# COMPARISON OF THE CALCULATED AND EXPERIMENTAL RESULTS FOR VISIBILITY LEVEL ON THE ROAD

**Önder GÜLER** **Sermin ONAYGİL**
*e-mail: onder@elk.itu.edu.tr* *e-mail: sermin@elk.itu.edu.tr*
*Istanbul Technical University, Faculty of Electric & Electronics, Department of Electrical Engineering, Maslak, 80626, Istanbul, Turkey*

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## ABSTRACT

**In this study, to take the visibility level as a parameter in road lighting calculations a computer program has been developed. To test the program some experiments are done on the model road. The measurement results were compared with the calculated values. The differences between the measurement and calculated values depending on the grid points were given graphically.**

## I. INTRODUCTION

It is a well-known fact that the necessity for high quality road illumination is very important for traffic safety and driver comfort. Since luminance is the most important criterion in vision, over the past thirty years the road illumination calculations have been based upon the average luminance levels on the surface of the road [1, 2]. 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 [3]. For that reason the newly developed recommendations for roadway lighting have chosen the visibility level as the quality criterion [4]. Visibility as a characteristic of road lighting has recently been discussed particularly in North America.

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 4-35) named “Visibility design for roadway lighting” of International Illumination Committee (CIE) is preparing a technical report about this subject. But this committee needs new research studies.

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 for application. Visibility level and visibility index is highly correlated and both of these can be used for predicting the visual performance [5, 6]. In this study, calculations and measurements are based on the visibility level. According to previous studies, the visibility level should be higher than 7 to get sufficient vision conditions. 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. 20cmx20cm 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 20% according to IES recommendations and Hansen & Larsen’s experimental data which depend upon measurements of the reflection factors for pedestrian’s clothing on the roads [4, 7]. 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, $\Delta L_{actual}$ 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

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

Where, $L_t$ : Target luminance
$L_b$ : Background luminance

The target can have a higher luminance than the background (positive contrast) or appear darker than $L_b$ (negative contrast). For both cases, a minimal luminance difference is needed to perceive the target with a certain probability level. Threshold luminance difference can be calculated as follows,

$$\Delta L_{threshold} = 2.6 \cdot \left(\frac{\Phi^{1/2}}{\alpha} + L^{1/2}\right)^2 \cdot F_{CP} \cdot \frac{a(\alpha, L_b) + t}{t} \cdot AF \qquad (3)$$

Where, $\Phi$ : Luminous flux function
$L$ : Luminance function
$\alpha$ : 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

In this study, a computer program has been developed for investigating the visibility level on the road surface. Calculated values by this computer program are compared with measured values obtained on the model road.

## II. COMPUTER PROGRAM

Average illumination level ($E_o$), average luminance level ($L_o$), overall uniformity ($U_o$), longitudinal uniformity for each lane ($U_l$), threshold increment (TI), veiling luminance ($L_v$), average visibility level ($VL_o$), minimum visibility level ($VL_{min}$) and maximum visibility level ($VL_{max}$) can be calculated by using this computer program. It is possible to use different interpolation methods such as linear or spline for predicting interval values. Calculating procedures of this developed computer program are appropriated to CIE-140 2000 publication [9].

To calculate these values input data should be given as follows:

-Lighting arrangement; It is possible to calculate for 6 different arrangements: Single sided (left and right), opposite, staggered, twin-bracket central and combined twin-bracket opposite

-Installation parameters; such as spacing, montage height, tilt angle, console length and road width

-Road type; It is possible to calculate for the different road type such as R1, R2, R3, R4, N1, N2, N3, N4, C1 and C2

-Luminaire type

-Maintenance factor

-Observer age

-Observation time

-Target size

-Target reflection factor

## III. EXPERIMENTAL STUDY

Testing the computer program, developed to calculate the visibility level, some measurements are realised on a model road. These measurements are done “Laboratoire Regional des Ponts et Chaussees de Rouen” which is a department of “Centre d’Etudes Techniques de I’Equipement Normandie Centre” (CETE), “Ministere de I’Equipement, des Transports et du Logement” in France. There is a model road in this laboratory which is closed to the traffic and restricted from the outside light. A photograph of this model road is shown in Figure 1.

