EVALUATION OF VISIBILITY LEVEL FORMULA IN ROAD LIGHTING WITH FIELD MEASUREMENTS

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ABSTRACT

In this study, to evaluate the visibility level formula in road lighting calculations, photometric measurements are done on the real road in Ayazağa Campus of Istanbul Technical University with the observers. The correlations between calculated and evaluated visibility levels are determined as approximately 0,75. It is shown that the visibility formula used in road lighting calculations is valid in view of real road conditions.

I. INTRODUCTION

The purpose of road lighting is to provide visual cues and reveal obstacles so that safe vehicular operation is possible. As we know the good quality road lighting is very important for traffic safety and driver comfort. Good quality road lighting can provide the visibility required at safe stopping distance so that evasive action can be taken in good time, without resort to an abrupt manoeuvre [1]. In most industrialised countries the number of night-time casualty accidents is about half the total number of accidents, whereas the night-time traffic flow is only some 20-35% of the total traffic flow. In addition, the night-time accidents are generally more severe and the proportion of severe accidents to the total number of accidents is higher at night [2]. Formerly the designs of roadway lighting were based the illuminance criteria especially in North America. Illuminance method determines how well the designer matched the luminaire's pattern with the geometry of the road. Then it was recognised that illuminance criteria is inadequate to measure that what driver see. Since luminance is the most important criterion in vision, over the past thirty years the road lighting calculations have been based upon the average luminance levels on the surface of the road [1, 3]. On the other hand, traffic safety is highly correlated to the amount of visual information that can be obtained from the road and its immediate environment [4]. For that reason the newly developed recommendations for roadway lighting have chosen the visibility as the quality criterion [5].

This criterion is still investigated as a new concept in the European countries. Studies are going on in the subject that the visibility factor should have been added the designs based on the luminance level. A technical committee (TC 4-36) named "Visibility design for roadway lighting" of International Illumination Committee (CIE) is preparing a technical report about this subject.

Visibility factor, which can be calculated as the visibility level (VL) or the visibility index (VI), is sometimes given a unique value or an average value on the road surface. Visibility level and visibility index is highly correlated and both of these can be used for predicting the visual performance [6, 7]. In this study, calculations and measurements are based on the visibility level. There is an empirical visibility level formula developed by Adrian [8]. This formula is used in the road lighting calculations based on visibility.

The aim of this study is to evaluate of visibility level formula in road lighting calculations with field measurements.

II. VISIBILITY LEVEL

For calculating the visibility level, initially a critical object must be determined. The critical size corresponds roughly to the least clearance between the road surface and the body structures of normal cars. 18cmx18cm size is selected as an object size, which is minimal danger size on the road for a normal size vehicle. Reflectance of the target can be chosen between 20% and 50%. The reflection factor of the critical object is taken 24% in this study [5, 9, 10]. Visibility level of the critical object on the road surface is defined as [8],

$$VL = \frac{\Delta L_{actual}}{\Delta L_{threshold}} \qquad (1)$$

Where, ΔL_{actual} is the luminance difference between the target and its background in the real conditions,

$\Delta L_{threshold}$ is the luminance difference needed for minimal visibility, between a target of certain angular size and its background.

Actual luminance difference between the target and its background can be calculated

$$\Delta L_{actual} = L_t - L_b \quad (2)$$

Where, L_t : Target luminance
L_b : Background luminance

If the target luminance is higher than the background, it is called positive contrast. However if the target luminance is lower than the background then it is called negative contrast. For both cases, the minimum luminance difference for perception of the target with a certain probability level has to be determined. Threshold luminance difference can be calculated as follows,

$$\Delta L_{threshold} = k \cdot \left(\frac{\Phi^{1/2}}{\alpha} + L^{1/2}\right)^2 \cdot F_{CP} \cdot \frac{a(\alpha, L_b) + t}{t} \cdot AF \quad (3)$$

Where, Φ : Luminous flux function
L : Luminance function
α : Target size
F_{CP} : Contrast polarity factor
$a(\alpha;L_b)$: Parameter depends on size of target and background luminance
t : Observation time
AF : Age factor
k : Factor for the probability of perception (k=2.6 for 100% probability) [8, 11].

III. EXPERIMENTAL STUDY

To evaluate the visibility level formula, photometric measurements are done on the real road in the Ayazağa Campus of Istanbul Technical University, which is closed to the traffic and restricted from the outside light. The road is lighted from right side, by using semi cut-off luminaires. Each luminaire has a high-pressure sodium (SON-H, 220W) lamp without ignition. The luminous flux of each lamp is 20000 lumen (Photo 1).

