Results of a full-scale crash test into an energy absorbing lighting pole on a sloped roadside.

Derbyshire A.C., Queensland Department of Main Roads,
Troutbeck, R., Queensland University of Technology.

Abstract

This paper presents the results of a full-scale crash test into an energy absorbing lighting pole situated on an unlevel or sloped roadside. With poles representing approximately one third of single vehicle accidents involving roadside objects it is important to ascertain the performance of luminaire supports in the Australian road environment. Operational performance of some pole types in unlevel road environments seriously diminishes the safe and predictable performance of lighting poles.

This research utilises a full-scale crash test with an instrumented vehicle and dummy to determine performance of the pole. Analysis of the data acquired during the test was conducted to determine the performance of the appurtenance and effect of an unlevel roadside on the test outcome. The test results suggest that the test article is suitable for use on Australian roadsides, particularly sloped roadsides, pending some minor changes to the design. The study is limited to one full-scale test due to the inherently high cost of full-scale destructive testing. It is recommended that further testing of Australian poles be conducted to allow the refinement of Australian appurtenances making Australian roads more forgiving, reducing the number of lives lost each year in Australia due to road crashes.

Keywords

Full-scale pole crash test, energy-absorbing pole, unlevel roadside, pole impact, roadside furniture

Introduction

Based on the massive social cost of road crashes on the Australian community it is necessary to improve the safety of Australia's road network by undertaking focused road safety initiatives such as full scale roadside furniture testing. Single vehicle run-off-road incidents with lighting poles contribute to a large proportion of road fatalities and therefore light poles are the focus of this research. Due to the poor in-service performance of slip base poles in unlevel road environments it is necessary to test in a manner that simulates an impact under these conditions. Energy absorbing poles have considerable performance advantages and thus were selected as the test article for this research. Also, with the emergence of new vehicle fleet characteristics it is necessary to develop understanding of safety feature performance.

Research objective

The objective of this research is to investigate the effectiveness of an energy-absorbing pole in an unlevel roadside environment.

Background

The rationale for testing an energy-absorbing pole is based on the operational ineffectiveness of slip base poles in unlevel roadside environments. Slip base poles are currently used extensively throughout Queensland in preference to energy absorbing poles. The disadvantage of using slip base poles is attributed to:

1. Reduced frangibility when impacted above the normal design height,
2. Reduced frangibility due to poor installation such as a buried or elevated slip plane,
3. Ineffective in low speed collisions where the falling column may penetrate the vehicle,
4. Increased decelerations for low mass vehicles,
5. Failure to contain the impacting vehicle,
6. Clamping or walking of the slip base connection, and
7. Represent an electrocution hazard if they fall on power lines.

Testing was conducted in accordance with the NCHRP report 350 guidelines with modification to the recommended procedure to incorporate the effects of an unlevel road environment. Due to the necessity for poles to be adjacent to the roadside for effective illumination they are often installed on the verge of fill slopes. Calculations were made to assess a typical range of increased impact heights. A test height of 600mm above the normal impact height that would occur on a level grade was selected based on an investigation of typical roadside topography and application of simple kinematic equations.

Investigation of crash testing literature resulted in the observation that there is a lack of Australian expertise involving the testing of roadside safety features. There was no background to the performance of Australian appurtenances on verges. Investigation of vehicle safety is well developed although; a distinct absence of appurtenance testing in recent times was noted. Changing passenger vehicle characteristics has created the climate for ongoing testing of safety features. The trend towards smaller passenger vehicles has heightened safety concerns for vehicles imp acting roadside appurtenances.

Pole testing has been primarily conducted from the mid seventies to early eighties by American testing facilities. The testing was conducted using early standards that are predecessors of the current testing standard NCHRP350. Specific reference to changed performance of slip base poles due to operational characteristics was an important aspect for the range of tests. Design of effective slip base poles must consider the actual characteristics of the test article surroundings. Breakaway joint height is important as the impact point of the vehicle governs the effectiveness of the slip base. Issues of slopping approaches and snagging of the root is of direct interest as it has the potential to undermine the vehicle fuel integrity and diminish the ability of the fixture to be repaired.

