REFLECTIVE PROPERTIES OF SELECTED ROAD SURFACES FOR AN AUTOMOBILE HEADLAMP GEOMETRY

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ABSTRACT

Luminance contrast based pavement marking visibility models are widely used in the design of street and automobile lighting systems, the design and evaluation of retro-reflective sheeting materials and pavement marking materials, and in the establishment of minimum visibility requirements for nighttime motorists. CARVE, a proprietary pavement marking visibility model, is currently being used to determine the minimum retro-reflectance requirements for pavement markings. Generally, such computer based visibility models determine the visibility of pavement markings by comparing the available luminance contrast formed between the pavement marking and the immediate surrounding road surface with a human threshold contrast value. However, in order to be able to calculate the luminance contrast between a pavement marking and the road surface, a pavement marking visibility model needs matrices of retro-reflectance as a function of the entrance angle and the observation angle, both for the pavement and the pavement markings. However, no extensive field data is available on the reflective properties of road surfaces under an automobile headlamp geometry (observation angles less than 1^o). The research presented in this paper was conducted to provide retro-reflectance matrices for old asphalt, new asphalt, old concrete, and new concrete road surfaces. The road surface retro-reflectance was measured with a specially designed apparatus in the field. Multiple linear regression models were developed with the retro-reflectance data obtained for each measured road surface. Traffic sign luminance measurements under automobile headlamp illumination conditions were conducted at night in the field in order to determine the degree to which a post mounted traffic sign (sign center 1.98m above the ground) receives indirect light reflected from the road surface. It was found that the specular reflectance of an old concrete road surface does affect the luminance of a sign under automobile headlamp illumination. The data presented in this paper is thought to be useful to visibility model builders.

INTRODUCTION

Pavement-markings on public roads provide driver guidance, convey advisory and/or warning information to the driver. Pavement markings are often used supplementary to other traffic control devices without redirecting the focus of attention from the road. Adequate visibility of pavement-markings is an important element of driver safety, especially in the absence of public lighting. Today, practically all painted pavement-markings and all prefabricated pavement marking tapes are equipped with glass beads to provide retro-reflectance, which increases the brightness of the markings at night under automobile headlamp illumination. In order to determine the visibility of road markings with a computer model [1][2] it is necessary to calculate the available luminance contrast along the pavement marking line. For the luminance contrast calculation one requires exact knowledge of the luminance of the pavement marking and the luminance of the immediate surrounding road surface. In a computer model, those luminances are calculated by multiplying the illuminance at the target normal to the illumination axis with the retro-reflectance of the pavement or the pavement marking. Mathematically, both the pavement and the pavement marking are treated as retro-reflectors. To build a pavement marking visibility model, one needs matrices of retro-reflectance values as a function of the entrance angle and the observation angle both for the pavement and the pavement markings. Pavement marking retro-reflectance data, especially for tapes, is readily available since the required measurements may be performed in the laboratory, using a regular goniometer and photoreceptor. However, no extensive field data is available on the reflective properties of road surfaces under an automobile headlamp geometry (observation angles less than 1^o). The research presented in this paper was conducted to provide retro-reflectance matrices for old asphalt, new asphalt, old concrete, and new concrete road surfaces.

Pavement markings and pavement surfaces are modeled by matrices tabulating the coefficient of retroreflected luminance (retro-reflectance, R_L) as a function of the entrance and observation angle. With the exception of the magnitude of the retro-reflectance, there is no difference between the pavement marking matrices and the pavement surface matrices, from a mathematical and implementation point of view. While pavement can be modeled as a retroreflector with R_L matrices, there is also a small specular reflectance component intrinsic to pavement. Light from the vehicle headlamps is reflected specularly by the pavement, adding to the light reaching a roadway object, such as a post-mounted traffic sign. Measurements were conducted by the authors to determine the degree to which light from the automobile headlamps is reflected by the road surface onto a post mounted traffic sign (1.98m above the ground).

Statement of the Problem

The human visual performance in a pavement marking detection task is mainly determined by the available contrast between the pavement surface and the pavement markings. However, since no data on the reflective properties of pavement surfaces under an automobile geometry is available, the validity of any computer model is limited by the validity and availability of pavement surface reflection data.

Measuring pavement markings on a regular goniometer is simple and straightforward. The luminous signal that is reflected from the pavement marking sample in the goniometer is sufficient for the photoreceptor. However, if a sample road surface would be installed on the goniometer, only a very small amount of light would be reflected back to the photoreceptor. Current photoreceptors are not designed to deal with such low luminances because they are generally used for measuring bright retroreflective materials and for measuring headlamps. Further, it is quite difficult to remove a thin specimen of a road surface for use on a goniometer. Most computer models that estimate the luminance of non-horizontal road objects, such as retro-reflective traffic signs or pedestrians, under vehicle headlamp illumination only calculate the luminance based on the light arriving at the object directly from the lamps. In reality, however, most pavement surfaces provide a specular reflection component, adding to the light arriving at the object. A computer model without the effect of pavement reflectance accounted for would result in luminance estimates lower than values measured in the field.

Study Objectives

The first objective of the present study was to obtain a limited set of luminance and illuminance measurements for two bituminous (used and relatively new) and two concrete (used and relatively new) roadway surfaces in the field. The obtained field luminance and illuminance values were then converted into R_L matrices. The second objective was to measure the effect of specular pavement reflectance on post-mounted traffic sign luminance.

REVIEW OF TECHNICAL LITERATURE

A substantial number of pavement marking visibility field experiments were conducted by the Human Factors and Ergonomics Laboratory at Ohio University [3][4][5][6][7][8][9] and [10]. The majority of the data provided by these experiments was used to design a regression model to determine threshold contrast multipliers as a function of the pavement marking configuration. These threshold contrast multipliers (field factors) allow for adjustment of the Blackwell human threshold contrast data [11] for use in the CARVE model [2].

Adrian and Gibbons [12] investigated the reflection properties of pavement surfaces for observation angles greater than 1^o. Their research ties into the calculation of the small target visibility level (STV), used in roadway lighting design. Because their reflectance data was obtained at observation angles greater than 1^o it cannot be readily used for pavement marking visibility calculations, where substantially smaller observation angles are obtained. Adrian and Gibbons also investigated the amount of light reflected onto the ground mounted small targets used in STV due to the specular reflectance component of the pavement. They found that a substantial proportion of the luminance measured on the STV targets (situated on and normal to the ground) is explained by the specular reflection characteristics of pavements.

A study conducted by Sorensen and Lundkvist [13] indicated that due to their greater contrast potential, dark concrete road surfaces in some cases provided longer detection distances than bright concrete surfaces. Sorensen and Lundkvist designed a portable goniometer that allowed the measurement of the coefficient of retro-reflected luminance of a pavement or pavement marking sample under dry and humid conditions. Their measurements showed that the coefficient of retro-reflection for road surfaces remained fairly constant as a function of the observation distance (entrance angle approaching 90^o, observation angle approaching 0^o). On the other hand they found that the coefficient of retro-reflectivity of pavement markings increased with increasing distance. In contrast to the findings of Sorensen and Lundkvist [13], the present study generally found an increase in the coefficient of retro-reflection of road surfaces with increasing distances. Overall, however, there is good agreement between the values published in [13] and the values found in the present study. Additional road luminance and illuminance research is located in [14] and [15].