The luminaires are put on a rail on the right side of the road. Spacing between luminaires can be adjusted up to 60 m. The maximum montage height is 15 m and the console length can be adjusted up to the 2.5 m. In addition to those, tilt angle can be changed. It is also capable to dim the flux luminous of the lamps to 100%, 75%, 50% and 25%.

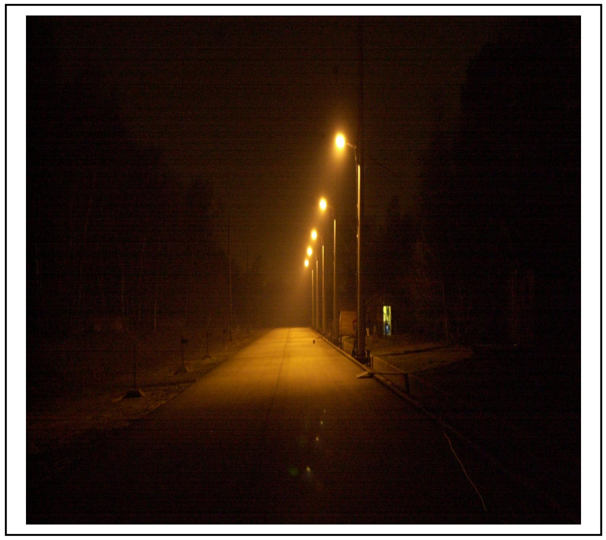

Figure 1. Model road

Measurements are done on the R1 type road, lighted from right side, by using semi cut-off luminaire. The luminous intensity diagram of the luminaires used in the experimental study is given in Figure 2. Each luminaire has a high-pressure sodium lamp with power 150W and luminous flux 17.500 lumen.

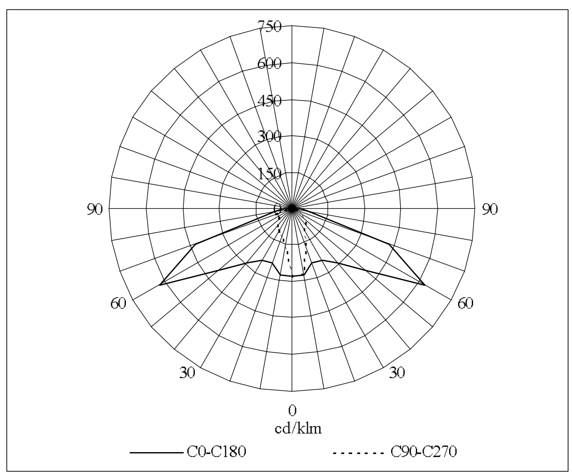


Figure 2. The luminous intensity diagram of the luminaire used in the experimental study

The road model used in this experiment is,

Spacing (s) : 30m
Road width (w) : 7m
Number of lane (l) : 2
Lane width ($w_l$) : 3.5m
Road type : R1
Montage height (h) : 8m
Console length (k) : 0m
Tilt angle ($t_k$) : 20°
Target size ($\alpha$) : 20cmx20cm square target
Target reflectance factor ($\rho$) : 20%

The measurement field and the locations of luminaires are shown in Figure 3.

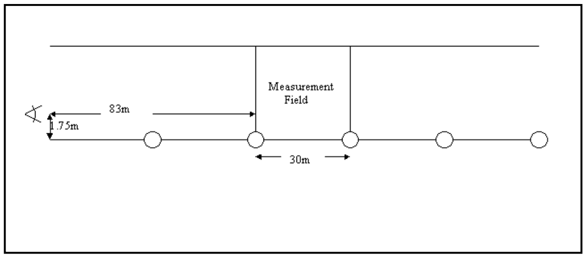


Figure 3. Measurement field and luminaires

The coordinates of the measurement grid points are shown in Figure 4. The measurements are done totally in 28 grids on the road with two lanes. Each lane contains two lines and each line has 7 grid points.

