Title: Provision of Sight Distance around Concrete Barriers and Structures on Freeways and Interchanges

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Abstract

Use of 1.1m high concrete barriers at both median and outer shoulder edges of freeways is common in Australia. Use of such barriers is also common on interchange ramps on or under structures. Where curved ramps form an overpass of a major road or a road crosses a rail line, 1.4m high concrete barriers and larger are used.

The provision of normal stopping sight distance criteria around these concrete barriers and other structures such as bridge abutments and retailing walls on horizontal curves (and on combinations of horizontal and vertical curves) can lead to very wide shoulders being required. This can have ramifications with decreased barrier performance. Previously, such shoulder widths were often considered uneconomical and only narrow shoulders were provided. This was either based on some artificially low design speed, or even worse, by ignoring the sight distance requirements altogether and simply providing what was considered to be 'practical'.

This paper discusses new criteria for the provision of sight distance around barriers and structures, as documented in the 2009 release of the Austroads 'Guide to Road Design Series'. This series forms the primary road design guides for Australia and New Zealand. The new criteria achieve practical, yet justifiable results by:

- Using the current stopping sight distance models to provide stopping to likely hazards (in most cases)
- Using less conservative, but realistic values within the stopping sight distance model based on the results on international and Australian research
- Ensuring supplementary manoeuvre capability, including minimum shoulder widths, for avoiding smaller objects
- Being based on the predicted operating (85th percentile speed) on each geometric element
- Considering sight distance capability for both cars and trucks

Provision of Sight Distance around Concrete Barriers and Structures on Freeways and Interchanges

INTRODUCTION

The purpose of this paper is to describe the development and use of practical, yet justifiable criteria for the provision of sight distance around concrete safety barriers and structures (eg bridge abutments and retaining walls) on freeways and interchanges. These criteria are documented in Part 3 of the 2009 release of the Austroads 'Guide to Road Design Series' (GRD) (*1*), the primary road design guides for Australia and New Zealand.

BACKGROUND

Concrete barrier heights of 1.1m and 1.4m are commonly being used in Australia on freeways and at interchanges. The normal stopping sight distance model in Part 3 of the GRD (*1*) (and previous Austroads publications) requires a driver of a passenger car with a 1.1m eye height to see a small object on the roadway of 0.2m height. On horizontal curves (or on combinations of horizontal and vertical crest curves), such a line of sight is normally not possible over concrete barriers. Nor is a line of sight to the taillight of a passenger vehicle of 0.8m height often achievable. In these cases, application of the normal stopping sight distance model requires the line of sight to be fully contained within the trafficable lane and shoulder.

The following situations also require the line of sight to be fully contained within the trafficable lane and shoulder on horizontal curves:

- Retaining walls of significant height
- Tunnels
- Bridge structures eg underpasses, abutments and piers

In areas where it is not possible to provide the normal stopping distance criteria over roadside safety barriers and structures, it is preferable to increase the horizontal curve radius or the offset as per AASHTO (*2*). However, increasing the horizontal curve radius on ramps will usually increase the operating speed. This means that much larger horizontal curves are usually required before the offset is significantly reduced. Further, in constrained areas, increasing the curve radius is difficult due to financial costs and social/ environmental impacts resulting from land resumptions.

In Australia in recent years, there has been increasing pressure to ensure road designs are suitable for trucks. In fact, since 2009, the design of all new roads should now cater for the requirements of trucks (*1*). When applying the normal stopping sight distance model, this means that truck drivers with a 2.4m eye height have sufficient distance to perceive/react and stop for a 0.2m high hazard on the roadway.

Over crest vertical curves, the normal stopping sight distance requirements for passenger cars in many cases provide sufficient sight distance for trucks. Although trucks take a longer distance to brake compared to a passenger car, their higher eye height over crests usually compensates for this. This is not the case for sight distance on horizontal curves where the higher truck eye height is usually of no advantage. Experience has shown that application of stopping sight distance for trucks on horizontal curves on ramps means that an additional offset of up to 4m is required over that for cars.

Prior to the release of the GRD (*1*), the provision of stopping sight distance around concrete barriers and structures on freeways and interchanges has varied within Australia. Some designers have insisted on strictly applying the normal stopping sight distance model, others have disregarded sight distance requirements altogether whilst many have simply assumed a lower design speed. Each of these techniques are discussed below, along with potential problems that each causes.

TECHNIQUE NUMBER 1 - APPLY THE NORMAL STOPPING SIGHT DISTANCE MODEL

Application of the normal stopping sight distance model around concrete safety barriers and structures often results in very wide shoulders being required, especially when allowing for trucks. An example of this is shown in Figure 1 where a horizontal curve radius of about 550m is used in combination with a crest vertical curve at the Bernera Road Interchange on the Sydney ring road. The road is of freeway standard with dual carriageways and two 3.5m lanes in each direction. Typically on the straighter sections of this freeway, the kerbside and median shoulders are 2.5m and 1m respectively. This motorway is controlled by variable speed limits with a maximum posted speed limit of 100km/h.