METHOD USED FOR THE MEASUREMENT OF THE REFLECTIVE PROPERTIES OF SELECTED ROAD SURFACES

Luminance and illuminance measurements were conducted on a selected used bituminous road surface (SR 349, Vinton County, Ohio), a selected relatively new bituminous road surface (3M Chemolite test range, St. Paul Minnesota), a selected used concrete road surface (SR 682, Athens County, Ohio), a selected relatively new concrete road surface (US 33, Hocking County, Ohio), and the old Ohio University concrete airstrip in Athens, Ohio. Initially, the measurements considered a geometry representative for edge lines that are located 1.82m (6ft) and 2.4m (8 ft) to the right of the longitudinal car axis and center lines that are located 1.82m (6ft) and 2.4m (8 ft) to the left of the longitudinal car axis. However, during the course of the measurements it became evident that the influence of the lateral measurement position was negligible. The findings reported herein are based upon the geometry of a center line that is located 2.43m (8ft) to the left of the longitudinal car center. Further, the geometry considered is valid for the range of observation angles and entrance angles found for vehicle/driver combinations ranging from a 5% female driver in a small passenger car to a 95% male driver in a semi truck [16]. The resulting observation angles range from 0.201° to 9.58°, and the resulting entrance angles range from 83.5° to 89.8°. It should be noted that the measurements in the field were not conducted for all possible combinations of these entrance and observation. For all practical purposes it can be assumed that only certain combinations of entrance and observation angles make sense. For example, a semi truck usually has its headlamps located far below the eye level of the driver, and the headlamp height in a sports car is usually not much lower than the driver eye height. Therefore it was felt that the pavement R_L matrix as a function of the entrance and observation angle does not need to be completely filled with measured R_L values.

It should be noted that although the smallest aperture of the Pritchart 1980A telephotometer was only 2 minutes of arc the resulting measured surface at the maximum measurement distance of 120m (393 ft) was an elongated ellipse of several feet length, depending on the observation angle. Although the observation geometry formed by a given entrance angle, observation angle, and observation distance is theoretically described by a single point, it is not possible to measure the luminance of an infinitely small point in the real world. The aperture limitations (2 minutes of arc minimum) imposed by the telephotometer cause the theoretical measurement point to be represented by an elongated ellipse within which some variation of luminous flux may be expected from the bottom to the top end of the ellipse. However, the length of the ellipse projected onto the road surface by the telephotometer aperture is short in proportion to the observation distance and the variation of luminous flux is fairly small and is averaged out across the aperture.

Test Sites

The Chemolite test range of the 3M Company was chosen as a representative site for relatively new asphalt. The test range meets standard roadway characteristics. The road surface that was in place at the time of the measurements was relatively fine grain asphalt, approximately 7 months old. The pavement was installed towards the end of 1995 and was thus exposed only to one winter cycle. The pavement color was uniform dark gray. No grease strip or other impurities were present. The pavement on SR 349 in Vinton county, Ohio, was used to measure worn asphalt. The pavement was smooth but relatively worn out by traffic. The pavement was approximately 8 years old at the time when the measurements were taken. The color was a light gray with a slight grease strip and other impurities due to traffic wear. The US 33 test site near Logan, Ohio, was part of a newly constructed section of 4 lane freeway that was not open to traffic yet at the time when the measurements were taken. The pavement consisted of new concrete with a lateral anti-skid ripple pattern having a period of about 25.4 mm (1 inch) and an amplitude of about 10 mm (0.4 inches). The pavement color was a very light gray with a thin layer of dust from nearby construction work. No other impurities were present. The SR 682 test site in Athens, Ohio, consisted of relatively worn concrete pavement approximately 10 years old. A worn lateral anti-skid ripple pattern having a period of about 25.4 mm (1 inch) and an amplitude of about 8 mm (0.31 inches) was present in the pavement. The pavement color was a relatively dark gray with a considerable grease strip in each lane. The measurements were performed on a long, slightly inclining entrance ramp to US 33 and US 50. The pavement was thus worn in a way consistent with freely moving uphill traffic (no braking marks or pavement deformation due to braking forces). Another set of measurements was taken on the old Ohio University airport runway in Athens, Ohio. This runway is located about 61m (200 ft) south of a parallel State highway with moderate traffic. A nearby shopping mall on the West end of the runway creates a considerable ambient illumination due to a number of luminaires. The pavement consists of smooth concrete plates, approximately 30 years old. No significant traffic wear is present on the runway since it was used only for small aircraft traffic until 1976 and for infrequent driving experiments since then. There are no grease strips or skid/brake marks present on the runway. Sporadic impurities and spots are found but were avoided upon setting up the apparatus. It should be noted that the signal to noise ratio of the measured luminances and illuminances (L_{on}/L_{off} , I_{on}/I_{off}) was somewhat less favorable than the ratio obtained on all other test sites, since the nearby shopping mall or the parallel State highway could not be controlled for ambient illumination. However, measurements were taken only when conditions were constant i.e. no moving vehicles may have disturbed the readings. Further, thanks to the error correction built into the measurement protocol it can be assumed that the luminance and illuminance values are adequate and accurate. All measurements were made during dry and clear conditions.

Apparatus

The reflectance of various road surfaces was determined using a specially designed apparatus that emulated the functionality of a goniometer without having to extract a sample of the road surface (see Figure 1). A light source and a Prichard 1980A tele-photometer were installed on a vertical column such that they could be moved up and down, along a millimeter scale. The light source could also be moved laterally but was fixed to a lateral offset of 0.3048m during the course of the measurements. The light source was aimed with a laser pointer such that the hot spot of the lamp was lined up with the target area.

The telephotometer was aimed at the target area by the experimenter. Using this light source-photometer combination, it was possible to determine the pavement luminance under a given entrance angle (determined by the lamp height and the distance to the target area) and observation angle (given by the vertical distance between light source and photometer on the column and the target distance). The measurements at each site took about 6 to 8 hrs to complete.

Two luminance measurements were taken for each entrance/observation angle pair, one while having the light source turned on and one while only the ambient illumination was present. With this technique, it was possible to minimize the influence of ambient illumination which may fluctuate over time and would thus bias the measurements. The illuminance at the target was measured immediately after the luminance was determined. Since the CR-100 cosine corrector could not be placed directly on the ground at the target area the vertical lens offset had to be accounted for by moving the entire illuminance Prichard closer to the light source, until the illumination axis was exactly lined up with the cosine corrector of the illuminance Prichard as illustrated in Figure 8. It was necessary to take this advance distance into consideration (inverse square law) in order to determine the illuminance [lx] on the ground, at the target. The illuminance was also measured under the lamp-on and the lamp-off condition. From the ratio between the pavement luminance and the illuminance at the target location it was then possible to compute R_L [mcd/m^2/lx].

Procedure

At each site the longitudinal and lateral target distances were measured and labeled with regard to the origin (0,0). The vertical instrument column was installed on a very sturdy tripod such that the lens of the luminance Prichard was located exactly above the origin (0,0). The center of the light source (H6054 headlamp, high-beam) front glass surface was adjusted such that it was located exactly 0.3048 m to the left of the origin. The control unit of the luminance Prichard was located in the rear of the nearby parked experimental vehicle that served as a mobile office. The readouts of the remote illuminance Prichard were captured by a CCD camera and transmitted to a LCD monitor in the experimental vehicle. The data collection assistant thus always had both the luminance and illuminance readings available side by side.

The measured data was immediately transferred into an elaborate Excel spreadsheet so that the resulting R_L values were instantly available. Measurements started as soon as the ambient illumination was at the nighttime level.

The measurements were conducted for ascending target distances, starting at 7.99 m 26.24 ft. The required light source height and luminance Prichard height was set to the nearest 3.1 mm (1/8 inch). The hot spot of the light source was aimed exactly at the target area, using the laser pointer located directly above the light source as directional indicator and the light source micrometer screw as vernier vertical adjustment. The parallax that resulted from the vertical distance from the center of the light source to the center of the laser pointer was accounted for by a longitudinal offset behind the target area. The luminance Prichard was accurately aimed at the target location, once the light source was precisely aimed. Both L_{on} and L_{off} were transferred into the spreadsheet. Then the illuminance Prichard was moved into a location ahead of the target area, thus compensating for the height of the CR-100 cosine corrector above the ground. The laser pointer was used again in order to line up the front of the illuminance Prichard with the illumination axis. Another laser pointer attached to the rear of the illuminance Prichard was used to line up the rear of the instrument with the target area. The measured values were representative for the illuminance in the illumination axis, at a well-defined distance ahead of the target area. The spreadsheet instantly translated the measured values (using the inverse square law) into values that would be obtained at the target location, exactly at ground level.

