University of Southern Queensland

Faculty of Engineering and Surveying

# A CONSISTENT APPROACH TO HEADLIGHT SCREENS IN NSW

A dissertation submitted by

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In fulfilment of the requirements of

**Courses ENG4111 and 4112 Research Project**

Towards the degree of

**Bachelor of Engineering (Civil)**

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# Abstract

The aim of this research project is to develop headlight screen design guidelines to provide road designers with a consistent approach to implementing screens into road design.

Literature has been examined including past and current road design principles that may have influence over where headlight screens should be implemented. The available literature based on road design was found not to be adequate to comprehensively develop a set of guidelines and therefore the current design principles have been analysed to determine if there is a standard method that could be adopted, including assessment of carriageway separation and horizontal curvature, to identify set locations for screening.

The carriageway separation analysis involved the conversion of the headlight beam pattern into trigonometric calculations for varying separation widths. This enabled sample glare impairment times and distances to be determined demonstrating the assumed risk to drivers of oncoming vehicles. It was determined that carriageway separation of greater than 10.4 metres should be sufficient to counteract the effect of headlight glare from oncoming vehicles, and for separations less than this width, the installation of headlight screens may demonstrate a reduction of time a driver could be affected by glare.

Assessment of the horizontal curvature included varying curve radii and lengths and analysis based on four common vehicle operating speeds. The results have been reported in the time that a vehicle spends on each curve, and it was found that when two vehicles are approaching each other this calculated time is considered negligible where headlight screening might be contemplated.

Following this analysis, it has been found that additional risk factors must also be incorporated into the assessment to ensure all site specific factors are considered. The factors that a road authority may have influence over and therefore further analysis undertaken include; lane widths, delineation such as line marking and guidepost positions, sign reflection, wildlife crossings, road lighting and catering for traffic volumes.

In this regard, further work will be required to enable sufficient completion of the headlight screen design guidelines to ensure road designers are aware of all relevant factors to consider.

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

**Yvonne Elizabeth Bowles**

**Student Number: 0050088457**

Signature

Date

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Finally, I dedicate this project and my entire degree to my parents, who, if were here to witness my achievements, would have been extremely proud to see what I have become.

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# 1. Introduction

The New South Wales (NSW) Roads and Maritime Services (RMS) was created from the amalgamation of the NSW Roads and Traffic Authority and NSW Maritime. RMS is a delivery arm of Transport for NSW.

The RMS website (Roads and Maritime Services 2013) provides the following statistics for the NSW road network, stating it is approximately 185,000km in length, of which RMS is responsible for managing approximately 18,000km. The population of NSW is projected to experience a growth of approximately 33% by 2036, typical to the remainder of Australia and the western world (Department of Planning, 2008). Additionally, vehicle ownership in NSW is currently realising an average of 2.3% annual growth with close to 5 million vehicles registered in NSW, an increase from approximately 4.3 million just five years ago (Australian Bureau of Statistics, 2013).

A particular function of RMS relates to road environment safety. The *NSW Road Safety Strategy 2012-2021* sets the key objectives and initiatives to further develop and improve safety on NSW roads. Within the strategy, the ñSafe Systemò approach defines key principles to provide an inclusive view of the entire road transport system and the many interactions between all road users and elements. Such an approach can maintain that people will continue to make mistakes while using the road network and therefore it is imperative that the roads, vehicles and speed limits are designed to reduce the risk of traffic accidents and aim to protect people in the event of a crash (Australian Government Department of Infrastructure and Regional Development 2013).

While driving is a complex activity, vision is the main source of information needed to operate a vehicle. The road environment can alter at any point in time, with pedestrians and other traffic, and it is therefore considered driving at night time can be the most difficult due to the level of visual impairment to a driverôs vision. Many factors can affect visibility while driving at night, including the environment, the vehicle itself and the driver. The environment incorporates road design and the level of illumination provided by vehicle headlights is vital to successful night time driving. When discussing the driver, night driving problems can include being impacted by glare from oncoming vehicles. It is also noted that visual function decreases as we age (ed. Karwowski 2006).

In terms of age, as at 30 June 2006 there were almost 4.5 million licence holders in NSW. With the projected growth of population, it is expected those aged between 65 to 84 years expected to increase from just over 800,000 in 2006 to almost 1.6 million by the year 2036 and those aged 85 and above projected to grow from 111,000 in 2006 to 353,000 in 2036 (Department of Planning, 2008). Therefore the probability of the volume of NSW elderly drivers increasing is high. Figure 1.1 demonstrates that the projected population increases in the elderly groups are the most notable.

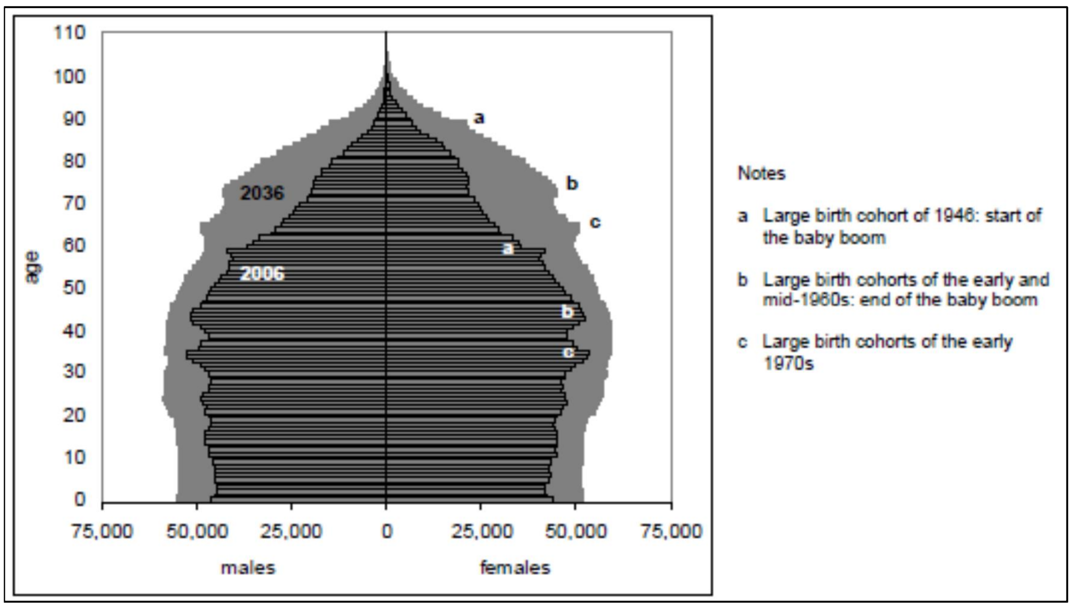


**Figure 1.1: The age-sex profile of the NSW population in 2006 and 2036 (projected)**
Source: (Department of Planning, 2008)

With the projected overall increase in population, and especially considering the elderly population increase, it is vital that RMS consider measures to aid road environment safety, including mitigations that can be implemented for night driving. Installation of countermeasures to help with the effects of glare is just one component of the road transport system that will aid the principles of road safety.

The online Oxford Dictionaries (The Oxford Dictionary) defines glare as a ŏ*dazzling brilliance (of a light, fire, sun, etc.)….*ö The glare phenomenon exists when parts of the visual field are significantly bright in relation to the general surroundings. When driving a motor vehicle, the ñdazzling brillianceò produced by the headlights of other vehicles, may have a glare effect on the driver. Glare has three aspects; blinding glare, disability glare and discomfort glare.

Several factors affect the amount and type of glare a driver may come across. These include; the actual amount of light that enters the eye, the angle at which the light enters the eye, eye disease and surrounding reflective surfaces. Each of these factors must be considered in road and/or vehicle design to best limit the total illumination a driver may encounter.

The Austroads Guide to Road Design (Austroads Limited, 2010) explains that projects requiring road design range from existing road improvements or restoration through to major ógreenfieldsô projects of new arterial carriageways. Worldwide there are road design guidelines, such as that of Austroads, providing principles and directives for which to base the design of road projects.

Design components that must be considered to assist in managing the amount of glare encountered include; geometric design, intersection and interchange design and location considerations. In addition to the actual configuration of the road, the attributes of the motor vehicles using the roadway are also reliant upon design guidelines.

National standards for vehicle safety in Australia are governed by the Australian Design Rules (ADRs). These are generally performance based to cover issues including lighting, structure and environmental emissions. There are four vehicle categories used in the ADRs; Category L ï two and three wheeled vehicles, Category M ï passenger vehicles, Category N ï goods vehicles and Category T ï Trailer vehicles. Generally the ADRs cover all but the Category L vehicles which are separated into their own ADRs (Australian Government ComLaw 2013).

## 1.1. Project Objective

To mitigate against glare, screening can be implemented within the road design in various forms, otherwise known as headlight or anti glare screening. RMS does not currently have a consistent approach to the design and installation of headlight screens across its road network. In general, the current method of determining the need for screening is based loosely on horizontal and vertical separation of carriageways. All other design requirements are currently left to the interpretation of the designer. Thorough knowledge of both the human factors and technical design components behind the need for screening are important considerations in the process of creating a consistent design and installation approach.

It is the objective of this project to develop draft headlight screen design guidelines to provide a consistent approach in NSW to the design and installation of screening.

The development of a consistent approach will provide guidance to road designers with parameters and assessment processes that may ultimately direct the best locations for headlight screen mechanisms. The basis of the draft guidelines will follow ó*Glare Screen Guidelines*ô developed as a result of the American National Cooperative Highway Research Program Synthesis of Highway Practice in 1979, the most comprehensive set of guidelines discovered during the literature review component of this project, however will incorporate current design practices.

The draft guidelines will be methodically produced using the abovementioned document and using the relevant research of Australian road transport departments and their design practices along with relevant industry practices. The following tasks will be undertaken to achieve the project objective:

1. Research literature and background information
2. Investigate past and current design practices to develop draft design guidelines and risk assessment procedures
3. Source specified locations where screening is currently installed or proposed, and analyse in accordance with current design practices to demonstrate whether the draft guidelines are applicable
4. Finalise the draft guideline

# 2. Literature Review

An important component of this research project is to undertake a literature review, an objective summary and critical analysis of relevant available research relating to the project topic. A comprehensive literature review will compile information from many sources and will contain a clear search and selection strategy.

The review is to identify research already undertaken and reported, and therefore provides a tool to ensure this project will not duplicate already completed research.

The focus of the literature review includes a background on; guidelines and their importance, human factors such as the reaction to glare, strategies of mitigation used in road and vehicle design, and the associated maintenance and current materials used for headlight screens. The literature review will be undertaken in consideration of the 1979 produced *Glare Screen Guidelines* to enable comparison to current design practices and appropriate updated strategies to satisfy modern road design. Information presented in the literature review will be consulted when undertaking the methodology component of the project.

## 2.1. The Need for Guidelines

A guideline is defined by the online Oxford Dictionaries (The Oxford Dictionary) as ñ*a general rule, principle, or piece of advice*ò. The purpose of a guideline is to provide valuable guidance and clarify specifications and information required to adequately provide the required outcome. The development of guidelines creates consistency and cohesiveness for a desired result.

Road design encompasses a broad collection of components and as such many design guidelines have been developed throughout time by world road authorities, however since 1979, no specific guidelines have been found to have been developed for headlight or anti glare screening.

## 2.2. Human Factors

Human perception and attention processes are important when studying road safety given the fact that a high percentage of traffic accidents are due to human error, many of which can be linked to visual problems (ed. Castro 2009).

The Australian Automobile Association (Australian Automobile Association, 2013) identifies the improvement in reducing traffic accident fatalities since 1970, a result of road safety and infrastructure initiatives. As part of the larger picture, in the year 2001, a National Road Safety Strategy was introduced for all of Australia, identifying measures to contribute to saving up to 700 lives by the year 2010 which equated to a 40% reduction in the per capita rate of road deaths. Just 34% reduction was realised by 2010, and so in May 2011 a fresh strategy was implemented titled the *National Road Safety Strategy 2011-2020* (Australian Government Department of Infrastructure and Regional Development 2013).

Traffic accidents are preventable, and historically it is seen that by implementing appropriate interventions, a significant improvement can be realised. Many of these interventions can be attributed to human factors including driver behaviour programs, however also include road design, construction improvements and safer vehicles. As can be seen in Figure 2.1, the annual number of Australian road deaths is progressively reducing largely as a result of the road safety strategies implemented.

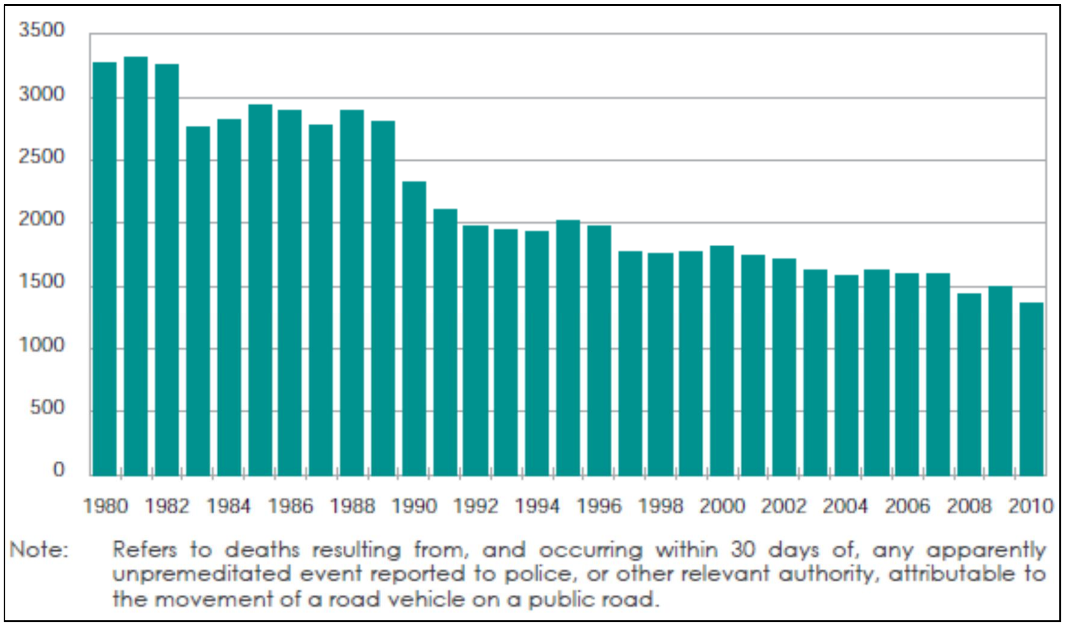


**Figure 2.1: Annual Number of Australian Road Deaths**
Source: (Australian Government Department of Infrastructure and Regional Development 2013)

It is imperative that the continuing modernisation of technology is considered. It is said that in a natural environment, the human perception system allows us to detect events around us quickly, however as we are abandoning the natural environment and taking on new activities such as the use of motor vehicles on modern roads, our perception systems are also altering. An example of this altered perception being the delay or failure of detecting objects when driving at night, potentially as a result of glare from oncoming vehicles (ed. Castro 2009).

### 2.2.1 The Eye

To best consider how humans are impacted and how we react to glare, and to aid in determining the most appropriate road safety mitigation measures to counteract the effects, it is first important to understand how the eye itself processes light sources and any factors that may impede our vision.

One of the most important human senses, sight, is enabled through the human eye. As we view the environment around us, our eyes take in light, a fundamental component to the visualising process. The light travels into the eyeball, passes through the cornea, pupil and lens, and continues all the way to the back to the retina where a unique set of cells receive the light. The cells then harness the lights energy, convert it to an electrical impulse that travels along neurons into the brain, terminating in a region known as the visual cortex.

The electrical signals from both eyes are processed and unified into a single image, a near instantaneous output (ed. Rogers 2011), a process demonstrated in Figure 2.2.

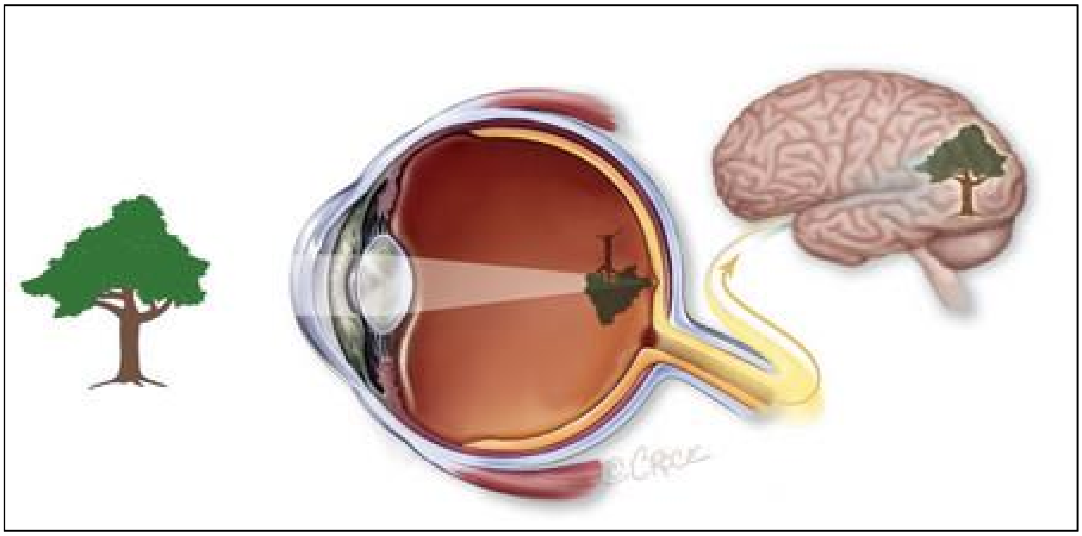

**Figure 2.2: How Healthy Vision Works**
Source: (BionicVision Australia, 2013)

The eye automatically controls the amount of light that enters into it, by widening or narrowing the pupil. In darkness the pupil is larger and dilated allowing more light to enter, whereas in brightness the pupil constricts to reduce the amount of light that enters the eye (Roberts & Ingram 2001). Therefore, when driving at night the pupil is reacting between dilation and constriction each time the glare of oncoming headlights occurs.

The angle at which the headlights actually enter the eye changes with the movement of both vehicles as is demonstrated by Figure 2.3.

Position 1a is the driver of a vehicle who theoretically should be looking straight to Object A (the road in front), and Object B is an oncoming vehicle with headlights on. The angle of the glare source to the driver's eye depends on the distance and road geometry between the two. The angle of light entering from both objects at this position, assuming a straight road and an appropriate distance, forms a pattern that is meaningful for the eye to process. As the driver moves forward to Position 2a, the angle of light entering from Object B increases the angle where both objects are concerned (Schmidt & Wrisberg 2008). As the headlights of Object B continue past the observer's eye, the contrast between the light coming from both objects increases and the glare effect begins to reduce.

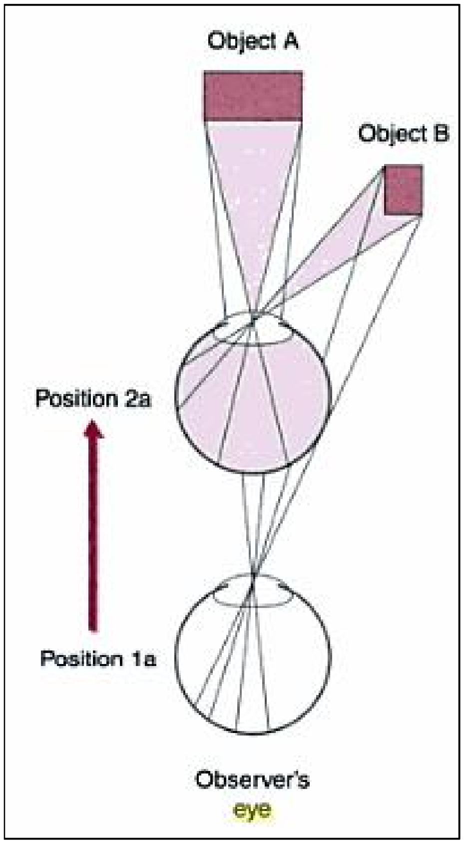


**Figure 2.3: Optical Flow Information**
Source: (Schmidt & Wrisberg, 2008)

Recovery from the glare effect will happen at some time after passing the brightness source with studies revealing that when moving from dark to light the recovery is generally 3 seconds, whereas moving from light to dark is double that at 6 seconds (Hoel, Garber & Sadek 2011).

Some eye diseases cause the effect of glare to worsen considerably. Common examples include ócataractôand óage-related macular degenerationô  A cataract is caused by the loss of clarity of the crystalline lens within the eye with a general blurring of vision occurring, lowering the contrast of what is being viewed.  This is a condition that is more pronounced at night when encountering the glare of oncoming headlights.  Cataracts will affect almost everyone eventually as they are associated with aging.  Age-related macular degeneration affects a very small region in the centre of the retinal area, called the macula which provides us with sharp vision.  Peripheral vision is not affected, however with the loss of central, sharp vision, visual perception can be severely reduced. Recovery from glare is accentuated and is often a diagnostic sign of the disease (Peli & Peli 2002).

Moving forward, now with a researched understanding of the eye, and its reaction to glare, it is important to now provide a critical analysis on the three aspects of glare to determine if any one type will be more prevalent in developing an appropriate design for headlight screens.

### 2.2.2 Blinding Glare

Blinding glare occurs when the intensity of the light source is greater than the maximum value the visual system can process and occurs in situations such as when, in the dark, a car travelling in the opposite direction does not switch back to low beam headlights or during the transition of leaving a dark road tunnel at daytime (Narisada & Schreuder 2004).

Unfortunately there is not a lot that can be done to counteract blinding glare, and quite often it can occur when undertaking day to day life. It can happen to anyone, at any age, and it is therefore anticipated that any mitigation measure would be better than none, including installation of screening and other appropriate road geometry controls to help prevent the occurrence of blinding glare.

### 2.2.3 Disability Glare

Disability glare, often called physiological glare, occurs when there is a competing light source in a location other than where the field of view is actually directed. The competing light source is scattered within the ocular media, otherwise known as the cornea, aqueous humour, crystalline lens and vitreous humour (see Figure 2.4 for basic eye structure), when striking the eye which causes a light veil that appears to stretch over the entire field of view.

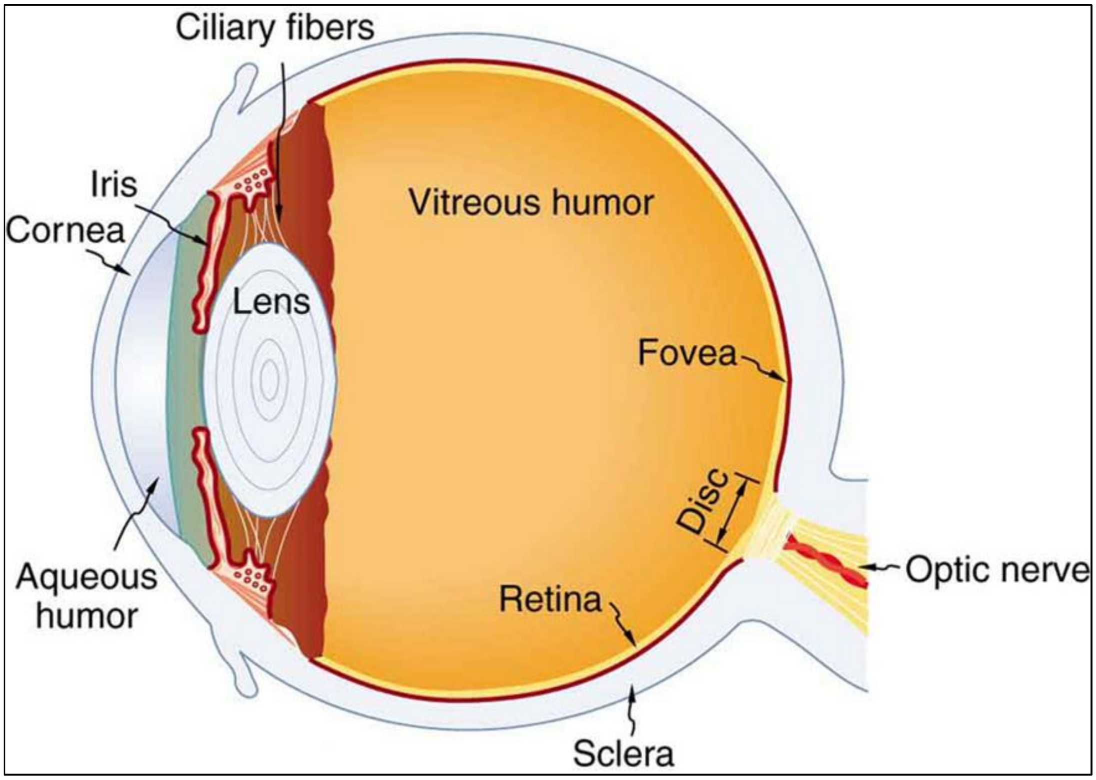


**Figure 2.4: Basic Eye Structure**
Source: (OpenStax College 2012)

Disability glare becomes more common as age increases, mainly due to the increase of cataract in the eye with age (Narisada & Schreuder 2004).

Catering for aged drivers is a must, given the expected increase in their population, and so overall it is hoped the mitigation measures identified in the draft guideline will provide improvements in the design of road safety measures to be implemented in the future.

## 2.2.4 Discomfort Glare

Discomfort glare is best described by the fact that a glare source in the field of view causes discomfort and is often called psychological glare due to its psychological nature. It is considered that a decrease in visual performance is not a direct result of discomfort glare (Narisada & Schreuder 2004), and therefore may not be the most applicable to this project.

Limited studies have been undertaken to assess the human reaction to glare, however one study documented by Jan Theeuwes and Johan Alferdinck concluded that in general people slowed their vehicle when encountering an oncoming headlight glare source, with the older test subjects displaying the largest speed reduction (Boyce 2009).

Based on the physiology of the eye and the likelihood of experiencing glare when driving at night, it is considered that the most likely human group to be significantly affected is the elderly population, especially when considering the effect of disability glare which worsens with age related eye disease. It is apparent that any headlight screening mitigation measures implemented as part of road design will benefit all road users.