The installation arrangement parameters and geometry of test road and target used in this experiment are,

Spacing (s) : 30m
Road width (w) : 7m
Number of lane (l) : 2
Lane width (w_l) : 3.5m
Road type : R3
Montage height (h) : 11m
Overhang (k) : 1.5m
Tilt angle (t_k) : 10°
Target size (α) : 18cmx18cm square target
Target reflectance factor (ρ) : 24%

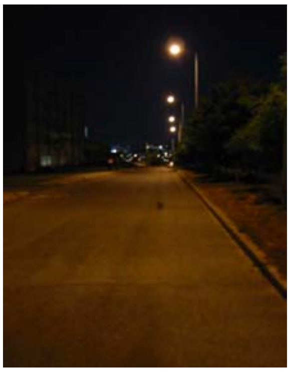

Photo 1. Test road

According to the previous studies, the visibility level should be between minimum 6 and 7 for M3 and M2 road lighting classes respectively. On the other hand, 1 cd/m^2 and 0.7 cd/m^2 average luminance levels are also recommended for M2 and M3 classes [1]. Our test road has a radial road characteristic therefore it can be classified as M2 or M3 depending on traffic control.

The measurement field and the locations of luminaires are shown in Figure 1. Seven luminaires are taken into consideration in the measurements.

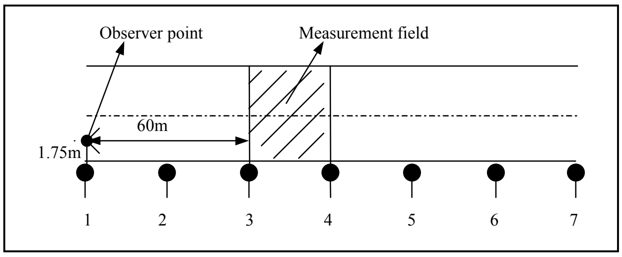

Figure 1. Measurement field and luminaires

The measurement grid points are located on the road surface as appropriated to CIE 140-2000 [12]. The coordinates of the measurement grid points are shown in Figure 2. The measurements are carried out totally in 60 grids on the road with two lanes. Each lane contains three lines and each line has 10 grid points.

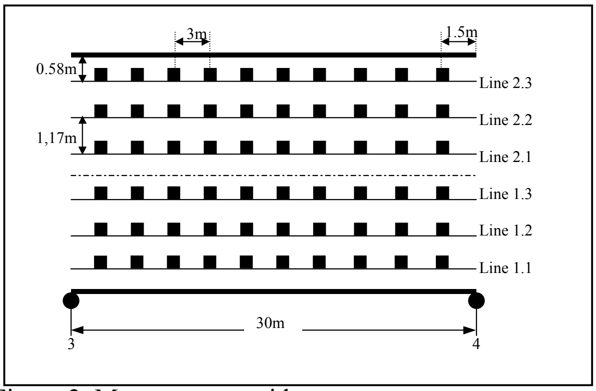

Figure 2. Measurement grids

Road and target luminance levels are measured by using LMT 1009 model luminance meter. 6′ aperture of the photometer is used to get the most accurate results from 60 m. The luminance meter is placed on a tripod 1.5m height from the road surface (Photo 2). At the beginning, the road luminance values are measured for each grid points. Then the target placed on the grid points and the luminance meter is focused the centre of the target. By the way, the target luminance values are measured. Luminance measurements for both road and target are repeated for each grid point.

Photo 2. Luminance meter

IV. CALCULATIONS and RESULTS

Visibility level of the target for each grid points calculated by using the measured values (road luminance and target luminance) and the observers' information (age=23 and observation time=0,2s). The variations of the visibility level (VL) depending on the grid points are given in graphics form in Figure 3.

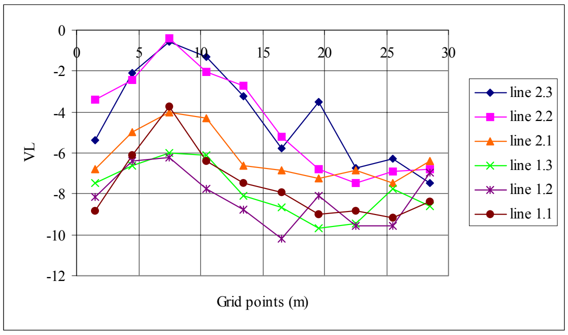

Figure 3. Variations of the visibility level

From the measured road (L_r) and target luminance (L_t) values, the average road luminance value (L_{avg}), average visibility level (VL_{avg}), overall (U_o), and the longitudinal uniformities for each lane (U_l) are calculated. The results are shown in Table 1. As it is seen from the table the uniformity values of the test road are appropriate to the CIE 115-1995 [1].