The process of measuring target luminance and illuminance was repeated for each receptor/light source height pair within a longitudinal distance. Then the illuminance Prichard was moved to the next longitudinal distance and the measurements would be continued for the relevant height settings.

RESULTS OF THE MEASUREMENT OF THE REFLECTIVE PROPERTIES OF SELECTED ROAD SURFACES

Linear Regression Model

As previously mentioned, the field measurements only partially covered the entire R_L matrix for the appropriate entrance/observation angle ranges. In order to provide values in the matrix between the measured points and outside the measured range it was necessary to apply a linear interpolation model. Several approaches including ridge regression were investigated and it was found that the general model shown in Equation (1) provided the best overall adjusted R^2 and the most reasonable R_L surface shape.

$$\begin{aligned}\log_{10}(R_L) = \beta_0 + \beta_1 \cdot \log_{10}(EA) + \beta_2 \cdot \log_{10}(OA) + \beta_3 \cdot \log_{10}(EA) \cdot \log_{10}(OA) \\ + \beta_4 \cdot \log_{10}(EA)^2 + \beta_5 \cdot \log_{10}(OA)^2 + \beta_6 \cdot \log_{10}(EA)^2 \cdot \log_{10}(OA)^2 + \varepsilon\end{aligned} \quad (1)$$

where

R_L is the pavement retro-reflectance in mcd/m^2

EA is the entrance angle in degrees [83.5° ≤ EA ≤ 89.8°]

OA is the observation angle in degrees [0.2° ≤ OA ≤ 10°]

The model was found to provide a significantly improved fit in the logarithmic domain, which is why the arguments appear in log operators. Figure 2a shows the two-factor linear regression model that was obtained with an adjusted R^2 of 0.961 for the worn asphalt road surface on SR 349 in Vinton county, Ohio. Figure 2b shows the two-factor linear regression model (adjusted R^2 of 0.96) for the new asphalt road surface measured at the 3M Chemolite test range in Minnesota. A comparison of the two reflectance surfaces clearly indicates that the new asphalt road surface is substantially less reflective than the weathered worn asphalt road surface. Figure 3a shows the two-factor model that was obtained with an adjusted R^2 of 0.946 for the worn concrete road surface on SR 682 in Athens, Ohio. Figure 3b shows the two-factor model that was obtained with an adjusted R^2 of 0.712 for the new concrete road surface on US33 in Logan, Ohio. A comparison between the two concrete road surfaces indicates that the worn road surface is considerably darker than the new concrete road surface. The worn road surface has been subjected to many years of service, resulting in rubber, dirt and grease deposits being embedded in that surface, thus leading to a darker appearance. The new concrete road surface (Figure 3b) provides a reflectance magnitude that is somewhat similar to the reflectance magnitude found in the worn asphalt road surface (Figure 2a, light gray appearance). Figure 4 shows the two-factor model that was obtained with an adjusted R^2 of 0.831 for the old concrete runway surface of the old Ohio University airport in Athens. Although the reflectance model for the Ohio University airport runway looks similar in shape as the model obtained for new concrete (Figure 3b), the magnitude of the reflectance is substantially lower and corresponds well to the magnitude found for the worn concrete (Figure 3a).

METHOD USED TO DETERMINE THE AMOUNT OF LIGHT REFLECTED FROM THE ROAD TO POST MOUNTED TRAFFIC SIGNS

Test Site

The traffic sign luminance measurements reported in this section were conducted on the old unused Ohio University airport runway which is about 23m wide and 500m long, running east to west, located on the outskirts of the city of Athens, Ohio. The runway surface is in adequate condition and exhibits minor waviness similar to what is typically found on moderately used concrete and asphalt roads. A two-lane state highway with moderate traffic runs parallel about 61m away from the North edge of the runway. A low volume four lane freeway, runs parallel to the runway about 800m to the south. The freeway is not visible from the runway since a dam running parallel to the Hocking river blocks the line of sight. At night, the Eastbound direction provided a nighttime driving environment with only a few luminaires in the left part of the driver's visual field (avg. sky luminance 0.019cd/m^2, one small building near horizon avg. 6.5cd/m^2, grass luminance near runway avg. 0.044cd/m^2). Therefore, it may be stated that the Eastbound direction provided a background that fairly closely resembled the conditions a single vehicle would encounter in a rural two-lane road driving situation. The measurements were conducted under dry, clear sky conditions during nighttime. It should be noted that the traffic sign luminance measurements were conducted once with the illuminating headlamps turned on and once with the headlamps turned off. This method allowed for elimination of the influence due to ambient illumination. While it would be interesting to investigate the specular reflection from road surfaces other than the old Ohio University airport runway, it should be noted that the present effort was conducted without funding. Of interest would also be the reflecting properties of wet roads.

Apparatus

Two Sylvania H6054 headlamps were mounted in a dual headlamp rig that simulated the front-end of a typical mid-sized car with a lateral headlamp separation of 1.13m (3.7ft) and a headlamp height of 0.66m (2.15ft). The headlamps were powered by a Honda gasoline generator and a Hewlett Packard power supply which regulated the lamp terminal voltage to exactly 13.3 volts. A 0.61m (2ft) square sign mounted on a sign post was attached to a movable cart. The sign face was blank and was made of white enclosed lens (type I) sheeting material. The center of the sign was 1.98m (6.5ft) off the ground.

The luminance of the sign was measured with a Pritchard 1980A tele-photometer. The lens of the photometer was positioned in relation to the headlamps at the driver's eye position, as is shown in Figure 5a and Figure 5b. To block the lower portion of the headlamp beam and to create a shadow on the pavement, baffles were set up between the headlamps and the sign. The baffles allowed the determination of the luminance component on the sign, solely provided by direct illumination of the headlamps. The baffles were then removed to allow the determination of the luminance component including both direct and reflected (from the runway surface) illumination. The baffles consisted of two right-angle side supports and a front face covered with thick black plastic, as shown in Figure 5c. The baffles were approximately 0.61m (2 ft) tall and 2.44m (8ft) wide. Two baffles in series easily produced a shadow that extended past the farthest measurement point. The black plastic was chosen as an inexpensive material due to the large surface area that needed to be covered. While the plastic is itself somewhat specularly reflective, the surface was quite dirty and wrinkled due to the plastic's loose fitting to the baffle structure. Stray light affecting the Pritchard's measurements was thus not a serious concern.

Procedure

The luminance of the sign was measured at longitudinal distances of 12.24m, 30.48m, 60.96m, 121.92m, and 243.84m (50ft, 100ft, 200ft, 400ft, and 800 ft) and at lateral distances of 7.31m (24ft) to the left and 3.65m (12ft) to the right from the center between the headlamps, resulting in 10 measurement locations. The luminance was measured for both headlamps together rather than for each individual lamp. The measurement positions were clearly marked on the runway. The sign luminance measurements were begun without baffles on the left-hand side, starting with the longitudinal distance of 15.24m (50ft) and proceeding until reaching 243.84m (800ft). The baffles were then set up and positioned appropriately to produce a shadow centered on the ground at the sign location. A laser pointer placed on each of the headlamps was used to insure that the headlamp beams did not reach the pavement surface anywhere in front of the sign. The luminance of the sign was then measured with the baffles in place at the longitudinal distance of 243.84m (800ft), and the measurements then proceeded back until a distance of 15.24m (50ft) was reached. Each time the sign was moved, the baffles were also adjusted. Upon completing the left-hand side measurements, the same process was repeated for the right-hand side. At each point, the sign luminance was measured once under low beam illumination, under high beam illumination, and without any headlamps to account for ambient illumination.

