An Analysis of Less Hazardous Roadside Signposts

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1 Abstract

This work arrives at an overview of requirements necessary to provide survivable impacts between a range of motorcars and energy-absorbing poles stand-up poles. Poles that are expected to remain upstanding after a crash. The requirements are for the space, forces and the energies that have to be dealt with in the development of such poles. The methods used include a validated force-intrusion model derived from full scale tests and the finite element crash simulation package LS-DYNA. These were used to estimate the intrusion into cars and the crush into the pole necessary to limit the car's accelerations. Solutions were sought that provide a maximum acceleration of 20g at the centre of mass of cars impacting onto poles from 60 km/h.

2 Introduction

It is possible to reduce the risks associated with rigid roadside poles or posts to motor car traffic by replacing them with either break-away or wrap-around energy-absorbing poles. In all these three types of poles represent extremes in the range of properties that can be expected from poles when impacted by cars. There is a need for a fourth type, one that is capable of absorbing a significant amount of energy, while remaining reasonably upright after an impact. The usefulness of such a pole would be that it may continue to provide the services that it was intended for after a vehicle has crashed into it, while not adding to the hazards involved by falling to the ground.

In many locations in older cities and towns (including Sydney, which is not old), due to the relatively narrow roads, a significant number of signals and signs have had to be mounted on single rigid steel poles close to carriageways. Furthermore it is unfortunate but very likely that the number of such installations will be added to in the future. This report investigates what opportunities and limitations exist for the application of significantly less hazardous stand-up poles and how they may compare with other expectations.

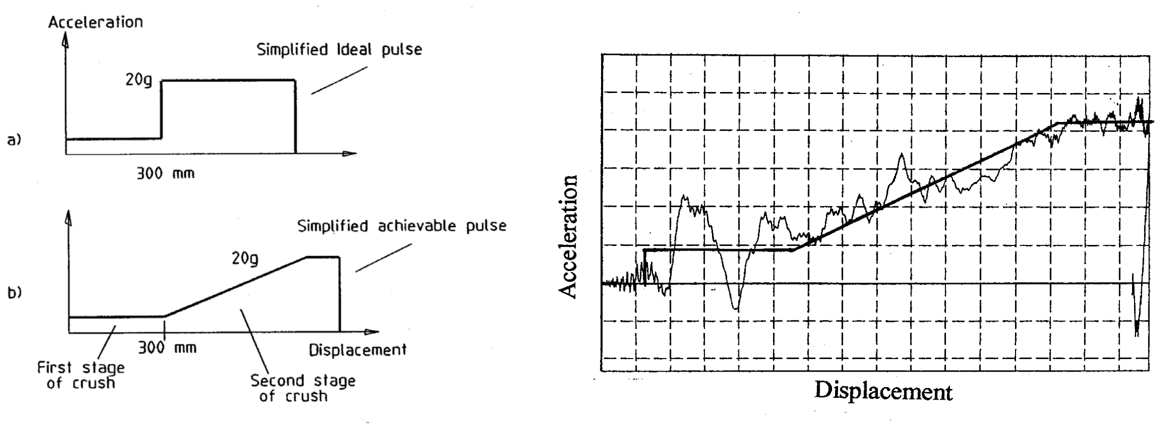
3 Modeling of car-to-pole collisions

D P Wood et al [1] reviewed the results of 202 barrier tests and 19 staged pole impacts and arrived at a mathematical model for some of the principle outcomes. Wood demonstrated that the energy absorbed per unit mass of the cars showed strong correlation to the total mass and dimensions of the cars. They also showed how the volume of the car displaced by the impact is a function of the depth of intrusion and pole diameter. They provided the means of calculating the depth of the intrusion, the resulting forces and accelerations for any impact velocity.

The results reported by Wood showed a distribution about the line of best fit of about ±30%, with the standard deviation being about 15%. This distribution may be viewed as a combination of uncertainty in the modelling and the variation in performance between cars. Nevertheless the results by Wood at this point appear to be practical means of representing the properties of the wide range of cars that currently exist on our roads.