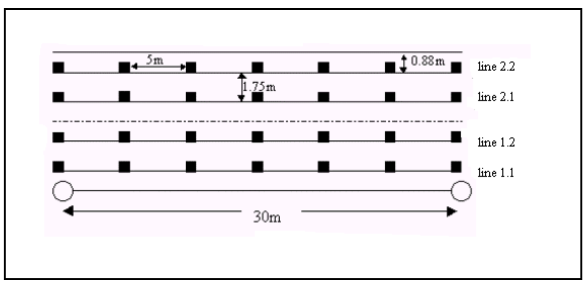


Figure 4. Measurement grids

Horizontal illuminance levels on the road, luminance levels of road and target are measured for each grid point that is shown in Figure 4. Illuminance levels are measured with appropriate luxmeter for road lighting conditions. Road and target luminance levels are measured by using PR-1980A Pritchard model photometer, which is marked to Photo Research Company. 2′ aperture of the photometer is used to get the most accurate results from 83 m.

## IV. MEASUREMENT AND CALCULATION RESULTS

The results obtained from computer program are compared with the results of experimental study. The observer's information, luminaire and lighting installation parameters are given as input in the computer program as the same value of model road. In the calculation, observer age 30, observation time 0.2 s and the height of the observer 1.5 m are taken for the experimental conditions. The measured and calculated values and differences between them are given in Table 1.

As it can be seen from Table 1 there are differences between measured and calculated values. Since reflection properties of road surfaces are changing with the time, there are big differences especially in the road luminance values. These properties aren't considered in the calculations of the illuminance levels so that differences between illuminance levels are smaller than differences between luminance levels. Moreover, calculated and measured values at target luminance can also be different because only direct components of the emitted light from the luminaire are taken into consideration in the computer program.

In previous studies, it is known that there are more differences between results from calculations and experiments. For example Janoff found maximum difference rate in calculation results of target luminance was 307% according to his experimental results in 1993. In 1999 Glenn and his friends show that there were differences in the calculated and experimental values as expected. The shape of graphics was the same but values were different [10, 11].

To determine the general trend of experimental and calculation results, variations of measured and calculated illuminance level, road luminance, target luminance and visibility level values are drawn in graphics depending on the grid points using the values of Table 1. These graphics are shown in Figure 5. It is seen that the shapes of calculated and measured graphics are similar to each other.

## V. CONCLUSION

In this study, a computer program is developed to calculate the visibility level on the road. In order to investigate the accuracy of this program, an experimental study is conducted on the model road.

When the calculated values are compared with the measured values, some differences are seen. Especially there are big differences at road luminance values, because the reflection properties of road surfaces are changing with time. On the other hand, the differences between illuminance levels are small since these properties aren't considered in the calculations of illuminance levels. Moreover, the differences at target luminance can cause differences between measured and calculated values of visibility level. The basic reason of the differences at the target luminance is that the lighting reflected from the surrounding on the target surface is not taken into consideration in the computer program.

It is a good point that the differences between the calculated values and the experimental results are smaller than the differences explained in previous comparative studies. It means that the computer program developed for this study is more sensitive than the previous programs.

As it is seen from the graphics, the variations of the calculated and measured values on the grid points in every lane along the road, is similar. For this reason, including a new criterion to the road lighting calculations to determine the distribution of the visibility level on the road is very useful in point of the determination of the appropriate visual conditions for real road situations.

