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ON SITE PHOTOMETRIC CHARACTERISATION OF CEMENT CONCRETE PAVEMENTS WITH COLUROUTE DEVICE*

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ABSTRACT

The standard tool for characterizing road surface photometry is the reduced luminance coefficient table (or *R*-table), as defined in the seventies by the CIE. Since these tables are no longer representative, measuring road photometry is necessary for optimizing a lighting installation and ensuring luminance level and uniformity. The objective of the study was to characterise and follow on site the photometric characteristics of different concretes with time and traffic. A first experiment was done with two concrete formulations (broomed and water jet scrubbed concrete) located around a much circulated concrete mixer plant. The photometric characterisation of these pavements was done with the portable reflectometer COLUROUTE device during three years. The selected surface treatment was applied in a tunnel and the photometric characteristics were measured during 30 months. It was shown that the concrete pavements are more diffuse and clear than classical pavements. Their use could generate significant energy saving.

Keywords: concrete, energy saving, exterior lighting, pavement photometry, portable reflectometer

I. INTRODUCTION

Designing a lighting installation involves accounting for site-specific geometric parameters and photometric characteristics of both the light sources and the road surface. By knowing the photometric characteristics of a pavement, the design of public lighting installations can be optimized in terms of positioning and energy saving. The reflection properties of the pavement material are expressed as a table of reduced luminance coefficient (or r-table) [1,2]. To simplify the calculation, a classification based on the specularity coefficient S_1 is made and standard tables are defined by the CIE. CIE2001 [2] recommends a scaling of the chosen table according to the measured brightness coefficient Q_0. Since the photometric characteristics are generally not known, one standard *R*-table is used for the design of lighting without any rescaling [3]. This generates important errors as shown in [4,5]. Moreover, studies have shown that there is an important evolution of photometric characteristics with time and that these tables are no longer representative [6,7]. In this context, measuring road photometry is necessary for optimizing a lighting installation and ensuring luminance level and uniformity.

Concrete pavements are said to be more diffuse and clear than classical pavements [8]. The aims of the study were the followings: photometric characterisation of concrete pavements with time and traffic, comparison of laboratory and on-site measurements and calculation of the amount of possible energy saving. This work was done within a collaboration of 6 years between the French cement and concrete pavement associations CIMBETON and

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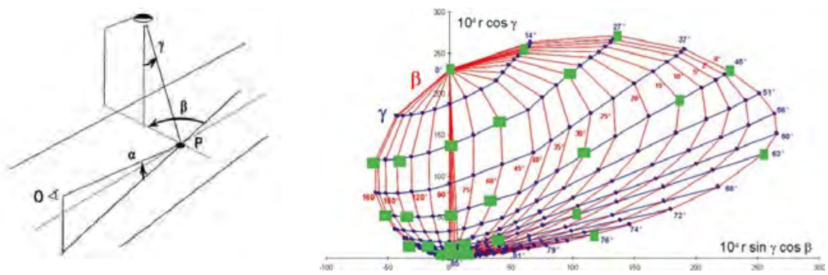


a) b)

Fig.1. a) The photometric characteristics of the road surface depend on the angles of observation α, sight β and incidence γ (following [2]); ***O*** represents the driver and ***P*** the point of observation; b) Representation of a pavement reflection indicatrix. The angle of sight β is in red, the angle of incidence γ is in blue and the location of COLUROUTE illuminating angles are in green

SPECBEA and the Cerema, which was in charge of the measurements and the technical evaluation. The section 2 of this paper describes the CIE methodology of photometric characterisation, the portable device COLUROUTE and the two experiments. The results obtained in the pilot study and in a highway tunnel are in the section 3.

1. MATERIAL AND METHODS

2.1. Introduction to Road Lighting

The *r*-table is a two-dimensional table with a number of standardized combinations of the incidence lighting angle γ and orientation angle β, the boundaries of which define the solid angle Ω (Fig.1a). The angle of observation α is set at 1°, which corresponds to a driver looking at about 100 m [1]. The reduced luminance coefficient *r* is defined by:

$$r\,(b, g) = ((L(b, g) / E_h)\cdot cos^3 g = q(b, g) \cdot cos^3 g, \qquad (1)$$

where L is the observed luminance in cd/m² and E_h is the horizontal illuminance in lx.