4 A simplified crash pulse

Wood simplified the force-intrusion pulse to just two adjacent rectangles, and referred to these as the first and second stages of the crash. These are shown on Figure 1 a). The first stage generates low accelerations and is the outcome of the soft components ahead of the engine being compacted. This initial displacement is of approximately 300 mm and it absorbs up to about 10% of the total energy. Large oscillations occur in this region, but because of their relatively insignificance in moderate to high energy impacts we continued to represent this region by a rectangle. The high-energy portion of the crash is contained by the second stage and in our calculations we refined its outline from that shown on Figure 1) a to that on 1 b). Energy may be absorbed over the shortest distance if the force is maintained at the highest acceptable level over the whole of the crush depth, which is of course by a rectangular pulse. Unfortunately in practice it has not been possible to maintain the force constant, some of the best practical results show a triangular rise followed by a plateau. Judging from our tests with deformable poles, an achievable pulse is one where acceleration is maintained constant for only about 25% of the high-energy stage. This results in the same maximum acceleration but a displacement that is 60% longer than that for the rectangular pulse. Figures 1 c) presents results obtained using the FEA crash simulation package LS-DYNA [2] of an FEA model of the 1993 Taurus impacting onto a crushable tubular pole.



c)

Figure 1. Simplified acceleration/displacement pulses. a) A rectangular ideal outline, showing the two stages of crush. b) A simplified but achievable outline, with the same energy and maximum accelerations as in a). c) The response from an FEA simulation of a crash between a medium size car and a thin wall tubular pole.

5 Estimates of intrusions and accelerations

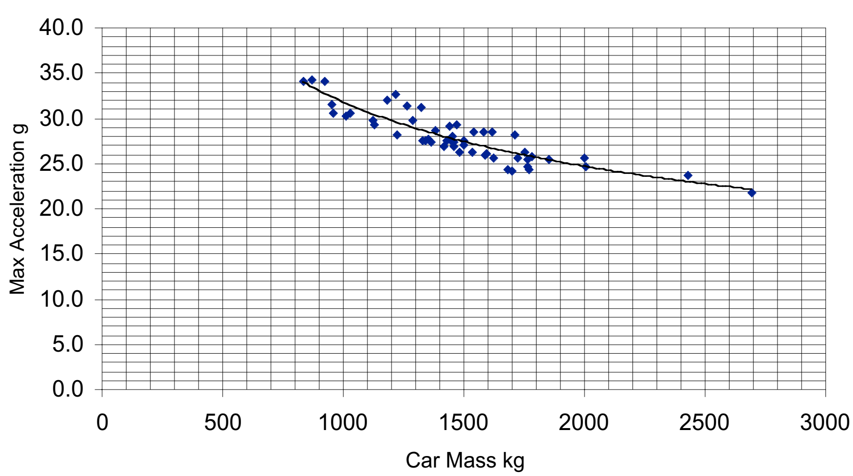


Figure 2 Maximum acceleration versus car mass for impacts from 60 km/h onto a rigid 500 mm diameter pole.

Figure 2 provides a plot of maximum acceleration against car mass for impacts from 60 km/h onto a 500 mm diameter pole. These and other graphs were generated using equations 12 and 13 of Wood's paper and the 'Equation Solver' built into Microsoft Excel spreadsheet. This solver has been developed by Frontline Systems [3] and is incorporated in several computer packages. The data points shown on this and following graphs are the result of applying the weight, width and length of 55 sedans of 10 years of age or less to Wood's analysis. These cars range from the lightest: a Toyota Starlet, to the heaviest: a long wheelbase Rolls Royce. They include Australian as well as overseas manufactured cars. No significant difference could be observed between local and imported cars, or between older and newer cars in this group. On the other hand sport cars and relatively rare and expensive 'personal' cars, because of their high densities, generated points well away from the lines of best fit and were for these and other reasons omitted from this study.

The results arrived at using the group of cars sampled here should be significant but should also be treated as a guide. A more thorough study may weigh any particular car by its numbers on the roads and possibly with its likelihood of being involved in a pole impact.