## 2.3. Road Design Factors

Austroads, the association of Australian and New Zealand road transport and traffic authorities, consists of members from all eight of Australia's states and territories, along with the Department of Infrastructure and Transport, the Australian Local Government Association and the New Zealand Transport Agency (Austroads Limited 2013). The organisation contributes to improved transport outcomes through its advice, research, facilitation of collaboration between all members and promotion of consistent approaches. The *Guide to Road Design* is the Austroads guide developed to provide guidance and capture contemporary road design practices of all members with the general purpose of producing safe, economical and efficient road designs (Austroads Limited 2010).

Each member organisation maintains control of their road design practices and it is to their judgement whether supplementary guidelines should be developed, and take precedence over Austroads guides. The intention of this research project, developing draft headlight screen guidelines, could form part of these supplementary guidelines.

There are similar road design guidelines worldwide, two examples of which being, the United States Department of Transportation listing roadway design manuals for each US state on their website (U.S. Department of Transportation 2013) and the Department of Transport in the United Kingdom (Department for Transport Highways Agency 2013) providing the same. In the course of conducting research for this project, both within Austroads guides and worldwide transport organisations, just one comprehensive document dedicated to providing specific guidelines to road designers on the topic of glare and design mitigating factors was discovered.

As far back as 1962, the American Association of State Highway and Transportation Officials initiated a national highway research program with the objective of making appropriate recommendations on various engineering practices. As part of this program, in 1979 a research document was produced entitled ó*Glare Screen Guidelines*ô specifically targeting the use of screening in medians and elsewhere to cut headlight glare from approaching traffic (Transportation Research Board 1979). A full copy of this document is provided as Appendix B.

Chapter 4 of the ó*Glare Screen Guidelines*ô (Transportation Research Board 1979) provides the design requirements considered applicable to providing the screens, and included the following:

- **Medians**

It was determined that the physical features of a median were the deciding factor for the need and design of a glare screen, including its ñ*width, cross section, curvature, grade, relative elevation of opposing roadways, and presence of a median barrier*ò.

- **Horizontal curvature**

In America, it was found that ñ*glare increases on roadways that bear to the left because the opposing headlights are directed into the driver’s eyes in proportion to the degree of curvature*ò (Transportation Research Board 1979). Note that the opposite applies for countries that drive on the left hand side of the road.

- **Horizontal Sight Distance**

The guideline detailed that the physical location of installed screens may obstruct sight distance on horizontal curves for driverõs travelling in the median lane, depending on the width of the median and the radius of the curvature. An example mitigation measure for this was in California where glare screens were not to be installed where the sight distance would have been reduced to less than the determined safe stopping sight distance.

- **Screen Height**

The screen height was generally required to be at least at driverøs eye level, however this was open for interpretation given the many design factors which can influence this including cross slope of pavement, differing roadway elevations, horizontal and vertical curvature and of course variation in eye height.

- **Nonmedian Applications**

It was noted that glare screens could also be effective when placed between two-way frontage, or service, roads and freeways where opposing headlights are seen on the õwrongö side of the driver. Additionally screening may have been required between highways and railway tracks, along with interchange ramps.

- **Location Considerations**

Many considerations were listed in terms of where screens should be placed, and although there had been no conclusive studies relating to accident reduction as a result of installing screening, there had been widespread public approval for the reduction of discomfort glare.

For each design requirement listed above, a thorough comparison of the current Austroads road design guideline, along with relevant supplementary guidelines implemented by RMS and other road authorities, has been reviewed to determine the continued relevance of, or alternate requirement to, the 1979 document.

### 2.3.1. Medians

Medians are provided between opposing road carriageways to improve safety through separation. Austroads õ*Guide to Road Design Part 3: Geometric Design*ö (Austroads Limited 2010) lists the main functions of medians, one of which being to õ*reduce the impact of headlight glare and air turbulence from opposing streams of traffic*ö. Medians can be either raised or depressed as demonstrated in Figure 2.5.

The õGlare Screen Guidelineö from 1979 concluded that further studies would be required as to the effects of õ*wet pavement, vertical curvature, and traffic* *volumes*ò (Transportation Research Board 1979) before a definitive median width design could be finalised. However it was determined that glare screens may be considered on tangents and very flat curves for medians 6.1m or less in width.

While Austroads (Austroads Limited 2010) have included the reduction of headlight glare from opposing streams of traffic as a main function of a median, a minimum median width is not specifically documented for this purpose. Table 1 provides the minimum recommended widths, measured between the kerb lines.

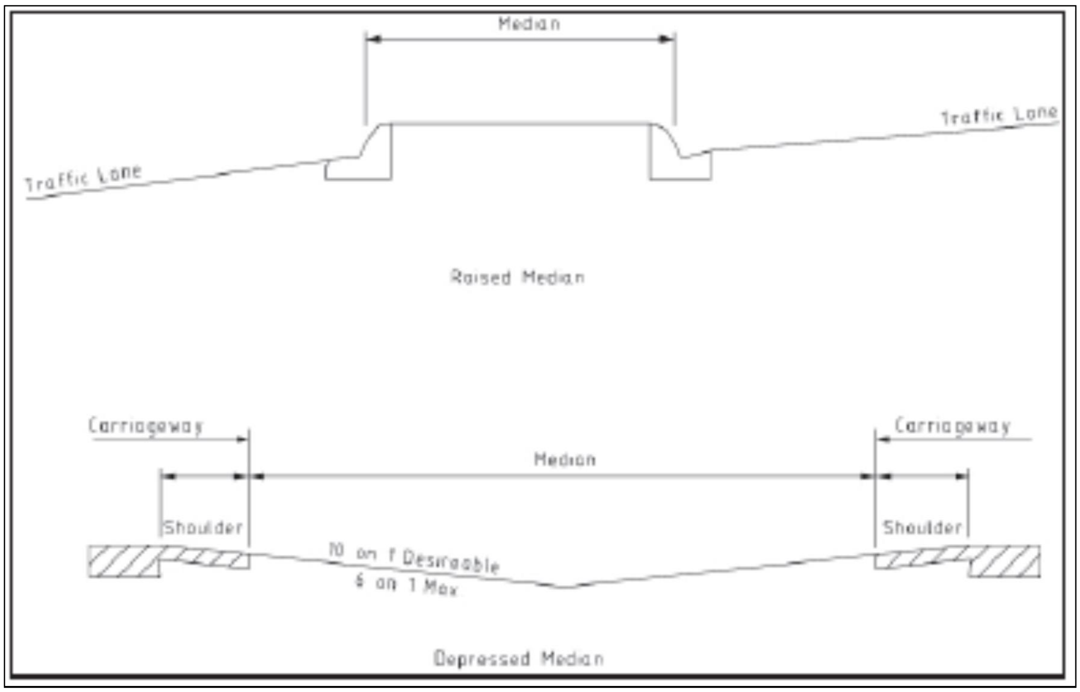


**Figure 2.5: Typical Median Cross Sections**
Source: (Austroads Limited 2010)

With relevance to screening for headlight glare, Austroads (Austroads Limited 2010) does document that medians wider than 10m allow for effective planting and landscaping, a recognised glare screen method. This is almost 4m greater than suggested in the 1979 guideline.

**Table 1: Minimum Recommended Median Widths**
Source: (Austroads Limited, 2010)

| Median Function | Minimum Width (m) |
|---|---|
| Separate traffic flows with a rigid safety barrier ï between traffic lanes | 0.8 |
| Shelter a small sign | 1.2 |
| Shelter signal pedestals or lighting poles | 2.0 |
| Shelter pedestrians and traffic signals | 2.5 |
| Shelter turning vehicles and traffic signals | 6.0 |
| Shelter crossing vehicles | 7.0 |
| For planting and drainage | 10.0 |
| Recovery area | 15.0 |

RMS have developed a supplementary guide to the Austroads Guide to Road Design Part 3, providing more specific minimum widths dependant on design variables, for both urban and rural scenarios. These are provided in Table 2 and 3.

**Table 2: Urban Median Widths**
Source: (Roads and Maritime Services 2013)

| Median Function | Minimum Width (m) |
|---|---|
| Adjacent to Right Turn Bay | 0.5 |
| Separate traffic flows with a rigid safety barrier ï between traffic lanes | 1.6 |
| Shelter a small sign | 1.2 |
| Shelter dual 200mm and single 300mm lantern display | 1.5 |
| Shelter dual 300mm lantern display | 1.8 |
| Shelter pedestrians (provision for Tactile Ground Surface Indicators) and traffic signals | 2.5 |
| Shelter pedestrians, two stage signalled pedestrian mid-block | 4.0 |
| Shelter turning vehicles and traffic signals (excluding width of adjacent lane) | 2.4 |
| Shelter crossing vehicles | 7.0 |

**Table 3: Minimum Recommended Rural Median Widths**
Source: (Roads and Maritime Services 2013)

| AADT in Adjacent Lane | Terrain | | |
|---|---|---|---|
| | **Easy** | **Average** | **Difficult** |
| 1000 | PM (1m) | BL | BL |
| 2000 | DM (7m) | PM (2m) | PM (1m) |
| 3000 | DM (8m) | SB | SB |
| 4000 | DM (9m) | SB | SB |
| 5000 | DM (9m) | DM (9m) | SB |
| 6000 | DM (9m) | DM (9m) | SB |
| 7000 | DM (9m) | DM (9m) | SB |
| 8000 | DM (9m) | DM (9m) | DM (9m) |
| 9000 | DM (9m) | DM (9m) | DM (9m) |
| Ó10000 | DM (9m) | DM (9m) | DM (9m) |

Key: BL = Barrier Lines, PM = Painted Median, SB = Safety Barrier, DM= Depressed Median

It is noted that a minimum median width especially for planting and landscaping has been removed from the RMS Supplementary Guide with focus for rural roads linked directly to traffic volume which provides a maximum width of 9m at the highest volumes of traffic. Landscaping and planting needs to be incorporated into the minimum width based on the guide, and RMS have developed a specific document to provide design guidance for landscaping, the *Landscape Guideline*.

Section 3.2.2 Rural Road Medians of the *Landscape Guideline* (Roads and Maritime Services 2008) documents the landscaping design approach that median landscape must be *"frangible within clear zones so that it is safe and helps slow vehicles that have left the road. It should also provide a screen to headlight glare where possible and needed*ò Section 3.2.6 Urban Road Medians provides a design approach that includes dense planting, simple and attractive in appearance. Examples of both rural and urban median planting provided for the purpose of headlight screening are provided in Figures 2.6 and 2.7.

**Figure 2.6: Rural Median Planting**
Source: (Roads and Maritime Services 2008)

Queensland Department of Transport and Main Roads have recommended guidelines based on whether the road is rural or urban, listing several factors to reach a determination. These include a minimum 15m median where future widening is possible, a desirable 5.9m median for urban roads and general treatment tips to maximise the median function (Department of Transport and Main Roads 2013).

**Figure 2.7: Urban Median Planting**
Source: (Roads and Maritime Services 2008)

Similarly to RMS, VicRoads have developed supplementary guidelines which include some minor variations to median width, such as minimum widths where wire rope safety fencing is to be installed, however have mostly adopted those minimum widths of the Austroads guide (VicRoads 2013) provided in Table 1.

This review of median widths shows there are inconsistencies between road authorities when determining the minimum width to be adopted.

It is considered that a consistent approach in the design of median width, dependant on factors that include the available road corridor width, topography, whether it is a rural or urban environment and traffic volume, will be an important contributing component to the design of headlight screens. The amount of glare encountered by oncoming vehicles is largely associated with the glare angle, as discussed previously in Section 2.2 Human Factors, and therefore an appropriate median width, with this as a consideration, can be determined. Further, the 1979 Glare Screen Guideline (Transportation Research Board 1979) states that ñ*although there are no published data on the relation of headlight glare to traffic volume, it seems logical that glare will increase in proportion to volume*ò.

Using a sample of median widths, it is proposed to undertake analysis to determine how median widths affect headlight glare and whether a relevant method of determining where screening may be most effectively installed can be established.

Median slope is another factor which may affect the need for an installation of headlight screens. The slope of a median is widely dependent on the determined width, terrain, safety and ancillary features such as drainage. The desirable slope for a depressed median is 10:1 with a minimum of 25:1 and maximum of 6:1 recommended. For a raised median it is recommended a minimum of 33:1 and maximum as for depressed medians (Austroads Limited 2010). It is considered that both the width and slope would be the most relevant to determining headlight screen requirements, as is demonstrated by Figures 2.8 and 2.9 from the Austroads *Guide to Road Design* (Austroads Limited 2010).

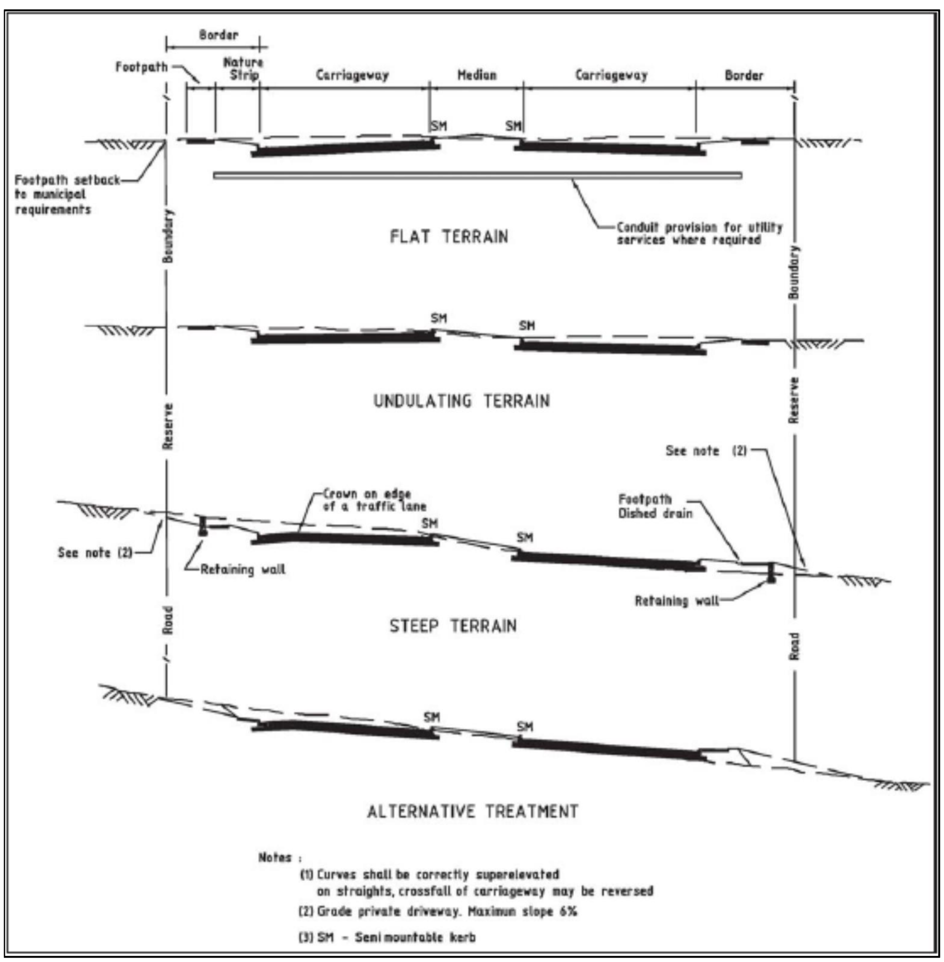


**Figure 2.8: Median Slope Treatment (Road Reserve 30-50m)**
Source: (Austroads Limited 2010)

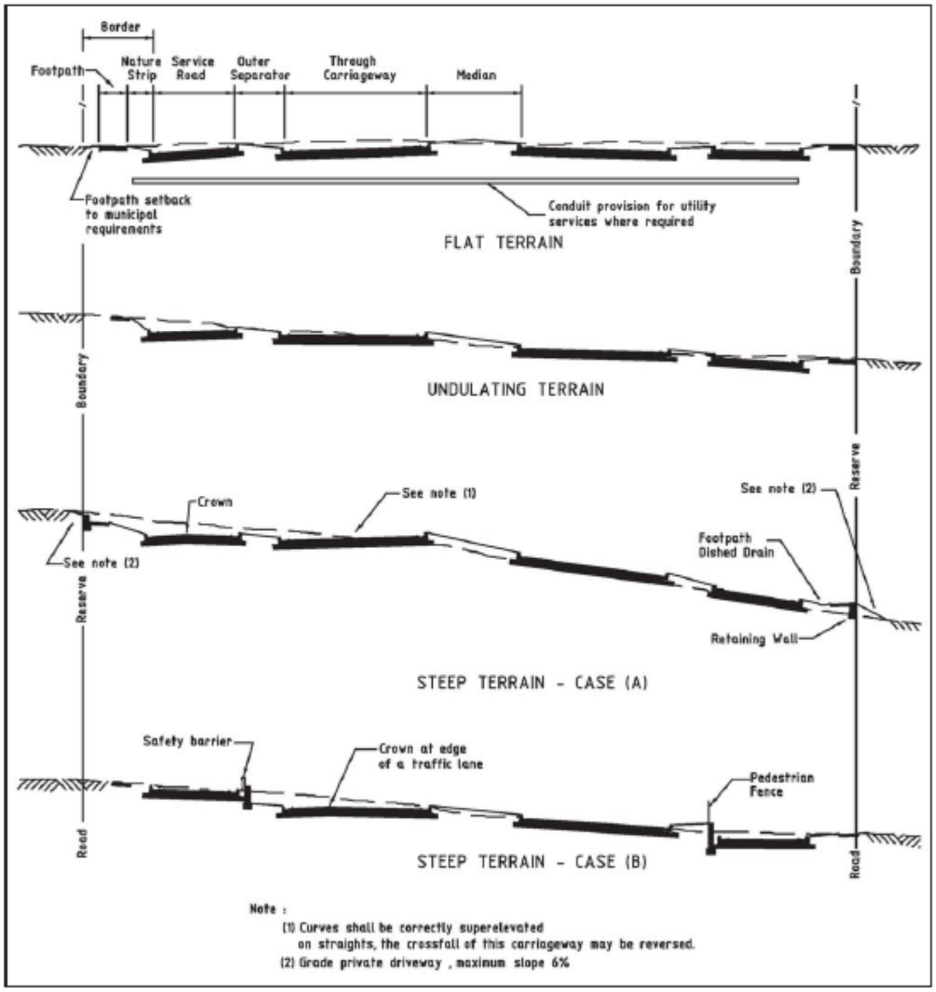


**Figure 2.9: Median Slope Treatment (Road Reserve > 50m)**
Source: (Austroads Limited 2010)

As is noted, where the terrain is steeper there is generally greater grade separation between main carriageways which may impact the need for screening.

## 2.3.2. Horizontal Curvature

Horizontal alignment of a road includes straight and curved sections of road. The tangent, or straight section of roadway, provides the driver clear orientation, however can become monotonous in long lengths. Glare is also considered an issue on straight sections of road, especially where the tangent is excessively long (ie: > 1000m) and to counteract this, curves are introduced (Austroads Limited 2010).

Glare from opposing vehicles must be considered when designing the horizontal curvature of a road. When a road curves to the right, headlights from those vehicles travelling in the opposite direction may be directed into the driverӳ eyes in direct proportion to the curvature degree. Factors of the horizontal curve considered most relevant to the impact of glare from oncoming vehicles are the curve radius, length and superelevation.

The Austroads *Guide to Road Design* (Austroads Limited 2010) provides a calculated set of approximate minimum radii of horizontal curves using varying superelevation percentages, side friction values and vehicle speeds, provided below in Table 4. It is noted that RMS adopt a maximum superelevation of 7% and so Table 4 has been modified to exclude maximum superelevation of 10%.

**Table 4: Minimum radii of horizontal curves based on superelevation and side friction at maximum values**
Source: (Austroads Limited 2010)

| Operating Speed (km/h) | Urban Roads | | Rural Roads | | | |
|---|---|---|---|---|---|---|
| | $e_{max}$ = 5% | | $e_{max}$ = 6% | | $e_{max}$ = 7% | |
| | $f_{max}$ = Des min | $f_{max}$ = Abs min | $f_{max}$ = Des min | $f_{max}$ = Abs min | $f_{max}$ = Des min | $f_{max}$ = Abs min |
| 40 | 36 | 31 | 35 | 31 | 34 | 30 |
| 50 | 56 | 49 | 55 | 48 | 53 | 47 |
| 60 | 98 | 75 | 94 | 73 | 91 | 71 |
| 70 | 161 | 107 | 154 | 104 | 148 | 102 |
| 80 | 240 | 163 | 229 | 157 | 219 | 153 |
| 90 | 354 | 255 | 336 | 245 | 319 | 236 |
| 100 | - | - | 437 | 358 | 414 | 342 |
| 110 | - | - | 529 | 529 | - | - |
| 120 | - | - | 667 | 667 | - | - |
| 130 | - | - | 783 | 783 | - | - |

Using these minimum radii values, it is proposed to analyse these radii to determine at which radii headlight glare may be considered at its worst.

In addition to this, the horizontal curve length must also be contemplated. The deflection angle of a curve can achieve a kinked look to the road alignment if the curve length is too small and therefore minimum curve lengths are required in horizontal design to avoid this, as demonstrated by Figure 2.10.


**Figure 2.10: Comparison of Short and Long Horizontal Curves**
Source: (Austroads Limited 2010)

RMS use the Austroads guide when determining the minimum allowable horizontal curve radii and lengths and have adopted a minimum radius of 600m for high speed roads and appropriately lesser radii for lower speed roads.

The ‘Road Planning and Design Manual’ (Department of Transport and Main Roads 2013) from Department of Transport and Main Roads, Queensland includes more specific provisions for the length of horizontal curves dependant on deflection angle size, stating *“with deflection angles less than 1 degree, a curve is not required”.* Additionally, minimum curve lengths for high speed roads are provided as per Table 5. It is also important to note that topography, especially mountainous terrain, cannot be considered with these guides and curves will need to be designed according to the available surroundings.

**Table 5: Curves for Small Deflection Angles**
Source: (Department of Transport and Main Roads 2013)

| **Angle** | **Minimum Length of Arc (m)** | **Radius Metres (Rounded Value)** |
|---|---|---|
| $5^o$ | 150 | 1800 |
| $4^o$ | 180 | 2600 |
| $3^o$ | 210 | 4000 |
| $2^o$ | 240 | 7000 |
| $1^o$ | 270 | 15000 |

Varying horizontal curve lengths will be considered in the minimum radii theoretical testing to be undertaken to ensure all relevant factors are consideration in the development of the headlight screen design guidelines.

### 2.3.3. Horizontal Sight Distance

Driving sight distance is the distance of clear visualisation between a driver an object or between two drivers. Having sufficient sight distance enables drivers to react in a hazardous situation and therefore the distance should be as long as is practical. Obstructions on horizontal curves can hinder sight distance, including headlight screening, and therefore all such obstructions must be considered during design (Austroads Limited 2010). A demonstration of sight distance is provided in Figure 2.11.

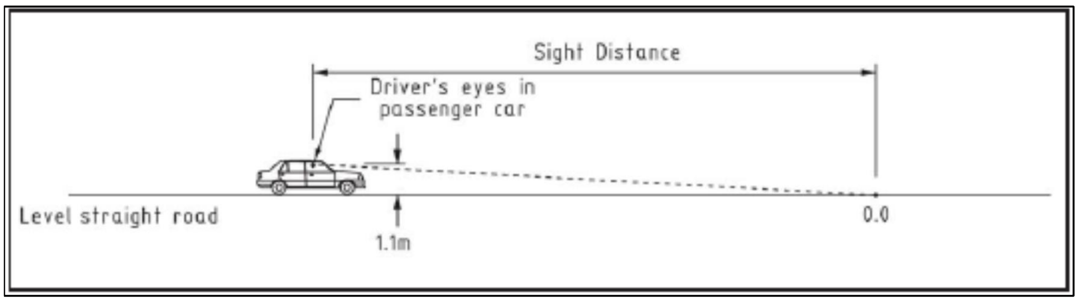


**Figure 2.11: Sight Distance**
Source: (Austroads Limited 2010)

The minimum curve radii in Table 4 do not include provision for obstructions that may occur on the inside of a horizontal curve. The Austroads (Austroads Limited 2010) guide includes that *"A driver needs to see sufficient length of the curve in order to judge its curvature. The driver must be able to see a minimum of; 5 degrees of arc, about 80m of arc, or the whole curve".*

When driving at night, sight distance is very much limited to the range of the vehicleؚs headlight beam which can be assumed to be between 120 to 150m when high beams are in operation (Austroads Limited 2010). Considering the glare angle and how it applies to the driver of an oncoming vehicle, as described in Section 2.2 Human Factors, this sight range will be an important consideration factor when developing a suitable design approach for headlight screens.

The 1979 Glare Screen Guidelines reference two studies undertaken that indicate drivers generally do not look very far ahead to obtain the necessary information to control the vehicle. A separate study also determined that driversô eyes tend to dwell on the centre of the lane at about 70m in front of them under night time conditions. It was found that the dwell point does move to the edge of the lane in the direction of the curvature, however does move toward the glare source when (Transportation Research Board 1979). For the purposes of analysis sight distance, a total distance of 150m will be assumed given that is the maximum headlight beam length when high beams are in operation.

Sight distance on horizontal curves as per current design principles is covered in more detail in Section 2.3.5 Non Median Applications.

### 2.3.4. Screen Height

It is considered that headlight screens would need to be of appropriate height in accordance with the height of the driverqs eye and the height of the headlight itself. Austroads *Guide to Road Design* (Austroads Limited 2010) stipulates that driver eye height ñ*is a combination of the height of driver stature and driver seat height*ö. Based upon research, a car driver eye height is 1.10 metres, a truck driver eye height is 2.40 metres and the driver eye height of a bus is 1.80 metres. Additionally the actual height of vehicle headlights are for a car, 0.65 metres and a commercial vehicle (truck and bus) 1.05 metres.