Part of this geometry is on structure and roadside barriers have been installed to protect vehicles from falling over the overpass. Significant sight distance widening is used on this element (shoulder width = 7.25m). The sight distance widening was based on truck stopping sight distance to downstream hazards.

Such application of sight distance, however, has the following negative effects:

- Drivers parking their vehicles (both cars and trucks) in the widened area, creating obstructions to sight distance for drivers in the traffic lanes
- Construction cost of providing the widened area becomes prohibitively expensive, especially when on or under structures
- Additional resumptions may be required (particularly in urban areas), which may not be politically or socially acceptable.

In addition to these effects, AASHTO (*2*) advises against using shoulder widths above 3.6m because of the concern that drivers will use the shoulders as passing or travelling lanes.

FIGURE 1 Sight Distance Widening on the Sydney Ring Road

TECHNIQUE NUMBER 2 - DISREGARD SIGHT DISTANCE REQUIREMENTS

In recognising the negative effects of applying the normal stopping sight distance model (as discussed above), some designers have disregarded sight distance requirements altogether. In some instances in Queensland, shoulder widths as low as 0.5m have been constructed. This has usually occurred in extremely constrained areas where designers have had no scope to achieve the normal stopping sight distance (which would require much greater shoulder widths, generally >3m). These designers have made no attempt to achieve any sight distance capability and have designed locations of extremely poor visibility. In these situations, the offsets provided are usually based only on what is considered to be practical and cost effective.

The negatives of this technique are the potential for increased accident rates given the very small amounts of sight distance provided. This would only be an issue if reductions in sight distance do indeed increase accident rates. When reviewing literature on this subject, it was seen that there have been numerous attempts at linking stopping sight distance and accident rates for midblock sections of roadway. Table 1 shows the results of a literature review by McLean et al (*3*). Many of the studies investigated restrictions to sight distance due to crest vertical curves on rural roads.

TABLE 1 Results of Studies Linking Stopping Sight Distance to Accident Rates for Midblock Sections of Roadway from McLean et al (*3*)

Study	Result	Effect on Accident Rates by Decreasing Sight Distance
Choueiri et al (*4*)	Suggests that accident rates are higher with low sight distances but change little when the sight distance exceeds 150m to 200m.	Increase
Olson et al (*5*)	The accident rate on low sight distance crests (36 – 94m long) was 50% greater than on high sight distance crests (over 215m long) for operating speeds between 90 and 100km/h.	Increase
Fambro et al (*6*)	Small increase in accident frequency with decreasing sight distance below 100m and negligible change with increasing sight distance above 100m.	Increase
Iyinam et al (*7*)	A 50% increase in accident rate for sight distance decreasing from 500m to 100m.	Increase
Elvik and Vaa (*8*)	Cited two studies (Danish and British). Both suggested that increasing sight distance from less than 200m to more than 200m leads to a 23% higher accident rate	Decrease (2 studies)

From Table 1, it can be seen that there is no strong, consistent result between studies linking sight distance to midblock accidents. All that can be deduced from Table 1 is that the number of studies indicating that a reduction in sight distance will increase accident rates is double the number indicating that a reduction in sight distance will reduce accident rates.

A review of accident reports on Queensland freeways in the vicinity of interchanges shows that the following accident types are quite common:

- Rear-end type and side swipe accidents with vehicles stopped due to traffic congestion or accidents
- Accidents involving vehicles hitting objects fallen from vehicles (especially trucks).

Providing some minimum level of sight distance on freeways and at interchanges may well be more important than for midblock sections of rural roads because of the increased exposure to hazards (stopped vehicles and fallen objects). Therefore, studies relating sight distance to accident rates on freeways and at interchanges may yield stronger results than those for midblock sections of rural roads given in Table 1.

Arndt (*9*) found a link between sight distance and rear-end vehicle accidents on the major road (the road with priority) at unsignalised intersections where a through vehicle collides with a turning vehicle. Almost all of these accidents occurred to right turning vehicles (equivalent to left turning vehicles in the USA and much of Europe) where there was no turn slot provided. Reduced sight distance was found to increase accident rates, particularly when the sight distance was less than about 150m for through speeds of 100km/h. In this type of accident, the turning vehicles (often stationary) are basically regular hazards on the through roadway.

In locations where extremely poor sight distance has been provided, the authors have observed some drivers actually reducing their speed from what they would normally choose for such a horizontal curve. This is likely to be due to the perceived risk of encountering a downstream hazard on the roadway. In itself, this reduction in speed may not cause any accident potential. However, there are some drivers that do not slow down in the absence of insufficient visibility. This behaviour may well increase accident potential, especially in areas where hazards are more likely (for example, where there are queued vehicles).

It is considered that the evidence given above (although only anecdotal) is sufficient to justify why sight distance requirements should not be ignored completely.