RESULTS OF THE MEASUREMENTS TO DETERMINE THE AMOUNT OF LIGHT REFLECTED FROM THE ROAD TO POST MOUNTED TRAFFIC SIGNS

Figure 6a compares the luminance of the test sign at a lateral distance of 7.31m (24ft) to the left with baffles and without baffles under low beam illumination. Figure 6b compares the luminance of the sign at a lateral distance of 3.65m (12ft) to the right with and without baffles under low beam illumination. Figure 7a compares the luminance of the sign at a lateral distance of 7.31m (24ft) to the left with and without baffles under high beam illumination. Figure 7b compares the luminance of the sign at a lateral distance of 3.65m (12ft) to the right with and without baffles under high beam illumination. Table 2 presents the data for the sign luminance with and without the baffles, along with the percent difference between the two conditions.

Based on the traffic sign luminance measurements it appears that the specular reflectance of an old concrete road surface does in fact affect the luminance of a sign under automobile headlamp illumination. From the two lateral sign positions (left of the rig and right of the rig) considered in the measurements, it seems that the lateral distance of 3.65m (12ft) to the right is affected more by the specular pavement reflectance than the lateral distance of 7.31m (24ft) to the left. This finding was expected as the left location was twice as far away from the longitudinal center line of the car (headlamp rig). Under lowbeam illumination, one would also expect the right side to be better illuminated than the left side, due to the asymetric headlamp aiming that is common for H6054 sealed beams (2^{o} down, 2^{o} to right). It is interesting to note that at a longitudinal distance of 60.96m (200 ft), the percent differences between the luminances obtained with the baffles and without the baffles approach a minimum (see Table 2), regardless of beam type and lateral position. In addition, the greatest difference in luminance always seems to occur at 121.92m (400 ft).

SUMMARY, DISCUSSION AND CONCLUSIONS

Luminance contrast based pavement marking visibility models generally determine the visibility of pavement markings by comparing the available luminance contrast formed between the pavement marking and the immediate surrounding road surface with a human threshold contrast value. The Ohio University proprietary pavement marking visibility model CARVE [1][2] uses the Blackwell 1946 human threshold contrast database [11], adjusted with a calibrated field factor function obtained based on Ohio University pavement marking visibility field data [3][4][5][6][7][8][9] and [10]. In order to be able to calculate the luminance contrast between a pavement marking and the road surface, a pavement marking visibility model needs matrices of retro-reflectance as a function of the entrance angle and the observation angle both for the pavement and the pavement markings. Pavement marking retro-reflectance data, especially for tapes, is readily available since the required measurements may be performed in the laboratory, using a regular goniometer and photoreceptor. However, no extensive field data is available on the reflective properties of road surfaces under an automobile headlamp geometry (observation angles less than 1^o). The research presented in this paper was conducted to provide retro-reflectance matrices for old asphalt, new asphalt, old concrete, and new concrete road surfaces. The road surface reflectances were measured with a specially designed apparatus in the field. Multiple linear regression models were developed for each measured road surface. These regression models are based on the measured retro-reflectance data (only partial matrix measured) and provide the retro-reflectance of a selected road surface (old/new asphalt, old/new concrete) as a function of the entrance angle and the observation angle.

Traffic sign luminance measurements under automobile headlamp illumination conditions were conducted at night in the field in order to determine the degree to which a post mounted traffic sign (1.98m above the ground) receives indirect light reflected from the road surface. It was found that the specular reflectance of an old concrete road surface does in fact affect the luminance of a sign under automobile headlamp illumination. The percent differences between the luminances obtained with the baffles and without the baffles approached a minimum at a longitudinal distance of 60.96m (200 ft), regardless of beam type and lateral position. The data presented in this paper is thought to be useful to visibility model builders.

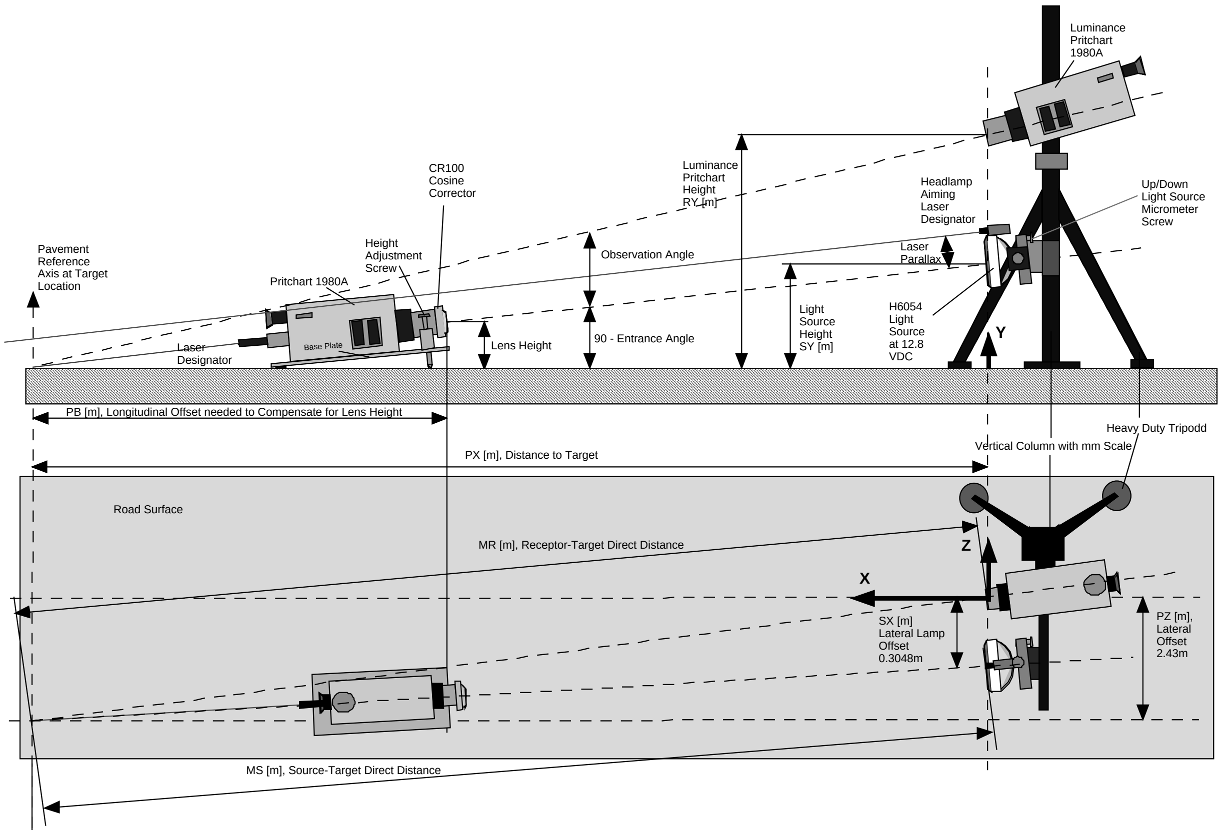
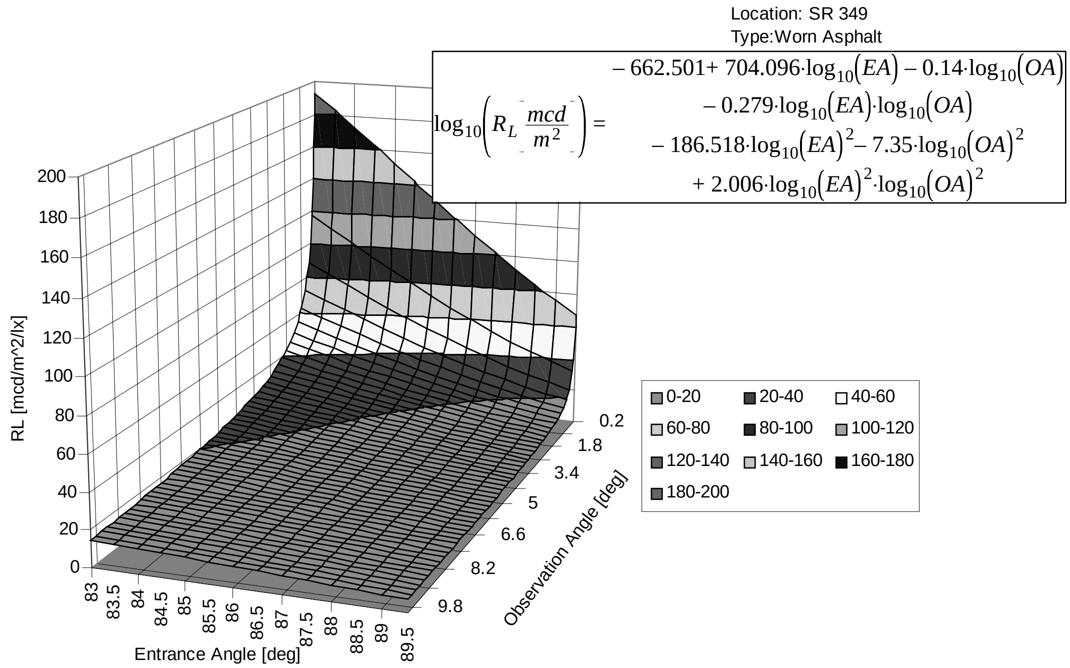