The height of screening will also be impacted by the terrain and grade of the roadway, which can be referred to as the vertical alignment of the road.

The Austroads *Guide to Road Design* (Austroads Limited 2010) explains vertical alignment of a road, in stating that ñ*it generally follows the natural terrain, however must consider earthworks balance, appearance and the maximum and minimum vertical curvature, expressed as the K value which is the length of a vertical curve measured in metres per 1% of grade change*ö. There are two types of vertical curves, crest and sag, as demonstrated in Figure 2.12.

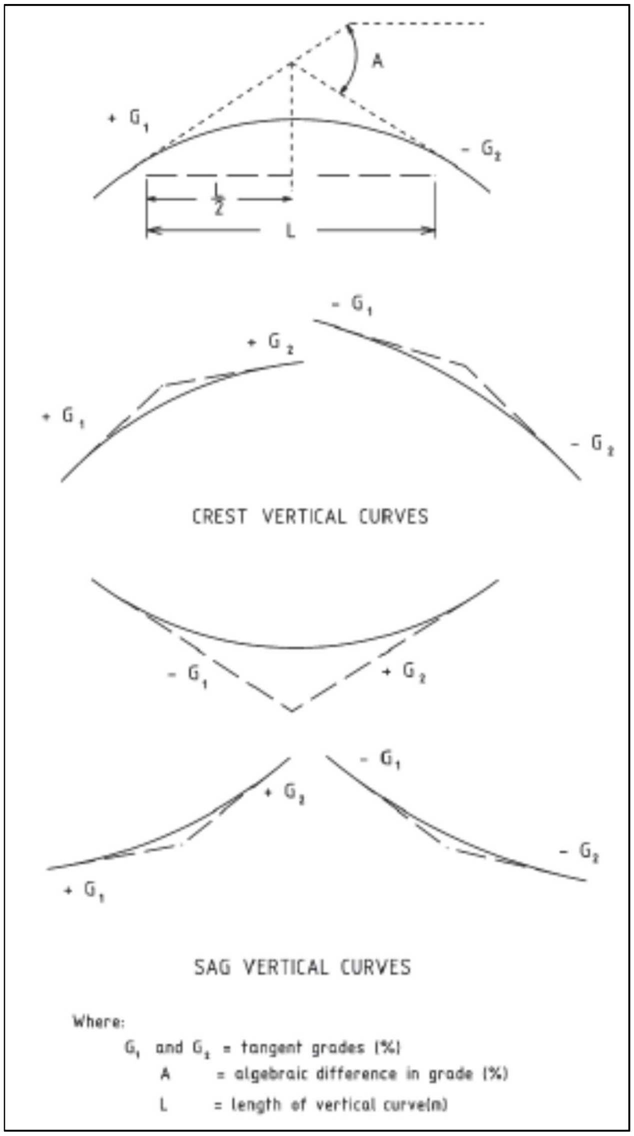


**Figure 2.12: Types of Vertical Curves**
Source: (Austroads Limited 2010)

Vertical curves can be designed using Equations 1, 2 and 3.

**Equation 1: Length of Vertical Curve Equation** (Austroads Limited 2010)

$L = KA$

Where:

L = length of vertical curve (m)

K = length of vertical curve (m) for 1% change in grade

A = algebraic grade change (%)

**Equation 2: K value Equation (Sight Distance < Curve Length)** (Austroads Limited 2010)

$$K = \frac{S^2}{200(\text{ã}h_1 + \text{ã}h_2)^2}$$

Where:

S = sight distance (m)

$h_1$ = driver eye height, as used to establish sight distance (m)

$h_2$ = object height, as used to establish sight distance (m)

**Equation 3: K value Equation (Sight Distance > Curve Length)** (Austroads Limited 2010)

$$K = \frac{2S}{A} - \frac{200(\text{ã}h_1 + \text{ã}h_2)^2}{A^2}$$

Crest curves are governed by sight distance, topography and drainage requirements. Curve lengths generally increase with higher operating speed roads, and lower grade changes. Unnecessarily large crest curves should be avoided for longitudinal drainage reasons and therefore where the grade is less than 0.3 to 0.5% the crest curve should be limited to no greater than 50m (Austroads Limited 2010).

The design of sag curves must consider headlight sight distance criteria. The *Glare Screen Guideline* (Transportation Research Board 1979) concludes that the height of the screening should be increased at a sag vertical curve where the curve length is approximately 180m and at 3% grade, as demonstrated in Figure 2.13.

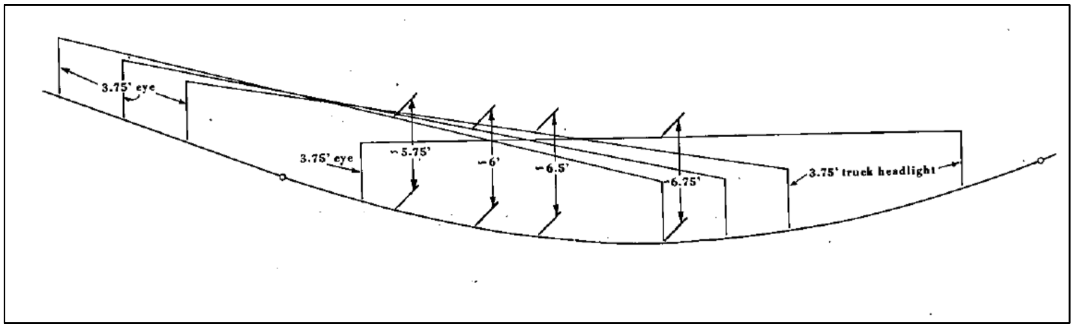


**Figure 2.13: Example Height of Screen Required**
Source: (Transportation Research Board 1979)

As previously mentioned in Section 2.3.3, sight distance is limited at night by the vehicle headlights which provide between 120m and 150m of visibility (Austroads Limited 2010), a distance required to be considered when determining the K value. When considering the glare produced by oncoming vehicles within a sag curve, it is once again the headlight sight distance which is of most importance. In addition to the provision of adequate screening, other countermeasures include providing appropriate reflective road furniture such as guideposts to help offset the difficulties of night time driving.

The height of headlight screening will need to consider the actual height of the driver along with the physical headlight on the vehicle, as well as the road geometry features to ensure the most appropriate solution is realised at varying locations.

### 2.3.5. Non Median Applications

Service roads are those which run parallel or separate to main arterial roads, serving to divide local road traffic from higher operating speed roads. Glare issues can occur from the opposing headlights of two way traffic on service roads. Outer separators are provided between the through carriageway and service road to form a traffic barrier and provide visual separation of two traffic flows, catering for installation of road furniture and screen planting. The provision of screening prevents drivers on the main road from thinking they are driving on the incorrect side of the road (Austroads Limited 2010).

The Austroads *Guide to Road Design* (Austroads Limited 2010) provides typical widths of outer separators for varying situations. It is suggested where there is two way traffic operation on a service road, the separation should be at least 5m width (excluding shoulders) for light traffic, and greater than 7m width for medium to heavy traffic. Additionally, it is suggested for headlight glare screening that between 2 to 5m of planting should be provided or alternatively an artificial screen.

A demonstration of how horizontal curve design can have an effect on headlight glare where there could be a service road running parallel is shown in Figure 2.14.

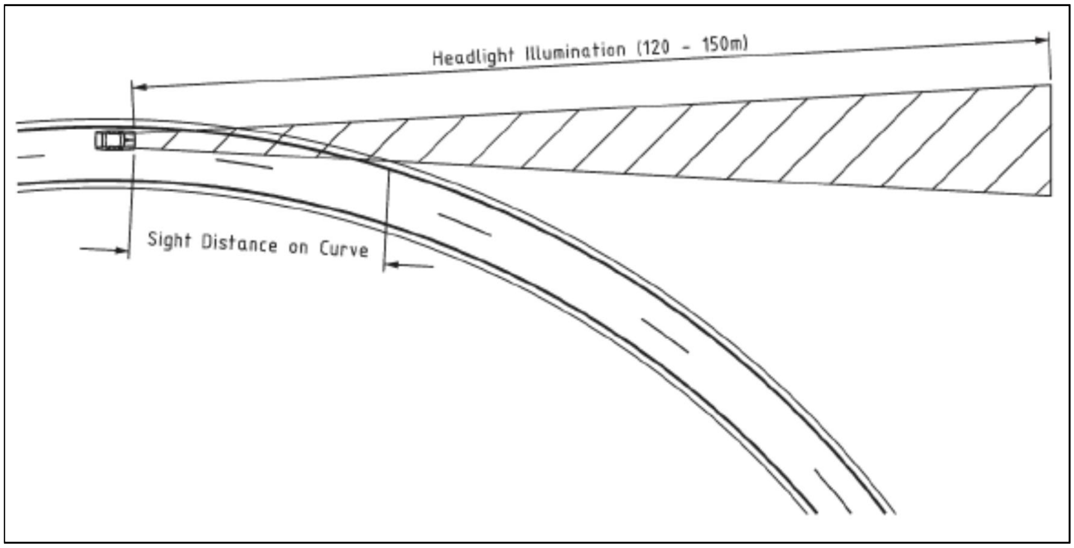


**Figure 2.14: Headlights and Horizontal Curves**
Source: (Austroads Limited 2010)

If it is assumed there is a service road for two way traffic on the left of the main carriageway, it is seen how headlights from oncoming vehicles may affect drivers, and is dependent on the length and radius of the curve. Therefore it is important to design the most appropriate treatment for the outer separator to mitigate against the potential glare effect.

### 2.3.6. Location Considerations

The location considerations included in the *'Glare Screen Guidelines*ô were generalised by factors that may impact night driving visibility and encountering glare. In terms of specific locations, and following industry research, the following location considerations have been researched:

- Interchanges

- Intersections on service roads adjacent to and directed at main carriageways

Interchanges generally fall in to two categories; service and system interchanges. A service interchange is one between a major highway carrying high traffic volumes and a minor road carrying lower traffic volumes, servicing towns. A system interchange relates more to two major highways that carry high traffic volumes, providing free flow for both highways and interconnecting ramps (Austroads Limited 2010). Interchanges are often provided as urban entry points and as such disturbance from headlights to residences and opposing vehicles, particularly on exit and entry ramps, needs to be minimised.

An intersection is generally described as where two roads meet and the four basic forms of intersections are shown in Figure 2.15. Where there is a service road directly adjacent to a main carriageway and an intersection is required, the direction of waiting traffic needs to be considered during design to cater for the direction of headlights. The Austroads *Guide to Road Design* (Austroads Limited 2010) provides that designers need to consider basic data which includes what the current situation is at the site and if the likely changes that may occur in the future.

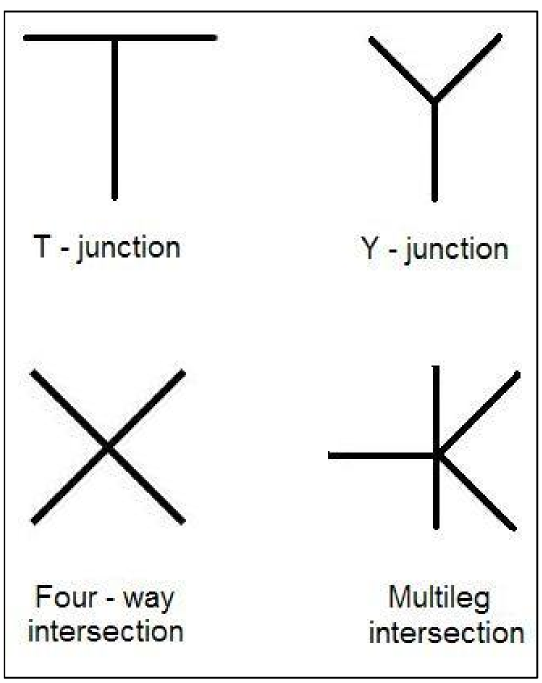


**Figure 2.15: Basic Intersection Forms**
Source: (Austroads Limited 2010)

The current situation data includes traffic volumes and hourly traffic counts along with the topography whereas changes in the future may be construction of new major roads nearby and predicted traffic volume increases.

Current design practices of both interchange and intersection headlight studies are presented in Section 3 of this dissertation, to demonstrate potential headlight glare issues for drivers. Location considerations such as these are hard to quantify into design criteria and need to be assessed on a site by site basis.

## 2.4. Accident Experience

The 1979 Glare Screen Guideline (Transportation Research Board 1979) includes information relating to traffic accidents at night. It is stated in the guideline there is ñ*no clear evidence*ò that the installation of headlight glare screen had reduced the accident statistics however does recognise that driving at night is made more difficult by glare from oncoming vehicles.

In 1997, the American Association of State Highway and Transportation Officials released the Highway Safety Design and Operations Guide which includes information on glare screens and reducing accident incidence. This document states ñ*the only effective ways to reduce headlight glare are to design or redesign the highway with wide medians or to provide higher median barriers with glare screens*ò (American Association of State Highway and Transportation Officials 1997).

Research for this project included efforts to obtain night time accident history statistics from both Roads and Maritime Services and also NSW Police. Unfortunately due to the nature of their database, no relevant data was provided that specifically linked accidents to headlight glare. Like with the 1979 Glare Screen Guideline, it is apparent that the value of headlight glare screens does relate to reducing night time accidents, however there is no data to support this conclusion. Other factors that may be significant in determining whether night accident data could provide guidance may include:

- Location of the vehicle, whether it be on the inside or outside lane, and the number of accidents that occur

- The ratio of night to day accidents
- Age of the driver
- Traffic volume statistics and occurrence of background lighting

As was the case in 1979, it is difficult to relate geometric data to specific night time accidents, such as horizontal curvature or median width. This may comprise future work for others, where a screen could be retro-fitted to an existing accident hot spot to determine whether the incidence of the accidents reduces or disappears as a result of the barrier.

## 2.5. Vehicle Design Factors

For vehicles manufactured from July 1989, the third edition ADRs for vehicles are administered by the Australian Government under the *Motor Vehicle Standards Act 1989*. For vehicles manufactured prior to July 1989, the application of the second edition ADRs were the responsibility of each state and territory. Of specific note to this project, the implementation of lighting ADRs was postponed until October 1991 and July 1992 for some vehicle categories. All road vehicles are to comply with the relevant ADRs at time of manufacture and supply into the Australian market (Australian Government Department of Infrastructure and Transport 2013).

Of specific interest to this project is the scope of ñADR13-Installation of Lighting and Light-signalling Devices on other than L-Group *Vehicles*ò which ñ*prescribes requirements for the number and mode of installation of lighting and light signalling devices on motor vehicle other than L-Group vehicles*ò and ñADR 46 ï Headlampsò which ñ*prescribes the photometric requirements for headlamps which will provide adequate illumination for the driver of the vehicle without producing undue glare for other road users*ò (Australian Government ComLaw 2013).

### 2.5.1. Headlamp Intensity

The intensity of the headlamp itself is governed by ADR46, and is a direct factor in the occurrence of glare effect.

ADR46 (Australian Government Department of Infrastructure and Transport 2013) includes general provisions for illumination, catering for suitable type ĩ*filament lamps that provide adequate illumination without dazzle in the case of the passing beam, and good illumination in the case of the driving beam*ȍ. A filament lamp, otherwise known as a halogen lamp, is the most commonly used sealed beam headlight, which is actually a bulb made of high resistant glass surrounding a tungsten filament. The power omitted from the lamp is documented as volts or watts and the amount of light produced is document in lumens, the SI unit of luminous flux.

The suitable headlamps listed in ADR46 and the relevant information relating to each is included in Table 6.

**Table 6: Suitable Headlamps for use in Vehicle Manufacture**
Source: (Australian Government Department of Infrastructure and Transport 2013)

| Filament Lamp Type | Nominal Power (Volts:Watts) | Light Flux (lumens) |
|---|---|---|
| H | 12V: 55W | 1150 |
| H2 | 12V: 55W | 1300 |
| H3 | 12V: 55W | 1100 |
| HB3 | 12V: 60W | 1300 |
| HB4 | 12V: 51W | 825 |
| H7 | 12V: 55W | 1100 |
| H8 | 12V: 35W | 600 |
| HIR1 | 12V: 60W | 1840 |
| HIR2 | 12V: 55W | 1355 |
| H9 | 12V: 65W | 1500 |

The Royal Automobile Club of Queensland (Royal Automobile Club of Queensland 2013), also known as the RACQ, devotes a section of their website to headlights, giving its readers up to date information on headlight technology and the rules governing their installation and use.

In particular, there is extensive discussion on high intensity discharge (HID) lamps which are popular alternatives to the halogen lamps. HID headlamps are a gas discharge lamp producing light via an electric arc between two electrodes housed inside a transparent quartz envelope. They have a greater light output and are considered more efficient electrically.

The higher output of light means that HID headlamps must comply with specifications on light colour, proportions of specified light wavelengths and ultra violet emissions, covered by ADRs 77-Gas Discharge Headlamps and 78-Gas Discharge Light Sources.

ADR77 provides the measurement of the properties of light requirements in vehicle headlamps equipped with gas discharge light sources, stating that headlamps made with a suitable gas discharge light source must give adequate luminance without dazzle when passing another vehicle, along with good illumination for forward vision when driving. ADR78 provides the more technical dimensional, electrical and photometric requirements for gas discharge light sources, ensuring correct functionality when installed into a gas discharge headlamp ((Australian Government ComLaw 2013).

ADR13 requires all headlamps in vehicles (including where HID lamps are fitted) that produce over 2000 lumens must have a self-levelling system and headlight washers to assist in reducing glare. A self-levelling system maintains headlamps at the correct level with sensors positioned between the suspension and the body of the vehicle to monitor the height of the body and readjust headlamp aim as required depending on the loading in the vehicle (Hillier & Coombes 2004) and headlight washers remove the road grime that gathers on headlamp lenses, which in HID lights causes glare issues.

In terms of the outward angle of the headlight itself, Department of Transport in Western Australia has declared that the angle of a retrofitted headlight may only be outwards of 20 degrees (Government of Western Australia Department of Transport 2012). Additionally, the 1979 Glare Screen Guideline accepts a cut off angle of 20 degrees on tangent as a practical value, demonstrating the value is suitable.

Throughout the research for this project, it became apparent that the headlight beam pattern will be important in determining which road design factors could be considered when determining if screening was required. Figure 2.16

provides the best representation to demonstrate a standard headlight beam pattern for both low beam and high beam.

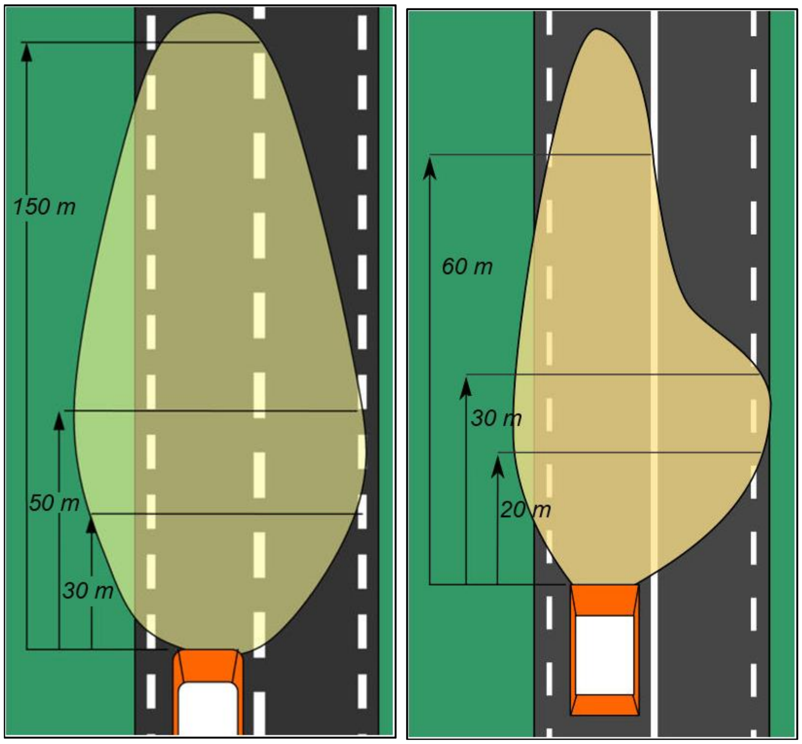


**Figure 2.16: High Beam Headlight pattern and Low Beam Headlight pattern**
Source: (AHW308 blogger 2010)

Using Figure 2.16, the information found in Transport Western Australia and basic mathematics a headlight beam envelope has been calculated and will be the assumption used within this dissertation for the purposes of testing potential headlight glare issues against road geometry. The details of this assumption are provided in Section 3, Figure 3.1.

## 2.5.2. Headlamp Positioning

Front exterior lights of a vehicle generally include low and high beam, along with signal and parking lights. Figure 2.17 shows the positioning of each of these on a typical passenger vehicle.

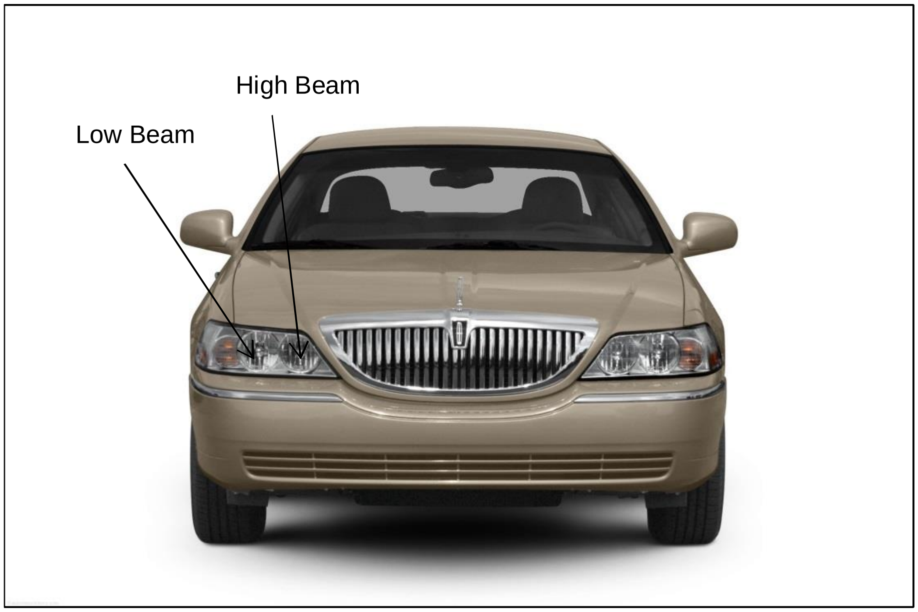


**Figure 2.17: Headlamp Position on Standard Vehicle**

Having the correct alignment of vehicle headlamps is critical in avoiding glare issues for oncoming drivers.

RACQ (Royal Automobile Club of Queensland 2013) provides discussion on how to test headlight alignment which involves parking the vehicle on a level surface approximately 8m away from and at right angles to a wall. With headlights on, reverse the vehicle approximately 4m and ensure at high beam that the spread of the two lights are at equal heights. When switching to low beam, the beams should drop slightly to just below the centre line of the headlight height and move marginally to the left. For the purposes of this dissertation, it is assumed this generality for headlight positioning is the case, however headlamp positioning does depend on the type and height of the vehicle overall.

### 2.5.3. Vehicle Innovations

It was in the late eighteenth century that steam powered vehicles were invented in Britain. Between 1905 to 1914 the technology of the vehicle grew with electronic ignition systems and many other innovations realised. By the 1990's major advancements were made in the way of online computers and safety with the ABS brake system and air bags being fitted as a standard feature to new vehicles (Auto & General Services Pty Ltd 2013).

Of specific relation to vehicle headlights, there are many innovations that have been, and are still being, recognised. Advances in vehicle equipment are mainly seen as breakthrough in the area of safety for all road users.

Mazda is one company who has incorporated high beam control safety technology which ŏ*detects oncoming and preceding vehicles and automatically switches between high and low beams during night driving”* (Mazda Motor Corporation 2013). This technology removes the risk of the driver not switching from high beam which can cause excessive glare to both oncoming vehicles and vehicles driving in front.

Toyota have also introduced a system in new vehicles sold in Japan and Europe in which the headlights use a camera to detect other cars and forces the lights to react by dimming the portions of the high beam which would shine in the oncoming drivers eyes (Automotive News 2013). Once again, this technology removes the need for the vehicle driver to switch between high and low beams. A representation of the system is provided in Figure 2.18.

**Figure 2.18: Toyota High Beam Filter Technology**
Source: (Automotive News 2013)

Other vehicle manufacturers are introducing similar innovations into their new models.

## 2.6. Headlight Screen Resources

Headlight screens are designed as road features primarily to reduce the risk of a traffic accident occurring. There are several manufacturers of screen systems located around the world including the German anti-glare screen system by 'Beilharz', the median barrier system created by 'Safe-hit' in Chicago and the headlight dazzle screen by 'Ingal Civil Products' here in Australia. It is important to note that whatever the type of screen installed, ongoing maintenance must be considered, and therefore appropriate access is to be available.

### 2.6.1. 'Beilharz' Anti–Glare Screen System

The 'Beilharz' system is made of oval shaped, completely closed, hollow body vanes made of green low pressure polyethylene designed to attach to barriers. There are three standard vane heights, 0.6m, 0.9m and 1.2m, and they can be placed at the desired intervals depending on the road geometry. The system has passed all relevant tests for its country and has proven performance in the event of impact with the product brochure stating that "*the vanes are very stable in shape and will bounce back to their initial position immediately whenever they are bent by force up to an angle of 80$^{o}$C. No vane parts will be ejected when the vanes are hit by a vehicle*." The service life has also been tested and it has been found the panels are resistant to UV radiation and exhaust gases and are temperature resistant at temperatures from -30$^{o}$C to +60$^{o}$C (Beilharz Road Delineation Systems 2013).

**Figure 2.19: Beilharz Anti-Glare Screen System**
Source: (Beilharz Road Delineation Systems 2013)

In terms of maintenance, it is said that because of the high material density and smooth surface of the vanes that no maintenance work is required after installation as the panels have a self cleaning effect.