Table 1. Measured and calculated values and differences

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Horizontal illuminance levels (lux)** | | | | | | | | | | | | | | | | | | | |
| **Measured** | | | | | **Calculated** | | | | | **Absolute difference** | | | | | **Relative difference (%)** | | | | |
| **30** | 27.2 | 55.0 | 74.0 | 47.8 | **30** | 28.8 | 53.3 | 62.6 | 41.2 | **30** | 1.55 | 1.72 | 11.4 | 6.6 | **30** | 6 | 3 | 15 | 14 |
| **25** | 24.7 | 39.3 | 43.1 | 30.4 | **25** | 24.7 | 35.8 | 38 | 27.4 | **25** | 0.01 | 3.50 | 5.15 | 3.05 | **25** | 0 | 9 | 12 | 10 |
| **20** | 24.0 | 32.8 | 33.1 | 23.7 | **20** | 25.9 | 32.2 | 30.2 | 21.8 | **20** | 1.93 | 0.64 | 2.88 | 1.86 | **20** | 8 | 2 | 9 | 8 |
| **15** | 23.9 | 33.0 | 34.8 | 28.4 | **15** | 27.2 | 34.5 | 33.1 | 24.5 | **15** | 3.33 | 1.46 | 1.72 | 3.86 | **15** | 14 | 4 | 5 | 14 |
| **10** | 24.5 | 31.7 | 33.2 | 25.5 | **10** | 25.9 | 32.2 | 30.2 | 21.8 | **10** | 1.43 | 0.46 | 2.98 | 3.66 | **10** | 6 | 1 | 9 | 14 |
| **5** | 25.9 | 40.2 | 42.8 | 31.7 | **5** | 24.7 | 35.8 | 38.0 | 27.4 | **5** | 1.19 | 4.41 | 4.85 | 4.35 | **5** | 5 | 11 | 11 | 14 |
| **0** | 29.7 | 57.0 | 64.3 | 42.6 | **0** | 28.8 | 53.3 | 62.6 | 41.2 | **0** | 0.95 | 3.72 | 1.67 | 1.40 | **0** | 3 | 7 | 3 | 3 |
| **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** |
| **Road luminance (cd/m$^2$)** | | | | | | | | | | | | | | | | | | | |
| **Measured** | | | | | **Calculated** | | | | | **Absolute difference** | | | | | **Relative difference (%)** | | | | |
| **30** | 2.19 | 3.30 | 4.61 | 3.74 | **30** | 2.22 | 3.80 | 4.48 | 3.16 | **30** | 0.03 | 0.50 | 0.13 | 0.58 | **30** | 1 | 15 | 3 | 16 |
| **25** | 2.41 | 3.29 | 3.92 | 3.53 | **25** | 2.13 | 3.05 | 3.30 | 2.61 | **25** | 0.28 | 0.24 | 0.62 | 0.92 | **25** | 12 | 7 | 16 | 26 |
| **20** | 2.42 | 3.38 | 4.40 | 3.63 | **20** | 2.52 | 3.28 | 3.41 | 2.80 | **20** | 0.10 | 0.10 | 0.99 | 0.83 | **20** | 4 | 3 | 23 | 23 |
| **15** | 2.71 | 3.05 | 5.17 | 4.90 | **15** | 2.79 | 3.87 | 4.22 | 3.68 | **15** | 0.08 | 0.37 | 0.95 | 1.22 | **15** | 3 | 11 | 18 | 25 |
| **10** | 2.60 | 3.41 | 4.43 | 4.55 | **10** | 2.52 | 3.24 | 3.40 | 2.90 | **10** | 0.08 | 0.17 | 1.03 | 1.65 | **10** | 3 | 5 | 23 | 36 |
| **5** | 2.30 | 3.49 | 4.24 | 4.14 | **5** | 2.12 | 3.02 | 3.33 | 2.71 | **5** | 0.18 | 0.47 | 0.91 | 1.43 | **5** | 8 | 13 | 21 | 35 |
| **0** | 2.23 | 3.62 | 4.02 | 3.74 | **0** | 2.22 | 3.80 | 4.48 | 3.16 | **0** | 0.01 | 0.18 | 0.46 | 0.58 | **0** | 0 | 5 | 11 | 16 |
| **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** |