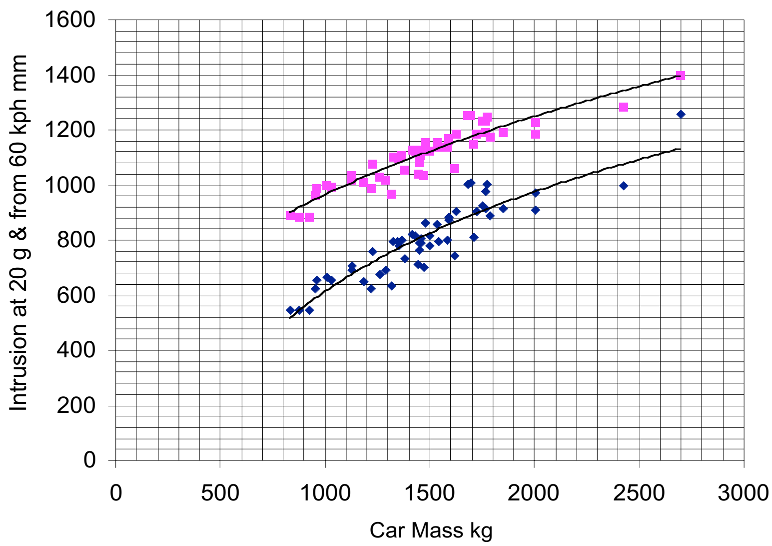


Figure 3, Car-to-pole intrusions for impacts from 60 km/h and intrusion that generate 20 g acceleration.

The upper graph of Figure 3 shows car-to-pole intrusions resulting from impacts from 60 km/h. The lower graph is of the intrusion at the point when 20 g acceleration is reached during an impact from a sufficient high velocity. Figures 2 and 3 show that lighter cars can be expected to be relatively stiffer than heavier ones. An acceleration of 20 g is reached with a shallower intrusion in the lighter cars and the maximum acceleration is almost 100% higher in the lightest cars than the heaviest. A possible explanation is that a larger fraction of the mass of lighter cars is utilised in their structure than may be the case for heavier and more luxurious cars.

6 Collision energy, to be absorbed by the car and pole

Figure 4 shows the collision kinetic energy remaining in the cars at the point when 20 g acceleration is reached, from a 60 km/h impact. The heavier cars had initially double the energy due to their being double the weight of the lighter ones, but had only 40% remaining as opposed to 70% for the lighter cars, when 20 g was reached. We note then that there is about the same amount of energy to be dissipated from the light cars as there is from the heavy cars, but for the lightest cars the resistive force has to be half that for the heaviest cars.

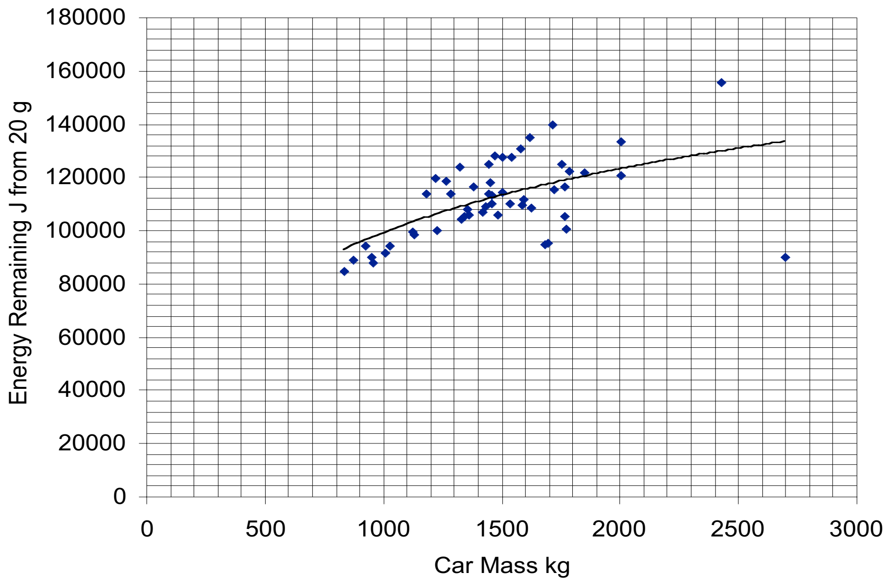


Figure 4. Collision kinetic energy remaining in cars at the point when 20 g acceleration is reached from a 60 km/h impact.