Figure 1. Experimental Apparatus and Setup used to Determine R_L [mcd/m^2/lx] of Various Road Surfaces



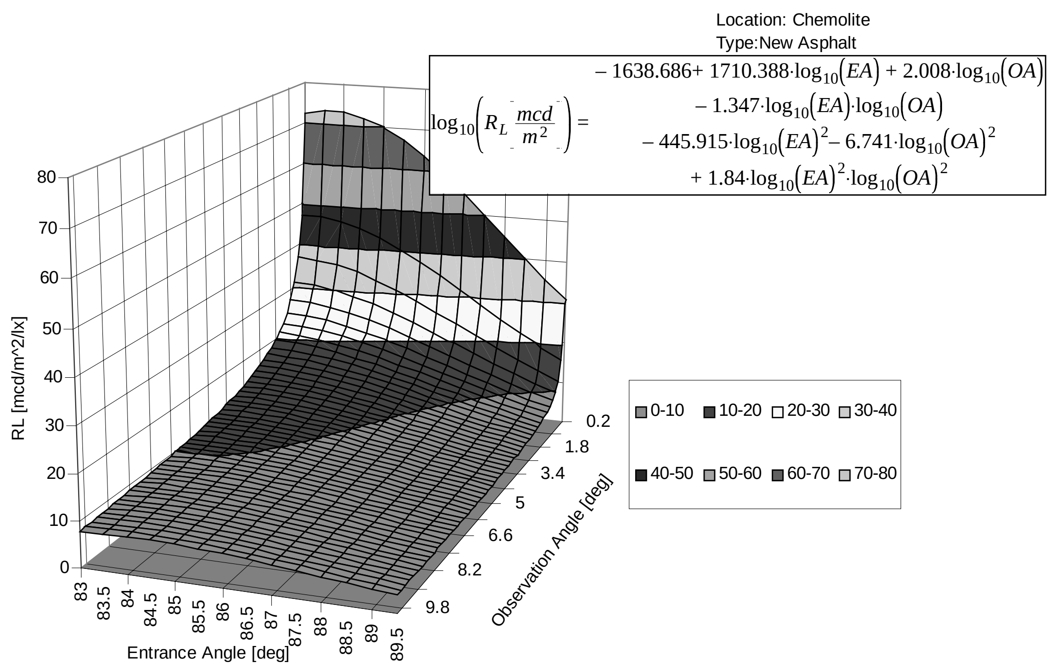
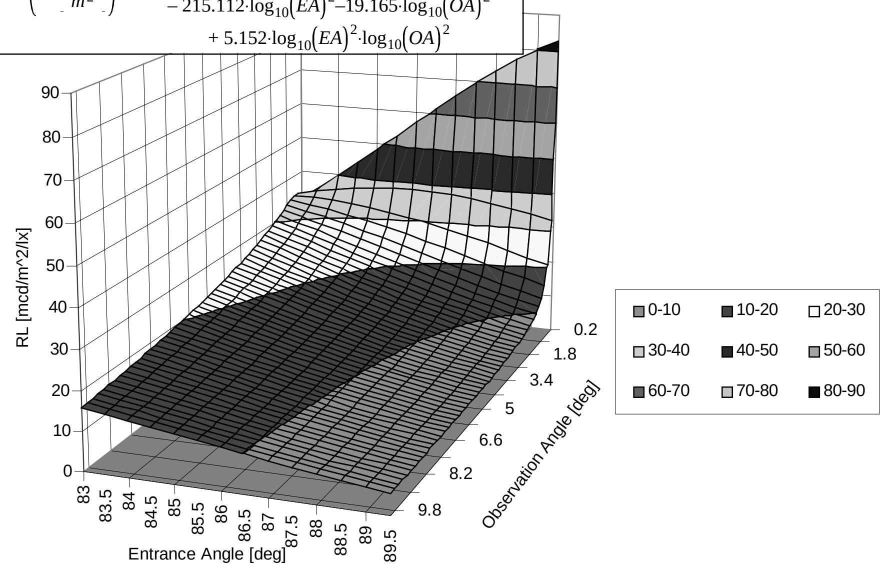


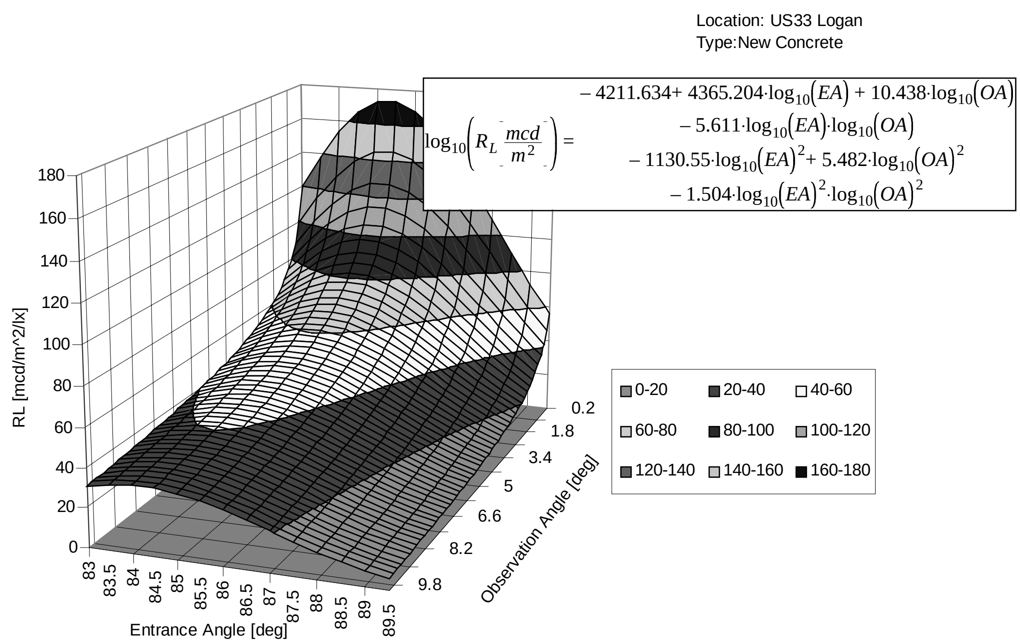
Figure 2. Two Factor Linear Regression of R_L as a Function of Entrance and Observation Angle.