| **Target luminance (cd/m$^2$)** | | | | | | | | | | | | | | | | | | | |
| **Measured** | | | | | **Calculated** | | | | | **Absolute difference** | | | | | **Relative difference (%)** | | | | |
| **30** | 1.38 | 1.33 | 1.33 | 1.05 | **30** | 0.41 | 0.34 | 0.26 | 0.19 | **30** | 0.97 | 0.99 | 1.07 | 0.86 | **30** | 70 | 74 | 80 | 82 |
| **25** | 1.55 | 1.60 | 1.45 | 1.25 | **25** | 0.75 | 0.70 | 0.57 | 0.43 | **25** | 0.80 | 0.90 | 0.88 | 0.82 | **25** | 52 | 56 | 61 | 66 |
| **20** | 1.85 | 1.85 | 1.85 | 1.80 | **20** | 1.47 | 1.39 | 1.18 | 0.84 | **20** | 0.38 | 0.46 | 0.67 | 0.96 | **20** | 21 | 25 | 36 | 53 |
| **15** | 1.90 | 2.60 | 2.81 | 2.51 | **15** | 1.93 | 2.31 | 2.09 | 1.47 | **15** | 0.03 | 0.29 | 0.72 | 1.04 | **15** | 2 | 11 | 26 | 41 |
| **10** | 1.84 | 2.60 | 2.71 | 2.21 | **10** | 1.91 | 2.37 | 2.06 | 1.33 | **10** | 0.07 | 0.23 | 0.65 | 0.88 | **10** | 4 | 9 | 24 | 40 |
| **5** | 1.56 | 2.31 | 2.62 | 1.96 | **5** | 1.64 | 2.13 | 1.84 | 1.02 | **5** | 0.08 | 0.18 | 0.78 | 0.94 | **5** | 5 | 8 | 30 | 48 |
| **0** | 0.81 | 1.48 | 0.92 | 0.83 | **0** | 0.41 | 0.34 | 0.26 | 0.19 | **0** | 0.40 | 1.14 | 0.66 | 0.64 | **0** | 49 | 77 | 72 | 77 |
| **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** |
| **Visibility level** | | | | | | | | | | | | | | | | | | | |
| **Measured** | | | | | **Calculated** | | | | | **Absolute difference** | | | | | **Relative difference (%)** | | | | |
| **30** | -6.48 | -11.8 | -15.3 | -14.7 | **30** | -13.6 | -18.0 | -19.5 | -17.5 | **30** | 7.07 | 6.18 | 4.16 | 2.85 | **30** | 109 | 52 | 27 | 19 |
| **25** | -6.45 | -10.2 | -13.0 | -13.0 | **25** | -10.6 | -14.3 | -15.7 | -14.7 | **25** | 4.11 | 4.13 | 2.64 | 1.66 | **25** | 64 | 41 | 20 | 13 |
| **20** | -4.27 | -9.03 | -12.3 | -10.2 | **20** | -7.23 | -10.9 | -12.6 | -12.6 | **20** | 2.96 | 1.87 | 0.22 | 2.37 | **20** | 69 | 21 | 2 | 23 |
| **15** | -5.61 | -5.18 | -10.1 | -10.6 | **15** | -5.56 | -8.02 | -10.3 | -11.8 | **15** | -0.05 | 2.84 | 0.20 | 1.14 | **15** | 1 | 55 | 2 | 11 |
| **10** | -5.42 | -4.75 | -8.28 | -11.0 | **10** | -4.18 | -5.08 | -7.58 | -9.84 | **10** | -1.24 | 0.33 | -0.70 | -1.19 | **10** | 23 | 7 | 8 | 11 |
| **5** | -5.74 | -6.80 | -8.06 | -11.0 | **5** | -3.73 | -5.43 | -8.51 | -11.1 | **5** | -2.01 | -1.37 | 0.45 | 0.07 | **5** | 35 | 20 | 6 | 1 |
| **0** | -11.3 | -12.0 | -16.1 | -15.9 | **0** | -13.5 | -18.0 | -19.5 | -17.6 | **0** | 2.27 | 6.00 | 3.41 | 1.66 | **0** | 20 | 50 | 21 | 10 |
| **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** | **x/y** | **0.88** | **2.63** | **4.38** | **6.13** |