### 2.6.2. 'Safe-hit' Glare Screen System

The system from Chicago is similar to the Beilharz arrangement, with modular glare screen units constructed of durable high impact polymer, being mounted on concrete barrier. The blades are designed to be green, orange or white with a height of up to 0.75m. The blades are flexible, durable and fit into a specially designed plastic blade base and base rail system. The system mounts to the top of median barriers to create a shield for the length of the median (Safe-Hit 2013).

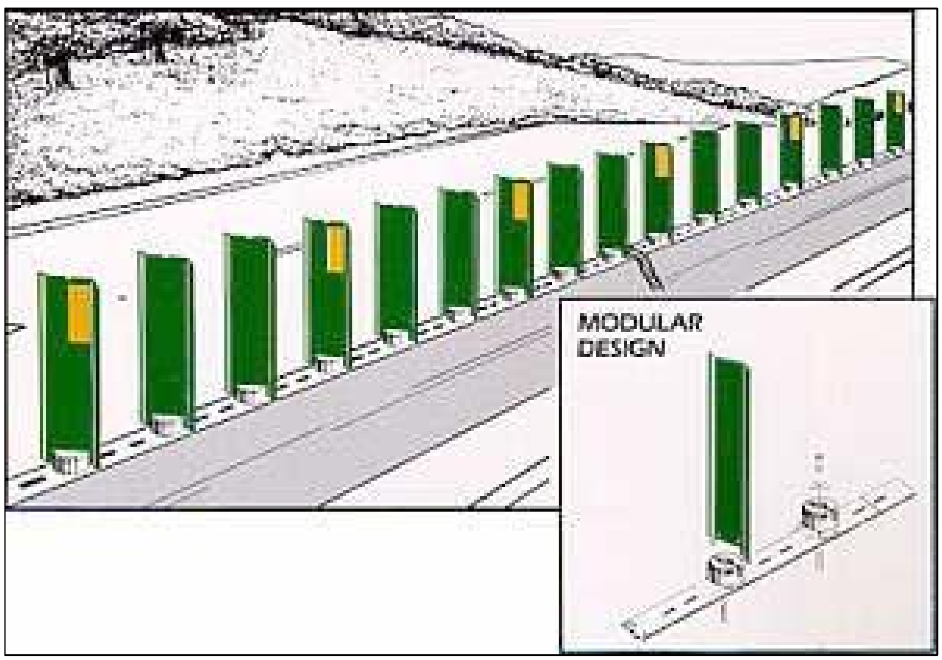


**Figure 2.20: Safe-Hit Glare screen System**
Source: (Safe-Hit 2013)

### 2.6.3. 'Ingal Civil Products' Headlight Dazzle Screen

The Ingal Headlight Dazzle screen shields headlight glare from oncoming motorists with its durable expanded metal sections that are hot dip galvanised prior to powder coating. The screen attaches to concrete barriers and can be customised to suit all barrier heights. The metal sections can be made with a variety of light filtration properties, ensuring the most appropriate solution is achieved for each location these barriers are installed (Ingal Civil Products 2013).

**Figure 2.21: Ingal Civil Products Headlight Dazzle Screen**
Source: (Ingal Civil Products 2013)

## 2.6.4. Landscaping and Earth Mounds

An increasingly common and economical form of headlight screening is to use strategic landscaping within medians and outer separators, as previously discussed in Section 2.3.1 Medians.

Earthworks associated with road works can produce excess materials to what is required, known as spoil. Spoil is defined as *"any earthen material that is surplus to requirements or unsuitable for re-use in fill and embankments …"* (Roads and Maritime Services 2013). It is the intent of road projects that the amount of spoil is kept to a minimum, however is unavoidable in most cases. Due to changes in waste management in NSW, removal of spoil from construction sites has become a costly exercise and so application of this material within projects is considered a cost saving. Methods for re-using the material includes; widening embankments, providing landscaped earth mounds which can double as a headlight screen.

Overall it is noted that artificial screens are generally more acceptable where there is a narrow width to be treated. Landscaping, by its nature, does require sufficient area to enable planting, along with earth mounds which require ample space to satisfy appropriate batters and benches, depending on their height. Where they can be applied, the preferred treatment in NSW is currently to providing landscaping, followed by the provision of an earth mound.

# 3. Application of Design Principles

Current road design practices identified in Austroads *Guide to Road Design* do not specifically cater for designing and implementing headlight screens as a counter measure to headlight glare issues created by oncoming vehicles for drivers.

It is considered however that these road design practices may be applied to developing design to best determine the most appropriate locations for headlight screens. Analysis has been undertaken to determine if road geometry alone might be factored in to assist road designers in eliminating headlight glare issues for night time drivers. The following factors have been analysed:

- Median treatments, including outer separators
- Curvature, including both horizontal and vertical

In addition, location considerations have been reviewed to demonstrate a site by site analysis is required and includes current design that has included the implementation of headlight screens.

## 3.1. Median and Outer Separator Width Analysis

Medians provide separation of carriageways and they are designed to be varying widths depending on their function, as is identified in Table 1. Outer separators allow for separation of service roads or parallel roads to the main carriageway, which generally carry traffic travelling in the opposite direction, having the potential to cause confusion for drivers seeing traffic on their left hand side.

The effect of headlight glare to oncoming traffic based on varying separation widths has been analysed for night time traffic using mathematical operations. The following assumptions have been adopted for median analysis:

- 3.5m carriageway width, vehicle position sitting centre of lane
- 2.0m vehicle width, driver position sitting 1.25m from road edge line
- High beam headlights, with a 150m sight distance

- Worst case scenario headlight beam envelope (high beam) as per Figure 2.16
- Flat terrain
- Medians of 0.8m, 6m, 9m, 12m and 15m widths

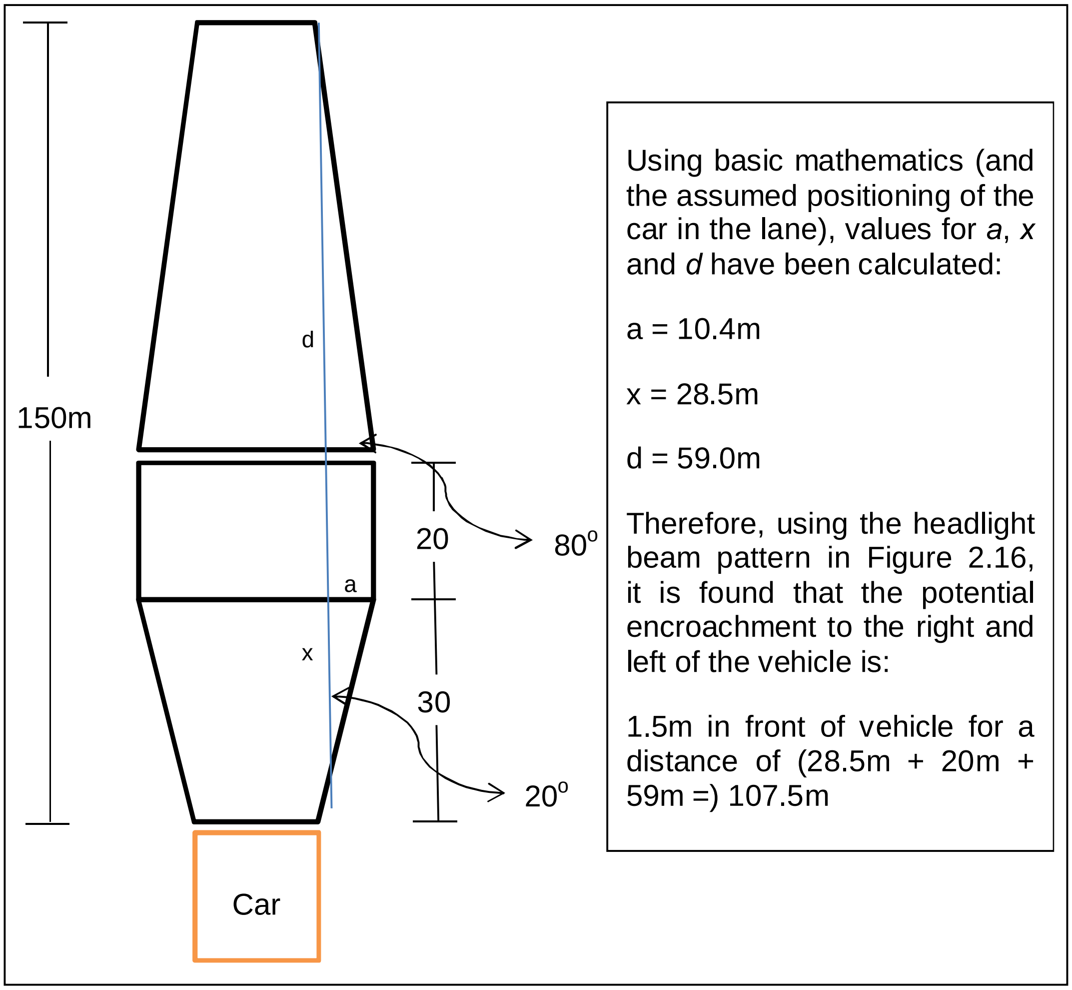


**Figure 3.1: Headlight Beam Envelope Scenario**

The following assumptions have been adopted for outer separator analysis:

- 3.5m carriageway width, vehicle position sitting centre of lane
- 2.0m vehicle width, driver position sitting 2.25m from road edge line
- High beam headlights, with a 150m sight distance
- Worst case scenario headlight beam envelope (high beam) as per Figure 2.16
- Flat terrain
- Separation of 7m, 9m, 12m and 15m widths

The median and outer separator widths analysed are based on RMS design practices as identified in Section 2.3.1 of this dissertation.

It is further assumed that the glare impairment distance with no separation (as calculated and demonstrated in Figure 3.1) to be 108m (this has been rounded up). It is important to note the total width of headlight beam impairment is 10.4m from the carriageway edge line and so it can immediately be assumed that medians and outer separators of widths greater than 10.4m will generally not require headlight screen treatment, however this decision may still depend on other road design criteria including curvature.

The 108m distance is converted into total time (in seconds) of impairment depending on the speed travelled, to which 6 seconds is added, the noted recovery time when moving from light to dark, as is outlined in Section 2.2.1.

Whilst full results are available in **Appendix C**, the following procedure was adopted when conducting the analysis:

1. For each separation width, trigonometry was used to determine the distance of encroachment based on the separation, using Figure 3.1.

2. The distance calculated has been converted into the time (in seconds) the driver of the oncoming vehicle will be impaired, assuming there is no screen protection. This has been determined for four speed limits; 60km/h, 80km/h, 100km/h and 110km/h and for two way traffic travelling at the same speed.

3. Using the time impaired, and the speed limit travelled, the actual distance travelled whilst glare impaired has then been determined.

4. A factor is then introduced to calculate the distance travelled within the hour, at each speed limit, based on traffic volume in any one hour, working in multiples of 50 vehicles, extending to 250 vehicles per hour.

5. A percentage has then been applied to the results of Step 5 to demonstrate how much time in the hour the driver of an oncoming vehicle is potentially impaired by headlight glare.

The results need then be analysed in relation to speeds and traffic volumes, against the percentage of time it is deemed that drivers may be impaired by the headlights of oncoming vehicles. It is apparent that a car travelling at 60km/hr can be considered to be at lesser risk of a more serious accident than one travelling at 110km/hr and therefore the percentages of impairment must be considered in relativity to the situation. To best demonstrate the results, a summary of the findings for a 6m median separation is provided (noting this is less than the suggested 10m median width treatment of Austroads).

1. Calculation of distance and the time (seconds) impaired by headlight glare for each speed limit:

**Table 7: Calculation of Impairment in Seconds**

| 6m separation | | D (km) | 0.0570 |
|---|---|---|---|
| km/hr | km/min | secs/D | |
| 60 | 1.0 | 9.4 | |
| 80 | 1.3 | 8.6 | |
| 100 | 1.7 | 8.1 | |
| 110 | 1.8 | 7.9 | |

| | | | |
|---|---|---|---|
| | | Background Distance calculations | 57.0 |
| Radian(20) = | 0.349 | (10.4-6)*tan(20)= | 12.1 |
| | | 20m straight | 20 |
| Radian(10) = | 0.175 | (10.4-6)*tan(10)= | 25.0 |

2. Total distance travelled (m) whilst the driver of the oncoming vehicle is assumed impaired by glare (including the 6 second recovery time) for each speed limit, considering two way traffic at the same speed:

**Table 8: Calculation Total Distance Travelled (m) Impaired**

| Distance travelled impaired (m)/vehicle | |
|---|---|
| =( ((secs/D)-6 seconds)/2) + (6 seconds) x (speed (km/hr)) x (1000/3600) | |
| km/hr | 6m |
| 60 | 128.5 |
| 80 | 161.9 |
| 100 | 195.2 |
| 110 | 211.9 |

3. Total distance travelled (km) for the hour, whilst the driver of the oncoming vehicle is assumed impaired by glare for each speed limit, considering two way traffic at the same speed:

**Table 9: Calculation Total Distance Travelled (p/h) Impaired**

**6.0m median**

| | | Speed km/hr | | | |
|---|---|---|---|---|---|
| | | **60** | **80** | **100** | **110** |
| Volume/hr | **50** | 6.4 | 8.1 | 9.8 | 10.6 |
| | **100** | 12.9 | 16.2 | 19.5 | 21.2 |
| | **150** | 19.3 | 24.3 | 29.3 | 31.8 |
| | **200** | 25.7 | 32.4 | 39.0 | 42.4 |
| | **250** | 32.1 | 40.5 | 48.8 | 53.0 |
| | | distance (km)/hr | | | |

4. Percentage of time it is assumed the driver of the oncoming vehicle is impaired by glare for each speed limit:

**Table 10: Calculation Percentage of Time Impaired**

**6.0m median**

| | | Speed km/hr | | | |
|---|---|---|---|---|---|
| | | **60** | **80** | **100** | **110** |
| Volume/hr | **50** | 11% | 10% | 10% | 10% |
| | **100** | 21% | 20% | 20% | 19% |
| | **150** | 32% | 30% | 29% | 29% |
| | **200** | 43% | 40% | 39% | 39% |
| | **250** | 54% | 51% | 49% | 48% |

As previously mentioned, the speed limit and situation would need to be considered. For instance, it could be assumed where there is a 60km/hr speed limit and up to 250 vehicles per hour that this is an urban environment and quite possibly has background lighting which would reduce the effect of glare. Therefore the percentage of 71%, whilst it is the highest result, may not be reflective of the actual situation. This does lead to the conclusion that road geometry alone may not be the most relevant factor to consider when determining where headlight screens should be installed.

To complete the analysis, it was determined that a demonstration of what, if any, effect screening would have on the above results. It was assumed that 50m long screens, whether it be appropriate landscaping or artificial apparatus, were placed at 100m intervals. It is further assumed for this analysis that there is no background lighting or other factor that would reduce glare. It is to be noted that these lengths were chosen for analysis purposes only, and other lengths could simply be implemented to test for specific road designs.

When 50m screens are applied with 100m spacing intervals between, the total length of road within the hour that the driver is assumed to be impaired by glare reduces. Table 7 provides the recalculated distance to be analysed.

**Table 11: Recalculated Distances for Analysis**

| | | | | |
|---|---|---|---|---|
| Total kms travelled within hour | 60 | 80 | 100 | 110 |
| No of treatments implemented | 400 | 533 | 667 | 733 |
| Length of treatments applied | 20 | 27 | 33 | 37 |
| Distance remaining as untreated | 40 | 53 | 67 | 73 |

To provide a direct comparison, the results for a 6m separation are provided.

1. Calculation of distance and the time (seconds) impaired by headlight glare for each speed limit remains unchanged for this analysis.

2. Total distance travelled (m) whilst the driver of the oncoming vehicle is assumed impaired by glare for each speed limit, using the recalculated values as per Table 6, considering two way traffic at the same speed:

**Table 12: Calculation Total Distance Travelled (m) Impaired – Screens Assumed**

| Distance Remaining | 6m |
|---|---|
| 40 | 85.7 |
| 53 | 107.2 |
| 67 | 130.8 |
| 73 | 140.6 |

3. Total distance travelled (km) for the hour, whilst the driver of the oncoming vehicle is assumed impaired by glare for each speed limit, considering two way traffic at the same speed:

**Table 13: Calculation Total Distance Travelled (p/h) Impaired – Screens Assumed**

**6.0m median**

| | | Speed km/hr | | | |
|---|---|---|---|---|---|
| | | **60** | **80** | **100** | **110** |
| Volume/hr | **50** | 4.3 | 5.4 | 6.5 | 7.0 |
| | **100** | 8.6 | 10.7 | 13.1 | 14.1 |
| | **150** | 12.9 | 16.1 | 19.6 | 21.1 |
| | **200** | 17.1 | 21.4 | 26.2 | 28.1 |
| | **250** | 21.4 | 26.8 | 32.7 | 35.1 |
| | | distance (km)/hr | | | |

4. Amended percentage of time it is assumed the driver of the oncoming vehicle is assumed impaired by glare for each speed limit:

**Table 14: Calculation Percentage of Time Impaired – Screens Assumed**

| | | Speed km/hr | | | |
|---|---|---|---|---|---|
| | | **60** | **80** | **100** | **110** |
| Volume/hr | **50** | 7% | 7% | 7% | 6% |
| | **100** | 14% | 13% | 13% | 13% |
| | **150** | 21% | 20% | 20% | 19% |
| | **200** | 29% | 27% | 26% | 26% |
| | **250** | 36% | 34% | 33% | 32% |

As is demonstrated above, if screens are applied the total percentage of time a driver is potentially impaired by headlight glare does significantly reduce, for example from 54% to 36%, a total reduction of 18% or greater than 10km travelled in the hour, for 60km/hr at 250 vehicles an hour.

This analysis can be applied to sample road design during project development providing designers with a guide to satisfy the safety of drivers where headlight glare may be an issue.

It is important to note that this analysis assumes the vehicle travels along an alignment that allows the driver the full calculated sight distance for the entire hour at the nominated speed and therefore road specific design criteria would need to be adopted on a case by case basis. The analysis provides the setup for the designer to input the required criteria to best determine if headlight screens should be considered. If the initial analysis, where it is assumed no screens are to be implemented, results in excessive percentage where the driver may be impaired by headlight glare, then the application of the screen lengths can also be altered depending on specific design criteria.

A separate method of using Poisson Distribution has been considered to determine if traffic volume can better be utilised. Vehicle arrivals at a certain point can be modelled, whether it be how many vehicles arrive in a given time period or what is the time period between arrival of vehicles. The probability method of Poisson Distribution is traditionally used to model the random nature of vehicle movements, however it was deemed that in terms of where screens could be installed to satisfactorily treat for headlight glare in direct relation to road design features that this method would not benefit the process. Site specific traffic volumes are generally available for main highways and can be individually modelled if required for other locations and therefore can be included in the design process if found to be relevant.

The same process of separation width analysis was undertaken for the outer separator, having a slightly different driver position, however the final results in terms of percentage of impairment were the same as for median separation. Full results are provided in **Appendix C**.

## 3.2. Horizontal Curve Analysis

Horizontal curves vary in radii, and also in their length. As is demonstrated by Figure 2.14, headlights may cause glare to drivers in oncoming carriageways should the curved road run parallel to each other. A depiction of how the horizontal curve is calculated is provided in Figure 3.2.

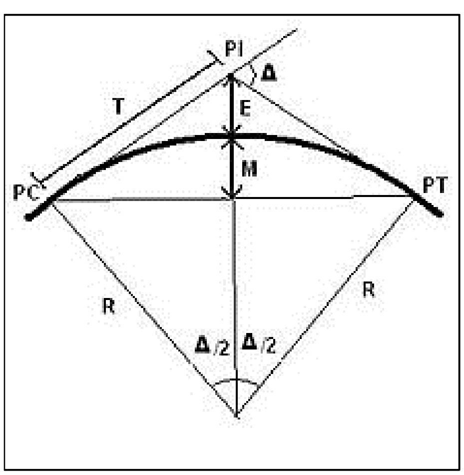


**Figure 3.2: Horizontal Curve Example for Simple Road Design**

The relevant factors in Figure 3.2 that has been included in the analysis undertaken for this dissertation are:

| | | |
|---|---|---|
| R | = | Radius of the curve |
| PC to PT | = | Curve length |
| M | = | Middle ordinate of the curve and represents the middle of the curve |
| æ | = | Central angle of the curve |

The purpose of this analysis is to determine whether the time a driver spends on a horizontal curve should be considered when designing for headlight screens. It has been assumed that there are no obstructions on the inside of the curve.

The values from Table 4 have been adopted in this analysis along with four common speed limits of 60km/hr, 80km/hr, 100km/hr and 110km/hr.

Whilst full results are available in **Appendix D**, the following procedure was adopted when conducting the analysis:

1. Varying central angles were assumed, including 20, 40, 60 and 80 degrees

2. Using basic mathematics equations for semi circles, the curve length and middle ordinate has been calculated

3. The time spent on the curve, travelling in one direction, was then calculated

To provide a demonstration of the calculations undertaken, the results for speed limit 80km/hr are provided below:

**Table 15: Sample Calculation Horizontal Curve Analysis**

| Operating Speed | Design Min Radii 5% super | 6% super | 7% super |
|---|---|---|---|
| 80 | 240 | 229 | 219 |
| | Central Angle = 20° | | |
| L (m) | 84 | 80 | 76 |
| M (m) | 3.6 | 3.5 | 3.3 |
| Time on curve (secs) | 4 | 4 | 4 |
| | Central Angle = 40° | | |
| L (m) | 168 | 160 | 153 |
| M (m) | 14.5 | 13.8 | 13.2 |
| Time on curve (secs) | 8 | 7 | 7 |
| | Central Angle = 60° | | |
| L (m) | 251 | 240 | 229 |
| M (m) | 32.2 | 30.7 | 29.3 |
| Time on curve (secs) | 12 | 11 | 11 |
| | Central Angle = 80° | | |
| L (m) | 335 | 320 | 306 |
| M (m) | 56.1 | 53.6 | 51.2 |
| Time on curve (secs) | 15 | 15 | 14 |

The results must be considered for two way traffic at each speed limit and so the results for the time on the curve in seconds, is then halved. As can be seen, for 80km/hr, for a 335m curve length, at 5% superelevation, a driver is on the curve for a total of 15 seconds. If it is assumed two vehicles are travelling in opposing lanes, the time that each driver may be affected by headlights of the other vehicle is approximately 7.5 seconds.

The greatest time on a curve has been determined to be when travelling at 110km/hr on a 6% superelevation curve where the length is calculated as 739m. A driver will be on the curve for 25 seconds in one direction, and so halved, gives 12.5 seconds that two drivers of opposing vehicles may be affected by the headlights of the other vehicle.

These results indicate that headlight screen implementation as a result of horizontal curvature alone is not warranted, given the time a driver spends on the curve is assumed to be negligible.

## 3.3. Vertical Curve Analysis

Treatments for headlight glare that may be applied on a vertical curve generally relate to the height of the driver and length of the curve, specifically sag curves. Like for horizontal curve analysis it is determined that given the time spent on a curve, and the fact that headlights are directed in a line ahead, therefore effectively reducing the potential impact to oncoming drivers who may be on the opposing downslope, that road geometry analysis alone would not provide the most appropriate guide.

As was indicated in the 1979 *Glare Screen Guideline*, should screening be found to be required on a sag curve, the height of this screening should be increased, a height that can be determined by incorporating the length and grade of the curve, along with the separation width.

Specific calculations have not been undertaken for vertical curve analysis due to previous results of median width and horizontal curves concluding that whilst road geometry is important and can be factored in to where headlight screens may be implemented, other risk factors should also be considered.

By using Equations 1, 2 and 3, road designers can determine the curve components and apply the finding of the 1979 document, in that if a curve length is approximately 180 metres and has a grade of 3%, then screening should be considered at an increased height to counteract the possible headlight glare impairment.

## 3.4. Application to Current Design

To best demonstrate certain location considerations, current design for major road construction in both NSW and QLD have been used. The designs include an artificial screen treatment to be constructed between the main highway alignment and adjacent service road on the mid north coast of NSW and another to be constructed at a major motorway interchange in QLD. For confidentiality reasons, the exact design location is not revealed as permission has not been granted by the road authority.

### 3.4.1. Outer Separator Artificial Screen

A major highway upgrade is being constructed adjacent to existing road infrastructure and therefore there are tight constraints along the entire 25km length of upgrade. It is expected when the project is completed, there will be high traffic volumes on both the main dual carriageway alignment as well as the service roads that run parallel for a large percentage of the project.

As is demonstrated by Figure 3.3, there is very little separation between the main alignment and the service road. At this location there is an intersection on the service road at a 90 degree angle to the main alignment. The vertical alignment of both roads is slightly separated, with the main alignment being approximately 1m below the service road. Interestingly, the local road intersection with the service road is on a downward slope and therefore headlights from vehicles stopped at the intersection, or even approaching it, would be directed on to the main carriageway if there were no screens in place.