Table 1. Lighting quality parameters

L_{avg} (cd/m^2)	VL_{avg}	U_o	U_{l1}	U_{l2}
0,86	6,40	0,65	0,80	0,82

The variations of the road (L_r) and target luminance (L_t) depending on the grid points are shown in Figure 4 and 5 respectively.

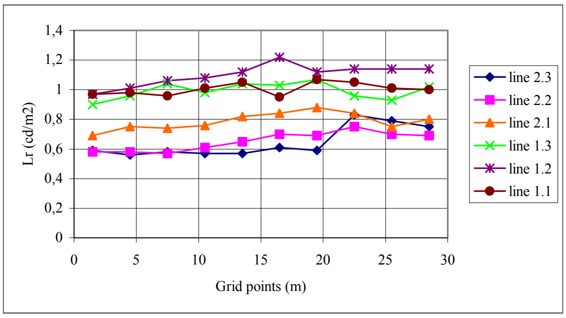

Figure 4. Variations of the road luminance

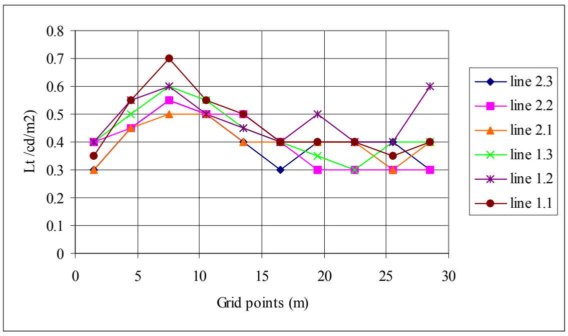

Figure 5. Variations of the target luminance

V. EVALUATION OF THE TARGET VISIBILITY

Seven observers who are 23 years old attended the experiments to evaluate the visibility conditions on the test road. Firstly, the main aim of the experiment and the procedure are explained them and the visibility evaluation scale given to each other. The visibility evaluation scale is shown in Figure 6.

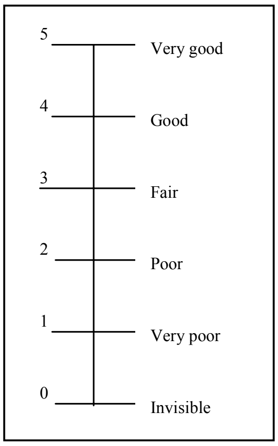

Figure 6. Visibility evaluation scale

The observers lined up at the proper location facing away from the target while the target are placed on the grid point. They are told to turn around and evaluate the condition and then give the point. This procedure is repeated for each grid point.

The maximum value is 5 in the visibility evaluation scale. According to the calculated the maximum absolute value of the visibility level of the target is 10,2. To compare the calculated visibility level with the subjective evaluation mark it is necessary to adapt the evaluation values to the calculated visibility value. The adaptation coefficient is found as 2,04 by dividing the maximum calculated visibility level to the maximum visibility evaluation scale value. So, the evaluated visibility levels (VL_{ev}) are obtained multiplying by 2,04. The average values of calculated visibility level (VL_{cal}) and evaluated visibility level (VL_{ev}) are taken in transverse positions of each grid points. Therefore, six calculated lines and six evaluated lines are decreased to only two lines.

The variations of average calculated visibility level (VL_{cal}), and average evaluated visibility level (VL_{ev}) depending on the grid points in the longitudinal positions for each observer are given in Figure 7-13 respectively.

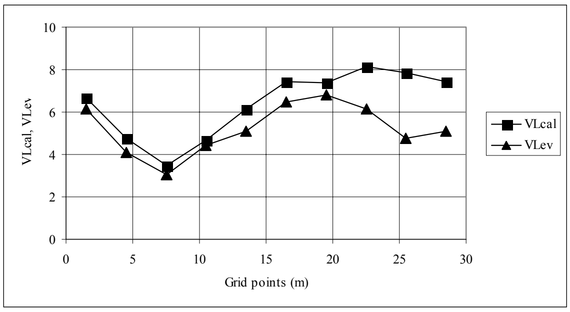

Figure 7. Variations of VL_{cal} and VL_{ev} depending grid points for observer **1**

