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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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.

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.

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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.

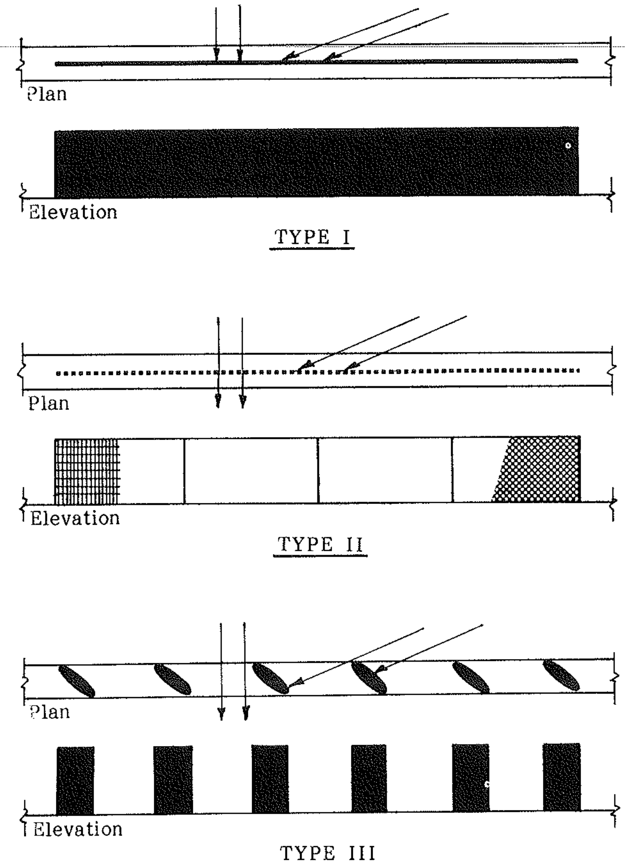

Figure 1. Plans and elevations of glare screen types I, II, and III.

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.

