THE VEILING LUMINANCE IN TUNNEL LIGHTING INSTALLATION

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7KH &,(WHFKQLFDO UHSRUW &,(UHSRUW (XURSHDQ 7HFKQ...
DQG VHYHUDO QDWLRQDO VWDQGDUGV ...
LQ WKH WKUHVKROG]RQH ZLWK WKH ...
LQ IURQW RI WKH WXQQHO SRUWDO ...

7KH PHDVXUHPHQW RI WKH YHLOLQJ OXPLQDQFH ...

x is the longitudinal coordinate, starting at the tunnel portal and positive in the driving direction, in metres;

d_s is the stopping distance, in metres.

The above condition is the extension of the safety condition of CIE 88 (equation 2). The second condition:

$$\frac{L_{th,r}(x+d_t)}{L_{th,r}(x)} \geq 0{,}55 \quad (4)$$

where d_t = 0,154 d_s, requires that the maximum rate of reduction of the luminance in the threshold zone shall be equal or lower than the value defined in CIE 88 for the second part of the threshold zone. This guarantees the same condition of visual adaptation of CIE 88, as required by the Italian law (MIT, 2005), and gives the ratio of the road luminance values between the background viewed at the bottom and at the top of the reference object.

To reduce the electrical energy consumption, the real average transversal road luminance cannot be greater than 1,5 times the minimum required values. To obtain this goal it is necessary to measure in real time the veiling luminance at least at the stopping distance.

3 The veiling luminance function

The veiling luminance measured along the access zone is named veiling luminance function $L_v(x, t)$. It is a function of the distance from the tunnel portal x and of the time t of evaluation.

When x approaches zero, the veiling luminance becomes very low because the L_{atm} decreases and L_{seq} is strongly influenced by the lighting level inside the tunnel. A conventional limit shall be considered to avoid unrealistic values or complex evaluation of L_v. The Italian standard suggest a limit distance d_{lim} when the cone with angle of opening of 36° for the evaluation of L_{seq} has at least a point in common with the portal hole. For two lines mountain tunnels this correspond at about 3 time the portal height. The last part of the veiling luminance function becomes $L_v(-d_{lim} \leq x < 0) = L_v(x = d_{lim})$.

For a given tunnel the veiling luminance function is a stochastic function that depends on the hour of the day, day of the year, and year. It can be defined:

- at a given instant t, e.g. if it is measured to control the luminous flux emitted by the luminaries to obtain the right average transversal road luminance values;
- t statistically considering one year period, e.g. to confirm the correct design of the installation;
- as a maximum values to be used for designing the lighting installation and for calculating the maximum installed luminous flux

The last possibility requires some compromises. The veiling luminance can rise at very high values for short periods of time or during peculiar climatic situations. It is not economical to design the lighting installation considering the maximum possible value of the veiling luminance. CIE 88 suggest to use the highest value likely to occur at least 75 daytime hours per years. This solution has the following main objections:

- during 75 h in a year the lighting conditions in the tunnel could not guarantee adequate safety conditions;
- there is not correlation between the 75 h and the traffic volume, i.e. the inadequate lighting level could statistically happens when traffic volume conditions create the highest probability of incidents;
- it is difficult to dimostrate that the 75 h limit is really satisfied by the design choices. What happens if after one year of continuous measurement it is verified that the real limit was 80 h?
- as a consequence, during the final testing/commissioning phase there are not standard rules that link measurements with compliance with standard requirements and/or with design expectations.

The solution generally adopted is to use values given as examples in CIE 88. This solution is adopted also in the Italian standard, if measurement cannot be done. This solution does not resolve the above perplexities, because the proposed values could require correction is some orographic situations, like in mountain tunnels and there is not a clear correlation with the 75 h requirement.