TECHNIQUE NUMBER 3 - ASSUME A LOWER DESIGN SPEED

In an attempt to provide a practical amount of sight distance around roadside barriers and structures, many designers have applied the normal stopping sight distance model by assuming an artificially low design speed. Such practice is common around the world as identified in the following examples:

- AASHTO (*2*) recommends reducing the design speed as an option when sufficient stopping sight distance is not available because a railing or longitudinal barrier constitutes a sight distance obstruction. It is unclear what constitutes a reduction in the design speed ie whether or not this entails simply assuming some artificially low design speed. It certainly does not provide any guidance on how such practice provides sufficient driver capability to avoid/evade hitting objects on the roadway when sight distance less than the normal values are provided.
- Clause 2.10 of Part 1 of Section 1 of Volume 6 the United Kingdom Department of Transport 'Design Manual for Roads and Bridges' (*10*) states that sight distance to the tops of vehicles (1.05m object height) will be obtained over parapets or safety fences or safety barriers. On Band A roads meeting this criterion, the stopping sight distance to the 0.26m object height may be relaxed by one design speed step. The one design speed step is an artificial lowering of the design speed by utilising some of the latitude available within the stopping sight distance model. As with the US approach, it does not show how such practice provides sufficient driver capability to avoid/evade hitting objects on the roadway when sight distance less than the normal values are provided.

Assuming a lower design speed has been a common approach used in Australia for the provision of sight distance around roadside safety barriers and structures. The authors strongly disagree with this approach for the following reasons:

- It is important that the design speed relates to all features of the highway. A reduction in design speed is unlikely to affect overall operating speeds. It will potentially result in the unnecessary reduction of all of the speed-related design criteria rather than just sight distance.
- It produces designs based on artificially low operating speeds instead of the anticipated operating speeds of the reasonable and prudent driver. The designs will therefore only to cater for a relatively small number of drivers using the roadway. This can result in the design of inappropriate geometric features that violate driver expectations and degrade the safety of the road. Such designs are less likely to be defendable in a court of law. The emphasis should be on the consistency of design so as not to surprise the motorist with unexpected features.
- There is no limit for how low the design speed (and thus the sight distance and the values of other parameters) can be made. This excludes the UK design speed step method.
- Our legal advice has indicated that we would have great difficulty in defending the practice of assuming an artificially low design speed.

For these reasons, it is recommended that design speed should never be less than the 85th percentile operating speed for the particular geometric element.

Wooldridge et al (*11*) identified a similar issue when undertaking case studies of stopping sight distance at ramps. They discussed how AASHTO (*12*) provides three different values for design speed, representing the various percentages of the design speed on the connecting highway (upper range - 85%, middle range - 70% and lower range - 50%). In one of the case studies, it was found that the horizontal offset provided only allowed for the 3rd percentile operating speed, based on a spot speed study. The middle range value (50%) was approximately equal to the actual 85th percentile speed on the ramp. Use of the lower range values in this case was stated as being questionable.

A NEW TECHNIQUE – USING LESS CONSERVATIVE, BUT JUSTIFIABLE SIGHT DISTANCE CRITERIA

As discussed above, it is often impractical to provide the normal stopping sight distance requirements around roadside safety barriers and structures. However, it is considered equally important that a minimum level of sight distance be provided so that drivers can avoid hazards in most situations. Given that we cannot currently quantify the 'substantive safety' [Hauer (*13*)] of providing sight distance around roadside safety barriers and structures, only 'nominal safety' techniques are available.

The proposed sight distance criteria around roadside safety barriers and structures presented in this paper use less conservative, but realistic values for many of the parameters within the stopping sight distance model (eg higher rates of deceleration, higher object heights). This can be justified because the normal stopping condition that has been universally used is extremely conservative. This is because the design stopping condition is a combination of 85th percentile conditions (or even higher). The use of 85th percentile conditions is common in road design. But the combination of many 85th percentile values does not yield something that is representative of the capability of most drivers travelling at the 85th percentile speed. This is explained in detail in Cox (*14*).

The proposed criteria also include supplementary manoeuvre capability in order for drivers to evade smaller objects.

The following sections set out the proposed sight distance criteria that are considered to be practical and cost effective, as documented in Part 3 of the GRD (*1*). The criteria are in the following two parts:

- Sight distance criteria where sighting over roadside barriers is possible
- Sight distance criteria where no line of sight is possible over roadside safety barriers and structures.

These criteria are developed based on similar principals as those used to develop the Extended Design Domain (EDD) criteria. EDD was developed for sight distance on existing roads as introduced by Cox and Arndt (*15*) at the 3rd International Symposium on Highway Geometric Design. The EDD criteria have been adopted in Appendix A of Parts 3 and 4A of the GRD (*1*).

Because the new criteria for sight distance around roadside safety barriers and structures are less conservative than that given by the normal stopping sight distance model, it is important that other road users have sufficient capability to avoid hazards on the roadway. For this reason, the new sight distance criteria around roadside safety barriers and structures is applied for two design vehicles – a passenger car and a truck. The latter is typically a 19m semi-trailer.

SIGHT DISTANCE CRITERIA WHERE SIGHTING OVER ROADSIDE SAFETY BARRIERS IS POSSIBLE

This section discusses the criteria used for sight distance around roadside safety barriers when a line of sight exists over the barrier. The criteria are documented in Section 5.5.1 of Part 3 of the GRD (*1*). Basically, the following is provided for cars and trucks:

- Stopping sight distance criteria- stopping capability to a downstream stationary vehicle as a minimum
- Manoeuvre criteria – capability to manoeuvre around smaller objects

Both of these criteria are discussed in the following sections.