The characterisation of a pavement is given by its degree of specularity S_1 and its total reflectivity Q_0 (also called brightness). These two parameters are calculated from the previous matrix called *r*-table. The reflection indicatrix is a graphic representation of the r-table (Fig. 1b). Its volume informs on the brightness factor of the pavement Q_0, given as:

$$Q_0 = \int_0^{\Omega} \frac{q(\beta, \mathrm{tg}\gamma)\cdot d\Omega}{\Omega}, \qquad (2)$$

and its form is an indicator of the specularity factor S_1, given as:

$$S_1 = \frac{r(\beta = 0, \mathrm{tg}\gamma = 2)}{r(\beta = 0, \mathrm{tg}\gamma = 0)}. \qquad (3)$$

1.2. COLUROUTE Device

The portable measurement device named COLUROUTE (french acronym "COefficient de LUminance des ROUTEs"), was developed by the Cerema and complies with the CIE recommendations [9]. With this instrument (Fig. 2a), the luminance coefficients of a road surface are measured on site, in daylight and without sampling.

COLUROUTE is equipped with a sensor directed at the measurement surface with an angle of 1° and has twenty-seven sources set to illuminate successively this surface with different combinations of angles β and γ (Fig. 2b). These angles were chosen judiciously to allow the calculation of the specularity factor S_1 and to reconstruct by interpolation the complete reflection table of the road surface. Calibration is performed on site using reference plates measured with a laboratory goniophotometer [10] (Fig. 2b). The outputs comprise the reduced luminance coefficient table (*r*-table), the average luminance coefficient Q_0 and the specularity factor S_1. With this portable device it is possible to analyse a great number of areas and increase the number of interventions without damaging the road.

1.3. Experimental Setup

The aim of this pilot study was to follow the photometric characteristics of different concretes in time and traffic during 3 years and to choose

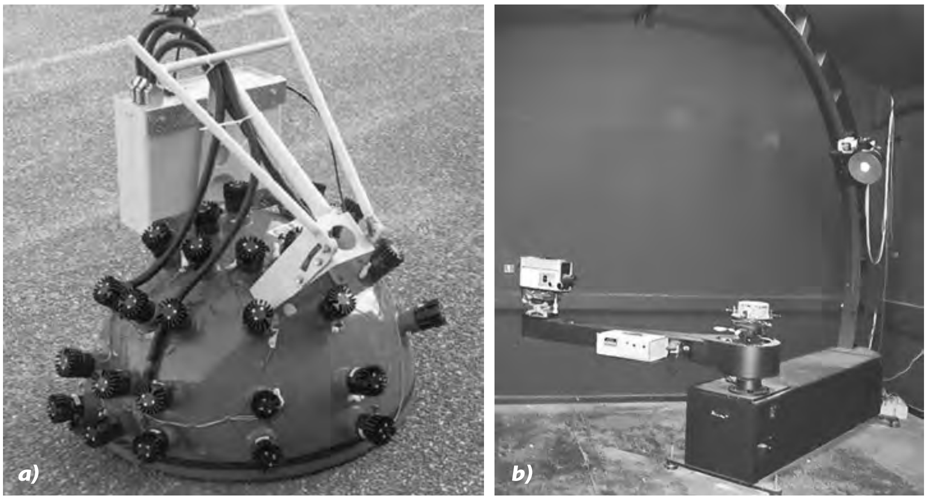


Fig.2. a) COLUROUTE device of the Cerema (Strasbourg); b) Goniophotometer of the Cerema (Clermont –Ferrand)

Fig.3. a) Localisation of the pilot study; b) View of the Sinard Tunnel; c) Picture of the broomed concrete (initial state)

a formulation for a tunnel pavement. The photometric characteristics of the two pavements were measured on site with COLUROUTE device and in laboratory on core samples with the Cerema goniophotometer. It was performed around a circulated concrete mixer plant near Lyon in France (Fig. 3a). The new concrete pavement was composed of local aggregates alluvial whose colour is a mixture of brown and beige more or less clear. Two surface treatments were used to obtain two different macrotextures: broomed and water jet scrubbed concrete. The circulation was composed of trucks carrying fresh concrete from the plant. The concretes surfaces were always watered to avoid dust. We assume that the presence of sand and water accelerates the corrosion.

The Sinard tunnel (length 980 meters), located South of Grenoble in the A51 highway, is one of the few in France to have a concrete pavement (Fig. 3b). It is an unreinforced, undowelled concrete pavement on a draining concrete subgrade. The concrete surface course was broomed across the traffic lanes using a hard brush, to provide the microroughness required for the grip of tires on the pavement (Fig. 3c). The surface concrete contains crushed materials to provide increased grip of tires after relative wear due to surface sweeping on newly laid concrete. The photometry of this pavement was measured periodically during 30 months with the COLUROUTE device.