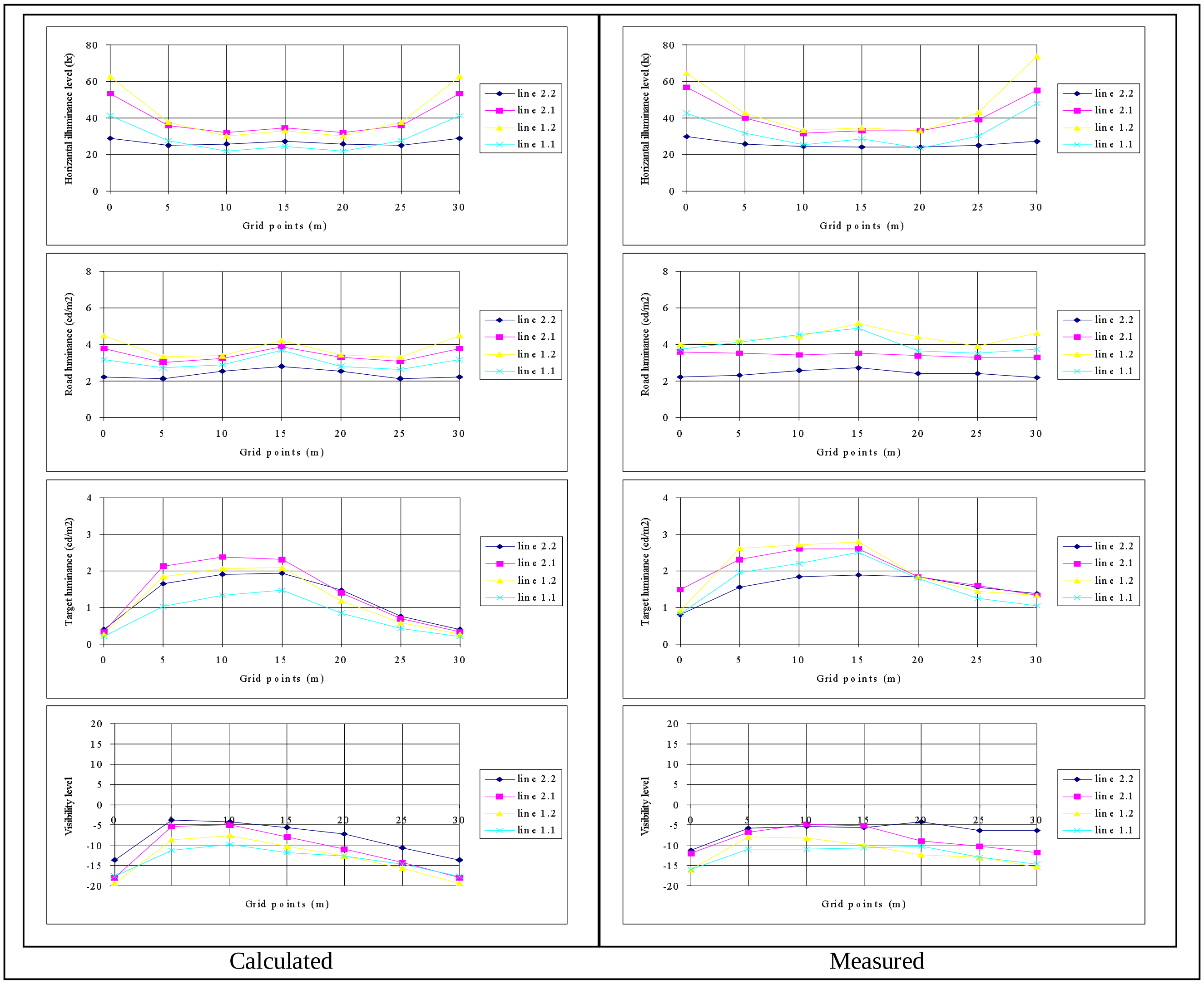


Figure 5. Variations of the calculated and measured values depending on the grid points


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## REFERENCES


1. CIE Pub. No. 12.2, "Recommendations for the lighting of roads for motorised traffic", 2nd ed., 1997.
2. CIE Pub. No. 115, "Recommendations for the lighting of roads for motor and pedestrian traffic", 1995.
3. CIE Pub. No. 93, "Road lighting as an accident countermeasure", 1992.
4. ANSI/IESNA RP-8, "American National Standard Practice for Roadway Lighting", 2000.
5. Federal Highway Administration U. S. Department of Transportation, "Safety Benefits of Roadway Lighting Using Small Target Visibility (STV) Design", Final Report, Washington, U.S.A., 1997.
6. Janoff, M.S., "Toward Development of a Visibility Model for Roadway Lighting Design", Journal of the Illuminating Engineering Society, Winter, pp. 122-130, 1993.
7. Hansen, E.R., Larsen, J.S., "Reflection Factors for Pedestrian's Clothing", Lighting Research and Technology, 11, 3, pp. 154-157, 1979.
8. Adrian, W., "Visibility of Targets: Model for Calculations", Lighting Research and Technology, 21, pp. 181-188, 1989.
9. CIE Pub. No. 140, "Road Lighting Calculations", 2000.
10. Janoff, M.S., "Measured vs Computer-Predicted Luminance in Roadway Lighting Applications", Journal of the Illuminating Engineering Society, 22, pp. 75-80, 1993.
11. Glenn, J., Robinson, R., Dempset, J., Dodds, G., "Automated Road Luminance Assesment Using Image Processing Techniques", CIBSE National Lighting Conference' 98, pp. 110-115, 1998.