7 Pole matched to each car

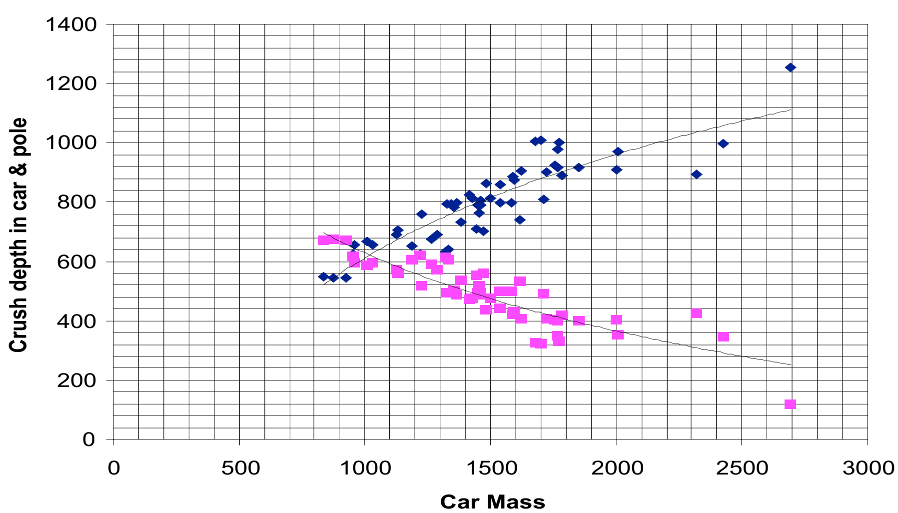


Figure 5. Crush depth in cars that generate 20 g acceleration (upper data points) and displacement required of the poles (lower data) to maintain that acceleration.

The lower graph on Figure 5 provides us with the depth of crush into a pole if the resistance provided by that pole could be precisely tailored to limit the acceleration to 20 g in each car. The upper graph on Figure 5 gives us the crush depth into the cars that generates that maximum acceleration. In all, if we sum the crush into the pole and car this figure provides us with the total crush that ideally suits each car to come to a halt, which is nearly constant at about 1300 mm. If one pole could somehow be made to provide this ideal function for the whole population of cars, then its stiffness would have to be adjusted by the acceleration that it would be subjected to, during an impact. When calculating the data points on Figure 5 the complete crash pulse was presumed to be of the type described by Figure 1 b). This expectation may at first appear to be conservative but as already indicated it has been our experience that it is practically impossible to make a pole or structure that deflects at anything like a constant force.

8 Poles matched to light and medium cars

It seems inescapable that the practical applications of the use of energy absorbing poles necessitate the use of poles that best suit one particular weight of car and is to a variable degree a mismatch to all the others. We will consider here the use of just two poles, one that best suit the lightest cars (840 kg) surveyed here and one for 'medium' cars (chosen to be about 1460 kg). Figure 6 shows the outcomes of using the softer pole. The crush in the cars is about 510 mm (as shown on Figure 3) for the lightest cars and decreases slightly as the weight of cars increases. The displacement of the pole begins at about 630 mm for the lightest cars but becomes very large for the heaviest, up to about 2500 mm. For medium size cars of 1460 kg, the pole displacement is 1600 mm. If the pole were of large diameter initially (say 800 mm) the pole may have remained up-standing after an impact with a very light cars, but its section would have been completely crushed by almost all other cars.