Stopping Sight Distance Criteria

Stopping distances are calculated from Equation 1.

$$d = \frac{Vt}{3.6} + \frac{V^2}{254\left(\frac{a}{9.81} + \frac{G}{100}\right)} \qquad (1)$$

where
d = braking distance (m)
V = initial speed (km/h)
t = perception-reaction time (s)
a = equivalent constant deceleration rate (m/s/s)
G = grade in %; + for upgrade, - for down grade.

Initial Speed (V)

Initial speed is a critical parameter when using the stopping distance model since braking distance is a function of the square of the initial vehicle speed. Because the new criteria for sight distance around roadside safety barriers is less conservative than that given by the normal stopping sight distance model (Technique Number 1), it is even more important to be sure that the initial speed (V) is not underestimated. There is no longer the latitude to cover an underestimate of V.

Because of the squared function and the absence of a lower limit of V, designers using Technique Number 3 'Assume a Lower Design Speed' can easily choose a speed too low. This is likely to result in the provision of insufficient sight distance.

In Australia, V has been clearly defined as being the 85th percentile speed since 1980. Data from speed surveys shows that the 85^{th} percentile speed for cars and trucks on midblock sections of freeways is typically 6km/h to 8km/h over the speed limit. Where the 85^{th} percentile speed on a particular roadway has been measured, it is permissible to use this speed (*1*). In the absence of any speed information, V is taken as 10km/h above the speed limit.

The operating speed model for intermediate and low speed rural roads is used to predict the 85th percentile car speed on direct, semi-direct, outer connector and loop ramps in the manner explained in Part 4C of (*1*). Based on observed driver behaviour, the speed model predicts the extent to which car drivers are prepared to slow for horizontal curves, given their desired driver speed and section operating speed. This gives a more accurate estimate of 85^{th} percentile speed than simply choosing an arbitrary side friction factor upon which to calculate speed.

An operating speed model for trucks travelling around horizontal curves currently does not exist in Australia. Based on anecdotal evidence, truck speeds tend to be 10km/h lower than car speeds for other than high speed roads, when car speeds are above 60km/h (*1*). In the absence of other information, the speed of trucks on direct, semi-direct, outer connector and loop ramps is based on this criterion. Where ramp geometry incorporates grades, the speeds of heavy vehicles are also calculated by the software package VEHSIM (*16*) or by graphs (*1*).

Research is currently underway in Australia to develop an operating speed model for trucks travelling around horizontal curves.

Perception-reaction time (t)

Table 2 lists the perception-reaction times from the GRD (*1*). The degree to which these values are representative of normal driving conditions are given below:

- 2.5s represents better than a 90th percentile value and possibly better than a 95th percentile value for all drivers – refer Fambro et al. (*6*) (see page 74).
- 2.0s represents at least an 85th percentile value and possibly a 95th percentile value for all car drivers – refer Fambro et al. (*6*) (see pages 32 and 74).
- 1.5s represents at least a mean value for surprise stopping for all drivers from a number of tests around the world – refer pages 24 and 32 of Fambro et al. (*6*), Summala (*17*), Green (*18*) and Exhibit 2-26 in AASHTO (*19*). The data in Summala (*17*) suggests that 'urgency' ensures that 1.5s may be an 85th percentile value or better (in good conditions at least) for drivers travelling at the 85th percentile speed. This is further supported by Figure 4 in Durth and Bernhard (*20*).

For determining sight distance around barriers on interchange ramps, a perception-reaction time of 1.5s is typically used for cars and trucks (see Table 2). For midblock sections of most freeways, a 2.0s perception-reaction time is typically used. Prior to the development of Table 2, Technique Numbers 1 and 3 ('Apply the Normal Stopping Sight Distance Model' and 'Assume a Lower Design Speed' respectively) would typically have used a 2.0s perception-reaction time in the sight distance cases above.

TABLE 2 Driver Perception-reaction Times for Cars and Trucks (t) [Source: Table 5.2 of Part 3 of the GRD (*1*)]

Reaction Time R_T (s)	Typical Road Conditions	Typical Use
2.5	Unalerted driving conditions due to the road only having isolated geometric features to maintain driver interest Areas with high driver workload/complex decisions High speed roads with long distances between towns	Absolute minimum value for high speed roads with unalerted driving conditions. General minimum value for High speed rural motorways High speed rural intersections.
2.0	Higher speed urban areas Few intersections Alerted driving situations in rural areas High speed roads in urban areas comprising numerous intersections or interchanges where the majority of driver trips are of relatively short length. Tunnels with operating speed ≥ 90m/h.	Absolute minimum value for the road conditions listed in this row. General minimum value for most road types, including those with alert driving conditions.
1.5	Alert driving conditions eg High expectancy of stopping due to traffic signals Consistently tight alignments for example, mountainous roads Restricted low speed urban areas Built-up areas – high traffic volumes Interchange ramps when sighting over or around barriers Tunnels with operating speed ≤ 90m/h.	Absolute minimum value. Only used in very constrained situations where drivers will be alert.
Notes: The driver reaction times are representative for cars at the 85^{th} percentile speed and for heavy vehicles. The deceleration rates for heavy vehicles cover the inherent delay times in the air braking systems for these vehicles. The above times typically afford an extra 0.5s to 1.0s reaction time to drivers who have to stop from the mean free speed. It is considered, for example, that the mean free speed is more representative of the speed travelled by older drivers.		