(top) Worn Asphalt (Adjusted R^2=0.961)

(bottom) New Asphalt (Adjusted R^2=0.96)



$$\log_{10}\left(R_L\,\frac{mcd}{m^2}\right) = \begin{array}{c} -780.344 + 820.23\cdot\log_{10}(EA) + 42.132\cdot\log_{10}(OA) \\ -22.018\cdot\log_{10}(EA)\cdot\log_{10}(OA) \\ -215.112\cdot\log_{10}(EA)^2 - 19.165\cdot\log_{10}(OA)^2 \\ +5.152\cdot\log_{10}(EA)^2\cdot\log_{10}(OA)^2 \end{array}$$



$$\log_{10}\left(R_L\,\frac{mcd}{m^2}\right) = \begin{array}{c} -4211.634 + 4365.204\cdot\log_{10}(EA) + 10.438\cdot\log_{10}(OA) \\ -5.611\cdot\log_{10}(EA)\cdot\log_{10}(OA) \\ -1130.55\cdot\log_{10}(EA)^2 + 5.482\cdot\log_{10}(OA)^2 \\ -1.504\cdot\log_{10}(EA)^2\cdot\log_{10}(OA)^2 \end{array}$$

Figure 3. Two Factor Linear Regression of R_L as a Function of Entrance and Observation Angle.
(top) Worn Concrete (Adjusted R^2=0.946)
(bottom) New Concrete (Adjusted R^2=0.712)

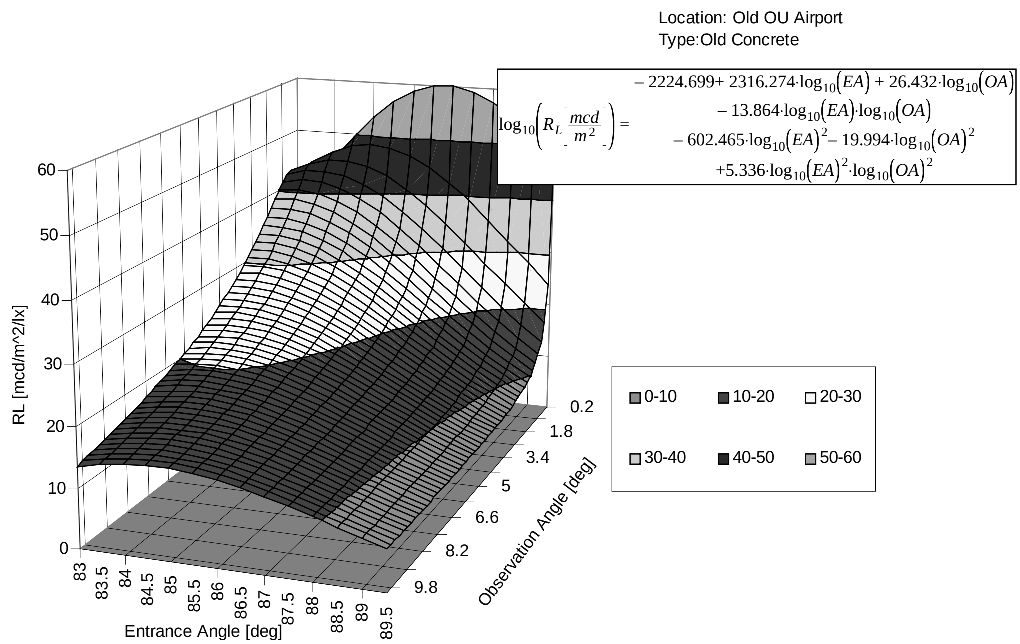
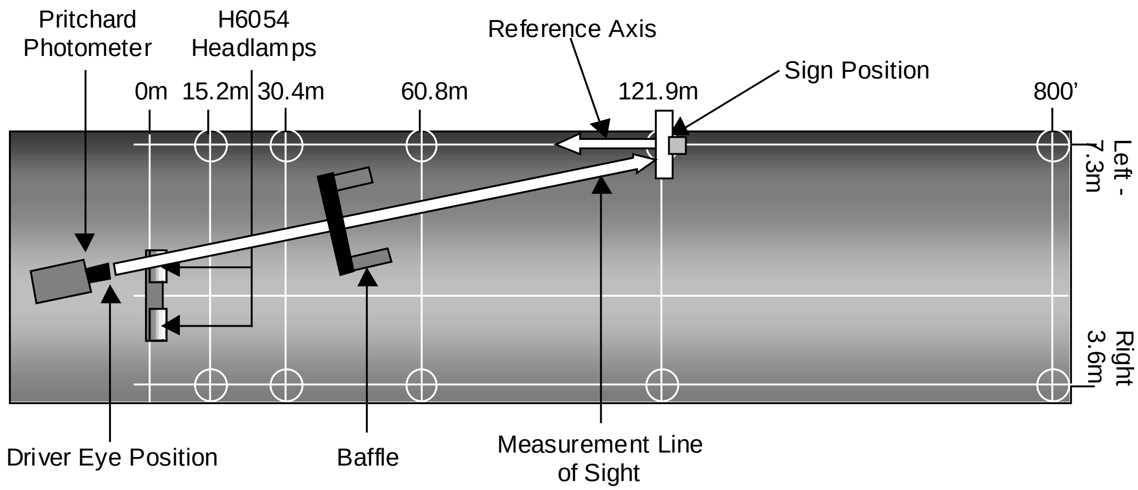
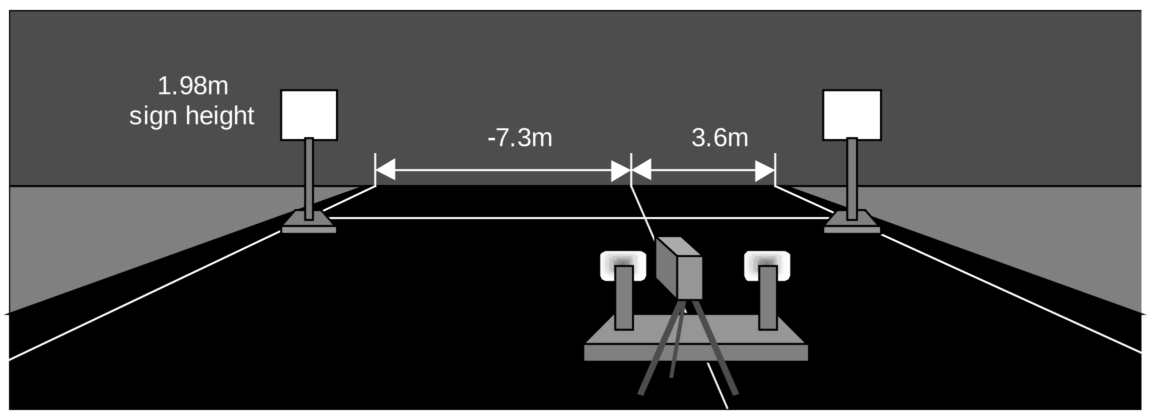


Figure 4. Two Dimensional Linear Regression of R_L as a Function of Entrance and Observation Angle. Concrete OU Runway (Adjusted R^2=0.831)



Note: 1 ft = 0.3048m

a. Experimental Setup: Position Of The Headlamps, The Pritchard Photometer, And The Sign Measurement Locations