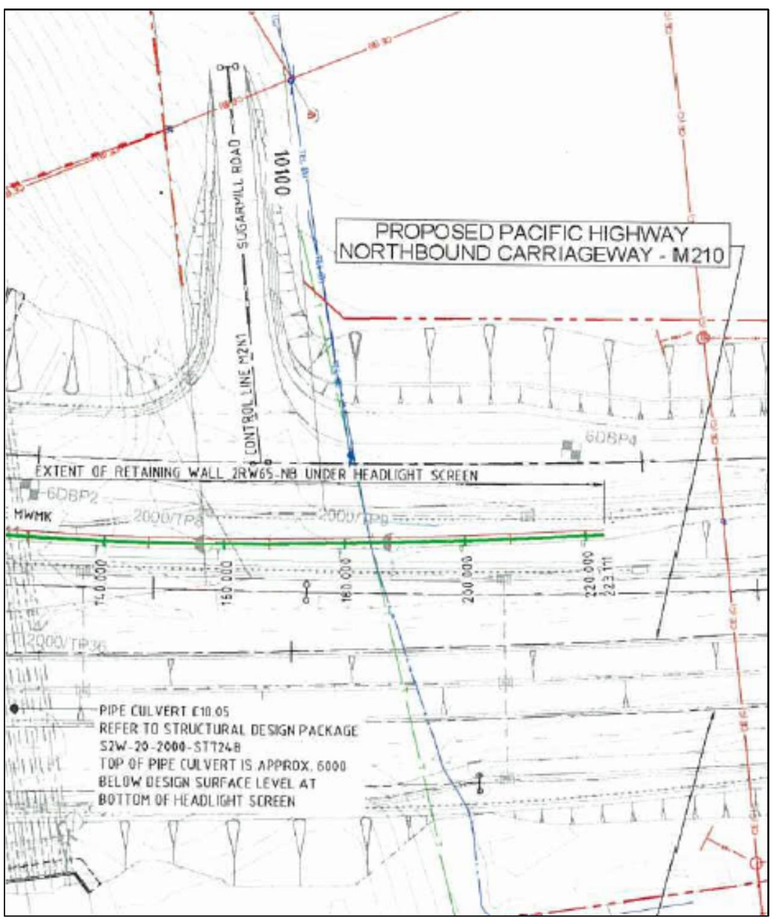


**Figure 3.3: Current Design Example Showing Headlight Screen in Outer Separator Between Main Alignment and Service Road**

A 220m long combined headlight screen/noise wall has been incorporated into the design to assist with both headlight glare and noise associated with the new upgrade.

Referring this back to the analysis undertaken for outer separator, it is apparent the minimum 7m width as determined by Austroads was not possible. Therefore a test could be applied to the actual separation, and along with the traffic volumes (not available for this dissertation) it could have been determined that due to the road geometry headlight screens were required.

It is important to recognise the added factor of the intersection on the service road, which would cause the headlights of vehicles waiting at that location to shine directly on to the main alignment. It is considered this may cause confusion for drivers on the main alignment.

### 3.4.2. Motorway Interchange Artificial Screen

An interchange constructed as part of a major motorway upgrade by the QLD Department of Main Roads included provision of a headlight glare study. As part of this study, the headlight sight distance of 150m was adopted and on the curve of the relevant ramps, this distance was tested to determine the potential glare envelope of the vehicle. Figure 3.4 provides a demonstration of the glare study on one of the ramps.

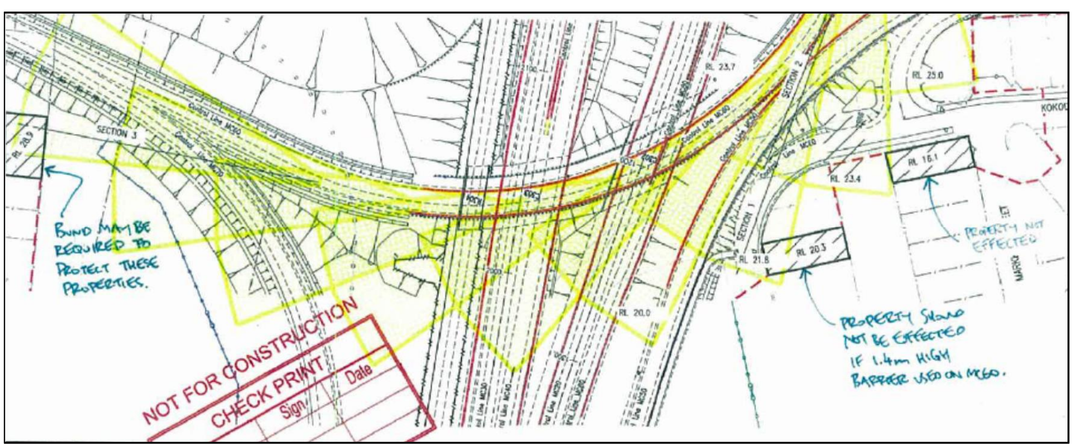


**Figure 3.4: Excerpt from Headlight Glare Study Demonstrating Results**

As a result of these expected glare envelopes it was determined that a 1.4m screen would be required on the associated ramps. Determination of this height was found by incorporating the grade lines of the ramp as is also shown in Figure 3.4.

Once again, this current design example shows how many road geometry factors combined can be considered in whether or not headlight screens may be required.  Location considerations must also be contemplated on a site by site basis to ensure all possible effects are captured.

# 4. Consideration of Risk Factors

It has been determined that road design principles can be applied in simple form to provide basic guidance in regards to appropriate locations for headlight screens. However given that road design can be quite complex and must consider location factors, it is considered that road geometry is not the only factor to be contemplated when assessing design for potential headlight screen implementation.

As was mentioned in the introduction to this dissertation, driving *is a complex activity* and *the road environment can alter at any point in time, with pedestrians and other traffic.* It is therefore proposed that external factors need also be considered when assessing design for headlight glare including those things that may distract the driver when travelling at night time. The list below are items that a road authority can have influence over, and therefore it would be prudent to include these factors in the draft Headlight Screen Design Guidelines to be developed.

- Narrow travel lane and shoulder widths, more prominent on rural roads
- Line marking and guideposts positioning
- Road signage reflection
- Locations of high number of wildlife crossing
- Road lighting, providing a bright background
- Traffic volumes
- Vehicle accident history

In addition to the above, it has been determined that the recovery time for a driver to return to normal sight once a vehicle has passed may be assessed as a risk factor. For the purposes of this analysis, a risk assessment table has been calculated using a total recovery time of 9 seconds, which caters for both the 6 seconds when moving from light to dark, and the 3 seconds when moving from dark to light. This differs to the previous analysis where only the 6 seconds was included. The intent of this analysis is to determine the total time a driver may be impaired purely as a result of passing a lit vehicle, and also when first encountering an oncoming vehicle.

A brief background to each of the risk factors is provided to demonstrate the potential issues each can have to a driver.

## 4.1. Narrow Travel Lane and Shoulder Widths

This may be a road geometry factor, however on older roads, generally in rural areas, the travel lane is often found to be less than the desirable 3.5m and there is quite often little or no paved shoulder. These roads also tend not to have any median separation. The driver faces greater risk on such roads where vehicles approach each other and given the narrow lane, there is very little room for error. If the road includes long straights, it is possible drivers may be inadvertently affected by headlight glare for substantial travel distances.

## 4.2. Linemarking and Guidepost Positioning

White line marking is used throughout Australia to delineate roadways. This delineation provides guidance to the travelling public in terms of the outer limits of travel lanes along with such things as intersection treatments and speed limits. It is possible that this linemarking will wear over time and become difficult to see, and so this may pose a hazard to drivers which adds to confusion on the road. Linemarking may be harder to see when driving at night, especially on off white concrete surfaces where the two colours are similar.

Placement of guideposts need also be considered. As was mentioned in Section 2.3.3, a drivers dwell point moves toward the glare source when approaching and it is considered if there is adequate reflection points provided on the outer side of the travel lane, the driver may use these as their dwell point when a vehicle with headlights on is approaching.

## 4.3. Road Signage Reflection

Road and traffic signs need to be visible to night time drivers and over time technology has allowed for signs today to be reflective, allowing drivers to see them at night. It is important to recognise that the reflection from the road signs needs to be applied correctly to ensure a scatter effect does not occur. Light does reflect off different materials in different ways and it has been found that road signs are only effective if they are retro reflective

Traffic signs are manufactured with retro reflective sheeting to ensure they are seen when the headlight reaches the sign, where the light beams bounce off the retro reflective surface in the same direction as they came (Road Traffic Signs 2013).

Should the retro reflection not be applied, it is possible drivers may be dazzled if the reflected surface provides a scattering effect. It is also noted that some road signs still in operation throughout Australia may be older than the technology of the retro reflection and so must be considered for upgrade.

## 4.4. Wildlife Crossing

Distraction to drivers comes in many forms, however one of the most unpredictable factors is wildlife which has access to cross roads. In rural Australia there is much wildlife, including kangaroos, koalas and critters which may all cross main roads. It is common for vehicles to hit these animals and is well known cause of vehicle accidents. Mitigation measures to assist in removing this distraction could be incorporated into road design or implemented at existing locations in high incident areas to ensure the safety of drivers at night time.

## 4.5. Road Lighting

Having sufficient road lighting at specific locations provides the driver with information about the upcoming road features. Good quality lighting will illuminate the roadway and remove the incidence of glare from oncoming headlights.

## 4.6. Traffic Volume

Included in the road geometry analysis were the factors of speed and traffic volumes. It was shown that these can provide guidance in determining if headlight screens should be applied.

High traffic volumes at unlit locations may cause excessive glare. As has been found in the median and outer separator analysis, the higher the traffic volume, the more time a driver is found to be impaired by glare.

## 4.7. Vehicle Accident History

As was mentioned in Section 2.4, it is possible that headlight glare may be the cause of vehicle accidents, however during the course of researching for this dissertation, it was difficult to find a clear resolution to support this. When combining the above mentioned risk factors and implementing appropriate mitigation measures it is determined that the incidence of vehicle accidents as a result of headlight glare may be reduced.

## 4.8. Recovery Time Risk Assessment

The total assumed impairment distance previously used for road geometry assessment included the 150m oncoming distance of the vehicle along with the 6 second recovery time when moving from light to dark. As a result of the findings of this road geometry analysis, further assessment has been undertaken specifically to analyse the impairment distance a driver may travel just during the recovery period. To provide a complete assessment, a total of 9 second recovery time has been used which incorporates the 3 seconds a person experiences when moving from dark to light.

To best demonstrate how a general risk assessment can be applied, hourly traffic volumes have been used in increments of 10, ranging from 50 vehicles/hr to 200 vehicles/hr. Using sample speed limits, the total assumed glare impairment distances have been calculated. To enable application of the risk, a standard risk assessment matrix has been developed where the number of vehicles per hour is deemed to be the likelihood of a traffic accident to occur as a result of headlight glare, and the distance travelled is the impact risk to the driver.

To best demonstrate how such a risk assessment matrix could apply, sample distances have been coloured in either green, orange or red indicating a sample traffic light system, with red being the highest risk and therefore where additional assessment is more likely to be required to assess whether headlight screening is to be implemented.

**Table 16: Possible Risk Assessment Matrix**

| LIKELIHOOD | | IMPACT – DISTANCE TRAVELLED (km) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Speed (km/h) | | | | | |
| Hourly Traffic Volume (veh/h) | | 60 | 70 | 80 | 90 | 100 | 110 |
| | 50 | 7.50 | 8.75 | 10.00 | 11.25 | 12.50 | 13.75 |
| | 60 | 9.00 | 10.50 | 12.00 | 13.50 | 15.00 | 16.50 |
| | 70 | 10.50 | 12.25 | 14.00 | 15.75 | 17.50 | 19.25 |
| | 80 | 12.00 | 14.00 | 16.00 | 18.00 | 20.00 | 22.00 |
| | 90 | 13.50 | 15.75 | 18.00 | 20.25 | 22.50 | 24.75 |
| | 100 | 15.00 | 17.50 | 20.00 | 22.50 | 25.00 | 27.50 |
| | 110 | 16.50 | 19.25 | 22.00 | 24.75 | 27.50 | 30.25 |
| | 120 | 18.00 | 21.00 | 24.00 | 27.00 | 30.00 | 33.00 |
| | 130 | 19.50 | 22.75 | 26.00 | 29.25 | 32.50 | 35.75 |
| | 140 | 21.00 | 24.50 | 28.00 | 31.50 | 35.00 | 38.50 |
| | 150 | 22.50 | 26.25 | 30.00 | 33.75 | 37.50 | 41.25 |
| | 160 | 24.00 | 28.00 | 32.00 | 36.00 | 40.00 | 44.00 |
| | 170 | 25.50 | 29.75 | 34.00 | 38.25 | 42.50 | 46.75 |
| | 180 | 27.00 | 31.50 | 36.00 | 40.50 | 45.00 | 49.50 |
| | 190 | 28.50 | 33.25 | 38.00 | 42.75 | 47.50 | 52.25 |
| | 200 | 30.00 | 35.00 | 40.00 | 45.00 | 50.00 | 55.00 |

The information provided in this section of the dissertation was necessary following the results of the road geometry assessment, where it was found that other factors would need to be considered.

There is much further work that may be undertaken in reference to each risk factor to best develop appropriate guidelines for road designers and this is discussed in Section 6 of this document.

# 5. Draft Guideline Development

RMS acknowledges in their many developed design guidelines that there are mitigation measures that can be implemented into our road configuration to counteract the effect of many factors, including noise, landscaping measures, urban design and pavement. As has been previously mentioned, there currently are no design guidelines for the application of headlight screens to mitigate against glare.

It has been found that developing guidelines specifically for headlight screens will require further work to be undertaken surrounding the risk factors discussed in Section 4. As such, the actual writing of the guidelines now forms part of the further work that could be conducted as part of this research project.

However, base information that may be used in a guideline has been initiated in the following sub sections, and provide the basis of what should be included in the Headlight Screen Design Guideline.

## 5.1. Introduction

Provide an introduction to the guideline outlining the research undertaken surrounding the implementation of headlight screens. Promote the fact the guidelines are just that, a guide for road designers to assist in providing a safer road environment for the travelling public.

It would be relevant to include an introduction to the road geometry factors that are the subject of the basic tool to be used to conduct analysis on specific design. Further, an introduction to the risk factors to be included in a design assessment should also be included.

## 5.2. Background

Include the background to the varying types of glare and their impairment factors and the human effects when encountering glare as is provided in this dissertation.

The assumptions made during the development of the guideline should be documented and clearly identified to enable the user to make informed decisions when applying the guideline to their designs.

## 5.3. Road Design Factors

Provide extended discussion on the basic analysis undertaken and include suggested calculations that may be applied to specific design. It would also be relevant to provide background information the road design factors that should be considered, including separation widths, horizontal and vertical alignment.

Discussion on location considerations should also form part of this section with previous examples provided to demonstrate how and what has been implemented.

## 5.4. Risk Factors

Full assessment of the risk factors has not been undertaken as part of this dissertation, however it has been demonstrated how a risk assessment matrix could be further developed to assist in determining where headlight screens may be implemented.

The risk factors where it has been identified that a road authority can influence include; lane widths, delineation such as line marking and guidepost positions, sign reflection, wildlife crossings, road lighting and catering for traffic volumes.

It would be relevant to include documentation on retro- fitting screen measures to existing roads as would be the case to mitigate against the majority of the risk factors identified. Further research and work needs to be undertaken to enable applicable data to be captured in this section of a draft guideline.

## 5.5. Headlight Screen Material

It would be relevant to include discussion on the available headlight screens available for use, including landscape and earth mounds. Further work may be undertaken to research the most appropriate materials for different design locations, such as medians, outer separators, interchanges and curves.

Cost should also be a consideration when choosing the most appropriate screen material as the feasibility and reasonable expenses need to be weighed against the value in terms of glare impairment reduction to the driver. Sample estimates should be developed to allow easy feasibility analysis.

This section of the guideline should include provisions for ongoing maintenance and access to the headlight screens. It is possible that a risk assessment matrix could also be applied to the available materials to provide a clear understanding of the varying materials and their maintenance requirements.

## 5.6. Constructed Headlight Screens

Photographs of existing headlight screens of all forms should be provided to allow designers a visual representation of applied screens.

# 6. Further Work

The original intent of this dissertation was to develop a draft Headlight Screen Design Guideline based on road geometry provisions. During the course of the project, it has been determined that additional risk factors need to be incorporated into any assessment relating to where headlight screens should be implemented.

Due to time constraints, full research has not been undertaken to best determine how risk factors could be measured and analysed in accordance with road designs. A general introduction has been provided with suggestions for further work that could be completed to enable the guideline to be produced.

It is suggested the following further work be undertaken:

- Conduct thorough research, both literary and industry, relating to the risk factors. It is possible these can be extended and added to should additional risk factors be identified during the research. It is thought an additional factor could be related to traffic accidents, which is dependent on the ability to obtain information from third parties;

- Further develop the risk assessment matrix relating to glare impairment recovery time, should it be determined it is relevant for the guideline;

- Conduct further research on available headlight screen materials and investigate the potential for a risk assessment matrix based on relevant factors that may help make a decision on whether to use the material or not. Items may include ease of maintenance, cost and dimension.

The final step to reaching a conclusion for this project would be the completion of the draft Headlight Screen Design Guideline for submission to RMS Policy Department for review and implementation.

# 7. Conclusions

This project has investigated the need for headlight screens to be incorporated in to road design principles to counteract the occurrence of headlight glare affecting oncoming drivers.

By implementing mathematics, the headlight envelope of a vehicle has been assessed against carriageway separation and curvature.

The analysis of separation widths determined that the greater the separation width, the glare effect to the oncoming driver is lessened. Additional research was undertaken to hypothetically assess the benefits of installing headlight screens within the carriageway separation and a reduction in the time a driver may be impacted by headlight glare was calculated. It is important to note that various assumptions were made during the analysis, one such being that there was an unobstructed view for the time period assessed.

Horizontal curvature was also analysed, taking in to consideration the time a vehicle is on the curve at varying speeds and curve radii. When considering two way traffic, it was found with the assumptions made, that the greatest time a driver is expected to remain on a horizontal curve is negligible when considering the effect of headlight glare.

Therefore the analysis of these road design principles has concluded that road geometry alone may not be the most relevant factor to consider when determining where headlight screens should be installed.

In this regard, other known risk factors will require further research and consideration before a comprehensive road design guide for headlight screen installation can be completed. These risk factors include delineation items, such as guideposts and linemarking provisions and sign posting reflection. It is important to note that whilst it may be a relatively smooth process to incorporate screening into new highway design, existing situations must also be considered and therefore retrofit opportunities should also be investigated.

It is recommended that continued research is undertaken for each risk factor documented in Chapter 4, and that the road design analysis be further refined to provide road designers a relatively simple tool to assess the requirement for headlight screens.

With this additional research, it is considered the Headlight Screen Road Design Guide may be implemented to provide guidance on a consistent approach for road designers, initially in NSW and potentially Australia wide.

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# Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project

**PROJECT SPECIFICATION**

**For:** **YVONNE BOWLES**

**Topic:** A Consistent Headlight Screen Approach for NSW

**Supervisors**: Dr Soma Somasundaraswaran

**Aim**: This research project seeks to investigate the use and design of headlight (anti-glare) screens on major road projects and the potential effect they have on road safety. It is intended to develop draft Headlight Screen Guidelines incorporating design and safety requirements which may be adopted by the NSW State Government organisation, Roads and Maritime Services.

**Program**: **Version B, 21 October 2013**

1. Research literature and background material relating to:
    a. Headlight (anti-glare) screen design requirements (both Australia and world wide) including urban design features. Research will include; whether there are any existing guidelines, human factors, background to glare and current mitigation measures that may be implemented.
    b. Review existing road design guidelines against the literature review.
    c. Review of existing road designs in specified locations where headlight screens are to be installed to determine if design guidelines are sufficient to counteract glare.
    d. Typical materials used, and associated testing undertaken on their performance on impact by a vehicle.
    e. Potential alternative mitigation measures to counter headlight glare (ie: vehicle modification, vehicle headlights, road design measures).
2. Source design of the specified locations where screens are to be constructed, and analyse in accordance with the literature review;
3. Identify current design practices. This will assist in preparing a set of consistent draft design guidelines for the varying alignment design scenarios;
4. Develop draft Guidelines for internal RMS discussion, to include:
    a. Introduction
    b. Safety Performance of Headlight Screens
    c. Typical Headlight Screen Materials
    d. Design Guidelines
5. Report findings in the required written and oral formats.

**If time permits**:

6. Prepare a concept screen design using most appropriate materials (determined from research);

Student: _____________ / /2013 Supervisor ___________ / /2013

# Appendix B – Glare Screen Guide, Transportation Research Board 1979

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **66**

# GLARE SCREEN GUIDELINES

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

- FACILITIES DESIGN
- TRANSPORTATION SAFETY
- HUMAN FACTORS
- (HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. DECEMBER 1979

## NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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### Notice

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

Each report is reviewed and processed according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.

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Published reports of the

**NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM**

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## PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

## FOREWORD

*By Staff*
*Transportation Research Board*

This synthesis will be of special interest and usefulness to design engineers and others seeking information on the use of glare screen to shield drivers' eyes from the headlights of oncoming vehicles. Information is presented on various types of glare screen and the parameters involved in their design.

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Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Screening is being used extensively in medians and elsewhere to cut headlight glare from approaching traffic. This report of the Transportation Research Board includes design requirements and factors to be considered for a proposed installation of glare screen. The report concludes by identifying questions in need of additional research.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

# CONTENTS

## ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Paul E. Irick, Assistant Director for Special Projects. The principal investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers. This synthesis was edited by Anne Ricker.

Special appreciation is expressed to Edmund R. Ricker, Harrisburg, Pennsylvania, who was responsible for the collection of data and the preparation of the report.

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David K. Witheford, Engineer of Traffic and Operations, Transportation Research Board, assisted the Special Projects Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

# GLARE SCREEN GUIDELINES


## SUMMARY

Glare screen is used in the medians of divided highways and in other locations to shield drivers' eyes from the headlights of oncoming vehicles.

Glare can be avoided through highway design (wide medians, separate alignment, earth mounds), barriers, plantings, fencing, or glare screen on median barriers. Glare screen may be a continuous partition (either opaque or with intermittent openings) or a series of objects of such width and spacing as to block out glare.

Studies of driver vision indicate that sensitivity to glare varies widely among individuals and also with age. There are two types of glare: disability glare, which causes a measurable decrease in visual performance, and discomfort glare, which bothers a driver without necessarily impairing visual performance. Various studies and tests of driver vision indicate that 20 degrees is an acceptable cutoff angle for glare screen design.

Among the factors that affect the glare problem are the height of a driver's eye; the lateral position of a vehicle; and headlight height, aim, and intensity.

Although some feel that the potential value of glare screen lies in reducing night accidents, the data from studies in several states do not support this view. Most state accident analysis systems do not provide the information necessary to relate accident patterns to glare.

Design parameters for glare screen include median width, barrier type, vertical curvature, and horizontal curvature. The last is important because (a) opposing headlights are directed into a driver's eye in proportion to the degree of horizontal curvature and (b) with narrow medians, a glare screen may obstruct sight distance on curves to the left. Therefore, spacing or width of glare screen elements must be adjusted in proportion to the degree of curvature, and calculations should be made to ensure that the glare screen does not reduce the sight distance required for safe stopping.

No specific warrants have been established for installation of glare screen. Among the many factors that should be considered are accident experience (day-night ratio, age of drivers in night accidents, unusual distribution by type of accident, etc.), high nighttime traffic volumes, comments from the public, measurement of veiling brightness (disability glare), and highway geometry.

Among the conclusions of the synthesis are: accepted cutoff angle for glare screens is 20 degrees plus the degree of curvature; more effort is needed to simplify glare screen hardware for easier maintenance; development of an accident warrant is not likely; veiling brightness should be studied to see if it can be used as a warrant for glare screen; and geometric design standards should be reviewed in relation to use of glare screens in medians.

CHAPTER ONE

# INTRODUCTION

A glare screen is a device placed between opposing streams of traffic to shield drivers' eyes from the headlights of oncoming vehicles and thus enable them to see the roadway, vehicles, and other objects in front of them.

## GLARE

Glare is caused by light that interferes with seeing. It is defined as "the sensation produced by brightnesses within the visual field that are sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort, or loss of visual performance and visibility" (*1*). There are many sources of glare on the roadway, including sunlight, roadway lighting, spotlights on advertising signs, and vehicle headlights, as well as reflections from pavement, rearview mirrors, windows, and other surfaces. The effect of glare is more serious when the intensity is varied sharply, such as when sunlight penetrates between trees at the side of the road or a single vehicle is encountered at the crest of a vertical curve. The effects of glare can also be intensified by a continuous source, such as when one is driving toward a rising or setting sun or a line of approaching vehicles.

Headlights present one of the more common glare problems associated with highways. Glare is most often encountered on two-way, two-lane roads. However, the term "glare screen" as used here refers to one installed in the median of divided highways or, in a few special cases, installed along frontage roads or railroad tracks. Limiting glare screen to divided roadways reflects the greater need for them created by multiple lanes and high traffic volumes on these roads.

## PROBLEM

Driving at night is more hazardous and more difficult than driving in the daytime. This is demonstrated by higher accident rates (*2*) and the reluctance of many older drivers to travel at night. Headlight glare, which reduces visibility of vehicles or other objects in the roadway, also causes driver fatigue. Glare logically appears to be a causative factor in accidents and is recognized as a discomfort to all who ride the highways.

## CHARACTERISTICS OF GLARE SCREEN

The primary function of a glare screen is to effectively shield the driver's eyes from oncoming headlights. This may be accomplished by introducing a continuous partition or a series of objects of a width and spacing that will effectively prevent the glare from reaching the driver's eyes. The continuous partition may be opaque or have intermittent openings that allow a relatively open view of the opposing lanes perpendicular to the roadway while they screen out headlight glare at angles less than 20 degrees. Typical screens of each type are described in Chapter Two.

The manner in which various screen types reduce glare and affect both visual and physical access to opposing lanes should be considered in selecting a screen. For example, some agencies feel that an opaque screen prevents people from gawking at accidents in the opposing roadway; others feel that a limited view is necessary for law enforcement and detection of problems in the opposing lanes; and still others see a need for access between opposing lanes, at least by emergency personnel on foot. Some characteristics of the different types of screens are given in Table 1. Types I, II, and III are shown in Figure 1.

TABLE 1

CHARACTERISTICS OF DIFFERENT KINDS OF GLARE SCREEN *

| Characteristic | Type I | Type II | Type III |
|---|---|---|---|
| Prevent gawking accidents | yes | no | no |
| Prevent pedestrian crossings | yes | yes | no |
| Prevent slush & other objects from being thrown into opposing lane | yes | yes | no |
| Permit police surveillance of opposing lanes | no | yes | yes |
| Permit access to opposing lanes by emergency personnel | no | no | yes |
| Permit scenic viewing | no | yes | yes |

*Type I is a continuous screen that is essentially opaque to light from all angles.
Type II is a continuous screen of an open material that is opaque to light at angles from 0° to about 20° and increasingly transparent beyond 20°.
Type III is composed of individual elements positioned to block light at angles from 0° to about 20°. Beyond 20°, visibility is clear between the elements.