Equivalent constant deceleration rate (a)
Table 3 lists the coefficient of deceleration values in the GRD (*1*). These values are numerically equal to the deceleration rate (a) divided by gravity (g). As can be seen, there is a range of values depending on type of vehicle and road type.

The degree to which the values of the coefficient of deceleration given in Table 2 are representative of driving conditions are given below:

- 0.61 represents the average braking capability in dry conditions – refer Fambro et al. (*6*).
- 0.46 represents the average braking capability in wet conditions – refer Fambro et al. (*6*) and Durth and Bernhard (*20*).
- 0.36 represents about a 90th percentile value for braking on wet, sealed roads – refer Fambro et al. (*6*). This value continues to be used in Austroads guides as the maximum coefficient of deceleration for the design of deceleration lanes at intersections and is therefore more conservative than what drivers use in emergency braking situations.
- 0.26 represents comfortable deceleration. This value continues to be used in Austroads guides as the desirable coefficient of deceleration for the design of deceleration lanes at intersections.
- 0.29 represents braking by large single unit trucks, semi-trailers (prime movers with one trailer) and B-doubles (prime movers with two trailers) on dry roads – refer Di Cristoforo et al. (*21*).

For determining sight distance around barriers on interchange ramps, a coefficient of deceleration of 0.46 is typically used for cars (refer Table 3). For trucks, a value of 0.29 is generally used. On ‘tight’ horizontal curves with a side friction factor greater than the desirable maximum value, the coefficient of deceleration is reduced by 0.05. This accounts for the more difficult braking manoeuvre when drivers are using a high degree of side friction.

Australian practice recognises that drivers use high degrees of side friction when travelling on smaller radii curves. For example, the desirable maximum value of side friction will be exceeded on horizontal curves of radii less than about 450m to 500m if the initial speed prior to the curve is 110km/h.

Prior to the development of Table 3, Technique Numbers 1 and 3 ('Apply the Normal Stopping Sight Distance Model' and 'Assume a Lower Design Speed' respectively) would typically have used smaller coefficients of deceleration for cars, particularly for higher speeds.

TABLE 3 Coefficient of Deceleration [Source: Table 5.3 of Part 3 of the GRD (*1*)]

Vehicle Type	Coefficient of Deceleration d	Driver / Road Capability	Typical Use
Cars	0.61 [1]	Braking on dry, sealed roads	Specific applications where the normal stopping sight distance criteria applied to horizontal curves produce excessive lateral offsets to roadside barriers/structures (used in conjunction with supplementary manoeuvre capability).
	0.46 [1]	Mean value for braking on wet, sealed roads for a hazard. Maximum values when decelerating at an intersection.	Absolute maximum value for stopping sight distance. Only to be used in constrained locations, typically on: Lower volume roads; Less important roads; Mountainous roads; Lower speed urban roads; Sighting over or around barriers; Tunnels.
	0.36	About a 90th percentile value for braking on wet, sealed roads. Maximum value allowed for deceleration at intersections.	General maximum value for stopping sight distance for most urban and rural road types.
	0.26	Comfortable deceleration on sealed roads.	General maximum value for stopping sight distance for major highways, motorways and for deceleration in turn lanes at intersections. Maximum value for curve perception distance.
	0.27	Braking on unsealed roads	Stopping sight distance on unsealed roads.
Trucks	0.29[1]	Braking by single unit trucks, semi-trailers and B-doubles on dry, sealed roads. Minimum value required by vehicle standards regulations.	Maximum value for truck stopping sight distance for most urban and rural road types.
	0.28[1]	Braking by Type 1 Road Trains on dry, sealed roads.	Check case for stopping sight distance for a Type 1 road train.
	0.26[1]	Braking by Type 2 Road Trains on dry, sealed roads.	Check case for stopping sight distance for a Type 2 road train.

[1] For any horizontal curve with a side friction factor greater than the desirable maximum value, the coefficient of deceleration should be reduced by 0.05.

Driver Eye Height and Object Height
Table 4 shows the eye and object heights adopted in (*1*).

TABLE 4 Driver Eye and Object Heights [Source: Table 5.1 of Part 3 of the GRD (*1*)]