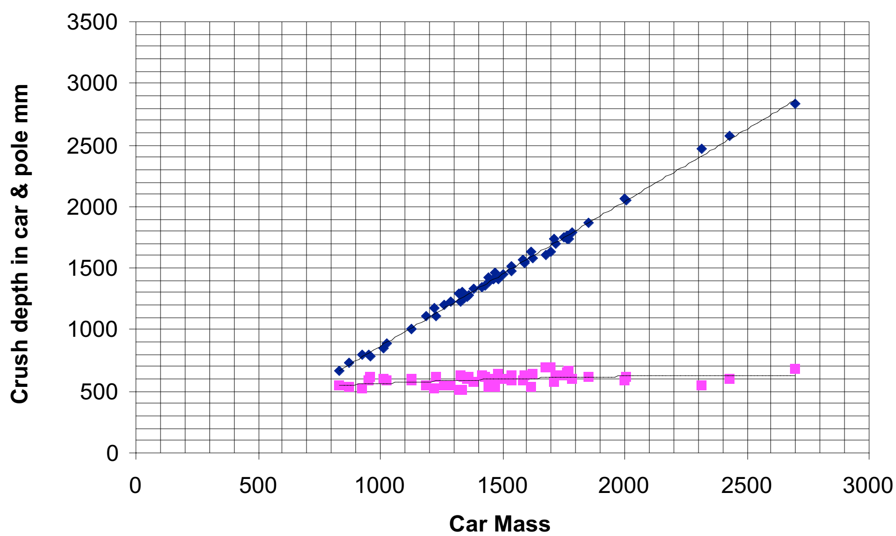


Figure 6. The use a pole that suit 840 kg cars in impacts with the whole population of cars. Pole displacement upper points, car crush lower points.

Figure 6 indicates that even for a car of 1200 kg, which is of quite small mass, the pole crush has to be of the order of 1200 mm. In short, the pole that suits the lightest cars becomes a wrap-around pole to nearly all other cars because it would be brought to the ground by all such impacts. Furthermore, it would be of such limited strength and rigidity that its use to carry signs or signals would find few applications. These observations are repeated for Figure 7, except that the danger here comes from just the heavier cars. A pole that suits mid-range cars would become a wrap-around pole to the heaviest ones. The mid-range poles would nevertheless provide some acceleration reduction to the lightest cars by crushing about 100 mm, but their beneficial effect would be small

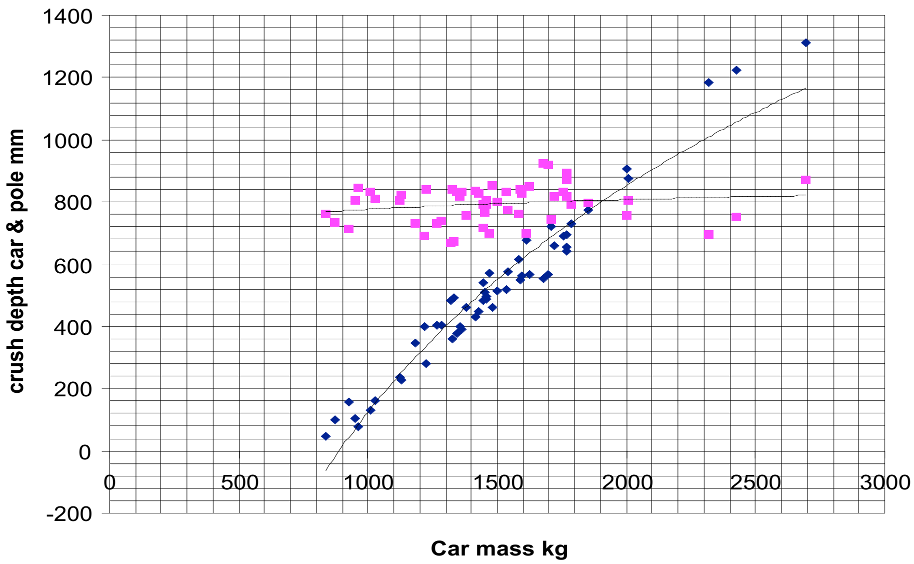


Figure7. The use a pole that suit 1640 kg cars in impacts with the whole population of cars. Car crush is now nearly constant at 800 mm, pole displacement ranges from about 100 to 1300 mm.