2. RESULTS

2.2. The Pilot Study

In the pilot study, there were 3 measurements per pavement (M1, M2, M3) with COLUROUTE device every 6 months and there was one core sample taken for the laboratory measurements. All the results are shown in the Table 1 for the scrubbed concrete and in the Table 2 for the broomed concrete.

Whatever the methodology of measurements, the brightness increases with time for both pavements and reaches around 0.15. With COLUROUTE measurements, the specularity of the scrubbed concrete increases significatively (class *R3* pavement) after 2 years (Fig. 4a) but returns to a class *R2* pavement after 3 years (Fig. 4b). For the broomed

Table 1. Results for the Scrubbed Concrete, *m* is for Month

Scrubbed concrete	Brightness coefficient Q_0					Specularity coefficient S_1				
	T0	*T3m*	*T12m*	*T24m*	*T36m*	*T0*	*T3m*	*T12m*	*T24m*	*T36m*
COLUROUTE M1	0.090	0.088	0.095	0.154	0.165	0.11	0.12	0.44	1.51	0.50
COLUROUTE M2	0.084	0.094	0.095	0.199	0.152	0.12	0.10	0.86	1.36	0.54
COLUROUTE M3	0.089	0.120	0.096	0.187	0.139	0.20	0.13	0.46	1.03	0.46
GONIO on core	0.088	0.121	0.142	no core	0.157	0.23	0.72	0.86	No core	1.03

Table 2. Results for the Broomed Concrete, *m* is for Month

Broomed concrete	Brightness coefficient Q_0					Specularity coefficient S_1				
	T0	*T3m*	*T12m*	*T24m*	*T36m*	*T0*	*T3m*	*T12m*	*T24m*	*T36m*
COLUROUTE M1	0.141	0.120	0.112	0.191	0.181	0.09	0.14	0.27	0.43	0.30
COLUROUTE M2	0.120	0.149	0.140	0.176	0.136	0.08	0.16	0.28	0.36	0.25
COLUROUTE M3	0.152	0.105	0.117	0.139	0.175	0.08	0.14	0.33	0.51	0.24
GONIO on core	0.099	0.123	0.166	no core	0.138	0.09	1.10	0.80	no core	0.42

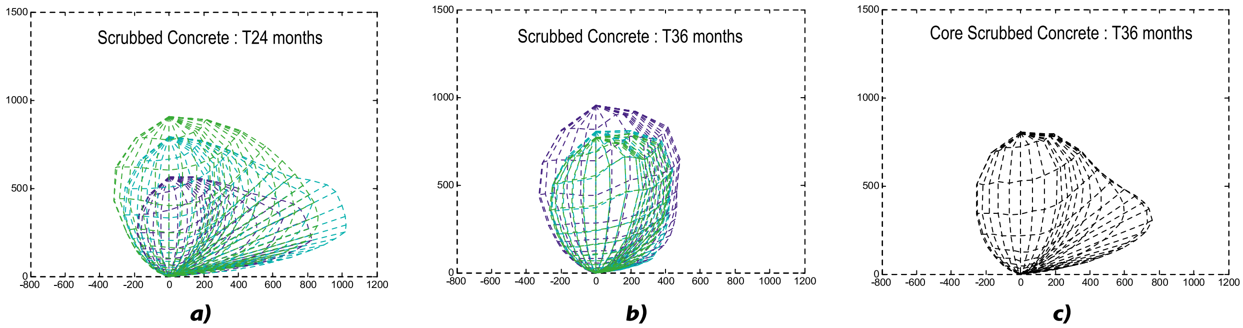
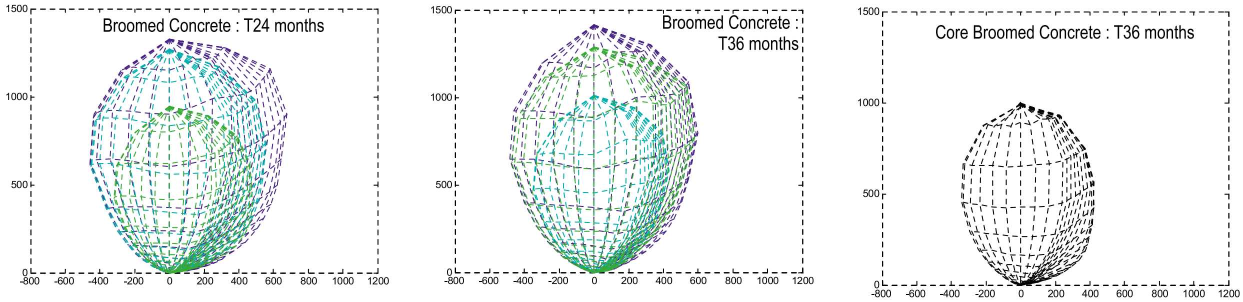