Vertical Height Parameter	**Height (m)**	**Typical Application**
Height of Eye of Driver h_1		
1. Passenger Car	1.1	All car sight distance models
2. Truck	2.4	All truck sight distance models where a truck is travelling in daylight hours and at night-time where the road is lit.
3. Bus	1.8	Specific case for bus only facilities, e.g. busways
Headlight Height h_1		
1. Passenger Car	0.65	Headlight stopping sight distance in sags Check case for night time stopping for cars (no overhead lighting)
2. Commercial Vehicle	1.05m	Check case for night time stopping for trucks (no overhead lighting)
Object cut-off Height h_2		
1. Road surface	0.0	Approach sight distance at intersections. Approach sight distance to taper at end of auxiliary lane. Headlight sight distance in sags. Horizontal curve perception distance. Water surface at floodways.
2. Stationary object on road	0.2	Normal stopping sight distance for cars and trucks to hazard on roadway.
3. Front turn indicator	0.65	Minimum gap sight distance at intersections.
4. Car tail light/stop light/turn indicator	0.8	Car stopping sight distance to hazards over roadside safety barriers in constrained locations [(1)] Truck stopping sight distance to hazards over roadside safety barriers in constrained locations Stopping sight distance where there are overhead obstructions.
5. Top of car	1.25	Car stopping sight distance to hazards over roadside safety barriers on a lit horizontally curved bridge [(1)] Truck stopping sight distance to hazards over roadside safety barriers in extremely constrained locations that are lit [(1)] Intermediate sight distance Overtaking sight distance Safe intersection sight distance Mutual visibility at merges
[(1)] Where car stopping sight distance over roadside barriers is applied to an object height of greater than 0.2m or truck stopping sight distance over roadside barriers is applied to an object height of greater than 0.8m, the minimum shoulder widths and manoeuvre times given in Table 5 apply.		

From Table 4, eye height are:

- 1.1m for cars. This represents the 15^{th} percentile driver eye height in Australia as determined by Cox (*22*).
- 2.4m for trucks. This represents a truck driver eye height of 19m semi trailers or larger vehicles, as determined by McLean (*23*)

Table 4 shows that the following object heights are used for sight distance over roadside safety barriers:

- 0.8m for car and truck stopping sight distance to hazards over roadside safety barriers in constrained locations. This value represents the 15% tail light height of passenger vehicles in Australia, as determined by Lennie et al (*24*).
- 1.25m for car stopping sight distance to hazards over roadside safety barriers on a horizontally curved bridge with road lighting. This value is also used for truck stopping sight distance to hazards over roadside safety barriers in extremely constrained locations with road lighting. 1.25 m represents a value 0.21 m lower than the 15th percentile passenger car height as determined by Lennie et al. (*24*). The value of 0.21 m was based on sufficient vehicle height available for other drivers to perceive the vehicle and allowance for the passenger car height to be a rounded value.

Prior to the development of Table 4, Technique Numbers 1 and 3 ('Apply the Normal Stopping Sight Distance Model' and 'Assume a Lower Design Speed' respectively) would typically have used similar eye heights but would have consistently used a 0.2m object height.

Manoeuvre Criteria

Application of the stopping sight distance criteria given in the previous section has meant that drivers of passenger cars and trucks can at least stop for a stationary downstream vehicle. If the roadway is unlit, this means stopping sight distance is at least provided to a design object height of 0.8m (taillight height of a passenger car). If the roadway is lit (typical of urban freeways and interchanges), it means that providing stopping sight distance to a design object height of 1.25m (top of a passenger car) is possible.

To provide drivers with capability to avoid objects smaller than the design object height, Section 5.5.1 of Part 3 of the GRD (*1*) requires that drivers have sufficient capability to avoid objects smaller than the design object height by manoeuvring around them. This is provided by the following:

- A minimum manoeuvre time – allows drivers travelling at the operating speed sufficient time to perceive/react to a hazard and manoeuvre around it
- A minimum manoeuvre width – allows drivers enough width to manoeuvre a hazard.

Where car stopping sight distance over roadside barriers is applied to an object height greater than 0.2 m, or truck stopping sight distance over roadside barriers is applied to an object height greater than 0.8 m, the minimum shoulder widths and manoeuvre times given in Table 5 apply. No supplementary manoeuvre capability needs to be provided where object heights of 0.2m for car stopping and 0.8m for truck stopping are used. This is because objects lower than these in the majority of circumstances are assumed not to be major hazards to the vehicles. Also, the latitude available under the design condition usually affords some stopping capability for the smaller hazards.

The minimum sight distance required to achieve manoeuvre capability is calculated according to Equation 2.

$$d = \frac{V \times t}{3.6} \qquad (2)$$

where

d = *manoeuvre distance (m)*
V = *initial speed (km/h)*
t = manoeuvre time = perception-reaction time + evasive action time (s)

For car stopping, the manoeuvre distance must be provided from a 1.1m passenger car eye height to a 0.2m high object. For truck stopping, this distance must be provided from a 2.4m truck eye height to a 0.8m high object.

TABLE 5 Minimum Shoulder Widths and Manoeuvre Times for Sight Distances over Roadside Safety Barriers on Horizontal Curves [Source: Table 5.6 of Part 3 of the GRD (*1*)]

Case	Object Height Adopted for Stopping Capability 'h_2' (m)	Minimum Shoulder Width on Inside of Horizontal Curve for Manoeuvring (m) (1)	Minimum Manoeuvre Time at the 85th Percentile Vehicle Speed(s) (2)
Car stopping sight distance	$0.2 < h_2 \le 1.25$	2.5	Reaction time plus 2.5s to a 0.2m high object.
Truck stopping sight distance	$0.8 < h_2 \le 1.25$	3.5	Reaction time plus 3.0s to a 0.8m high object

(1) The minimum shoulder width enables vehicles (on the inner most lane) to manoeuvre around objects lower than the chosen object height. The minimum shoulder width must be the greatest dimension that satisfies both the car and truck stopping sight distance cases given in this table. It is preferred that the shoulder is fully sealed.