4 Measurement of the veiling luminance

The veiling luminance at a given instant *t* can be measured using an Image Luminance Measuring Device (ILMD) and the method described in CIE 88 (Adrian diagram) or using the integral equation from with the Adrian diagram was derived (Adrian, 1987). The values and measurement uncertainty of the two methods are comparable but the second approach is more simple if data are elaborated automatically. The important points are the calibration of the ILMD, considering also the angular direction framed by each detector pixels, its dynamic range (linearity between dark and bright zones) and its spectral correction. For continuous measurement the ILMD cannot be positioned in the point the standard requires. This problem can be solved considering a set measurement as described in EN 13201-4 (CEN, 2015) for road lighting system. During the set measurement two ILMDs are used. The first one is a reference system aligned in the correct position, the second one is the measured system installed in a fixed position, e.g. in a column at the kerbside. Comparing the two measures at the same instant a sort of on-site calibration is carried out. The correction is not constant with time, but in tunnel with straight access road discrepancies are acceptable and comparable with the measurement uncertainty of these instruments (5 % - 8 %). A more accurate correction can be done using photogrammetry methodologies considering that during the set measurement, the tunnel portal is framed from two different points of view. The correction considers the framed surfaces as lambertian diffusers and modifies the weighting each pixel have with directions. This methodology requires a modification of the firmware of the ILMD but can drastically reduce the influence of the incorrect position of the instrument.

The measurement of the veiling luminance function can be done with a mobile laboratory as a sequence of L_v measurements approaching the tunnel portal. The Italian standard requires at least 3 measures and a linear approximation between points, but a step of 5 m is commonly used, except when manual system are adopted. This limit is a compromise considering also the situation when the design of the lighting system shall be done while the tunnel is under construction and measurements are difficult.

A possible alternative technique uses the frame acquired at the stopping distance and changes the angular value of each pixel to simulate the different distances from the tunnel portal. In tunnel with straight access road, generally this technique introduces differences respect to the correct measured values lower than 5%, but this figure greatly changes from tunnel to tunnel. The variation of the atmospheric luminance with distance cannot be measured with this technique, and a linear decrement is usually considered.

The measurement of L_v at a given instant *t* is useful for controlling the lighting installation or for verifying its correct operation but does not give information of the effective performance of the installation without other data.

The solution is to measure also some other environmental parameters able to give a correlation between the measured veiling luminance and the valued that shall be used for design. The following procedure is under testing for some Italian tunnels that have installed permanently an ILMD for controlling the lighting installation. The results will be available after one year of testing.

During the measurement of the veiling luminance carried out with a mobile laboratory the horizontal illuminance is measured and the sky condition are recorded considering the CIE classification (CIE, 2014). The measurement of the horizontal illuminance can be done with a illuminance meter on the top of the vehicle and the sky condition can be recorded using a second ILMD with a wide-angle lens. With this data it is possible to evaluate the vertical illuminance on the tunnel portal and the veiling luminance with different illumination levels and sky conditions. Inter-reflection between lighted surfaces could be important but, as a first approximation, their contribution can be considered proportional to horizontal luminance, and therefore considered in the measurement. A Montecarlo statistical analysis adapting the tolerance methodology described in (CEN, 2015) to this situation can produce a probability density function of the veiling luminance values. The design value can be selected considering the corresponding distribution function, for example the veiling luminance that gives a coverage probability of less than 95 %.

To improve the evaluation accuracy, measurements can be carried out in different seasons if the orography behind the portal changes (e.g. snow during the winter and green grasses during summer). The presence of sun in the visual field used for veiling luminance calculation (a cone with an angle of opening of 56,8°) can be verified using free tools available on-line for evaluating the daily and hourly position of the sun. The presence of the sun increases the veiling luminance at a level that suggest the use of additional shading settings such as grille entrances.

A completely different approach starting from the measurement of the veiling luminance and horizontal illuminance is to correlate these data with table used for evaluation of energy need for buildings heating and cooling. For example the Italian standard UNI TR 10349 (UNI, 2008) gives formula and methods for splitting global solar irradiance into the direct and diffuse parts and for calculate the solar irradiance on tilted and vertical planes. The standard gives tables of solar irradiance data for 102 Italian localities, considering the average value for each months of the year. From these values it is possible to calculate the monthly average value of illuminance using the solar luminous efficacy value of 94,2 lm W^{-1}. Using these data and the measurement results, the greatest value of the average monthly veiling luminance can be obtained. Adding a safety factor conventionally introduced by standard, the value of the veiling luminance to be accepted in design can be defined.

This approach is interesting because with a single measurement and the use of standard data, without the tedious calculation of the alternative procedure proposed, gives a result without any other verification like the actual method of the 75 h formally requires.

5 Conclusion

Two different methods that can be adopted in design optimised tunnel lighting installation are proposed. The possible energy saving justify the greater effort to obtain more detailed data and information before defining the characteristic of a tunnel lighting installation. The methods will be compared using data acquired during summer in several Italian tunnel equipped with ILMD for the veiling luminance real time measurement.

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