Testing method

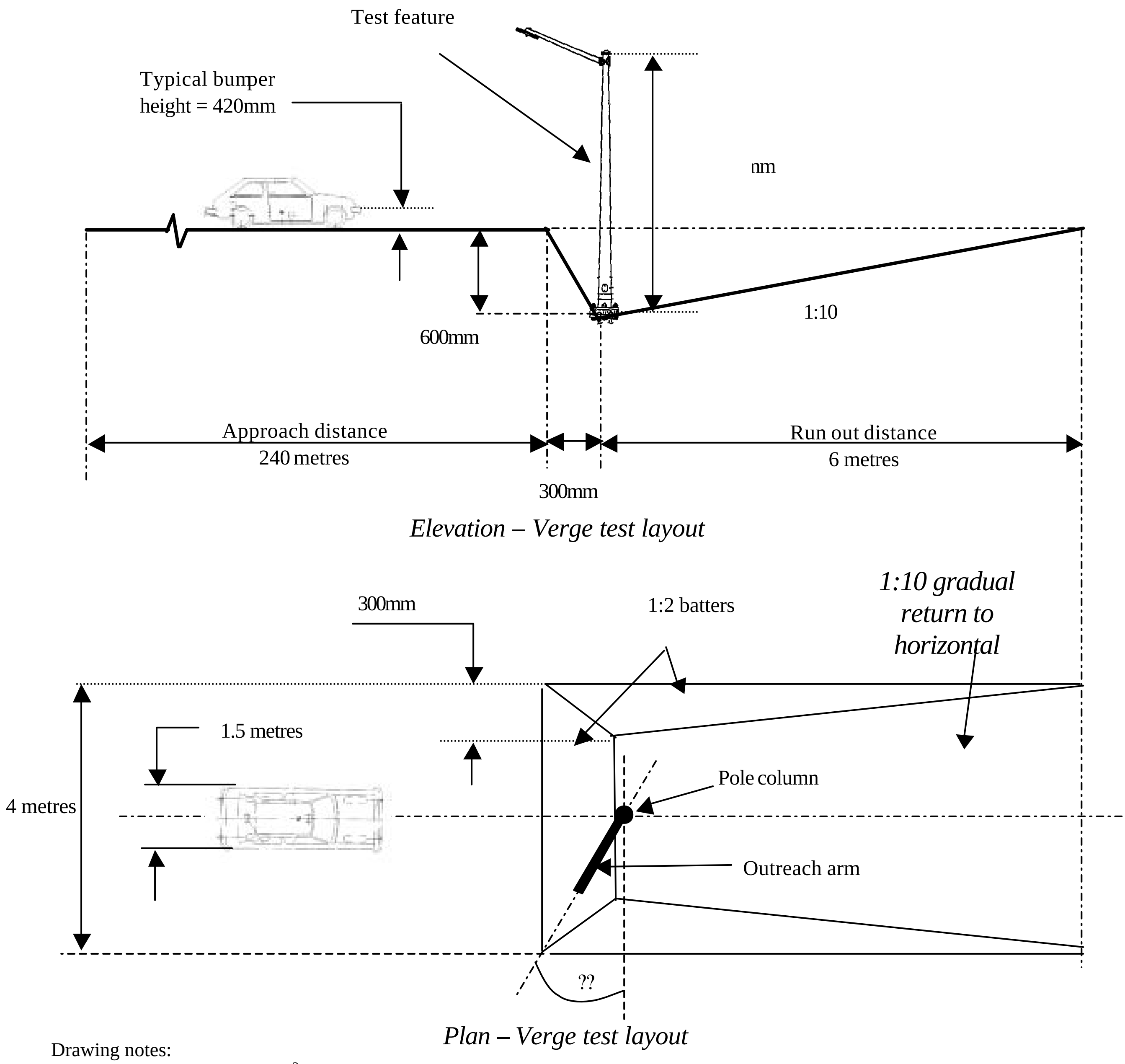
The testing method uses a cable and breakaway steering attachment to guide the test vehicle. Acceleration involves a tow vehicle and cable connected to the test vehicle using a breakaway tow connection, allowing disconnection prior to impact. The tow vehicle is capable of accelerating a 2 tonne mass to 100 km/h. A radio controlled braking system was developed to arrest the vehicle in case of emergency. The system employs a radio modem, maintaining a real-time link between the base station and the test vehicle. The brakes are applied using pressure from an onboard compressed air reservoir. The system incorporates fail-safe features to ensure that the vehicle is arrested reliably. Development and refinement was undertaken to ensure that the method was repeatable and safe.

Testing arrangement

The testing arrangement shown in Figure 1 was designed to provide an increased impact height of 0.6 metres above the normal bumper height. It places the 8.5 metre energy absorbing luminaire support a short distance (300mm) from the level test approach to ensure an accurate impact height. The centreline of the pole was aligned with the centreline of the vehicle. The pole was placed at the bottom of the test verge, 600mm below the level approach surface. A run out batter of 10:1 was used to return the vehicle to the natural surface. Compacted batters of 1:2 were placed around the vehicle entry area. Compaction of the faces was necessary to ensure that the vehicle did not undermine the verge hinge as it left the level approach. Ample space on either side of the vehicle was provided to ensure no secondary impacts with the surrounding cut slopes occured. An exit angle of 20 degrees was adopted in accordance with recommended procedures detailed in NCHRP report 350. The angle marked ? in Figure 1, represents the orientation of the pole in a typical roadside situation. An approach distance of 200 metres was adopted to accelerate the vehicle to a test speed of 70 km/h.

