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Natural lighting of road pre-tunnels: A methodology to assess the luminance on the pavement – Part II

Giuseppe Cantisani, Antonio D'Andrea, Laura Moretti*

Department of Civil, Constructional and Environmental Engineering, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy

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ABSTRACT

This two-part paper presents a comprehensive methodology for lighting calculation of a road pre-tunnel. The adequate lighting of road tunnels, especially in their entrance zone during the day-time hours, is a very important factor to maintain road safety and to ensure a good level of service. These targets are commonly achieved by means of artificial lighting systems. In some cases, nevertheless, it could be preferable to build a pre-tunnel, which reduces and controls the natural lighting contribution in the threshold zone of the tunnel. The structure, in fact, filters the natural light and permits to achieve the required luminance levels on the road pavement, so ensuring the correct visibility to the drivers. Analytical models were developed in the first part of the paper to describe the sky illumination of a clear but not terse sky, which is typical in large cities and industrial areas, and to evaluate the consequences related to the construction of a pre-tunnel lighting (PTL).

This second part presents the validation procedures adopted to verify the proposed models. Particularly, a luxmeter photo-radiometer has been used for validating the clear not terse sky model and several PTL scale models were used to validate the methodology proposed to assess the pavement luminance. The geometry of the PTL, its alignment and materials have been varied to obtain several results under various meteorological and climatic conditions. The results obtained from the experimental research program showed that the proposed models, inherent both the sky luminance and the illuminance on the road, ensure a good approximation respect to the real measures performed. In particular, for the sky luminance, the proposed theoretical distribution implies an average deviation respect to the experimental data equal to 5%. The calculated illuminance under the PTL differs on average from the measured values for −1.26%.

1. Introduction

Road tunnel lighting implies an important cost for road agencies because the luminance levels required to ensure regular and safe circulation of traffic. Several studies showed solutions to reduce this economic effort, using high efficiency lamps (Salata et al., 2015), pavement materials with high average luminance coefficient (Moretti et al., 2016, 2017), building a pre-tunnel lighting (PTL) above the access of the tunnel (Peña-García and Gil-Martín, 2013; Drakou et al., 2015, 2016) or semi-transparent structures (Gil-Martín et al., 2014 and Peña-García et al., 2012), or modifying the user's visual at the entrance of the tunnel (Peña-García et al., 2015). Other studies presented solutions to improve the use of sunlight under PTL (Gil-Martín et al., 2015; Peña-García et al., 2011).

Generally, PTLs can offer good design solutions to realize transitions toward tunnels and to reduce energy consumption, but, in order to ensure 24 h working safety, lighting systems have to be provided inside them just the same, for avoiding the black hole effect during night time. According to the more recent developments of research lines regarding natural lighting, a comprehensive approach can be adopted for designing tunnel shifting (or PLT) structures. In particular, the SLT equation (Peña-García, 2017) is an important tool to guide the research for an optimal configuration, so avoiding the risk to build mock-ups and adopt solutions that are not able to maximize energy savings.

The first part of this paper focused on the development of analytical methods to define the sky model in the case of a clear not terse sky and to assess the illuminance on the road in presence of a PTL composed of an upper grid (or lattice) and lateral windows. The obtained results can be applied for climatic and meteorological conditions typical of latitudes where the maximum elevation angle of the sun is about 70° throughout the year.

The methodology proposed in this study has been used to assess the luminance at a road asphalt pavement in presence of a PTL, composed of an open and reflective upper grid and diffusive lateral windows. The analytical results have been compared to experimental data obtained in a scale model of a PTL built in Rome, Italy. The comparison had positive

* Corresponding author.
E-mail addresses: giuseppe.cantisani@uniroma1.it (G. Cantisani), Antonio.dandrea@uniroma1.it (A. D'Andrea), laura.moretti@uniroma1.it (L. Moretti).

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results; therefore the methodology proposed and validated in this study is useful to evaluate the PLT effects of a specific tunnel. The method offers the road management body the possibility of implementing appropriate strategies to achieve specific visibility requirements laid by CIE (Commision Internationale de l'Eclairage, 2004) balancing often conflicting safety and environmental objectives (especially considering the energy consumption) (Miccoli et al. 2014, 2015).

2. Materials and methods

The proposed models permit to describe the luminance of clear not terse sky and calculate its lighting contributions on the road surface. They have been verified by means of measures of the sky luminance and the construction of scale models of PTL built and placed at latitude 41°53′, where the city of Rome, Italy, is located (D'Andrea and Cantisani, 2002).

2.1. Measure of sky luminance

The validation of the clear not terse sky model needed for the measures of the sky luminance during several days. The measurements were performed in accordance with a pattern of 360 points (nodes), obtained dividing the sky in angular sectors of 10°, both azimuthal and zenithal.