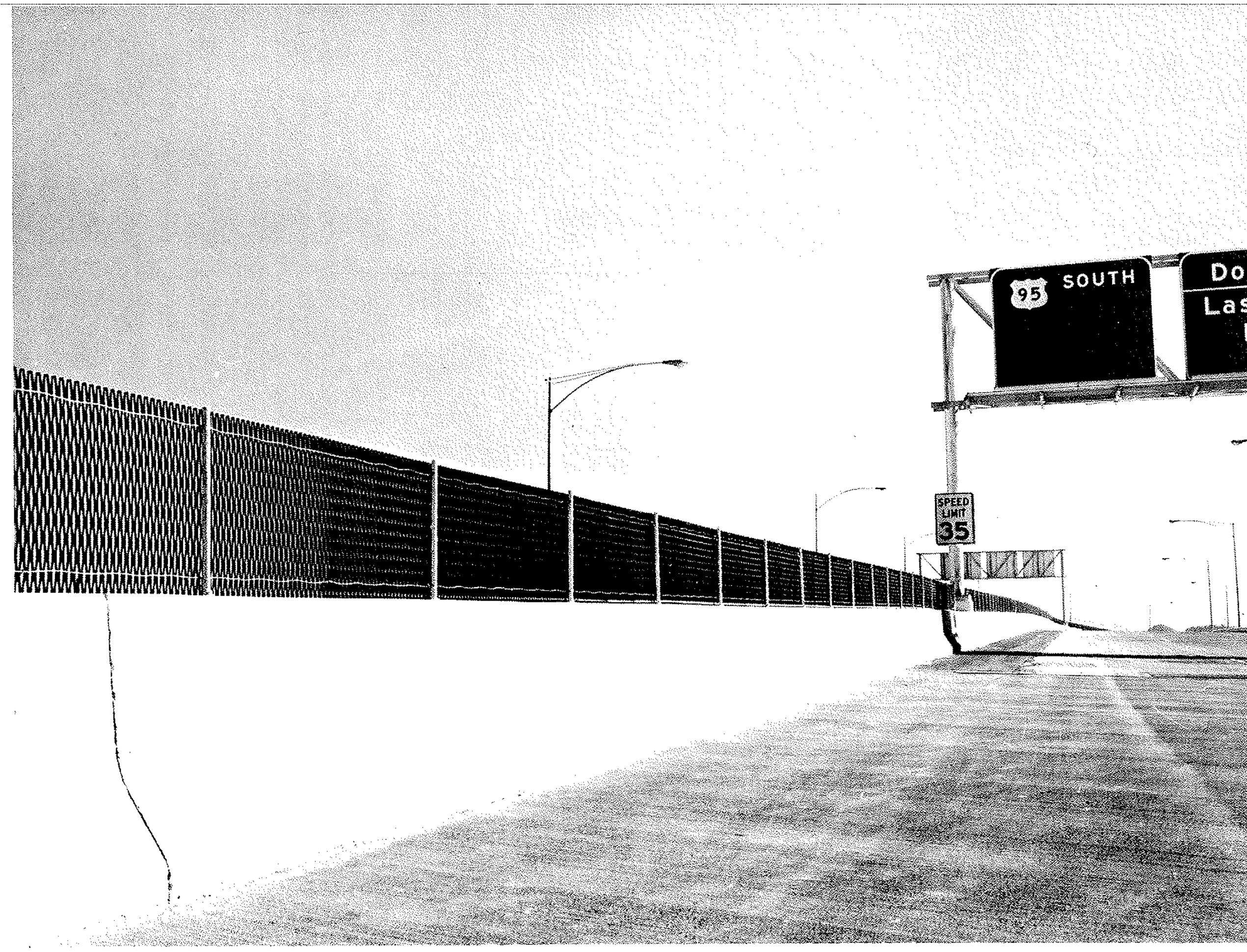

Figure 3. Expanded metal mesh used as a type I glare screen cuts off glare from oncoming traffic (narrow angles) but admits light at greater angles.

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.

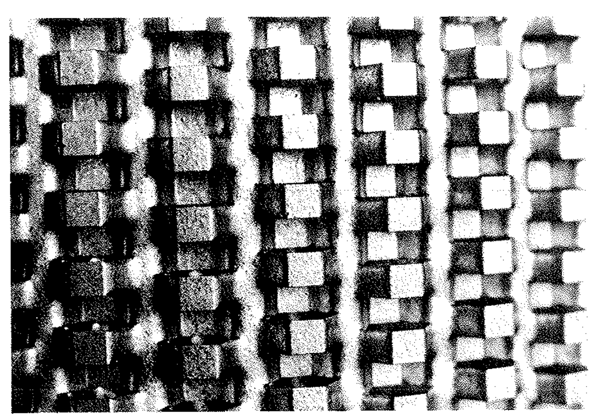

Figure 4. Double reverse corrugated steel (type I) screen completely blocks glare.