Desirable attributes of glare screen include the following:

- Effectively reducing glare.
- Simplicity of installation.
- Resistance to vandalism and vehicle damage.

- Quickly and safely repairable.
- Minimal cleaning and painting requirements.
- Minimal accumulation of litter and snow.
- Wind resistance.
- Reasonable cost, including maintenance.
- Good appearance.
- Emergency access to opposing lanes.

Each of these attributes is related to the fact that any installation, repair, or maintenance work to be performed in the middle of a high-speed, high-volume roadway will require effective traffic control during the work period.

On narrower medians, glare screen is usually placed in combination with a median barrier, the design of which will dictate the screen height and mounting details. It should be noted that the placement of a glare screen on the median exposes it to damage by moving vehicles, whether associated with accidents or not.

### EXPERIENCE TO DATE

Of the many different kinds of glare screen now in use, the most common is made of expanded metal mesh. Other types include shrubbery, earth mounds, tall median barriers, metal and polyester mesh, and plastic paddles.

Most installations to date have been successful in controlling glare and thus improving driver comfort. Nevertheless, means of measuring this improvement have not been developed (*3*). A few installations have been shown to reduce accidents, but in most cases there has not been a documented and statistically significant change. Maintenance and repair are difficult and expensive.

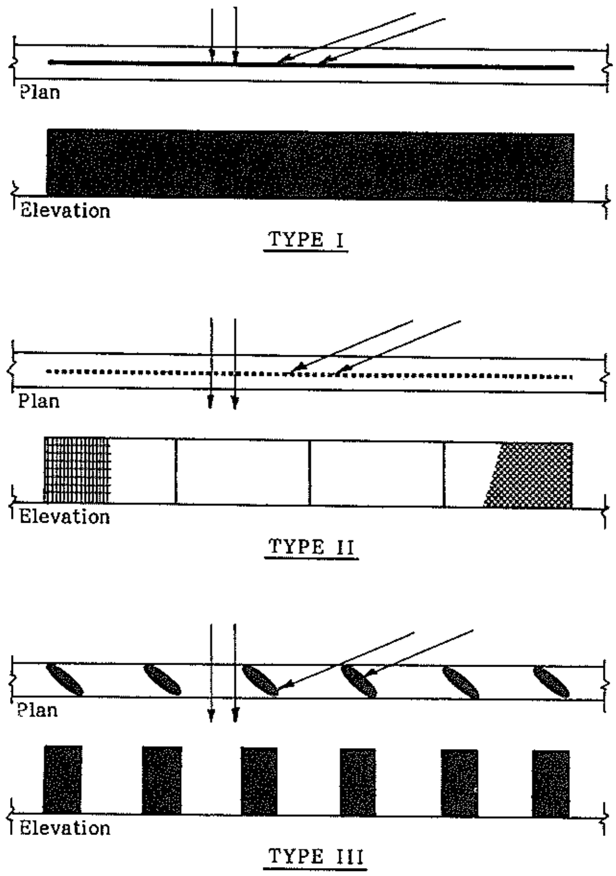


*Figure 1. Plans and elevations of glare screen types I, II, and III.*

CHAPTER TWO

# KINDS OF GLARE SCREEN

## GLARE AVOIDANCE BY HIGHWAY DESIGN

### Width of Median

Except on horizontal curves, glare can be controlled by separating traffic with a wide median of 50 ft (15 m) or more. In addition, the natural topography and trees left in the wider medians also block glare.

### Separate Alignment

The characteristic separation of grades in hilly or mountainous terrain can control glare even if the median is not wide. Specific consideration should be given to the possible incidence of glare where grades and alignment of opposing roadways change.

### Earth Mounds

In areas of excess cut material, grades and cross-sections can be modified to leave—or build—excess earth in the median and thus block glare. This requires minimum maintenance. However, current requirements for clear roadside design preclude the use of earth mounds on narrow medians.

## PHYSICAL BARRIERS

### Guardrail

Just like any other object introduced into the median, back-to-back guardrails will only partially reduce glare because their height is 27 to 33 in. (690 to 840 mm).

### Concrete Barrier

The standard 32-in. (810-mm) high concrete barrier, which is similar to guardrails, will also partially obstruct glare. The use of standard-height concrete barrier on projects involving widening into the median often results in glare control on curves because of the differences in elevation. Some jurisdictions have extended the height in other areas so that a fully effective glare screen is provided; this would be classified as type I (Fig. 2).

New Jersey has used a height of 42 in. (1070 mm)—10 in. (250 mm) above the standard median barrier on the Garden State Parkway. Michigan had adopted a height of 51 in. (1300 mm), thus adding 19 in. (490 mm) to the standard barrier (*4*). When placed on an existing barrier, the extension tapers from 6 in. (150 mm) to 3.5 in. (90 mm) and is attached by no. 4 bars set in the barrier. Crash testing is needed to determine whether the additional height interferes with the effectiveness of the concrete barrier in redirecting vehicles.

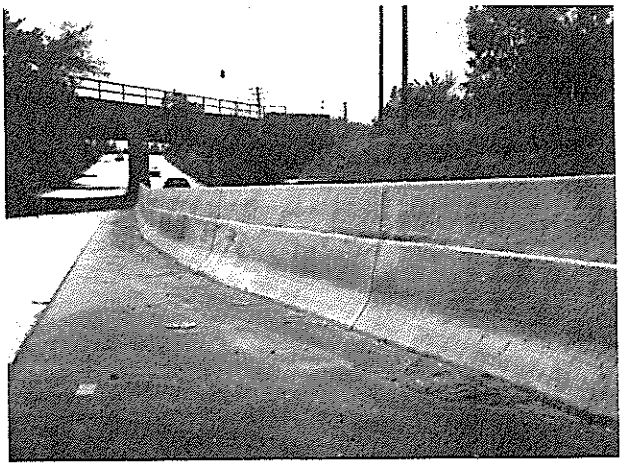

*Figure 2. Type I glare screen is effective in eliminating glare sources from both wide and narrow angles.*

### Plantings

Plantings were perhaps the first glare-screening devices tested. They were found to be effective and to contribute to noise control and a better appearance. The choice of plants depends on temperature and rainfall conditions, and is generally determined by the individual states; no national standards have been published (*5*).

Plants are particularly suitable for use on curves in wider medians as part of the general landscaping effort. They have been most used on parkways to help make the road look natural.

Maintenance needs are similar to those of any landscaping project and include litter removal, pruning and watering, and repair of damage from accidents or from salt used to control ice.

To avoid discontinuities where median plantings are used, it is customary to place some other type of screen on bridges and in areas where the median is too narrow for plantings.

### Fencing

Chain-link fencing has been used as glare screen, but often this is incidental to other use, such as to control access to the roadway.

The pattern of intertwining wires of chain-link fence makes a type II screen, which is effective if spacing of the wires is 1-in. (25-mm). The more standard 2-in. (50-mm) spacing has been used with plastic, metal, or wooden slats, which provide an almost opaque type I screen. Tests have shown that the slats should be inserted at an angle, rather than vertically.

## GLARE SCREEN MOUNTED ON BARRIER

Most recent glare screens have been mounted on top of steel or concrete median barriers. Hardware has been provided by the screen manufacturers as needed. Opinions differ about how the screen and barrier interact when a vehicle rides high enough up the barrier to strike the screen or when a wheel crosses the barrier. Some of the paddle screens are mounted so that they do not protrude over the edge of the barrier, a requirement that may reduce their effectiveness in blocking glare. Likewise, the size and placement of supporting brackets are dictated by the role the screen might play under crash conditions. Crash tests of several screen and barrier combinations appear warranted.

### Expanded Metal Mesh

The most widely used glare screen is expanded metal mesh (Fig. 3), which typifies a type II screen and has been in use for 15 years or more. It is manufactured from steel or aluminum sheets by cutting parallel slits and then stretching the sheets so that the slits open into a diamond pattern. The metal between the slits twists at an angle and forms an intermittent screen. The most common opening size is 1.3 in. by 4.0 in. (34 mm by 102 mm) with 0.25-in (6.4-mm) strands between. These are effective for a 20 degree cutoff angle, and smaller sizes are available for use on curves. The steel is galvanized before fabrication and electrostatically coated, usually green, after fabrication. The aluminum is coated with baked enamel after fabrication.

The mesh is mounted in either continuous or short sections, 10 to 12.5 ft (3 to 4 m) long, and is supported at the top and bottom by tension wires. The aluminum mesh has been known to break apart when mounted across bridge joints; otherwise the two metals seem comparable. Because more expanded metal mesh has been in use for a longer time, there has been considerably more maintenance experience with it.

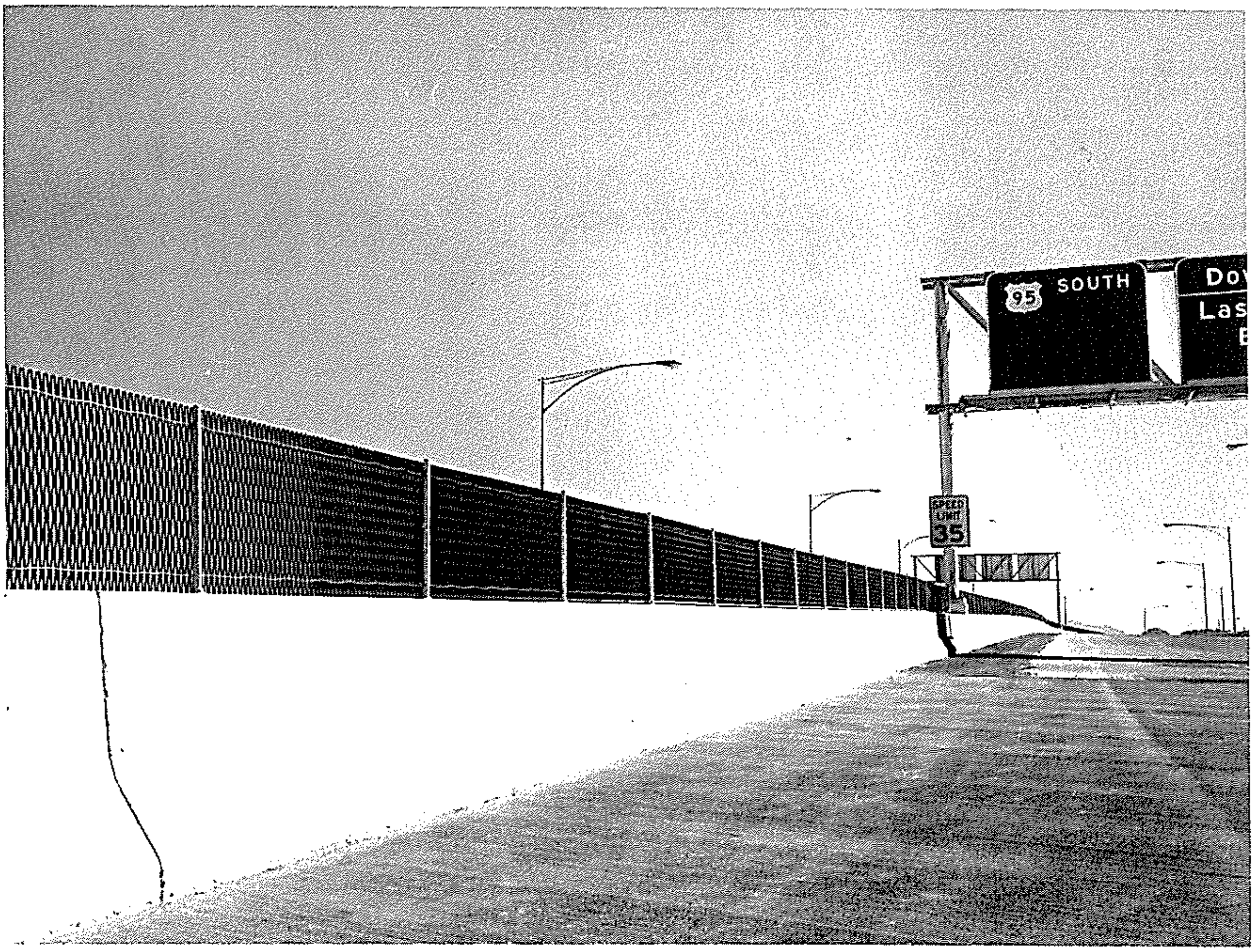


*Figure 3. Expanded metal mesh used as a type I glare screen cuts off glare from oncoming traffic (narrow angles) but admits light at greater angles.*

**Double Reverse Corrugated Steel**

Another type of metal screen, called double reverse corrugated steel screen, is slit horizontally and compressed so that alternate sections are formed into semihexagonal shapes to provide strength (Fig. 4). It is galvanized after fabrication and is held in place by bolts threaded through the hexagonal openings and spaced about 8 ft (2.4 m) apart. The standard height is 24 in. (610 mm). It forms a type I screen.

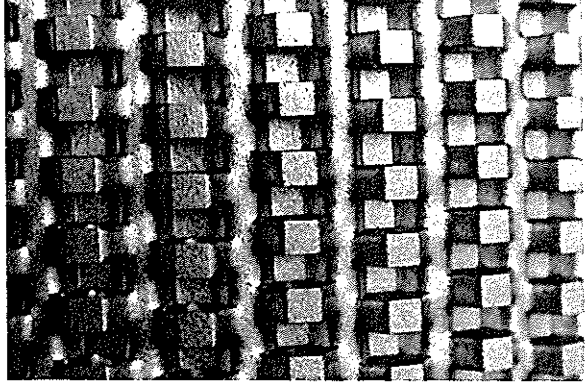

*Figure 4. Double reverse corrugated steel (type I) screen completely blocks glare.*

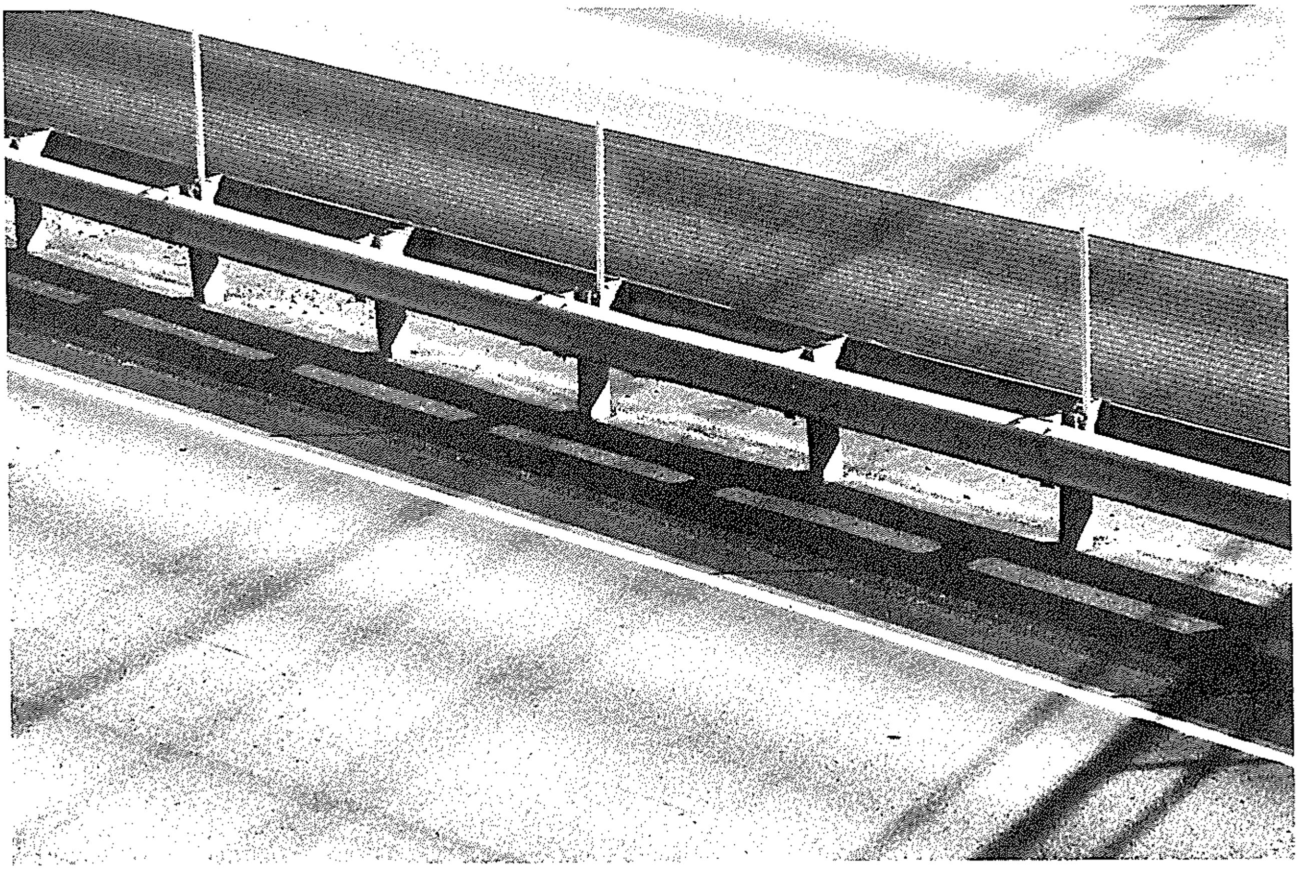

*Figure 5. Knit polyester fabric (type II) screen diffuses glare.*

**Knit Polyester Fabric**

A knit polyester fabric (Fig. 5) is used as a type II screen, although it diffuses rather than blocks light coming from shallow angles. The maximum angle for full diffusion is determined by the size and spacing of the vertical plastic threads and can best be checked visually, as opposed to being physically measured. The type and quality of plastic are laboratory tested to determine weatherability. The fabric mesh is fastened to vertical supports at 10- to 15-ft (3.1- to 4.5-m) spacings and brought to the proper tension with chains and turnbuckles.

**Paddles**

This type of glare screen is characterized by paddles supported individually and placed at intervals such that they block opposing headlights at a predetermined angle (Fig. 6). Design parameters are width of paddle [about 8 in. (200 mm)], angle to centerline (about 45 degrees), spacing [about 2 ft (0.6 m)], and height of paddle (varies according to location and highway geometry—see arrows on Figure 6). Hardware is available for fastening to concrete or steel median. Paddles typify the type III glare screen.

*Figure 6. Paddles (type III) used as screen block opposing headlights at predetermined angles but permit surveillance of and access to the opposing lane by police and emergency personnel.*

CHAPTER THREE

# DRIVER AND VEHICLE RELATIONSHIPS

## VISION

Visual abilities and visual problems related to driving have been studied intensively for many years. Particular attention has been paid to night vision and the effects of glare. Most of the following conclusions relating to the driver's ability to deal with glare are generally accepted.

### Sensitivity to Glare

Sensitivity to glare varies widely among individuals and most importantly with age. Older drivers are more sensitive to glare, particularly after they reach the age of 45 or 50 (*6*) (Fig. 7).

### Types of Glare

Two types of glare are recognized—that which causes disability and that which causes discomfort. Disability glare causes a decrease in visual performance; it can be measured in terms of reduced seeing distance of a target under varying glare conditions. Discomfort glare causes discomfort to the driver without necessarily impairing visual performance; there is no generally recognized measure. Actually, the effects of the two types overlap and may result in a driver's losing orientation relative to the roadway or to other traffic.

### Optical Devices

Except for polarized headlamp systems, there are no optical devices that will overcome glare for the driver.

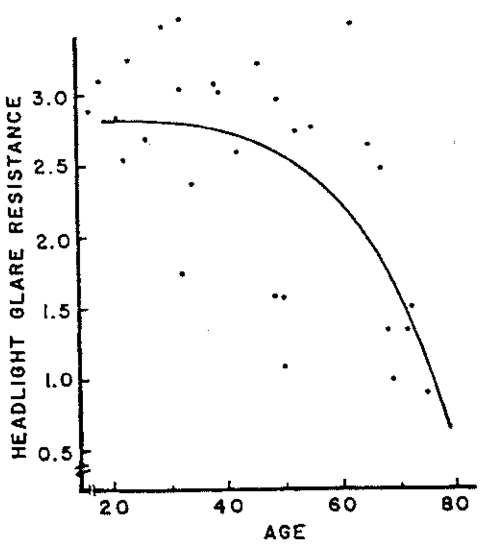


*Figure 7. Headlight glare vs. age.*

In particular, colored glasses and tinted windshields, although seemingly helpful in reducing glare, actually reduce seeing ability at night. Polarized headlamp systems have been shown to be effective, but they have never gained the acceptance necessary for general use (*7*).

### Driver Licensing

Current legal requirements for obtaining a driver's license do not include a test for glare sensitivity and probably will not in the foreseeable future.

### Design Cutoff Angle

The accepted cutoff angle of 20 degrees on tangent for the design of type II and type III glare screens comes from an AASHO book on urban highway design (*8*). This value was derived from measurements of peripheral vision and the limitation of tunnel vision (*9, 10*). In any event, experience has shown that 20 degrees is a practical value.

### Dwell Points

Two different studies indicate that drivers do not normally look very far ahead in order to obtain information necessary for vehicle control. *NCHRP Report No. 99* (*11*) indicates that information farther than 90 ft (27 m) from the driver is of relatively little value for determining velocity. Another study (*12*) on two-lane roads, disclosed that drivers' eyes normally dwell on the center of the lane about 500 ft (152.4 m) in front of them under daytime conditions and about 230 ft (70.1 m) at night. On curves, the dwell point moves toward the edge of the lane in the direction of curvature. The dwell point also shifts toward glare sources.

### Intensifying Effects of Glare

Relatively common conditions, such as rainfall, dirty windshields, dirty eyeglasses, and driver fatigue intensify the effects of glare.

### Veiling Brightness

Veiling brightness, which is defined as the intensity of disability glare from all sources, can be measured by a Fry-Pritchard glare lens used with a Pritchard Telephotometer. Measurements on Interstate highways in Michigan, for example, showed that a glare screen reduced glare 75 to 90 percent and eliminated large variations in glare intensity (*13*). In that study, "disability veiling brightness," or glare, was defined as light on the retina of the eye that does not contribute to the image being viewed.

### Targets

Controlled tests of the detection distance under glare conditions are usually conducted with black, diffuse targets that correspond roughly to a pedestrian in dark clothing. In other studies, retrodirective reflectors such as those in the rear lighting systems of automobiles have been used. The diffuse targets obviously are much more difficult to see under glare conditions; however, the vehicle reflectors might seem to be more realistic and usable targets for tests on divided highways (*14*).

### Glare Distance

Unexpectedly, tests conducted by the Bureau of Public Roads found that for a given lateral separation the effects of disability glare were present even at distances of 3000 ft (914 m) or more and that the rate of change of the effect with distance was small for most of this distance (*15*). This may account for the observed brightness of headlights on a highway with a narrow median, in that the glare sources in all lanes seem to be of equal brightness.

### Glare Test Vehicles

Most reported tests of target detection distance have been conducted with single vehicles, some with high beams and some with low beams, as glare sources (*16*).

### Alertness of Drivers

In most of the reported tests, the drivers have been aware that they were looking for a specific object. Studies made to compare the detection distance of "alerted" and "nonalerted" drivers show that the alerted ones are able to see targets at much greater distances—up to twice as far (*17*).

## VEHICLE CHARACTERISTICS

Some aspects of the highway glare problem are determined by vehicle design. The following vehicle characteristics are usually accepted as normal and are frequently adjusted to accommodate the design of new vehicles.

### Height of Driver's Eye

The accepted height of a driver's eye for highway design purposes is 3.75 ft (1.14 m) (*18*). A recent study (*19*) shows the driver's eye height for the 15th percentile of sample cars to be 3.49 ft (1.06 m), for cab-over-engine trucks to be 8.41 ft (2.56 m), and for cab-behind-engine trucks to be 7.80 ft (2.38 m). There is also a trend toward greater eye heights in vans and pickup trucks, which represent an increasing share of vehicle sales.

### Lateral Dimensions

One study (*15*) has suggested that test vehicles be assumed to drive the center of a 12-ft (3.7-m) lane, that the driver's eye be assumed to be at 4.25 ft (1.3 m) from the edge of the lane, and that the headlights and taillights be considered to be at the side of the vehicle 2.75 ft (0.8 m) from the edge of the lane. These dimensions allow calculations to be made on the basis of lateral separation; the minimum separation of an undivided highway is 7 ft (2.1 m). The lateral separation of divided roadways can be calculated by adding the width of the median and any intervening lanes to the basic 7 ft.

### Headlight Height

An average height for automobile headlights is about 26 in. (660 mm). The height of truck headlights is more variable; some are mounted very low for seeing in fog. An average of 3.75 ft (1.1 m) for the higher lights has been used for one design (*20*).

### Headlight Aim

The standard established by the American Association of Motor Vehicle Administrators for motor vehicle inspection provides that the top of the headlight beam (either high or low) shall be aimed within 4 in. (100 mm) above or below horizontal at a distance of 25 ft (7.6 m). In practice, however, many headlights are misaimed, either through neglect or by the loading of the vehicle.

### Taillight Height

There seems to be no standard placement of automobile taillights. A few random measurements show the average mounting height on smaller passenger vehicles to be about 32 in. (800 mm).

### Headlamp Intensity

The National Highway Traffic Safety Administration recently increased the permissible intensity of headlamp systems from 75 000 to 150 000 candlepower (candela) by a revision to Federal Motor Vehicle Safety Standard No. 108. Information on which this decision was made included an apparent 20 percent increase in seeing distance when no car is approaching and only a 1.5 percent decrease when approaching vehicles use high beams when the 150 000 candlepower lamps are compared to the present 75 000 candlepower lamps.