A photo-radiometer luxmeter with a probe has been used. The system was moved on a topographic total station, maintaining the probe parallel to the telescope axis, with the aim to detect the sky under precise and regular angular intervals (Fig. 1).

Measurements were carried out in several days, between July and September, every hour from sunrise to sunset.

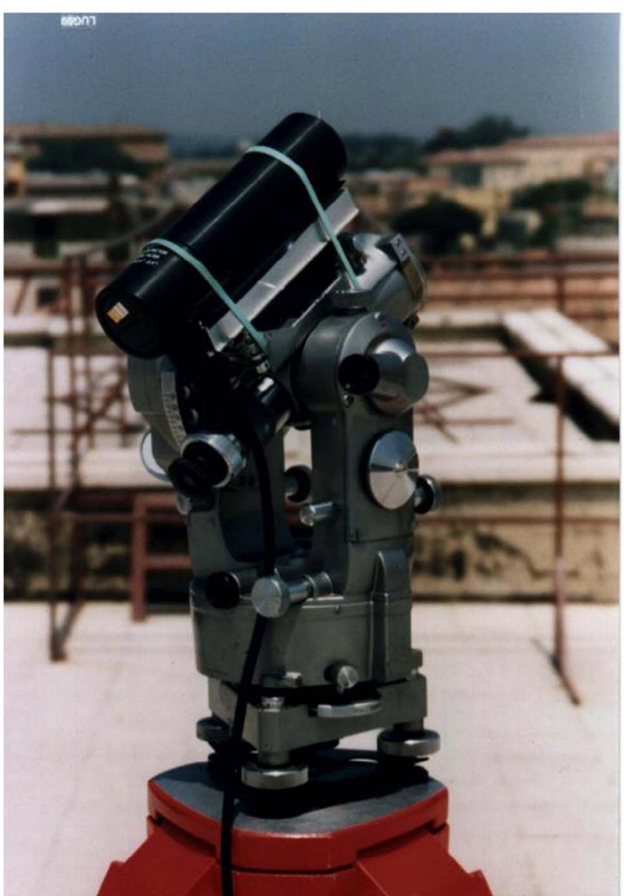

Fig. 1. Instruments used for measurements.

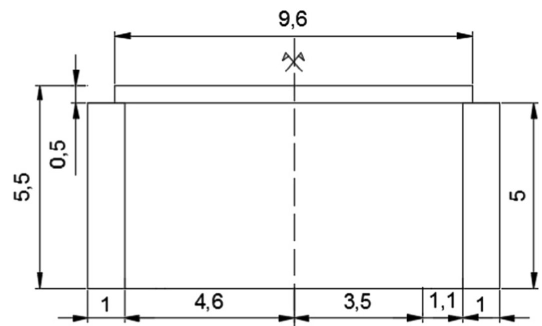

Fig. 2. Transversal section of the PTL model. Unit of measure: m.

2.2. Design and construction of a scale model of a pre-tunnel lighting

A scale model 1:10 of PTL for a unidirectional tunnel belonging to a primary road was built. The carriageway is composed of two 3.5 m wide lanes, two 1.10 m wide shoulders. Fig. 2 represents the transversal section of the real considered PTL (real scale).

The scale model was composed of a rectangular transversal section 102 cm wide and 55 cm high; it was 192 cm long, therefore it represented a 19.2 m long PLT. It had a white modular structure composed of an upper grid and lateral windows; one PTL portal was composed of a black sheet, as represented in Fig. 3. The pavement of the model was black because this color represents a typical Italian road condition, where the vast majority of road pavements have the wearing course of bituminous concrete. White longitudinal road markings were painted on the pavement.

Three wood frames supported two upper lattice modules and four lateral windows. The upper grid was composed of square (96 × 96 cm) plan 5 cm thick meshes in poliplat (or foamboard, or foamcore), while windows were composed of wood louvers and/or sheets of plexiglass to simulate several configurations (Fig. 4). All surfaces of PLT were matt to have a prevalence of diffused, rather than concentrated light.

Two PLT alignments, North-South and East-West, were studied. They were chosen as consequence of the latitude where the PLT was built because they represent extreme cases.

2.2.1. Windows – Case 1

For the defined latitude (Rome) and the North-South alignment, a driver travelling toward the South will have, for most of the day, the sun in the fourth place of the celestial sphere in front of him. However, during sunlight and sunrise, between March 21st and September 21st, the sun is behind the driver, with an angle on the horizon θ ranging from 0° to about 38° (Fig. 5).

For $\theta = 0°$, the azimuth angle of the sun with respect to the tunnel

Fig. 3. The PLT model.