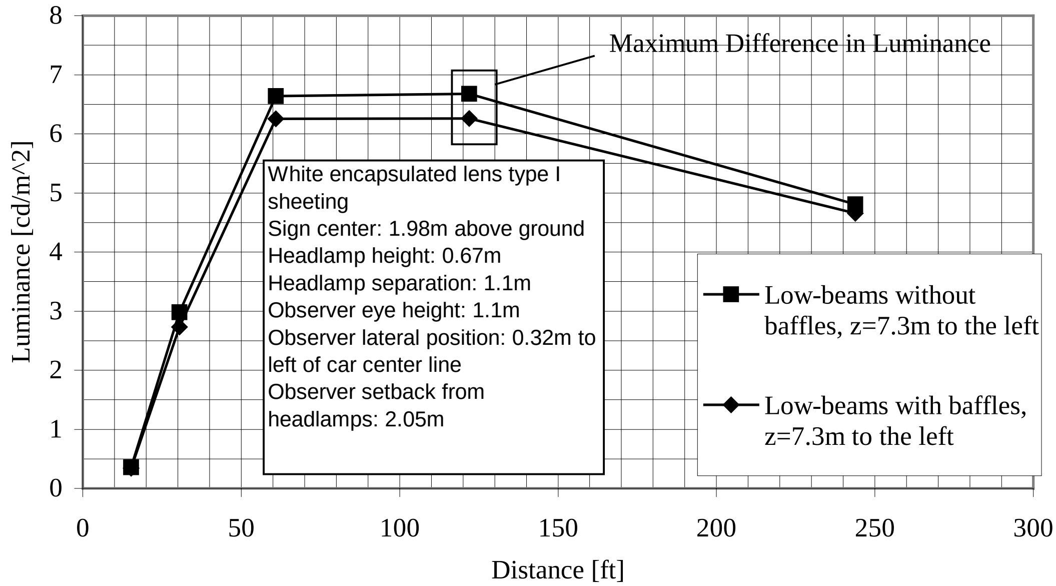
Note: 1 ft = 0.3048m

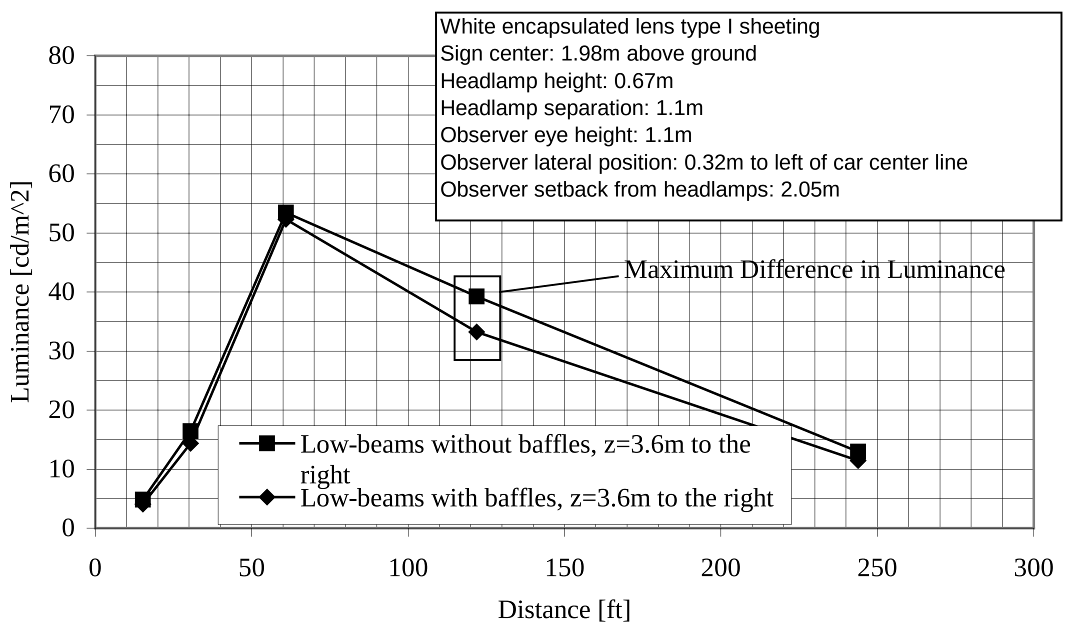
b. Rear View of the Experimental Setup

Note: 1 ft = 0.3048m

C. Baffles Used To Block Lower Portion Of Headlamp Beam And To Produce A Shadow On The Runway Surface

Figure 5. Setup used on the Old Ohio University Airport Runway to Determine the Amount of Headlamp Light Reflected by the Road Surface to a Post Mounted Traffic Sign



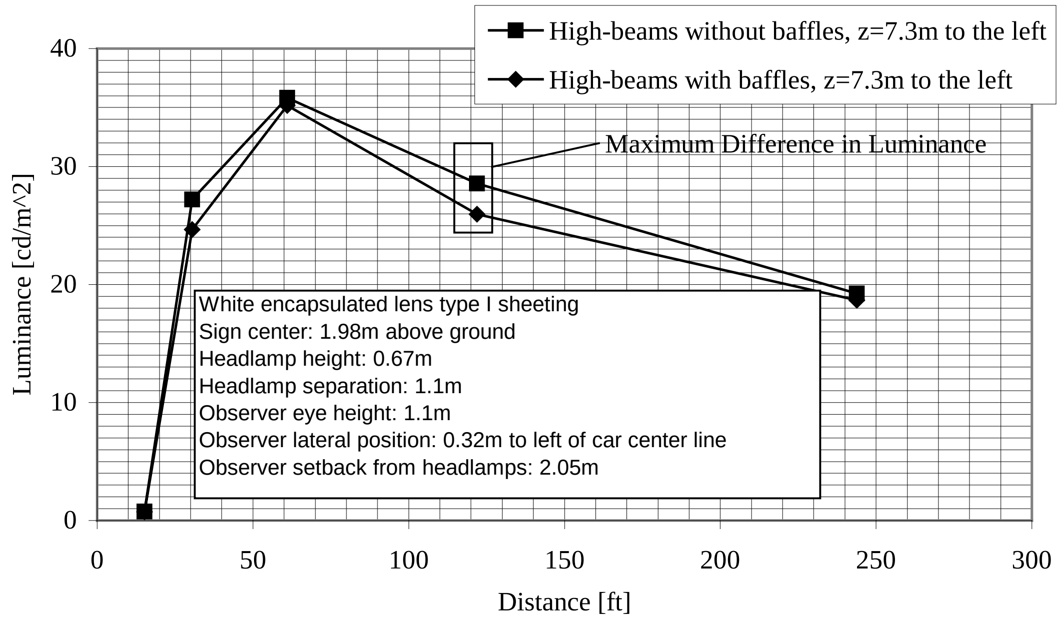


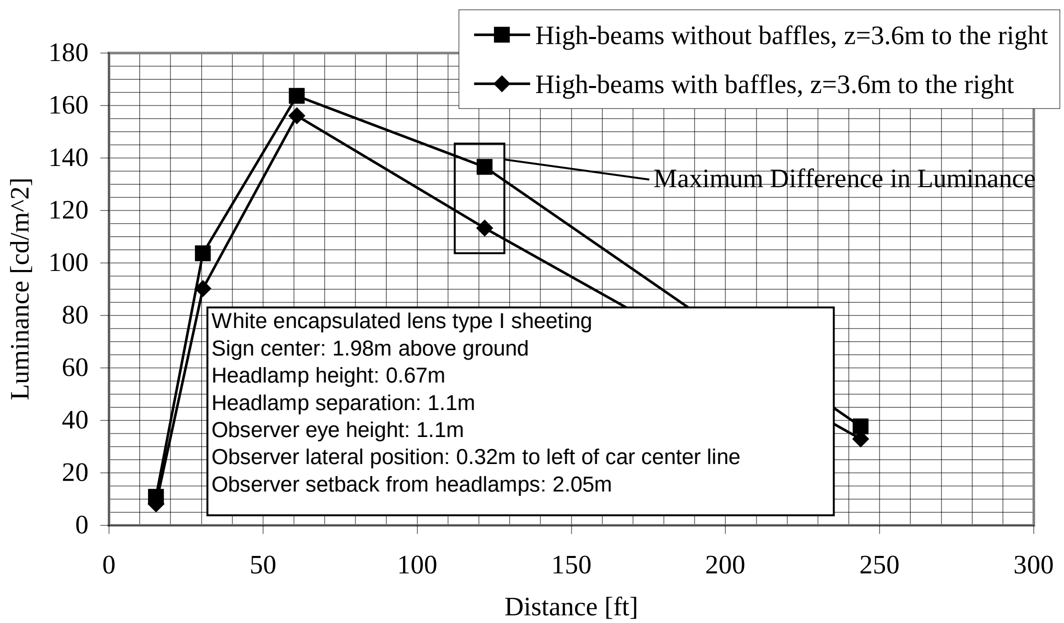
Note: 1 ft = 0.3048m

Figure 6. The Effect of Specular Road Surface Reflection As Shown by Comparison of Sign Luminance with and Without Baffles, Low-beams

(top) H6054 Low Beams, z = 7.3m (24ft) to the Left.