### Use of High and Low Beams

The rules of the road in most states require that motorists use the low beam when approaching an oncoming vehicle within 500 ft (152 m) and when approaching another vehicle from the rear within 300 ft (91 m). If followed, this would limit headlight use to low beams on any divided roadway with an appreciable amount of traffic. Little information was found that related headlight use to traffic volume on divided highways (*21, 22*).

## TRAFFIC VOLUMES

Although there are no published data on the relation of headlight glare to traffic volume, it seems logical that glare will increase in proportion to volume. However, the effect of multiple lanes is not known. Wider roadways, i.e., those with more lanes, have the same effect as wider medians, so a six-lane roadway with a 12-ft (3.7-m) median carrying the same volume as a similar four-lane roadway might have considerably less glare. However, when all lanes on both roadways are carrying heavy traffic, it is difficult to visually observe a difference in the glare on the various opposing lanes.

It may also be observed that vehicles traveling in a single line on a two-way roadway tend to block the glare from those traveling behind them, so that even in heavy traffic glare is received from two headlights on only the nearest vehicle and from one headlight on a limited number (say five) of others (*16*). On a divided highway, opposing vehicles are moving at a greater angle to the drivers' eyes and thus do not block each other's lights. To the extent that this is true, the effect of increasing volumes on glare must be greater than on a two-way roadway.

## ACCIDENT EXPERIENCE

The task of driving is more difficult at night, and glare makes it even more so. Tabulation of data from several states (not on comparable bases) indicates glare to be reported as involved in 0.2 to 3.8 percent of all night accidents (*23*). Logically, a reduction in glare should reduce accidents. However, there is no clear evidence relating the installation of glare screen to accident reduction. This is apparently due to the random nature of accidents, the complexity of accident causes, and the relatively low accident rate on the types of highways involved. Some reported accident experiences follow.

### California

Expanded metal screen was installed on a 7-mile (11-km) section of an eight-lane freeway with a 140 000 average daily traffic (ADT). The total accident rate was 2.00 accidents per million vehicle-miles (1.3 per million vehicle-km) on the test section and 1.40 (0.9) on the control section. Total accidents decreased more on the test section (glare screen added) than on the control section, but night accidents decreased more on the control section.

TABLE 2

OHIO ACCIDENT DATA BEFORE AND AFTER INSTALLATION OF GLARE SCREEN (*20*)

| | Before 7/1/64-4/1/66 | | After 5/1/66-2/1/68 | | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|
| | 21 mon. | Annual | 21 mon. | Annual | | | |
| All Accidents | 52 | 30 | 39 | 22 | 28 | 19 | 29 |
| All Night | 17 | 10 | 15 | 9 | 11 | 3 | 11 |
| All Day | 35 | 20 | 24 | 14 | 17 | 16 | 18 |
| Northbound Night | 13 | 7 | 5 | 3 | 5 | 1 | 9 |
| Northbound Day | 16 | 9 | 18 | 10 | 4 | 2 | 9 |
| Southbound Night | 4 | 2 | 10 | 6 | 6 | 2 | 2 |
| Southbound Day | 19 | 11 | 6 | 3 | 13 | 14 | 9 |

### Indiana

Plastic paddles were installed on a concrete median for a 5.3-mile (8.5-km) section of a four-lane freeway carrying 50 000 ADT. Accidents were not significantly reduced, although the night driving task was much easier (*24*).

### Michigan

Another aspect of the relation of glare screen to accidents was studied in Michigan. The assumption that accidents are caused by motorists gawking at accidents in the opposite roadway was checked by studying those accidents (both day and night) that happened in opposite directions at nearly the same time as compared to the number of probable random occurrences of nearly simultaneous accidents. It was concluded that the installation of opaque partition screen could be justified by the elimination of these gawking accidents on highways with sufficiently high volumes (*13*).

### New Jersey

A 1000-ft (305-m) test section of expanded metal was placed on a concrete median barrier on a heavily traveled section of US-22 in New Jersey. Studies were made for 28.5-month periods before and after installation. Comparing the night accidents in a test section to those in adjacent control sections, 35.3 percent occurred in the test section before and 21.6 percent after, which was termed "of weak statistical significance" (*25*).

### Ohio

One of the best-documented accident studies (*20*) was on an installation in Columbus, Ohio, where expanded metal mesh was initially installed on back-to-back guardrail and later replaced by mesh on a concrete median. The installation was made on a 3000-ft (900-m) section on a 2.5 degree curve on a six-lane roadway carrying 80 000 to 100 000 ADT. Initial studies showed a rather large reduction in night accidents in the "glare" direction.

An analysis of the original data, plus those for three recent years, is shown in Table 2. Looking at the table, northbound traffic is on the outside of the curve, or turning left in the direction where glare would be encountered. Although the annualized number of night accidents in this direction was reduced from seven before to three after, later years show five, one, and nine accidents, a random pattern. In addition, the other categories have not changed significantly, and no relation to the erection of glare screen is indicated. It is noted that the night accidents represent 33 percent of the total in the before period and 35 percent in the after.

### Pennsylvania

Expanded metal mesh was installed on back-to-back steel guardrail on a 2-mile (3-km) section of the most heavily traveled four-lane freeway in the state. Daytime accidents decreased 11 percent, nighttime accidents 23 percent, compared to two adjacent control (no screen) sections where daytime accidents increased 28 percent and nighttime accidents decreased 3 percent. The report concludes: "Anti-Glare Screen . . . does not negatively affect the accident history" (*26*).

An informal analysis of accidents at another glare screen installation (expanded metal on a concrete barrier) revealed no significant relation in the day-night accident ratio (60 to 40 before, 51 to 49 after), severity (43 percent injury accidents before, 46 percent after), average age of drivers, or involvement of older drivers.

### England

In England, a 2-mile (3-km) section of screen was removed after five years. The accident experience had been unsatisfactory (Table 3). Night accidents represent 43 percent of the total on the screened section and 46 percent on the unscreened (*27*).

TABLE 3

ACCIDENT EXPERIENCE WITH GLARE SCREEN (ENGLAND) (*27*)

| | Screened | Unscreened |
|---|---|---|
| Slight injuries | 27 | 14 |
| Serious injuries | 32 | 17 |
| Property damage | 51 | 39 |
| Total accidents | 110 | 70 |
| Night accidents | 47 | 32 |

## DISCUSSION

It would seem that the potential value of glare screens lies in reducing night accidents, particularly on the outside lanes of sharper curves. The reported accident data do not support this conclusion, perhaps because there are too many other factors influencing the occurrence of accidents.

Attempts have been made to determine whether some other factors could be related to accident patterns at potential or existing glare screen locations. The following information might be significant:

- Relative number of accidents on inside and outside curves.
- Ratio of night to day accidents.
- Relative number of night accidents involving older drivers.
- Concentration of night accidents at sag vertical curves.
- Unusual distribution of accidents by type at night, e.g., running off the road at the outside of a curve.
- Severity of accidents.
- Involvement of vehicles by type.
- Weather conditions.
- Skid resistance of pavement.

Most state accident analysis systems do not provide the type of information listed above, although some of it could be obtained in several states. A major deficiency is the lack of geometric data to relate specific accidents to physical conditions such as the degree of curvature or width of the median. Some analysis was made of Pennsylvania data for a section of glare screen about 3.75 miles (6 km) long, as indicated previously. No logical conclusions could be reached from this analysis, but it was interesting to note that the night involvement of drivers over 50 years old decreased from 18 to 11 percent of the total after installation of the screen.

Observations and experience of maintenance personnel indicate that glare screens, like median barriers and guardrails, are often struck but that few such accidents are reported. Some damage is outright vandalism but cannot be proved as such. On some very sharp curves, such as those on ramps with narrow medians, the glare screen has been so severely damaged that it has been removed.

CHAPTER FOUR

# DESIGN REQUIREMENTS

## MEDIANS

Many types and sizes of medians have been built, and they vary markedly over short distances, particularly in urban areas. Physical features of medians that affect the need for and design of glare screens include width, cross-section, curvature, grade, relative elevation of opposing roadways, and presence of a median barrier.

The design of glare screens is closely related to the design of median barriers, as well as to that of the roadway itself. Most glare screens are placed in narrow medians, where many other design features present problems, particularly in the protection of bridge piers, light standards, and sign supports.

Depressed medians, in the sense that cross-median movements are prevented by ditches, are not suitable for the installation of glare screens or median barriers. Several types of screens can be adapted to the multiple changes in raised median cross-sections, particularly if barriers are present. The design of glare screens in such areas should provide for longitudinal continuity; no bright glare spots, such as those near light standards, should be left open. Vertical continuity, as in closing the gap between the top of the median barrier and the bottom of the screen, is also needed.

### Median Width

Median widths reflect highway design history and the standards in force at the time the roadway was constructed. Narrow medians, 2, 4, or 6 ft (0.6, 1.2, or 1.8 m) wide, are often found on older freeways, particularly in urban areas (unfortunately, these are in combination with sharper curvature, narrower lanes, and other features that intensify the problems associated with glare). Other common median widths on older highways are 10 and 20 ft (3.1 and 6.1 m). The median width on several major toll roads is 26 ft (7.9 m). The design requirements of the Interstate system have resulted in wider medians so that headlight glare is not generally a serious problem. However, the widening of these highways by adding lanes within the median often reduces the remaining median to the narrower width and hence reintroduces glare.

Table 4, derived from data on Pennsylvania highways, shows the relative occurrence of different widths of medians and barriers in the available data classification. Nationwide data of this type are not available, but they must certainly vary widely among the states, according to the age of the highways and the rural-urban split.

TABLE 4

RELATIVE OCCURRENCE OF DIFFERENT MEDIAN AND BARRIER WIDTHS (PENNSYLVANIA)

| Width | Median Type | Mileage |
|---|---|---|
| 2' | Concrete curb | 126 |
| 4' | Concrete curb | 527 |
| >4' | Concrete curb | 75 |
| 4' to 20' | Concrete barrier | 102 |
| 4' to 20' | Double guardrail | 137 |
| 4' to 20' | Box beam | 76 |
| ≤ 20' | Earth | 267 |
| > 20' | Earth | 1387 |
| | Separate routes | 78 |
| | Total | 2775 |

1' equals 0.30 m

### Minimum Width for Glare Screen

On tangent or slightly curving parallel roadways, a glare screen may be needed when the glare from opposing headlights reduces the sight distance for objects in the roadway to less than the safe-stopping sight distance. The minimum safe-stopping sight distance, related to vertical curvature, according to AASHTO policy (*18*), measured for a 6-in. (150-mm) object and a driver's eye height of 3.75 ft (1.1 m), is 350 ft (107 m) for 50 mph (80 km/h) and 475 ft (145 m) for 60 mph (96 km/h). An interpolated value for 55 mph (88 km/h) would be 413 ft (126 m).

*California Design Policy, 1976*

Based on a review of available data on experience with glare screens, and considering budgetary limitations, California has adopted a policy of not erecting glare screens on medians wider than 20 ft (6.1 m).

*Idaho Tests, 1957* (28)

Two vehicles were used with high-beam headlights (two-lamp style). The test object was made of wood in an "A" shape about 2 ft (0.6 m) high. Conclusions were that a 30- to 40-ft (9.1- to 12.2-m) median was required for a design speed of 50 mph (80 km/h) and a 50- to 60-ft (15.2- to 18.3-m) median was necessary for a design speed of 60 mph (96 km/h).

*Illinois, 1968* (29)

A pair of vehicles with high-beam and low-beam headlights (four-lamp type) was used with a variety of targets ranging from taillight retro-reflectors to a wooden cube covered with green felt. To provide seeing distance greater than safe-stopping sight distance, it was necessary to use high-beam meeting conditions. For disability glare, a 33-ft (10.1-m) separation [equivalent to a 26-ft (7.9-m) median] was needed to provide adequate seeing distance at 70 mph (112 km/h). On low beams and with low-reflectance targets, safe-stopping sight distance could not be provided for speeds over 50 mph (80 km/h) for any of the median widths tested [up to 94 ft (28.7 m)].

*Discussion*

It should be noted that only limited tests have been made to determine the relation of median width to glare. More information is needed as to the effects of wet pavement, vertical curvature, and traffic volumes. Nevertheless, from the available data, it appears that glare screens might be considered for installation on tangents and very flat curves for medians 20 ft (6.1 m) or less in width [a 20-ft median width is equivalent to a 27-ft (8.2-m) separation between drivers' eyes and glare sources].

### Barriers

Median barriers have proved effective in preventing crossover accidents and have been widely adopted for installation on narrow medians. They can be combined easily with glare screens and provide a stable base for mounting and reducing the damage to glare screen by redirecting errant vehicles. Some people believe that glare screen should be included on every median barrier installation. Conversely, it should be noted that none of the toll roads has installed glare screen on 26-ft (7.9-m) medians, although they have installed many miles of barriers.

A difference of opinion continues regarding median openings. When a glare screen is placed on top of a barrier in a narrow median, sight distance for U-turns even by emergency vehicles is insufficient. The lack of sight distance creates an accident potential; so does the discontinuity of the barrier.

Some states have adopted a policy of omitting all openings in narrow medians. Michigan, for example, has done so after considerable experience with movable barrier closures. California does not provide openings in medians less than 32 ft (9.8 m) wide if barriers are erected but does provide openings in glare screen mounted on top of barriers for access by emergency personnel. Some police units, perennially short of personnel, feel that cross-median access for emergency vehicles is needed at spacings of not more than 1 mile (1.6 km).

## HORIZONTAL CURVATURE

Glare increases on roadways that bear to the left because the opposing headlights are directed into the driver's eyes in proportion to the degree of curvature. Thus, glare screen may be needed on horizontal curves of a road even though it is not otherwise justified on the intervening tangents.

If a type II screen is installed on curves, the spacing or width of the glare-blocking units must be adjusted in proportion to the sharpness of curvature. To make the cutoff angle comparable to the 20 degree value on tangents, the relation can be expressed as follows:

$$\theta = \cos^{-1}\frac{R - B}{R}\cos 20^\circ$$

where

$\theta$ = cutoff angle desired,
R = radius of curvature of roadway centerline, and
B = distance from driver's eye to glare screen.

As an example, assume a 3 degree curve [R = 1909.9 ft (582.1 m)] on a six-lane highway with a 20-ft (6.1 m) median with the vehicle in the outside lane and the driver's eye 38.25 ft (11.7 m) from the screen [10 ft + 12 ft + 12 ft + 4.25 ft = 38.25 ft (3.1 m + 3.7 m + 3.7 m + 1.3 m = 11.8 m)]. Then

$$\theta = \cos^{-1}\frac{1909.9 - 38.25}{1909.9} \times 0.9397$$

and $\theta$ = 23 degrees.

Computations for median widths from 4 to 30 ft (1.2 to 9.1 m) and curvatures up to 20 degrees indicate that the desired cutoff angle can be expressed as 20 degrees plus the degree of curvature of the centerline. Given the basis (*9, 10*) on which the 20 degree value was determined, it is probably not worthwhile to make more accurate determinations of the effect of curvature.

For each kind of types II and III glare screen, the cutoff angle is determined by the width and spacing of the individual elements. As an example, the cutoff angle for expanded metal mesh is determined by the strand width and spacing of the adjacent strands, plus the amount of twist obtained when the metal is expanded.

## HORIZONTAL SIGHT DISTANCE

Glare screens may obstruct sight distance on horizontal curves to the left for drivers traveling in the median lane. The extent of obstruction is related inversely to the width of median and the radius of curvature, but glare increases as a median narrows and curves sharpen. Thus, the sight distance problem occurs where the need for glare screen is greatest.

California, for example, excludes the use of glare screen where its installation would reduce the sight distance to less than safe-stopping sight distance. "Safe-stopping sight distance" is a term usually related to design speed and curvature and depends on a driver's eye height of 3.75 ft (1.1 m) and an object 6 in. (150 mm) high (*8, 18*).

Another approach is to limit the height of the screen so that a driver can look over it and see the tops of vehicles ahead (obviously, a daytime condition). A New Jersey study (*25*) determined that a driver could see cars over a barrier-screen combination 46 in. (1170 mm) high and that this height blocked out almost all the glare. Oregon similarly limited the height of screen on a narrow median on a sharply curving section.

Another method of improving sight distance is to offset the barrier toward the inside of the curve. Figure 8 illustrates the effect of offsetting 3 ft (0.9 m) in a 10-ft (3.1-m) median and 2 ft (0.6 m) in a 20-ft (6.1-m) median. The offsets allow a greater degree of curvature for the same design speed. However, care should be exercised when an offset barrier is used because it reduces shoulder width on the inside of the curve. For example, a 3-ft offset in a 10-ft median will leave only a 1-ft (0.3-m) shoulder on one side.

Where there is a narrow median or a sharp curve, a sight distance analysis should be made before glare screen is installed.

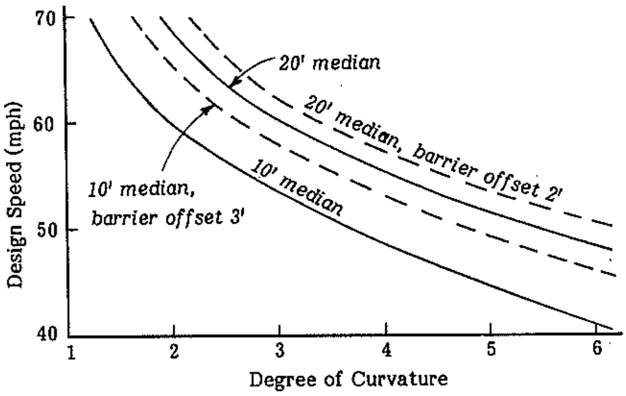


*Figure 8. Design speed vs. curvature for medians with barriers and glare screen, based on AASHTO safe-stopping sight distance on horizontal curves* (8).

**SCREEN HEIGHT**

On a flat and level divided highway without cross-slope, glare screen would have to be the same height as the average driver's eye, or 45 in. (1140 mm), in accordance with AASHTO standards. Some of the many factors that may require a somewhat greater height follow:

- Cross-slope of pavement.
- Difference in elevation between two roadways.
- Horizontal curvature.
- Vertical curvature.
- Separate grades on two roadways.
- Variations in eye height.

Except for sag vertical curves, these effects are small, and the states have selected heights of 46 in. (1170 mm), 49 in. (1240 mm), 50 in. (1270 mm), and 56 in. (1420 mm) for the flat-tangent installation. Because most of the screening materials are fabricated in 6-in. (150-mm) increments and are placed on top of a 32-in. (810-mm) concrete barrier, it can be seen that the commonly chosen heights will be 50 in. and 56 in. When screens are placed on steel-beam median barrier, a similar range may be obtained, depending on the height of the rail and the type of mounting that is chosen.

The height of the screen should be increased at or near sag vertical curves (Fig. 9). This may be calculated by a computer program (the Virginia Department of Highways and Transportation has such a program) incorporating the variables of cross-section, grade, width of median, and curvature as appropriate, or by "eyeballing" the installation in the field. For either method, it is desirable to increase the height of the screen, by beginning at the first point where any oncoming headlights can be seen over the top of the standard height. This will usually be accomplished in 6-in. (150-mm) steps.

Many jurisdictions do not attempt to provide for screening in the larger sag verticals, partly because no screening materials or mounting methods are available at the heights

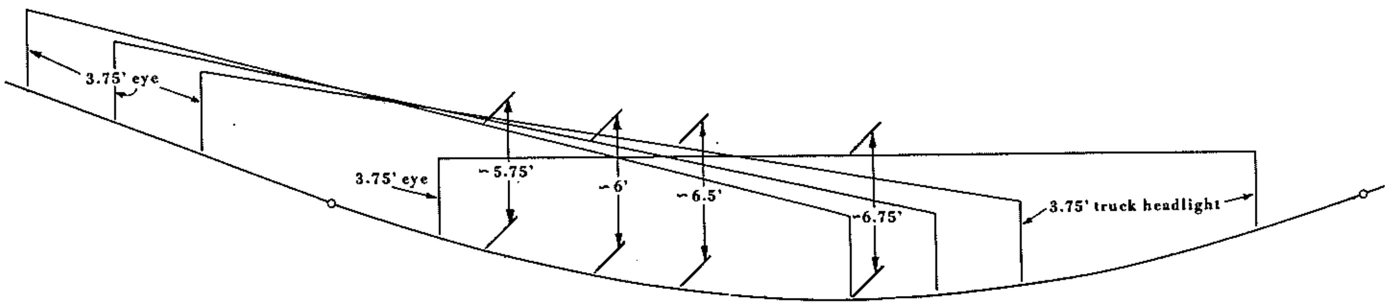


*Figure 9. Height of screen needed on sag vertical curves where the length of the curve is 600 ft and the grades are 3 percent.*

needed [calculated by one author (*26*) as 15 ft (4.5 m) for the intersection of two 3 percent grades]. As the sudden appearance of glare is known to be more serious to a driver who has been traveling in a no-glare situation, the height of screen should be increased to the maximum practical. Because none of the present screening materials exceeds 4 ft (1.2 m), the practical limit on top of concrete barriers is 80 in. (2.0 m). (On curves of a freeway with a wide median, a combination of earthwork and shrubbery planting can be effective at any reasonable height.)

## NONMEDIAN APPLICATIONS

Glare screen can be effective when it is placed between two-way frontage roads and freeways, especially because the opposing headlights are seen to be on the "wrong" side of the drivers. Two differences should be noted. First, the aiming pattern of headlights directs more light to the right and hence increases the glare problem; second, conventional snowplowing will more seriously affect glare screen placed to the right.

Glare screen may be needed between highways and railroad tracks where locomotive headlights can cause glare. The same design principles should be followed except that the height of the screen must be increased to shield the locomotive headlight.

Although pedestrians should not be on freeways, it is sometimes difficult to keep them off, particularly near interchanges. A combination of median barrier and continuous glare screen can effectively discourage pedestrian crossings.

Glare effects on interchange ramps are often noted. However, the application of glare screen is limited because of the small space between ramps and because the overhang of right-turning trucks brings them into frequent contact with the glare screen. One state (*26*) removed a trial installation on a 400-ft (123-m) radius curve because it could not be maintained.

## LOCATION CONSIDERATIONS

No specific warrants have been established for the installation of glare screen. Nor have there been any conclusive studies relating glare screen to accident reduction. On the other hand, the reduction or elimination of discomfort glare has received widespread public approval in almost every instance.

Review of the problems of night visibility indicates certain factors that should be assessed for any proposed glare screen installation. When analyzed together, they may indicate whether the installation is justified, but they cannot determine the cost-benefit ratio. Some of these factors are:

- High incidence or high rate of accidents compared to similar locations or to statewide experience.
- High night-to-day accident ratio.
- More night accidents on the convex or left-turning side of a curve than on the concave or right-turning side.
- More older drivers involved in night accidents.
- High severity of night accidents unrelated to other highway features.
- Concentration of night and wet weather accidents.
- Unusual distribution of night accidents by type, e.g., rear-end or striking a fixed object such as barrier.
- Concentration of night accidents in a sag vertical curve.
- High night traffic volumes, particularly of trucks.
- Comments from public about glare.
- Direct observation.
- Measurement of veiling brightness. (Standards have not been established, but the procedures used in Michigan do point out the relative glare problem at different locations.)
- Median width 20 ft (6.1 m) or less.
- Curvature greater than 1 degree.
- Combination of horizontal and vertical curvature.

CHAPTER FIVE

# CONCLUSIONS

General agreement exists on the design elements of the cutoff angle, the height of the screen above the roadway, and the maximum median width that justifies screening:

- Cutoff angle—tangents, 20 degrees; horizontal curves, 20 degrees plus degree of curvature.
- Height—normal, 50 in. (1270 mm); sag verticals, up to 80 in. (2032 mm).
- Width of median—20 ft (6.1 m) or less.

Reports from agencies that have had experience with different types of screens do not indicate that snow drifting or trash accumulating is a serious problem with any type.

Maintenance is a problem, particularly because extensive traffic protection is needed for work in the median. Comments received are usually negative, and it is evident that continued effort is needed from users and manufacturers to simplify and improve mounting hardware and methods.

There is not much likelihood that an accident warrant for the use of glare screen can be developed.

As part of the design of glare screen at a particular location, consideration should be given to whether or not operating agencies want physical and visual access to the opposing roadway.

More information is needed on the relation between glare and volume of opposing traffic, number of opposing lanes, degree of horizontal curvature, and sag vertical curvature.

The measurement of veiling brightness should be studied to determine whether it can be used as a warrant for installing glare screen. An approach might be to measure the veiling brightness by means of the Fry-Pritchard glare lens used with a Pritchard Telephotometer.

Insufficient information is available on crash involvement of concrete median and screens taller than 32 in. (810 mm) or any of the more popular screens mounted on standard steel or concrete barriers. Crash tests seem to be warranted.

Analysis of safe-stopping sight distance as limited by median barriers with glare screens indicates that glare screen is perhaps being omitted where it is needed most. A review of the geometric design standards to employ more realistic assumptions seems to be in order. Offsetting the median barrier and screen toward the inside of the curve appreciably increases the sight distance.