(2) The minimum manoeuvre time provides drivers with sufficient time to react and take evasive action.

(3) Where a sight line passes over a median barrier, the line of sight should not be interrupted by vehicles in the on-coming carriageway. Typically, this means that the line of sight should not intrude more than 0.5m into the closest on-coming traffic lane.

Justification of Manoeuvre Capability

Manoeuvre sight distance has been an alternative design criterion in Australia since 1980 (*25*). Given the chance, drivers will elect to manoeuvre around a hazard rather than stop for it – refer Olsen et al. (*5*)

The software program HVE (*26*) dynamically simulates vehicle movement over any given environment and has been used to show that the minimum manoeuvre times and minimum shoulder widths in Table 5 are realistic and achievable in practice. Figure 2 shows preliminary results from HVE. The hazard, a stationary vehicle, takes up most of the lane. The minimum manoeuvre time is 4.5s (1.5s perception/reaction time plus 3s evasive action time) and the shoulder width is 3.5m. HVE shows that such a manoeuvre is achievable by drivers of heavy vehicles.

SIGHT DISTANCE CRITERIA WHERE SIGHTING OVER ROADSIDE SAFETY BARRIERS / STRUCTURES IS NOT POSSIBLE

A line of sight is not possible over the following:

- Special high performance safety barriers (eg 1.4m or 2m high), except if in combination with a significant sag vertical curve,
- Retaining walls of significant height,
- Tunnels,
- Bridge structures eg underpasses, abutments and piers, or
- Roadside safety barriers in combination with a significant crest vertical curve.

In these cases, there is often limited ability to widen the shoulder due to cost and/or practical constraints e.g. the geometry comprises a motorway ramp on structure. This can make it very difficult to provide any stopping sight distance capability for trucks.

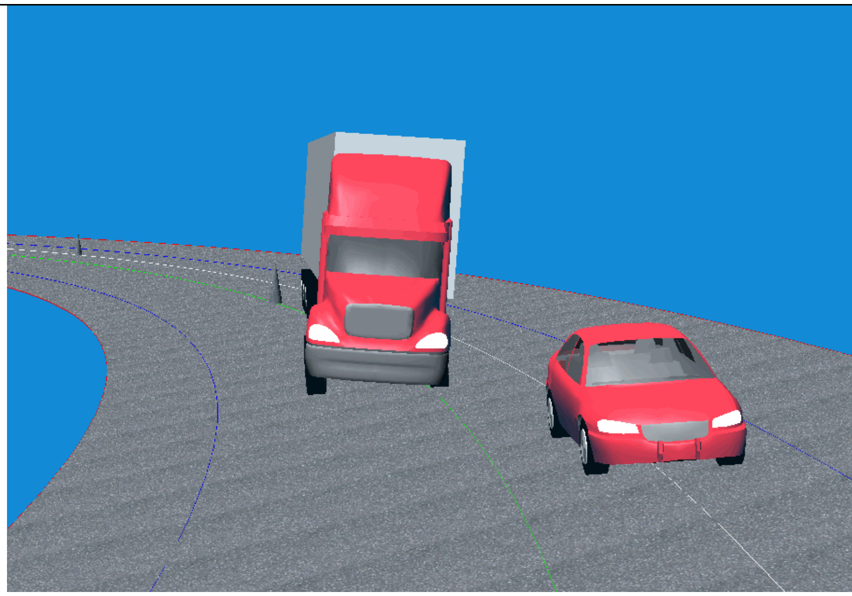
Where this occurs and all other design options have been investigated, Section 5.5.2 of Part 3 of the GRD (*1*) gives the following capabilities as the minimum which should be provided:

- Car stopping sight distance on a dry road using a coefficient of deceleration of 0.61 (refer Table 3), supplemented by the required minimum shoulder width and minimum manoeuvre time according to Table 5. As per Table 3, a horizontal curve with a side friction factor greater than the desirable maximum value requires that the coefficient of deceleration be reduced by 0.05. The justification for using braking on a dry road is based on the difficulty in achieving practical sight distance criteria in these instances combined with the fact that Australia is a very dry country and only a very small area of the country ever encounters snow or ice.

- Truck manoeuvre only capability – provide a minimum shoulder width of 4m and a minimum manoeuvre time to a 0.8m high object equal to the reaction time plus 3.5 seconds.

These criteria effectively limit the width of the shoulder to 4m.

Where sighting over roadside safety barriers was not possible, Technique Numbers 1 and 3 ('Apply the Normal Stopping Sight Distance Model' and 'Assume a Lower Design Speed' respectively) would have used the same parameter values in the stopping sight distance model as discussed in the previous section titled 'Sight Distance Criteria Where Sighting over Roadside Safety Barriers is Possible'. This required stopping to a 0.2m high object at all locations.