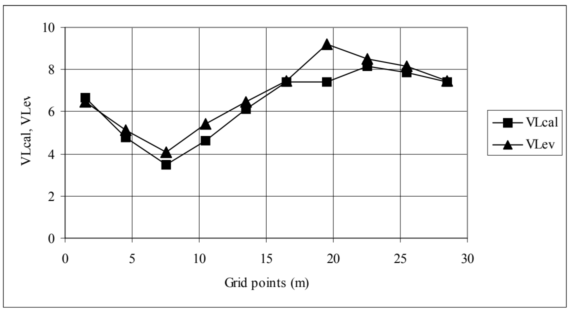

Figure 8. Variations of VL_{cal} and VL_{ev} depending grid points for observer **2**

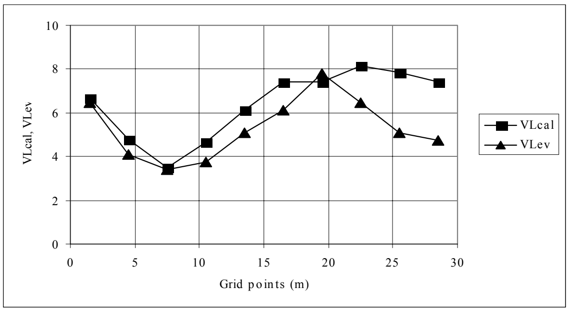

Figure 9. Variations of VL_{cal} and VL_{ev} depending grid points for observer **3**

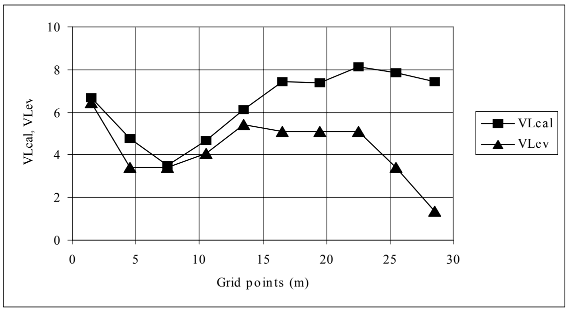

Figure 10. Variations of VL_{cal} and VL_{ev} depending grid points for observer **4**

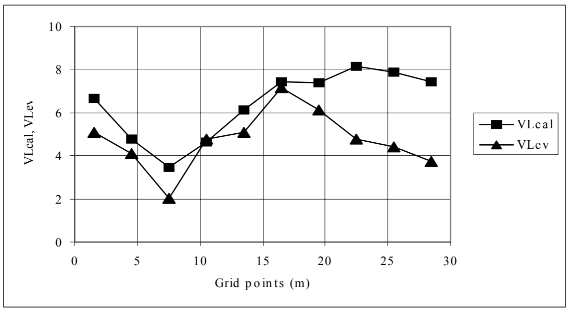

Figure 11. Variations of VL_{cal} and VL_{ev} depending grid points for observer **5**

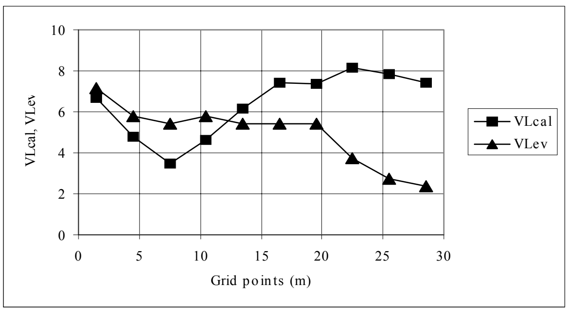

Figure 12. Variations of VL_{cal} and VL_{ev} depending grid points for observer **6**

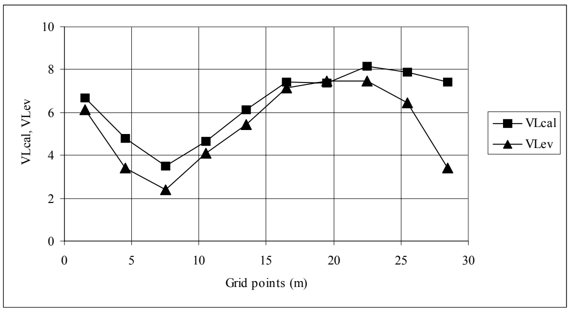

Figure 13. Variations of VL_{cal} and VL_{ev} depending grid points for observer **7**

VI. CONCLUSION

It is observed that calculated values are appropriate to the evaluated values obtained from the field measurements. The correlations between calculated and evaluated visibility levels are determined as approximately 0,75. It is shown that the visibility formula used in road lighting calculations is valid in view of real road conditions. It is clear that these kind of experimental studies should be continued for different lighting arrangements with more observers. If visibility level values can be recommended from the results of these experimental studies, the appropriate visual conditions can be obtained with lower luminance levels on the road surface. This situation causes energy saving in road lighting.

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