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Study of light-pipes for the use of sunlight in road tunnels: From a scale model to real tunnels

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ABSTRACT

The necessity of saving energy from the electrical lighting in road tunnels demands alternative solutions, especially concerning the use of the cheapest and most ecological light source: the sun. In this work, the principles of sunlight distribution inside the tunnels themselves by means of light-pipes are developed and considered. The study is based on a scale model in which exhaustive calibration and adaptation to the situation in real tunnels is presented and discussed. Finally, the advantages of the philosophy of light distribution versus other means of using sunlight in road tunnels are analyzed and highlighted.

1. Introduction

The main objective of the lighting design in tunnels is to help drivers detect the presence and movement of objects in front of them (CIE Publ. 88, 2004). The design of lighting, which can be relatively easy for nighttime conditions, becomes more complicated in daytime conditions (Adrian, 1982; Schreuder, 1971) because the time needed for visual adaptation from a bright environment to the darkness of a tunnel is longer during the day than at night. Therefore, paradoxically, the higher the level of lighting outside the tunnel, the higher illuminance requirements inside. So, in areas of high brightness (like the South of Spain) the energy cost associated to the lighting of tunnels is very high.

Regarding electrical lightning, road tunnels are divided into several zones with different requirements for luminance, L (luminous flux emitted per unit of surface and solid angle in any given direction) and illuminance, E (luminous flux received per unit of surface from all directions). The luminous flux, Φ, is the power emitted, transported or received in the form of visible light.

These road tunnel zones are the following: (i) *access zone* (the opencast sky zone just before the beginning of the tunnel), (ii) *threshold zone* (the first section of the tunnel), (iii) *transition zone* (the section after the threshold zone), *interior zone* (the inner section of the tunnel), and (iv) *exit zone* (the last section before the tunnel ends). A more detailed description of road tunnel zones can be found in (CIE Publ. 88, 2004; Parise et al., 2010).

The luminance required in the threshold zone, L_{th}, is higher than in any other section inside the tunnel in order to allow the drivers time to adapt from the very bright environment to the relatively dark one within the tunnel. For this reason, any way to reduce electrical lighting in this zone will mean an important energy saving, especially if we consider that lighting in tunnels operates continuously (24 h a day and 365 days a year).

In previous works (Peña-García et al., 2010, 2011, 2012; Gil-Martín et al., 2011, 2012) it has been proven that the shift of the threshold zone out of the tunnel by means of semi-transparent tension structures allows for the use of sunlight in order to achieve the required levels of illuminance for this zone. This yields very remarkable energy savings without negatively affecting the visual capacity of drivers and thereby reducing traffic safety.

In this work, a different alternative complementary to artificial lighting in the threshold zone of tunnels is investigated. Instead of shifting the threshold zone, the sunlight is collected, transported and distributed into the tunnel by means of pipes.

2. Materials and methods

In modern architecture, light-pipes have been widely used to illuminate rooms with few windows providing natural light (Al-Marwaee and Carter, 2006a, 2006b; Carter, 2002). This system consists of a pipe that sticks out of a building's roof and guides

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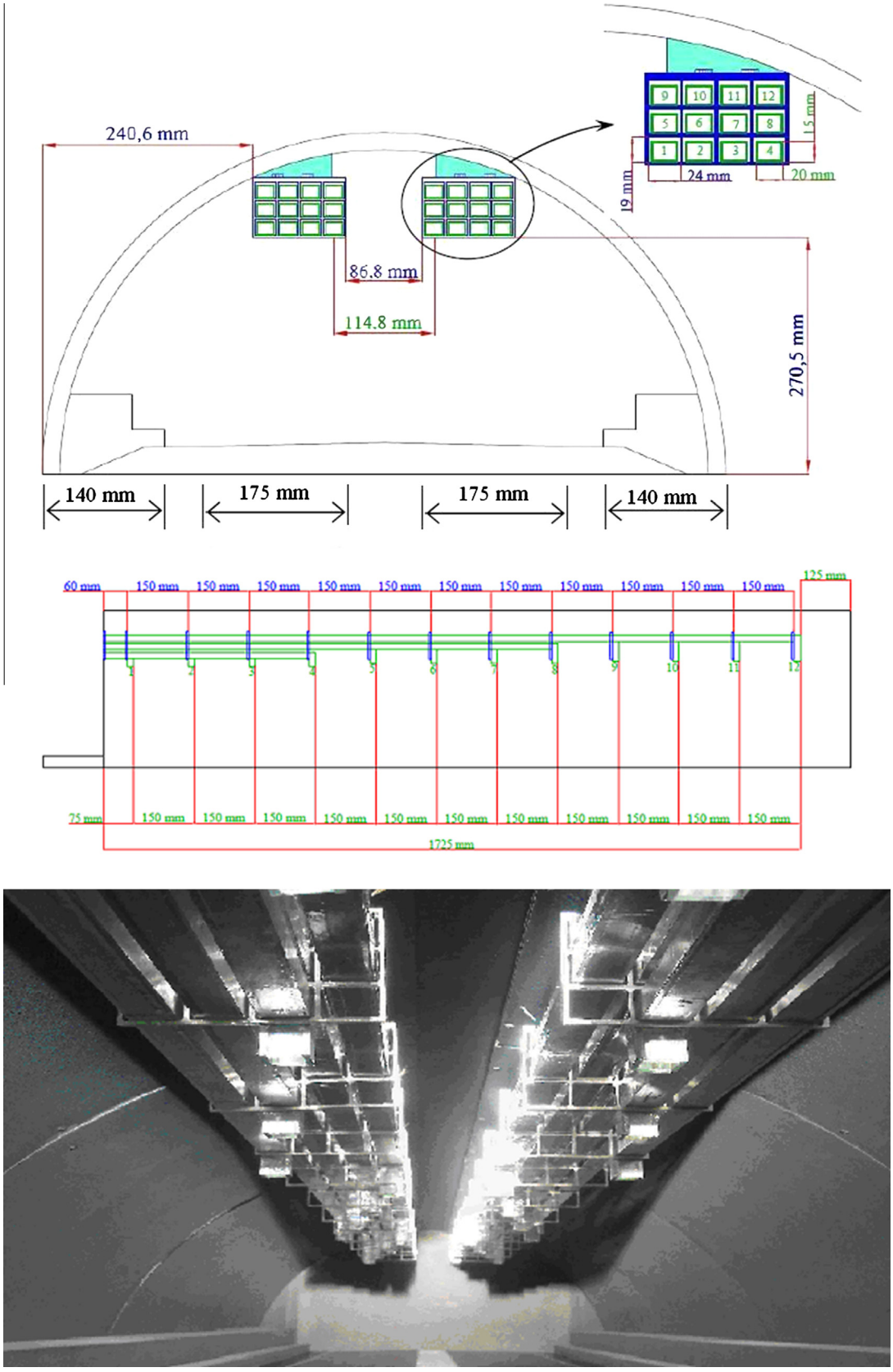

Fig. 1. Scale model of a road tunnel using light-pipes for illuminating its threshold zone. (a) Cross section. (b) Longitudinal section of the first half of the threshold zone of the tunnel. (c) View of the whole installation from the driver's perspective.