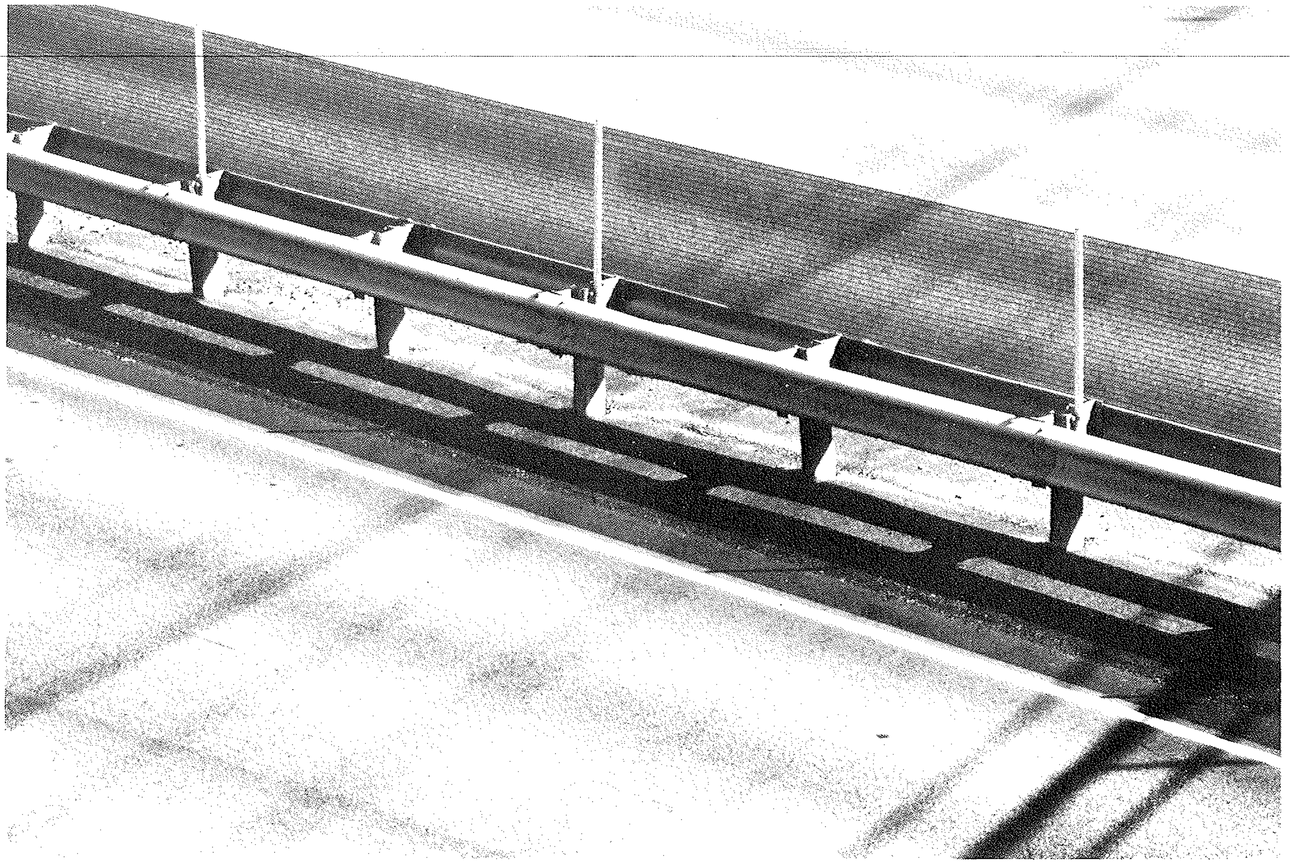

Figure 5. Knit polyester fabric (type II) screen diffuses glare.

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.