Test vehicle and instrumentation

The vehicle was a 1999 Toyota Echo four-door hatch back. The vehicle had a gross static mass of 868 kilograms. An instrumented dummy was included in the test for demonstration purposes. The test vehicle was instrumented using a triaxial piezoresistance accelerometer placed near the vehicle's centre of gravity to measure longitudinal, lateral and vertical acceleration levels. Three solid-state angular rate transducers were situated near the centre of gravity to measure the yaw pitch and roll of the test vehicle. The electronic signals that were produced were stored in an onboard data acquisition unit, which is a proprietary product known as a "MiniDAU" or Mini Data Acquisition Unit. The MiniDAU stores up to 20,000 samples per second per channel of input. The unit stores up to 30 seconds of data depending on the sample rate. An accurate time reference signal was recorded with the data for analysis purposes. Pressure sensitive tape was used on the bumper of the test vehicle to produce an event mark on the data log to establish the exact moment of impact with the pole.



Drawing notes:

1. Approximately 10 m^3 of soil was excavated for the construction of the test verge.
2. The angle ? should be 20 degrees and reflects the orientation of the pole, as it would be relevant to an errant vehicle leaving the roadside at 20 degrees.
3. The release point of the steering mechanism was positioned as close a practically possible to the edge of the verge.

Figure 1 Testing arrangement

Observations

The test vehicle was steered effectively into the test feature at the designated design speed of 70 km/h. The guidance system breakaway released the test vehicle with no detectable influence on the vehicle stability or path prior to impact. No damage was sustained to the testing apparatus. Tow cable disconnection was effective with no detectable effect on the test vehicle stability. The tow cable was disengaged effectively with no fouling or damage sustained to the direction changer. The final position of the test vehicle, pole and luminaire was shown in Figure 2.

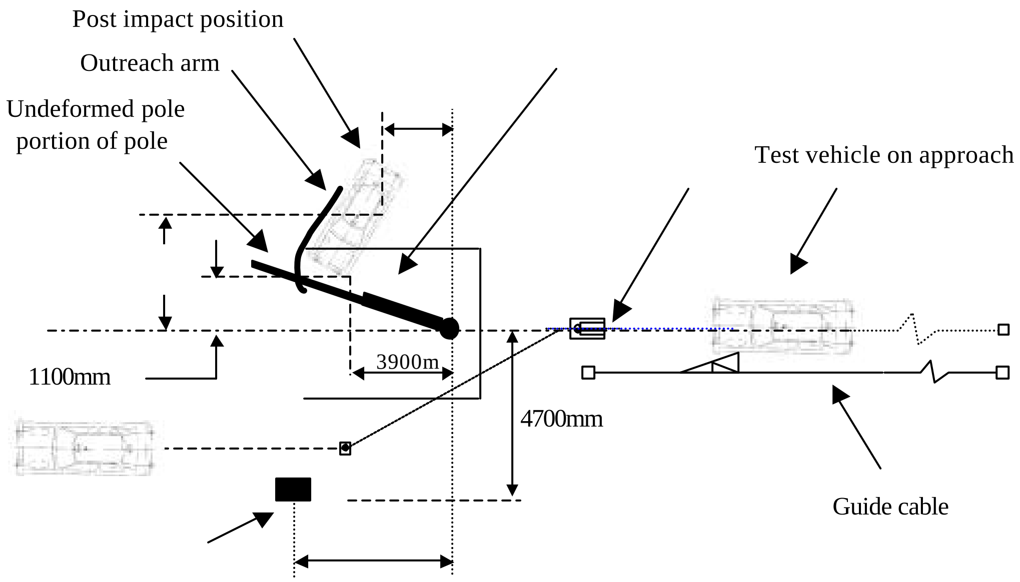


Figure 2 Post-impact position of test vehicle

Crash footage demonstrated that the vehicle was unstable during the collision, primarily due to the influence of the verge arrangement. After the frangible portion of the pole had been deformed, the front of the vehicle snagged on the return grade, lifting the rear of the vehicle. An angle of approximately 60 degrees between the undercarriage and level ground resulted. Airbags were not activated by the collision. During the collision the outreach arm and luminaire broke free and landed in the position shown in Figure 2. The outreach arm impacted the ground, and underwent considerable movement before coming to rest. The arresting properties of the pole were apparent with the vehicle coming to rest a short distance from the impact point. The post collision position of the vehicle is shown in Figure 3.