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# Appendix C – Median and Separator Assessment

DISTANCE TRAVELLED BY ONE WAY TRAFFIC OVER 150m HEADLIGHT BEAM SIGHT DISTANCE AT VARYING SPEEDS AND OVER VARYING MEDIAN SEPARATION

**0.8m separation** — D (km) 0.1008

| km/hr | km/min | secs/D |
|---|---|---|
| 60 | 1.0 | 12.0 |
| 80 | 1.3 | 10.5 |
| 100 | 1.7 | 9.6 |
| 110 | 1.8 | 9.3 |

**6m separation** — D (km) 0.0570

| km/hr | km/min | secs/D |
|---|---|---|
| 60 | 1.0 | 9.4 |
| 80 | 1.3 | 8.6 |
| 100 | 1.7 | 8.1 |
| 110 | 1.8 | 7.9 |

**9m separation** — D (km) 0.0318

| km/hr | km/min | secs/D |
|---|---|---|
| 60 | 1.0 | 7.9 |
| 80 | 1.3 | 7.4 |
| 100 | 1.7 | 7.1 |
| 110 | 1.8 | 7.0 |

**10m separation** — D (km) 0.0234

| km/hr | km/min | secs/D |
|---|---|---|
| 60 | 1.0 | 7.4 |
| 80 | 1.3 | 7.1 |
| 100 | 1.7 | 6.8 |
| 110 | 1.8 | 6.8 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Background Distance calculations | 100.8 | | | Background Distance calculations | 57.0 | | | Background Distance calculations | 31.8 | | | Background Distance calculations | 23.4 |
| Radian(20) = | 0.349 | (10.4-0.8)*tan(20)= | 26.4 | Radian(20) = | 0.349 | (10.4-6)*tan(20)= | 12.1 | Radian(20) = | 0.349 | (10.4-9)*tan(20)= | 3.8 | Radian(20) = | 0.349 | (10.4-10)*tan(20)= | 1.1 |
| | | 20m straight | 20 | | | 20m straight | 20 | | | 20m straight | 20 | | | 20m straight | 20 |
| Radian(10) = | 0.175 | (10.4-0.8)*tan(10)= | 54.4 | Radian(10) = | 0.175 | (10.4-6)*tan(10)= | 25.0 | Radian(10) = | 0.175 | (10.4-9)*tan(10)= | 7.9 | Radian(10) = | 0.175 | (10.4-10)*tan(10)= | 2.3 |

DETERMINE DISTANCE TRAVELLED (m) OVER THE 'GLARE IMPAIRMENT DISTANCE' FOR THE HOUR, CONSIDERING TWO WAY TRAFFIC

| Distance travelled impaired (m)/vehicle | =( ((secs/D)-6 seconds)/2) + (6 seconds) x (speed (km/hr)) x (1000/3600) |
|---|---|

| km/hr | 0.8m | 6m | 9m | 10m |
|---|---|---|---|---|
| 60 | 150.4 | 128.5 | 115.9 | 111.7 |
| 80 | 183.7 | 161.9 | 149.2 | 145.0 |
| 100 | 217.1 | 195.2 | 182.6 | 178.4 |
| 110 | 233.7 | 211.9 | 199.2 | 195.0 |

DETERMINE DISTANCE IMPAIRED DEPENDING ON SPEED TRAVELLED (km/hr) AND TRAFFIC (volume/hr) FOR TWO WAY TRAFFIC

**0.8m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 7.5 | 9.2 | 10.9 | 11.7 |
| 100 | 15.0 | 18.4 | 21.7 | 23.4 |
| 150 | 22.6 | 27.6 | 32.6 | 35.1 |
| 200 | 30.1 | 36.7 | 43.4 | 46.7 |
| 250 | 37.6 | 45.9 | 54.3 | 58.4 |
| | distance (km)/hr | | | |

**6.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 6.4 | 8.1 | 9.8 | 10.6 |
| 100 | 12.9 | 16.2 | 19.5 | 21.2 |
| 150 | 19.3 | 24.3 | 29.3 | 31.8 |
| 200 | 25.7 | 32.4 | 39.0 | 42.4 |
| 250 | 32.1 | 40.5 | 48.8 | 53.0 |
| | distance (km)/hr | | | |

**9.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 5.8 | 7.5 | 9.1 | 10.0 |
| 100 | 11.6 | 14.9 | 18.3 | 19.9 |
| 150 | 17.4 | 22.4 | 27.4 | 29.9 |
| 200 | 23.2 | 29.8 | 36.5 | 39.8 |
| 250 | 29.0 | 37.3 | 45.6 | 49.8 |
| | distance (km)/hr | | | |

**10.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 5.6 | 7.3 | 8.9 | 9.8 |
| 100 | 11.2 | 14.5 | 17.8 | 19.5 |
| 150 | 16.8 | 21.8 | 26.8 | 29.3 |
| 200 | 22.3 | 29.0 | 35.7 | 39.0 |
| 250 | 27.9 | 36.3 | 44.6 | 48.8 |
| | distance (km)/hr | | | |

**15.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 0.0 | 0.0 | 0.0 | 0.0 |
| 100 | 0.0 | 0.0 | 0.0 | 0.0 |
| 150 | 0.0 | 0.0 | 0.0 | 0.0 |
| 200 | 0.0 | 0.0 | 0.0 | 0.0 |
| 250 | 0.0 | 0.0 | 0.0 | 0.0 |
| | distance (km)/hr | | | |

**Travelling xxkm for the hour, % of distance driver is impaired by glare**

**0.8m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 13% | 11% | 11% | 11% |
| 100 | 25% | 23% | 22% | 21% |
| 150 | 38% | 34% | 33% | 32% |
| 200 | 50% | 46% | 43% | 42% |
| 250 | 63% | 57% | 54% | 53% |

**6.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 11% | 10% | 10% | 10% |
| 100 | 21% | 20% | 20% | 19% |
| 150 | 32% | 30% | 29% | 29% |
| 200 | 43% | 40% | 39% | 39% |
| 250 | 54% | 51% | 49% | 48% |

**9.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 10% | 9% | 9% | 9% |
| 100 | 19% | 19% | 18% | 18% |
| 150 | 29% | 28% | 27% | 27% |
| 200 | 39% | 37% | 37% | 36% |
| 250 | 48% | 47% | 46% | 45% |

**10.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 9% | 9% | 9% | 9% |
| 100 | 19% | 18% | 18% | 18% |
| 150 | 28% | 27% | 27% | 27% |
| 200 | 37% | 36% | 36% | 35% |
| 250 | 47% | 45% | 45% | 44% |

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 0% | 0% | 0% | 0% |
| 100 | 0% | 0% | 0% | 0% |
| 150 | 0% | 0% | 0% | 0% |
| 200 | 0% | 0% | 0% | 0% |
| 250 | 0% | 0% | 0% | 0% |

RESULTS ASSUMING TREATMENT

Apply 50m screen treatment at 100m intervals

| | | | | |
|---|---|---|---|---|
| Total kms travelled within hour | 60 | 80 | 100 | 110 |
| No of treatments implemented | 400 | 533 | 667 | 733 |
| Length of treatments applied | 20 | 27 | 33 | 37 |
| Distance remaining as untreated | 40 | 53 | 67 | 73 |

using amended impairment distance

DISTANCE TRAVELLED BY ONE WAY TRAFFIC OVER 150m HEADLIGHT BEAM SIGHT DISTANCE AT VARYING SPEEDS AND OVER VARYING MEDIAN SEPARATION

**0.8m separation** — D (km) 0.1008

| km/hr | km/min | secs/D |
|---|---|---|
| 60 | 1.0 | 12.0 |
| 80 | 1.3 | 10.5 |
| 100 | 1.7 | 9.6 |
| 110 | 1.8 | 9.3 |

**6m separation** — D (km) 0.0570

| km/hr | km/min | secs/D |
|---|---|---|
| 60 | 1.0 | 9.4 |
| 80 | 1.3 | 8.6 |
| 100 | 1.7 | 8.1 |
| 110 | 1.8 | 7.9 |

**9m separation** — D (km) 0.0318

| km/hr | km/min | secs/D |
|---|---|---|
| 60 | 1.0 | 7.9 |
| 80 | 1.3 | 7.4 |
| 100 | 1.7 | 7.1 |
| 110 | 1.8 | 7.0 |

**10m separation** — D (km) 0.0234

| km/hr | km/min | secs/D |
|---|---|---|
| 60 | 1.0 | 7.4 |
| 80 | 1.3 | 7.1 |
| 100 | 1.7 | 6.8 |
| 110 | 1.8 | 6.8 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Background Distance calculations | 100.8 | | | Background Distance calculations | 57.0 | | | Background Distance calculations | 31.8 | | | Background Distance calculations | 23.4 |
| Radian(20) = | 0.349 | (10.4-0.8)*tan(20)= | 26.4 | Radian(20) = | 0.349 | (10.4-6)*tan(20)= | 12.1 | Radian(20) = | 0.349 | (10.4-9)*tan(20)= | 3.8 | Radian(20) = | 0.349 | (10.4-10)*tan(20)= | 1.1 |
| | | 20m straight | 20 | | | 20m straight | 20 | | | 20m straight | 20 | | | 20m straight | 20 |
| Radian(10) = | 0.175 | (10.4-0.8)*tan(10)= | 54.4 | Radian(10) = | 0.175 | (10.4-6)*tan(10)= | 25.0 | Radian(10) = | 0.175 | (10.4-9)*tan(10)= | 7.9 | Radian(10) = | 0.175 | (10.4-10)*tan(10)= | 2.3 |

DETERMINE DISTANCE TRAVELLED (m) OVER THE 'GLARE IMPAIRMENT DISTANCE', CONSIDERING TWO WAY TRAFFIC

**Distance travelled impaired (m)/vehicle** =( ((secs/D)-6 seconds)/2) + (6 seconds) x (speed (km/hr)) x (1000/3600)

| | km/hr | 0.8m | 6m | 9m | 10m |
|---|---|---|---|---|---|
| 60 | 40 | 100.3 | 85.7 | 77.3 | 74.5 |
| 80 | 53 | 121.7 | 107.2 | 98.9 | 96.1 |
| 100 | 67 | 145.4 | 130.8 | 122.3 | 119.5 |
| 110 | 73 | 155.1 | 140.6 | 132.2 | 129.4 |

DETERMINE DISTANCE IMPAIRED DEPENDING ON SPEED TRAVELLED (km/hr) AND TRAFFIC (volume/hr) FOR TWO WAY TRAFFIC

**0.8m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 5.0 | 6.1 | 7.3 | 7.8 |
| 100 | 10.0 | 12.2 | 14.5 | 15.5 |
| 150 | 15.0 | 18.3 | 21.8 | 23.3 |
| 200 | 20.1 | 24.3 | 29.1 | 31.0 |
| 250 | 25.1 | 30.4 | 36.4 | 38.8 |
| | distance (km)/hr | | | |

**6.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 4.3 | 5.4 | 6.5 | 7.0 |
| 100 | 8.6 | 10.7 | 13.1 | 14.1 |
| 150 | 12.9 | 16.1 | 19.6 | 21.1 |
| 200 | 17.1 | 21.4 | 26.2 | 28.1 |
| 250 | 21.4 | 26.8 | 32.7 | 35.1 |
| | distance (km)/hr | | | |

**9.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 3.9 | 4.9 | 6.1 | 6.6 |
| 100 | 7.7 | 9.9 | 12.2 | 13.2 |
| 150 | 11.6 | 14.8 | 18.3 | 19.8 |
| 200 | 15.5 | 19.8 | 24.5 | 26.4 |
| 250 | 19.3 | 24.7 | 30.6 | 33.1 |
| | distance (km)/hr | | | |

**12.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 3.7 | 4.8 | 6.0 | 6.5 |
| 100 | 7.4 | 9.6 | 11.9 | 12.9 |
| 150 | 11.2 | 14.4 | 17.9 | 19.4 |
| 200 | 14.9 | 19.2 | 23.9 | 25.9 |
| 250 | 18.6 | 24.0 | 29.9 | 32.4 |
| | distance (km)/hr | | | |

**15.0m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 0.0 | 0.0 | 0.0 | 0.0 |
| 100 | 0.0 | 0.0 | 0.0 | 0.0 |
| 150 | 0.0 | 0.0 | 0.0 | 0.0 |
| 200 | 0.0 | 0.0 | 0.0 | 0.0 |
| 250 | 0.0 | 0.0 | 0.0 | 0.0 |
| | distance (km)/hr | | | |

**Travelling xxkm for the hour, % of distance driver is impaired by glare**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 8% | 8% | 7% | 7% |
| 100 | 17% | 15% | 15% | 14% |
| 150 | 25% | 23% | 22% | 21% |
| 200 | 33% | 30% | 29% | 28% |
| 250 | 42% | 38% | 36% | 35% |

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 7% | 7% | 7% | 6% |
| 100 | 14% | 13% | 13% | 13% |
| 150 | 21% | 20% | 20% | 19% |
| 200 | 29% | 27% | 26% | 26% |
| 250 | 36% | 34% | 33% | 32% |

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 6% | 6% | 6% | 6% |
| 100 | 13% | 12% | 12% | 12% |
| 150 | 19% | 19% | 18% | 18% |
| 200 | 26% | 25% | 24% | 24% |
| 250 | 32% | 31% | 31% | 30% |

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 6% | 6% | 6% | 6% |
| 100 | 12% | 12% | 12% | 12% |
| 150 | 19% | 18% | 18% | 18% |
| 200 | 25% | 24% | 24% | 24% |
| 250 | 31% | 30% | 30% | 29% |

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 0% | 0% | 0% | 0% |
| 100 | 0% | 0% | 0% | 0% |
| 150 | 0% | 0% | 0% | 0% |
| 200 | 0% | 0% | 0% | 0% |
| 250 | 0% | 0% | 0% | 0% |

DISTANCE TRAVELLED BY ONE WAY TRAFFIC OVER 150m HEADLIGHT BEAM SIGHT DISTANCE AT VARYING SPEEDS AND OVER VARYING MEDIAN SEPARATION

| 7m separation | | D (km) 0.0486 | 9m separation | | D (km) 0.0318 | 10m separation | | D (km) 0.0234 |
|---|---|---|---|---|---|---|---|---|
| km/hr | km/min | secs/D | km/hr | km/min | secs/D | km/hr | km/min | secs/D |
| 60 | 1.0 | 8.9 | 60 | 1.0 | 7.9 | 60 | 1.0 | 7.4 |
| 80 | 1.3 | 8.2 | 80 | 1.3 | 7.4 | 80 | 1.3 | 7.1 |
| 100 | 1.7 | 7.8 | 100 | 1.7 | 7.1 | 100 | 1.7 | 6.8 |
| 110 | 1.8 | 7.6 | 110 | 1.8 | 7.0 | 110 | 1.8 | 6.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Background Distance calculations | 48.6 | | | Background Distance calculations | 31.8 | | | Background Distance calculations | 23.4 |
| Radian(20) = | 0.349 | (10.4-7)*tan(20)= | 9.3 | Radian(20) = | 0.349 | (10.4-9)*tan(20)= | 3.8 | Radian(20) = | 0.349 | (10.4-10)*tan(20)= | 1.1 |
| | | 20m straight | 20 | | | 20m straight | 20 | | | 20m straight | 20 |
| Radian(10) = | 0.175 | (10.4-7)*tan(10)= | 19.3 | Radian(10) = | 0.175 | (10.4-9)*tan(10)= | 7.9 | Radian(10) = | 0.175 | (10.4-10)*tan(10)= | 2.3 |

DETERMINE DISTANCE TRAVELLED (m) OVER THE 'GLARE IMPAIRMENT DISTANCE' FOR THE HOUR, CONSIDERING TWO WAY TRAFFIC

**Distance travelled impaired (m)/vehicle** =( ((secs/D)-6 seconds)/2) + (6 seconds) x (speed (km/hr)) x (1000/3600)

| km/hr | 7m | 9m | 10m |
|---|---|---|---|
| 60 | 124.3 | 115.9 | 111.7 |
| 80 | 157.6 | 149.2 | 145.0 |
| 100 | 191.0 | 182.6 | 178.4 |
| 110 | 207.6 | 199.2 | 195.0 |

DETERMINE DISTANCE IMPAIRED DEPENDING ON SPEED TRAVELLED (km/hr) AND TRAFFIC (volume/hr) FOR TWO WAY TRAFFIC

**7m separation**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 6.2 | 7.9 | 9.5 | 10.4 |
| 100 | 12.4 | 15.8 | 19.1 | 20.8 |
| 150 | 18.6 | 23.6 | 28.6 | 31.1 |
| 200 | 24.9 | 31.5 | 38.2 | 41.5 |
| 250 | 31.1 | 39.4 | 47.7 | 51.9 |
| | distance (km)/hr | | | |

**9m separation**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 5.8 | 7.5 | 9.1 | 10.0 |
| 100 | 11.6 | 14.9 | 18.3 | 19.9 |
| 150 | 17.4 | 22.4 | 27.4 | 29.9 |
| 200 | 23.2 | 29.8 | 36.5 | 39.8 |
| 250 | 29.0 | 37.3 | 45.6 | 49.8 |
| | distance (km)/hr | | | |

**10m separation**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 5.6 | 7.3 | 8.9 | 9.8 |
| 100 | 11.2 | 14.5 | 17.8 | 19.5 |
| 150 | 16.8 | 21.8 | 26.8 | 29.3 |
| 200 | 22.3 | 29.0 | 35.7 | 39.0 |
| 250 | 27.9 | 36.3 | 44.6 | 48.8 |
| | distance (km)/hr | | | |

**Travelling xxkm for the hour, % of distance driver is impaired by glare**

**7m separation**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 10% | 10% | 10% | 9% |
| 100 | 21% | 20% | 19% | 19% |
| 150 | 31% | 30% | 29% | 28% |
| 200 | 41% | 39% | 38% | 38% |
| 250 | 52% | 49% | 48% | 47% |

**9m separation**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 10% | 9% | 9% | 9% |
| 100 | 19% | 19% | 18% | 18% |
| 150 | 29% | 28% | 27% | 27% |
| 200 | 39% | 37% | 37% | 36% |
| 250 | 48% | 47% | 46% | 45% |

**10m separation**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 9% | 9% | 9% | 9% |
| 100 | 19% | 18% | 18% | 18% |
| 150 | 28% | 27% | 27% | 27% |
| 200 | 37% | 36% | 36% | 35% |
| 250 | 47% | 45% | 45% | 44% |

RESULTS ASSUMING TREATMENT

Apply 50m screen treatment at 100m intervals

| | | | | |
|---|---|---|---|---|
| Total kms travelled within hour | 60 | 80 | 100 | 110 |
| No of treatments implemented | 400 | 533 | 667 | 733 |
| Length of treatments applied | 20 | 27 | 33 | 37 |
| Distance remaining as untreated | 40 | 53 | 67 | 73 |

using amended impairment distance

DISTANCE TRAVELLED BY ONE WAY TRAFFIC OVER 150m HEADLIGHT BEAM SIGHT DISTANCE AT VARYING SPEEDS AND OVER VARYING MEDIAN SEPARATION

| 7m separation | | D (km) 0.0486 | 9m separation | | D (km) 0.0318 | 10m separation | | D (km) 0.0234 |
|---|---|---|---|---|---|---|---|---|
| km/hr | km/min | secs/D | km/hr | km/min | secs/D | km/hr | km/min | secs/D |
| 60 | 1.0 | 8.9 | 60 | 1.0 | 7.9 | 60 | 1.0 | 7.4 |
| 80 | 1.3 | 8.2 | 80 | 1.3 | 7.4 | 80 | 1.3 | 7.1 |
| 100 | 1.7 | 7.8 | 100 | 1.7 | 7.1 | 100 | 1.7 | 6.8 |
| 110 | 1.8 | 7.6 | 110 | 1.8 | 7.0 | 110 | 1.8 | 6.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Background Distance calculations | 48.6 | | | Background Distance calculations | 31.8 | | | Background Distance calculations | 23.4 |
| Radian(20) = | 0.349 | (10.4-7)*tan(20)= | 9.3 | Radian(20) = | 0.349 | (10.4-9)*tan(20)= | 3.8 | Radian(20) = | 0.349 | (10.4-10)*tan(20)= | 1.1 |
| | | 20m straight | 20 | | | 20m straight | 20 | | | 20m straight | 20 |
| Radian(10) = | 0.175 | (10.4-7)*tan(10)= | 19.3 | Radian(10) = | 0.175 | (10.4-9)*tan(10)= | 7.9 | Radian(10) = | 0.175 | (10.4-10)*tan(10)= | 2.3 |

DETERMINE DISTANCE TRAVELLED (m) OVER THE 'GLARE IMPAIRMENT DISTANCE', CONSIDERING TWO WAY TRAFFIC

**Distance travelled impaired (m)/vehicle** =( ((secs/D)-6 seconds)/2) + (6 seconds) x (speed (km/hr)) x (1000/3600)

| | km/hr | 7m | 9m | 10m |
|---|---|---|---|---|
| 60 | 40 | 82.9 | 77.3 | 74.5 |
| 80 | 53 | 104.4 | 98.9 | 96.1 |
| 100 | 67 | 128.0 | 122.3 | 119.5 |
| 110 | 73 | 137.8 | 132.2 | 129.4 |

DETERMINE DISTANCE IMPAIRED DEPENDING ON SPEED TRAVELLED (km/hr) AND TRAFFIC (volume/hr) FOR TWO WAY TRAFFIC

**7m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 4.1 | 5.2 | 6.4 | 6.9 |
| 100 | 8.3 | 10.4 | 12.8 | 13.8 |
| 150 | 12.4 | 15.7 | 19.2 | 20.7 |
| 200 | 16.6 | 20.9 | 25.6 | 27.6 |
| 250 | 20.7 | 26.1 | 32.0 | 34.5 |
| | distance (km)/hr | | | |

**9m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 3.9 | 4.9 | 6.1 | 6.6 |
| 100 | 7.7 | 9.9 | 12.2 | 13.2 |
| 150 | 11.6 | 14.8 | 18.3 | 19.8 |
| 200 | 15.5 | 19.8 | 24.5 | 26.4 |
| 250 | 19.3 | 24.7 | 30.6 | 33.1 |
| | distance (km)/hr | | | |

**10m median**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 3.7 | 4.8 | 6.0 | 6.5 |
| 100 | 7.4 | 9.6 | 11.9 | 12.9 |
| 150 | 11.2 | 14.4 | 17.9 | 19.4 |
| 200 | 14.9 | 19.2 | 23.9 | 25.9 |
| 250 | 18.6 | 24.0 | 29.9 | 32.4 |
| | distance (km)/hr | | | |

**Travelling xxkm for the hour, % of distance driver is impaired by glare**

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 7% | 7% | 6% | 6% |
| 100 | 14% | 13% | 13% | 13% |
| 150 | 21% | 20% | 19% | 19% |
| 200 | 28% | 26% | 26% | 25% |
| 250 | 35% | 33% | 32% | 31% |

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 6% | 6% | 6% | 6% |
| 100 | 13% | 12% | 12% | 12% |
| 150 | 19% | 19% | 18% | 18% |
| 200 | 26% | 25% | 24% | 24% |
| 250 | 32% | 31% | 31% | 30% |

| Volume/hr | Speed km/hr 60 | 80 | 100 | 110 |
|---|---|---|---|---|
| 50 | 6% | 6% | 6% | 6% |
| 100 | 12% | 12% | 12% | 12% |
| 150 | 19% | 18% | 18% | 18% |
| 200 | 25% | 24% | 24% | 24% |
| 250 | 31% | 30% | 30% | 29% |

# Appendix D – Horizontal Curve Assessment

| Operating Speed | Design Min Radii | | |
|---|---|---|---|
| | 5% super | 6% super | 7% super |
| 60 | 98 | 94 | 91 |
| 80 | 240 | 229 | 219 |
| 100 | | 437 | 414 |
| 110 | | 529 | |

| Operating Speed | Design Min Radii | | | Operating Speed | Design Min Radii | | |
|---|---|---|---|---|---|---|---|
| | 5% super | 6% super | 7% super | | 5% super | 6% super | 7% super |
| 60 | 98 | 94 | 91 | 60 | 98 | 94 | 91 |
| 80 | 240 | 229 | 219 | 80 | 240 | 229 | 219 |
| 100 | | 437 | 414 | 100 | | 437 | 414 |
| 110 | | 529 | | 110 | | 529 | |

**Operating Speed = 60km/h**

| | Central Angle = 20° | | |
|---|---|---|---|
| L (m) | 34 | 33 | 32 |
| M (m) | 1.5 | 1.4 | 1.4 |
| Time on curve (secs) | 2 | 2 | 2 |

| | Central Angle = 40° | | |
|---|---|---|---|
| L (m) | 68 | 66 | 64 |
| M (m) | 5.9 | 5.7 | 5.5 |
| Time on curve (secs) | 4 | 4 | 4 |

| | Central Angle = 60° | | |
|---|---|---|---|
| L (m) | 103 | 98 | 95 |
| M (m) | 13.1 | 12.6 | 12.2 |
| Time on curve (secs) | 6 | 6 | 6 |

| | Central Angle = 80° | | |
|---|---|---|---|
| L (m) | 137 | 131 | 127 |
| M (m) | 22.9 | 22.0 | 21.3 |
| Time on curve (secs) | 8 | 8 | 8 |

**Operating Speed = 80km/h**

| | Central Angle = 20° | | |
|---|---|---|---|
| L (m) | 84 | 80 | 76 |
| M (m) | 3.6 | 3.5 | 3.3 |
| Time on curve (secs) | 4 | 4 | 4 |

| | Central Angle = 40° | | |
|---|---|---|---|
| L (m) | 168 | 160 | 153 |
| M (m) | 14.5 | 13.8 | 13.2 |
| Time on curve (secs) | 8 | 7 | 7 |

| | Central Angle = 60° | | |
|---|---|---|---|
| L (m) | 251 | 240 | 229 |
| M (m) | 32.2 | 30.7 | 29.3 |
| Time on curve (secs) | 12 | 11 | 11 |

| | Central Angle = 80° | | |
|---|---|---|---|
| L (m) | 335 | 320 | 306 |
| M (m) | 56.1 | 53.6 | 51.2 |
| Time on curve (secs) | 15 | 15 | 14 |

**Operating Speed = 110km/h**

| | Central Angle = 20° | | |
|---|---|---|---|
| L (m) | | 185 | |
| M (m) | | 8.0 | |
| Time on curve (secs) | | 6 | |

| | Central Angle = 40° | | |
|---|---|---|---|
| L (m) | | 369 | |
| M (m) | | 31.9 | |
| Time on curve (secs) | | 12 | |

| | Central Angle = 60° | | |
|---|---|---|---|
| L (m) | | 554 | |
| M (m) | | 70.9 | |
| Time on curve (secs) | | 18 | |

| | Central Angle = 80° | | |
|---|---|---|---|
| L (m) | | 739 | |
| M (m) | | 123.8 | |
| Time on curve (secs) | | 25 | |