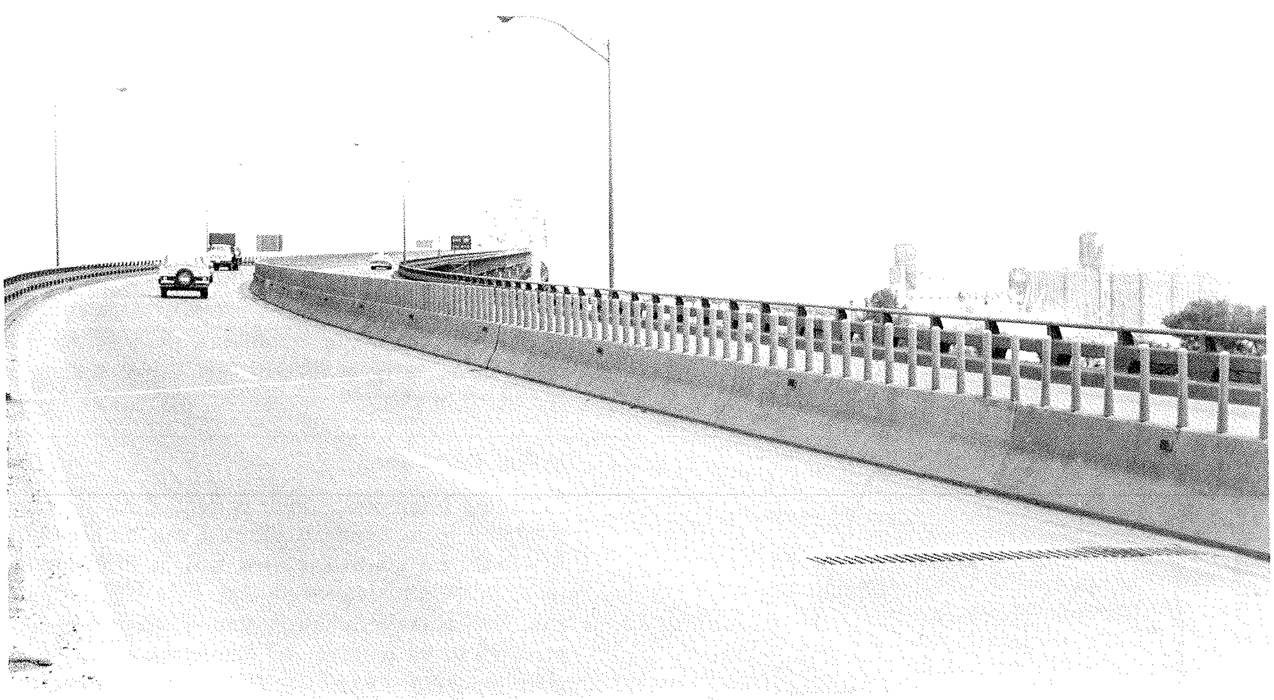

Figure 6. Paddles (type III) used as screen block opposing headlights at predetermined angles but permit surveillance of and access to the opposing lane by police and emergency personnel.

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.

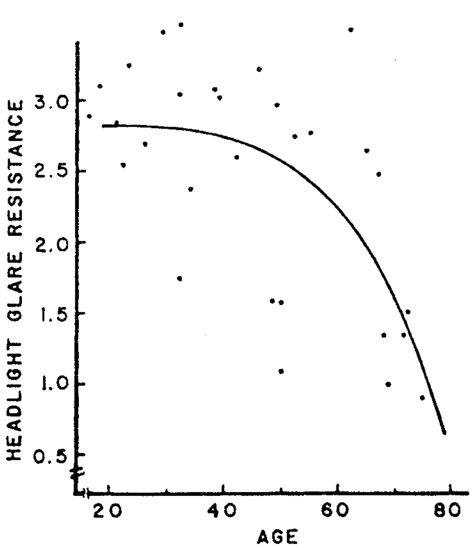

Figure 7. Headlight glare vs. age.

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 m).

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

θ = 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 θ = 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.

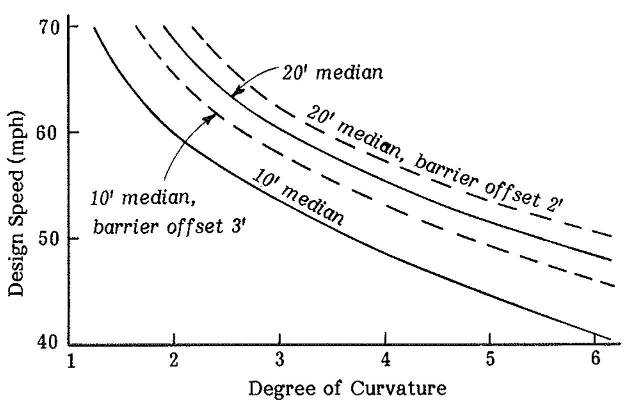

Figure 8. Design speed vs. curvature for medians with barriers and glare screen, based on AASHTO safe-stopping sight distance on horizontal curves (8).

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

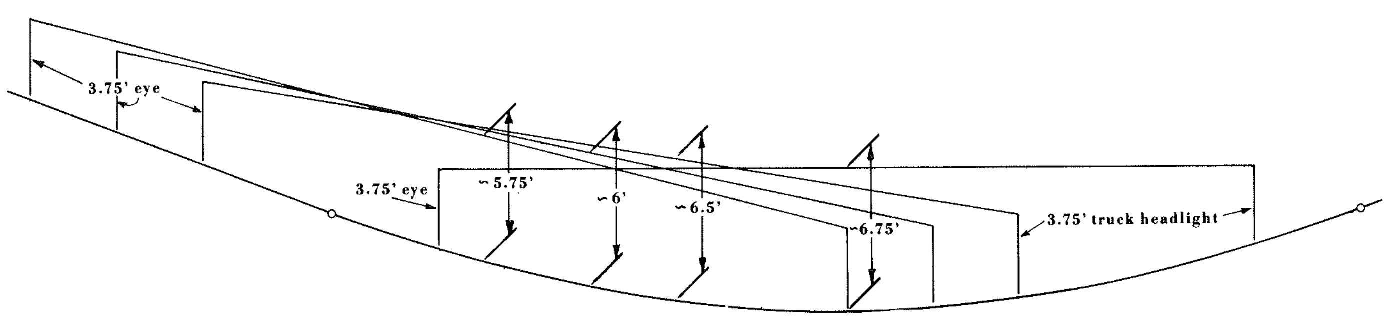

Figure 9. Height of screen needed on sag vertical curves where the length of the curve is 600 ft and the grades are 3 percent.

