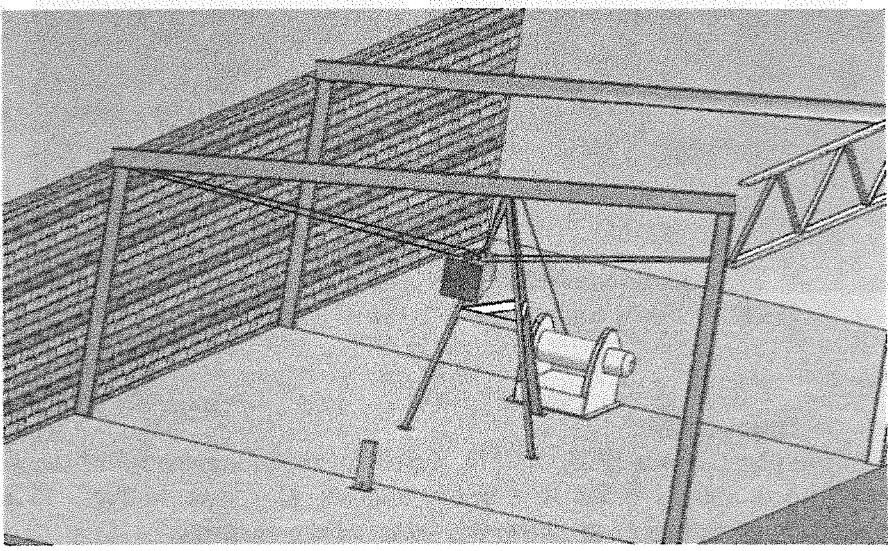

**Fig. 7 – Concept drawing of proposed impact testing set-up**

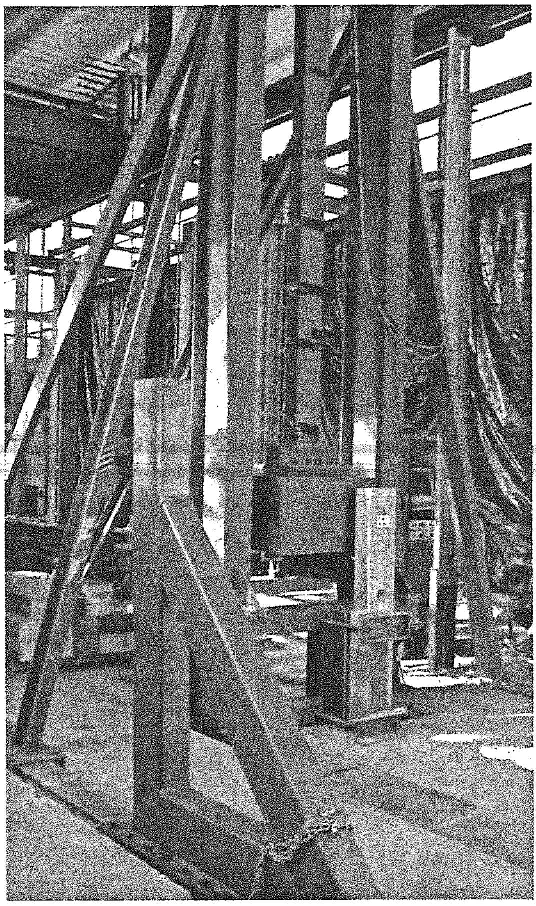

Fig. 8 – Pendulum impact tester

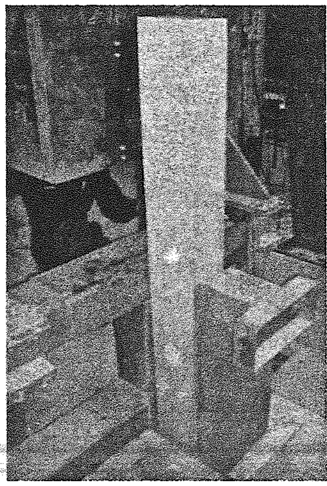

Fig. 9 – Post in position for testing strong axis

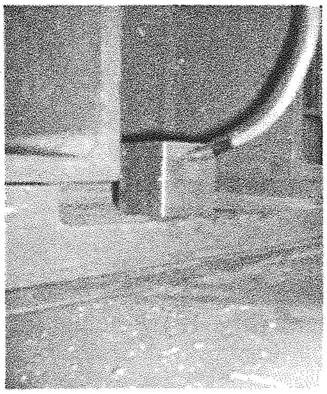

Fig. 10 – Accelerometer

measure the impact velocity (see Fig. 11). A high-speed video camera (capturing at 500 frames per second) was used to record the impact dynamics and to measure the pendulum speed before and after impact.