Figure 3 Final position of test vehicle

Data analysis and assumptions

The data was processed using a software package called the Test Risk Assessment Program (TRAP) produced by the Texas Transportation Institute (TTI). The software was used to calculate the following injury quantities:

?? Occupant to compartment impact velocity
?? Time of occupant compartment impact
?? Highest 10-ms average ridedown acceleration

Injury quantities were calculated from data measured using accelerometers near the test vehicle's centre-of-gravity and are based on the flail space model, assuming a simplified point mass acting under vehicular accelerations is free to travel forward and laterally distances of 0.6 and 0.3 metres respectively. This is based on a series of assumptions, as follows (NCHRP350):

?? Occupant positioned at the centre of mass
?? Lateral and longitudinal motions were evaluated independently
?? Vehicle and occupant motions are planar (x-y)
?? The allowed occupant movement is based on an idealised interior such that the prescribed displacements result in an occupant impact

Results and discussion

Structural Adequacy Evaluation Criteria for crash cushions were used in place of regular pole requirements due to recommendations contained in NCHRP350 (Section 3.2.3) for energy absorbing pole tests. Table 1 describes the relevant structural adequacy evaluation criteria and the result obtained.

Table 1 Structural adequacy criteria for energy absorbing pole

Structural Adequacy Evaluation Criteria			
NCHRP350 Type C Criteria	Acceptable test article performance may be redirection, controlled penetration, or controlled stopping of the vehicle.	The pole displayed controlled stopping characteristics	Pass

Occupant risk evaluation criteria that apply to this test were types D, H, I and J (NCHRP350, 1996). The result of these evaluation criteria is given in Table 2.

Table 2 Occupant risk evaluation criteria

Occupant Risk Evaluation Criteria					
NCHRP350 Type D Criteria	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could case serious injuries should not be permitted.			The detachment of the outreach and luminaire represent a hazard.	Conditional pass
NCHRP350 Type H Criteria	Occupant Impact Velocity Limits				
	Component	Preferred	Maximum	Result	
	Longitudinal and Lateral	9	12	7	Pass
	Longitudinal	3	5	-0.6	Pass
	Occupant Ridedown Accelerations Limits				
	Component	Preferred	Maximum	Result	
	Longitudinal and Lateral	15	20	11.3	Pass
NCHRP350 Type J Criteria	[OPTIONAL] Dummy of type hybrid III should respond in a manner that conforms to Code of Federal Regulation			Not applicable. Included for demonstration purposes only.	TBA

Evaluation criteria D resulted in a conditional pass. This was due to the detachment of the outreach arm and luminaire. Although neither component penetrated the cabin of the vehicle, this behaviour had the potential to injure the occupants or vulnerable road users such as pedestrians or cyclists that may be in the area during the time of impact. An unconditional pass would be dependant on the pole design being revised such that luminaire and outreach were less probable to release, however it is recognised that the test conducted is not a standard test due to the introduction of the verge. The Occupant Impact Velocity Limits and Ridedown Accelerations Limits were satisfied suggesting that energy absorbing capabilities and frangibility characteristics of the pole were satisfactory.

Post-Impact Vehicular Trajectory was satisfactory with the test vehicle travelling a short distance of 4 metres from the impact point. Vehicle trajectory behind the test article is acceptable for support structures. The result and criteria is shown in Table 3.

Table 3 Post-Impact vehicular trajectory criteria

	Post-Impact Vehicular Trajectory	
NCHRP350 Type K Criteria	After the collision, it is preferable that the vehicle's trajectory does not intrude into adjacent traffic lanes.	Pass
NCHRP350 Type N Criteria	Vehicle trajectory behind the test article is acceptable	Pass

Conclusion

The performance of the pole was satisfactory according to the evaluation criteria contained in NCHRP350. The detachment of the luminaire and outreach arm was an area of concern to the overall performance of the appurtenance. Detachment of elements could represent a danger to pedestrians or motorists, particularly if the pole is situated in urban areas. A conditional pass applies considering that the pole was tested on a verge arrangement.

Recommendations

The following recommendations are made:

- ?? The energy-absorbing pole should be refined to ensure that the luminaire and outreach arm remain attached,
- ?? Energy-absorbing poles should be selected in preference to slip base poles for unlevel roadside applications, and
- ?? Incorporation of testing requirements into the Australian pole standard, to insure tested and reliable appurtenances are used in Australia.

Acknowledgments

The authors would like to acknowledge the following bodies/persons for making this research possible:

- ?? School of Civil Engineering at the Queensland University of Technology;
- ?? Ross Dal Nevo and Colin Jackson and RTA Crashlab;
- ?? Motor Accident Insurance Commission; and
- ?? Queensland Department of Main Roads.

References

Transportation Research Board, 1994, Recommended Procedures for Safety performance Evaluation of Highway features, NCHRP report 350, Washington, D.C.