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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page 17, column 2, reference 4
Change "1976" to "1966"

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page 36, column 2, line 20
Change "$6000" to "$660 000"

Transportation Research Record 790

page 74, column 1, Equation 1
Change to "$Y = b_0X_0 + b_1X_1 + b_2X_2 + b_3X_1^2 + b_4X_2^2 + b_5X_1X_2$"

page 75, column 1, Table 1
Change "Variable" column to
"Variable
X_0
X_1
X_2
X_1^2
X_2^2
R^2"

Transportation Research Record 792

page 2, column 2
Insert the following before the last paragraph:

"The speakers present papers that indicate how they have taken steps to reduce such adversary relationships in contractual work, and provide various evaluations of the resulting work. The various papers are placed in proper perspective to provide an overall introductory picture of the subjects to follow this introduction. Three teams of three authors each present viewpoints on three projects, and two authors add their thinking to the seminar."

"This seminar examines three other projects, each of which is addressed by three speakers with three different points of view, namely the owner's, the contractor's, and the engineer's or the Federal Highway Administration's representative. The projects are

1. West Virginia Department of Highways Quality Assurance Program;
2. Eisenhower Memorial Tunnel, Second Bore, in Colorado under Loveland Pass; and
3. Pittsburgh's South Busway.

"In addition we have

1. A paper by two researchers from Virginia.
2. Some thoughts by a service engineer of a large corporation who is constantly out in the field looking at all these problems and thus is in a position to observe what is going on."

Transportation Research Record 797

page ii, price should be $7.20

Transportation Research Record 816

page 34, Table 6, line 9, column "Realistic Saving"
Footnote b-Change to "0 to 3.8"
Change "Annual liters of fuel saved . . ." to "1000's of liters of fuel saved annually . . ."

page 29, column 1, line 21
Change "millileters" to "milliliters"

Transportation Research Record 834

page ii
Change subject areas to 13, 15, 25
Change mode to 01 only

Preprint Volume for the National Seminar on Portland Cement Concrete Pavement Recycling and Rehabilitation

page 94, column 2, last line
Change "a 0.241-cm (3/4-in.)" to "0.241-cm (0.095-in.) diamond sawblades at 1.9 cm (3/4 in.)"

page 96, column 2, paragraph 2, line 3
Change "(3/15-in.)" to "(3/16-in.)"

page 98, Figure 33, line 3
Change "apepar" to "appear"

page 98, column 2, line 5 below Figure 35
Change "(51,000 sq. yds.)" to "(57,000 sq. yds.)"

NCHRP Report 238

title page, author's name
Change "Shebr" to "Shelar"

NCHRP Synthesis of Highway Practice 66

page 5, caption for Figure 3
Change to ". . . as a type II . . ."

NCHRP Synthesis of Highway Practice 69

Foreword, page iv
Delete paragraph 3

page 13, Table 2, item 2.6
Change formula to $T_t = \Sigma P_i(t_i + \sqrt{h})$

page 41, column 2
Change formula to $T_t = \Sigma P_i(t_i + \sqrt{h})$

page 45, Table 15, title
Change to "GUIDELINES FOR SERVICE CHANGES: (Port Authority of Allegheny County)"

page 86, box under Toronto, item 2-6
Change formula to $T_t = \Sigma P_i(t_i + \sqrt{h})$

NCHRP Synthesis of Highway Practice 76

page 2, line 5
Change "$50" to "$25"

page 7, column 2
Change "i = 1" to "l = 1"

i=l to i=1

page 13, Table 9, under Pennsylvania
Change "10%" to "100%"

page 16, column 1, line 18
Change "$50" to "$25"

page 23, column 1, line 29
Change "$50" to "$25"

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