(bottom) H6054 Low Beams, z = 3.6m (12ft) to the Right.





Note: 1 ft = 0.3048m

Figure 7. The Effect of Specular Road Surface Reflection As Shown by Comparison of Sign Luminance with and Without Baffles, High-beams

(top) H6054 High Beams, z = 7.3m (24ft) to the Left.

(bottom) H6054 High Beams, z = 3.6m (12ft) to the Right.

Table 1. Reflection Values R_L [mcd/m^2/lx] for New Asphalt, Old Asphalt, New Concrete, Old Concrete, and Concrete on the Old OU Airport Runway.

New Asphalt

Observation Angle [deg]	Entrance Angle [deg] 83	84	85	86	87	88	89
1	27.5	26.4	24.0	20.7	17.0	13.3	9.9
2	18.6	17.9	16.3	14.1	11.6	9.1	6.8
3	14.9	14.4	13.3	11.6	9.6	7.6	5.7
4	12.7	12.5	11.6	10.2	8.5	6.8	5.2
5	11.3	11.2	10.5	9.3	7.9	6.3	4.9
6	10.3	10.3	9.7	8.7	7.4	6.0	4.7
7	9.5	9.5	9.1	8.2	7.1	5.8	4.5
8	8.9	9.0	8.6	7.8	6.8	5.6	4.4
9	8.3	8.5	8.2	7.5	6.6	5.5	4.3
10	7.9	8.1	7.9	7.3	6.4	5.4	4.3

Old Asphalt

Observation Angle [deg]	Entrance Angle [deg] 83	84	85	86	87	88	89
1	62.2	53.4	44.9	37.0	29.9	23.7	18.4
2	39.3	34.0	28.8	23.9	19.4	15.5	12.1
3	30.2	26.5	22.7	19.0	15.7	12.7	10.0
4	25.2	22.3	19.4	16.4	13.7	11.2	9.0
5	21.9	19.6	17.2	14.8	12.4	10.3	8.3
6	19.6	17.7	15.7	13.6	11.6	9.7	7.9
7	17.8	16.3	14.6	12.8	11.0	9.2	7.6
8	16.4	15.1	13.7	12.1	10.5	8.9	7.4
9	15.3	14.2	13.0	11.6	10.1	8.6	7.3
10	14.3	13.5	12.4	11.1	9.8	8.4	7.2

New Concrete

Observation Angle [deg]	Entrance Angle [deg] 83	84	85	86	87	88	89
1	75.0	95.4	105.4	101.6	85.8	63.9	42.0
2	59.0	73.1	78.6	73.8	60.8	44.1	28.3
3	50.7	61.4	64.7	59.5	48.0	34.2	21.5
4	45.3	53.9	55.8	50.5	40.0	28.0	17.3
5	41.4	48.5	49.5	44.1	34.4	23.7	14.5
6	38.4	44.4	44.7	39.3	30.3	20.6	12.4
7	35.9	41.1	40.9	35.5	27.1	18.2	10.8
8	33.9	38.4	37.8	32.5	24.5	16.3	9.6
9	32.2	36.1	35.2	29.9	22.4	14.7	8.6
10	30.8	34.2	33.0	27.8	20.6	13.4	7.8

Old Concrete

Observation Angle [deg]	Entrance Angle [deg] 83	84	85	86	87	88	89
1	32.6	30.2	27.2	23.9	20.6	17.3	14.2
2	28.8	25.2	21.4	17.8	14.5	11.5	9.0
3	25.8	22.2	18.7	15.3	12.3	9.6	7.4
4	23.5	20.2	17.0	13.9	11.1	8.7	6.7
5	21.6	18.7	15.8	13.0	10.4	8.2	6.3
6	20.1	17.5	14.8	12.3	10.0	7.9	6.1
7	18.8	16.5	14.1	11.8	9.6	7.7	6.0
8	17.7	15.6	13.5	11.4	9.4	7.6	6.0
9	16.7	14.9	13.0	11.1	9.2	7.5	6.0
10	15.9	14.3	12.6	10.8	9.1	7.4	6.0

Old OU Airport Runway Concrete

Observation Angle [deg]	Entrance Angle [deg] 83	84	85	86	87	88	89
1	41.4	41.8	39.2	34.2	27.9	21.3	15.2
2	35.0	34.4	31.3	26.6	21.1	15.7	11.0
3	29.7	29.3	26.8	22.9	18.3	13.6	9.5
4	25.6	25.6	23.8	20.5	16.6	12.5	8.9
5	22.5	22.8	21.5	18.8	15.4	11.8	8.5
6	20.0	20.6	19.7	17.5	14.6	11.4	8.3
7	18.0	18.8	18.3	16.5	13.9	11.0	8.2
8	16.3	17.3	17.1	15.7	13.4	10.8	8.1
9	14.9	16.0	16.0	14.9	13.0	10.6	8.1
10	13.7	14.9	15.2	14.3	12.6	10.4	8.1

Table 2. The Effect of Specular Road Surface Reflection As Shown by Comparison of Sign Luminance with and Without Baffles, Low-beams and High-beams

	Distances to Sign [m]		Actual Luminance [cd/m^2]		Difference (without - with)		
Beam	Lateral	Longitudinal	Without Baffles	With Baffles	[cd/m^2]	[%]	
Low	z = -7.31	15.24	0.36	0.34	0.02	4.32%	
	z = -7.31	30.48	2.98	2.73	0.25	8.47%	
	z = -7.31	60.96	6.64	6.26	0.38	5.78%	
	z = -7.31	121.92	6.68	6.26	0.42	6.25%	*Average*
	z = -7.31	243.84	4.81	4.66	0.15	3.14%	5.59%
	z = 3.65	15.24	4.85	4.06	0.79	16.25%	
	z = 3.65	30.48	16.44	14.37	2.07	12.57%	
	z = 3.65	60.96	53.42	52.30	1.12	2.10%	
	z = 3.65	121.92	39.26	33.20	6.06	15.43%	*Average*
	z = 3.65	243.84	12.95	11.42	1.52	11.78%	11.63%
High	z = -7.31	15.24	0.76	0.74	0.02	2.91%	
	z = -7.31	30.48	27.22	24.66	2.56	9.40%	
	z = -7.31	60.96	35.84	35.18	0.66	1.84%	
	z = -7.31	121.92	28.57	25.96	2.62	9.16%	*Average*
	z = -7.31	243.84	19.24	18.67	0.57	2.96%	5.25%
	z = 3.65	15.24	10.81	8.11	2.69	24.92%	
	z = 3.65	30.48	103.62	90.28	13.34	12.87%	
	z = 3.65	60.96	163.63	156.10	7.53	4.60%	
	z = 3.65	121.92	136.55	113.29	23.26	17.04%	*Average*
	z = 3.65	243.84	37.69	32.91	4.78	12.68%	14.42%

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