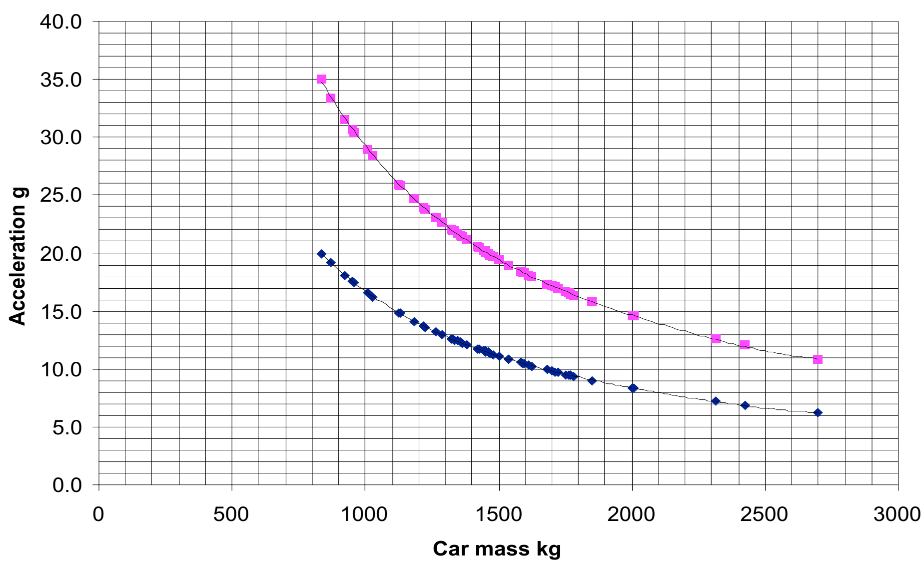


Figure 8. The accelerations that would result for the whole group of cars if either a pole that suits 1460 kg cars were used (upper data points) or for the 840 kg cars (lower data points).

Figure 8 plots the accelerations that would results to the whole range of cars if the light and medium poles were impacted on by all cars. This Figure provides the accelerations that would accompany the crush shown on Figures 6 and 7. The upper curve shows the estimated accelerations if the mid-weight pole were to be used and the lower for the lightweight pole. It is clear that the lighter pole would have beneficial effects to the whole range of cars and that the heavier pole would have only slight benefits to the lightest cars. The problem with the lightweight poles is that they would effectively be wrap around poles, as mentioned in the Introduction our aim is to find less hazardous stand-up poles to replace current rigid steel posts for constrained spaces. These steel posts support large signs and signals that are typically heavy and generate large aerodynamic drag during storms. Although a more complete analysis is out of the scope of this paper, it is clear from Figures 6 and 7 that these posts would have to be meters in diameter if they had to carry their assigned loads *and* limit the acceleration to 20 g in small cars.

9 Discussion and conclusions

The Transport Research Board of the USA in their Report 350 [4] provide guidelines on the tests conditions and required performances for general support structures and breakaway utility poles. These guidelines have for good reasons achieved broad support. They require that when impacted by vehicles with masses of 700 to 2000 kg no more than 20g acceleration be generated. Figure 6 was developed to suit an 840 kg car, and it shows that more than 2 meter displacement would be required to stop the heaviest cars. This crush space can be provided on wide new or refurbished roads (while maintaining the sign off the roadway) but in narrow inner city roads the requirements of Report 350 seem possible to meet with the single post structure considered here.

In the development of less hazardous roadside signposts on tight city roads a number of contrary requirements have to be considered. There is a need for large traffic signs supported high above the roadway. The roadside real estate at times dictates that single posts of considerable strength support these signs. The dangers associated with these posts may be reduced but may not quite be eliminated. There typically is not be the space to replace these signposts with wrap-around posts or to pad them to a sufficient depth with energy absorbing cushions. Since the desirable performance requirements indicated in Report 350 does not seem possible here, then a solution may be to develop crushable poles that will reduce the acceleration as much as may be practical while allowing space for pedestrians and traffic. This approach may not result in reducing acceleration to 20 g even for medium size cars at the most restricted locations, but should result in a significant hazard reduction.

10 References

1. Wood, D. P., Doody, M., & Moomey, S., "Application of a Generalised frontal Crush Model of the Car Population to Pole and Narrow Object Impacts". SAE paper 930894, Society of Automotive Engineers, 1993.

2 LS-DYNA, Livermore Software Technology Corp, 2876 Waverley Way, Livermore, CA 94550.

3 Frontline System Inc. 1999. http://www.frontsys.com/.

4 Report 350, "Recommended Procedures for the Safety Evaluation of Highway features", National Cooperative Research Program, Washington, D.C., 1993.