Photographs of each specimen were taken after impact, showing the failure mode.

## 5.0 Results

The numerical results of the pendulum tests are yet to be analysed. The data from the accelerometers must first be calibrated against the acceleration of the pendulum during a "free swing" with no specimen to impact. The results of the high-speed camera must be analysed to determine the velocity of the impactor before and after impact, thus determining the energy absorbed by the post. This can be done by measuring the distance the impactor moves in the photograph relative to the known dimensions of the post.

However, discussion can be made regarding the photographic results presented in this paper.

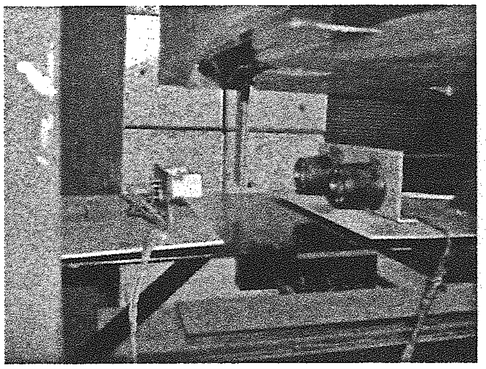

Fig. 11 – Velocity sensor

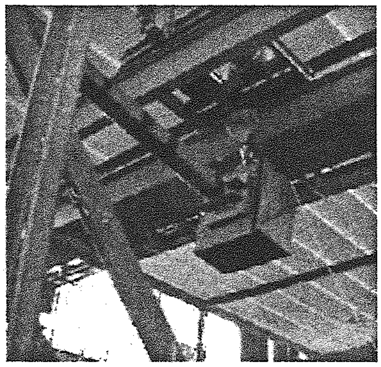

Fig. 12 – Pendulum before release

## 6.0 Discussion

From the photographs (Figs. 13-17), the different failure modes of the posts can be observed. The timber posts always failed in a brittle manner, as shown in Figs. 13 and 15. This behaviour is common to all timber posts due to the nature of the material.