Radius (m)	Superelevation (%)	Surface Condition	Initial Speed (km/h)	Typical Speed Reduction (km/hr)	Manoeuvre Successful within 3s of Travel
120	7	Dry	64	4-10	Yes (1)
		Wet		12	Yes (1)
200	6	Dry	75	3	Yes
		Wet		9	Yes
400	5	Dry	91	3	Yes
		Wet		8	Yes
600	5	Dry	100	4	Yes

(1) Some difficultly experienced in achieving a successful manoeuvre with some vehicle instability evident.
Notes:
Horizontal Curve for the Criteria given in Table 5 and detailed results can be provided by authors.

FIGURE 2 Check on HV Manoeuvre Capability over Distance ≡ 3s of Travel at Initial Speed.

CASE STUDY OF THE PROVISION OF SIGHT DISTANCE AROUND ROADSIDE SAFETY BARRIERS AND STRUCTURES ON FREEWAYS AND INTERCHANGES

Figure 3 shows the southbound ramp between the Port of Brisbane Motorway and the Gateway Motorway in Brisbane. The ramp at this location forms an overpass of a railway line. The ramp comprises a left turning horizontal curve of 170m radius on a downgrade of 3%. The lane width is 4.3m and the left shoulder width is 3.3m. The speed limit on the ramp is 70km/h. The roadside safety barriers are 1.4m high on the rail overpass so sighting to stationary vehicles over the barrier is not possible. This layout existed prior to the development of the new sight distance criteria around roadside safety barriers and structures in (*1*).

Using the operating speed model in (*1*) for a desired driver speed of 80km/h (speed limit plus 10km/h), the model indicates the drivers of passenger cars will slow to 74km/h on the ramp. It is assumed that trucks will be travelling at 70km/h (the speed limit). It is unlikely that truck drivers will be travelling slower than this because at 70km/h, they have not yet reached their maximum side friction demand.

Table 6 shows what sight distances and shoulder widths are required in order for drivers of passenger cars and trucks to have sufficient visibility around the roadside barrier. Both the sight distance required under previous Austroads documents (using the normal stopping sight distance model) and the sight distance required in the new GRD (*1*) are shown.

As would be expected, sight distance for trucks is the overriding criteria. A shoulder width of 6.8m would have been required under the previous Austroads documents. The new criteria, which allows manoeuvre only capability for trucks where a line of sight is not possible over the barrier, indicate that a shoulder width of 4m is required.

If the ramp in Figure 3 was being built new, an additional 0.7m shoulder width would be required to meet the new sight distance criteria.

FIGURE 2 Sight Distance Widening on Southbound Ramp between the Port of Brisbane Motorway and the Gateway Motorway

TABLE 6 Sight Distance and Shoulder Widths Required for the Case Study

Criteria	Sight Distance Required (m)		Shoulder Width Required (m)	
	Cars	Trucks	Cars	Trucks
Normal stopping sight distance model in previous Austroads documents	81	113	2.7	6.8
New criteria where sighting over roadside safety barriers/structures is not possible – stopping sight distance	68	-	1.2	-
New criteria where sighting over roadside safety barriers/structures is not possible – manoeuvre sight distance	82	88	2.8	4.0

CONCLUSION

The provision of stopping sight distance around concrete barriers and structures on freeways and interchanges has varied within Australia (and the world). Some designers have insisted on strictly applying the normal stopping sight distance model, others have disregarded sight distance requirements altogether whilst many have simply assumed a lower design speed. Each method creates its own problems.

As well as being uneconomical, strict application of the normal stopping sight distance model yields very wide shoulders that can act as parking area and decrease barrier performance. Based on anecdotal evidence, ignoring sight distance requirements altogether is likely to decrease safety. Assuming a lower design speed can result in the design of inappropriate geometric features that violate driver expectations and degrade the safety of the road, especially if the design speed chosen is too low. It will potentially result in the unnecessary reduction of all of the speed-related design criteria rather than just sight distance.This practice is also less likely to be defendable in a court of law.

The criteria proposed for sight distance around concrete barriers and structures in this paper have been developed by using less conservative, but realistic values for many of the parameters within the stopping sight distance model (eg higher rates of deceleration, higher object heights). This can be justified because the normal stopping condition that has been universally used is extremely conservative. This is because the design stopping condition is a combination of 85th percentile conditions (or even higher). The use of 85th percentile conditions is common in road design. But the combination of many 85th percentile values does not yield something that is representative of the capability of most drivers travelling at the 85th percentile speed.

The new criteria retain the intents of the sight distance models by providing reasonable stopping and manoeuvring capability. The intent of the sight distance models is to ensure that for the whole length of a road, motorists may see some hazard then stop for it or avoid it. No court is likely to find that this is not reasonable. Using some different model and technical foundation will not serve the inevitable comparison with what is used for the remainder of the road network.

When using these criteria, it is paramount that the design speed is not underestimated because of the smaller latitude that exists within the models.

The new criteria comprise two sections. One is for where sight distance over roadside safety barriers is possible. The other is for where sight distance over roadside barriers and structures is not possible. The new criteria are incorporated into the latest Australian road design guidelines (*1*). There is scope to also apply the criteria to sight distance over roadside barriers on roads other than freeways and at interchanges.

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