Fig. 13 – High speed timber post impact photo


Fig. 14 – High speed steel post impact photo

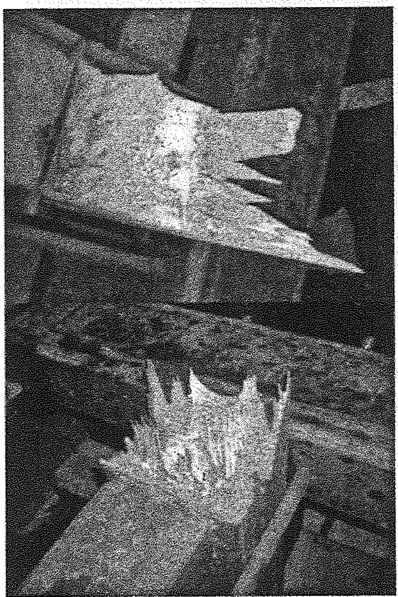

Fig. 15 – Timber post failure mode

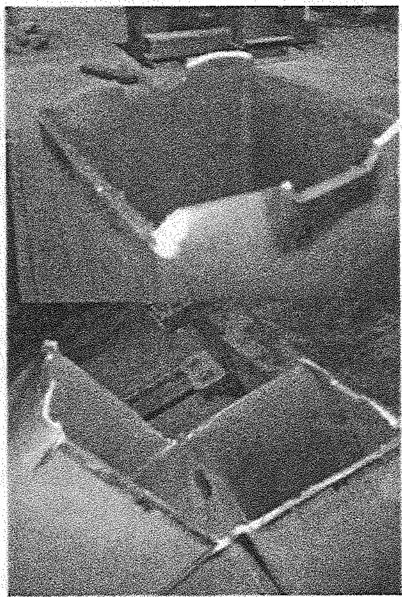

Fig. 16 – Brittle steel post failure

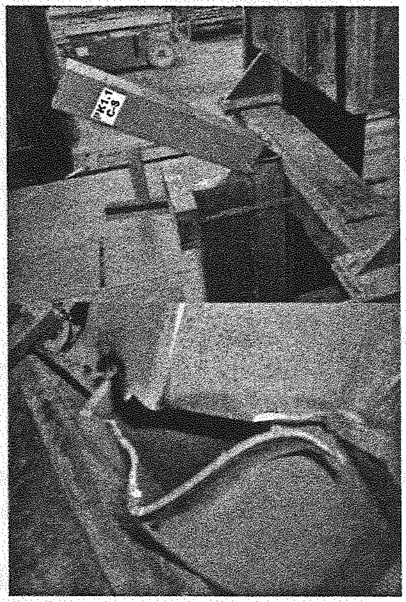

Fig. 17 – Combined ductile/brittle steel post failure

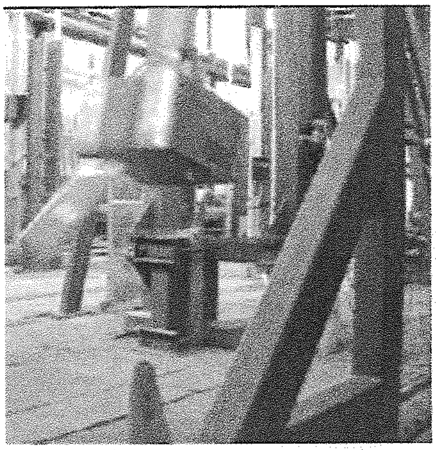

Fig. 18 – Timber post impact

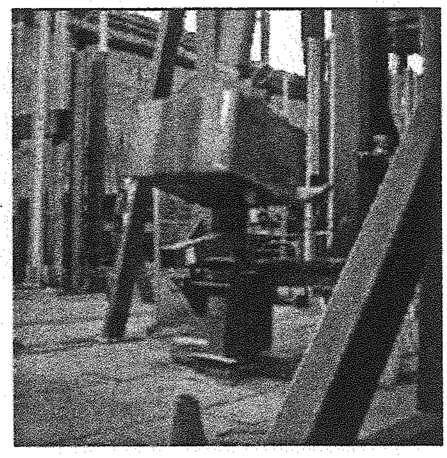

Fig. 19 – Steel post impact

The steel posts however, failed in a number of different ways. Some failed in a brittle manner, as shown in Fig. 16. Of these posts, some broke off cleanly, while others exhibited predominantly brittle failure with plastic deformation about a "hinge", as shown in the lower image of Fig. 16. Other posts failed in a combined manner, exhibiting ductile and brittle failure, as shown in Fig. 17. Here, energy was absorbed by the post as plastic deformation (including plastic buckling) occurred. The failure mode of the steel posts depended on the thickness of the section, the length of the slots, and whether the posts were tested on their strong or weak axes.

The failure mode of the posts is quite an important consideration in evaluating their success as replacement posts. The more brittle the failure, the smaller the obstacle left in the ground after impact. If posts do not break cleanly enough, they have the potential to snag a wheel of the errant vehicle and cause it to roll over.

On the other hand, the more ductile the failure, the more energy absorbed by the posts. Absorbing a certain amount of energy in the post impact is desirable, as this will slow the vehicle down and make any later collisions safer. However if too much energy is absorbed, the occupants of the vehicle will experience high deceleration forces which can be harmful. Therefore, the selection of the final design will involve optimisation of a number of criteria.

## 7.0 Conclusions

The pendulum tests have provided sufficient data to evaluate the breaking force and energy absorption characteristics of the prototype posts. Even if the prototype posts do not satisfactorily match the failure characteristics of the original posts, there is now enough data to extrapolate a final design revision.

## 8.0 References

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Woon, R., Karpinksi, J., Scanlon, J., Fisher, J. 2003, *Review Report and Investigation into Standard Safety Barriers, Part 1: Barrier End Treatments*, MRWA, Perth, Australia