Fig.4. Reflection indicatrix of the scrubbed concrete measured with COLUROUTE device on site after 24 months (a) and 36 months (b), the three measurements are represented in blue, cyan and green; measurement made on a core extracted after 36 months and measured with the laboratory goniophotometer (c), the axes are as defined in Fig. 1b

concrete, the specularity remains low (class *R1* pavement, Fig. 5). The specularity obtained in laboratory on the core samples is generally higher (Figs. 4c and 5c) than on the field. This is probably due to the presence of residual dust around the cement plant that could have an impact on the on site measurement. However, the goniophotometer and COLUROUTE measurements have shown that the specularity of the broomed concrete is lower than the scrubbed one.

The photometric measures show an important effect of erosion with time and traffic as illustrated by the pictures taken on each COLUROUTE intervention (Fig.6). The broomed surface looked like a water jet scrubbed concrete after two years (Fig. 6 b, d).

Since it is easier to obtain uniform illumination with diffuse pavements, the surface treatment chosen in the Sinard tunnel was a broomed one because of its lower specularity.



a) b) c)

Fig.5. Reflection indicatrix of the broomed concrete measured with COLUROUTE device on site after 24 months (a) and 36 months (b), the three measurements are represented in blue, cyan and green; measurement made on a core extracted after 36 months and measured with the laboratory goniophotometer (c), the axes are as defined in Fig. 1b

a) b) c) d)

Fig.6. Pictures of the water jet scrubbed concrete (a. initial state, b. after two years); pictures of the broomed surface (c. initial state, d. after 2 years)

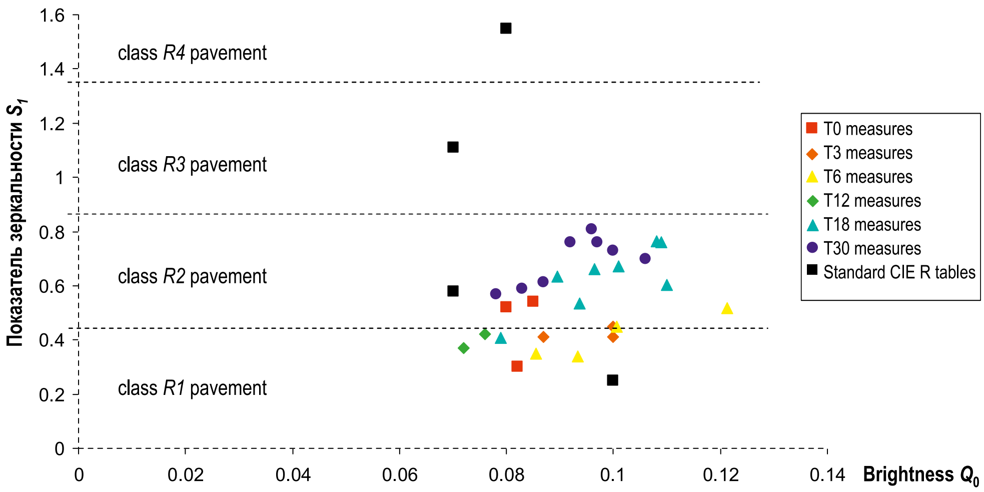


Fig.7. Representation of the photometric characteristics of the standard R tables (in black) and of all the measures done with COLUROUTE device in Sinard tunnel. In red for T0 measures, in orange for T3 measures, in yellow for T6, green for T12, light blue for T18, blue for T30

2.3. Experiments on the Sinard Tunnel

Since it was not possible to extract core sample on the A51 highway, only COLUROUTE device was used to make on site measurements on the right lane of the pavement during 30 months. They were performed on the central and on the tyre lane. At each intervention, the specularity was relatively homogenous but there were differences on the brightness factor Q_0 that could reach 30 %, as illustrated in the Fig. 7. At the initial state (Fig. 8a), the broomed concrete road surface was not very specula (class *R2*), probably because residual curing compound was still present. After 6 months of traffic, the pavement surface had an average brightness of 0.1 and was very close to *R1* pavement types (Fig. 8b). There were more specula areas, in particular on the left tyre tread and on the centre lane. After 18 and 30 months of traffic (Fig.7 and Fig. 8c), the pavement remained of class *R2* but was bright-

Table 3. Results of the DIALUX Calculation and Corresponding Electrical Consumption

Description of pavement	Q_0	Light Power in W	Consumption in kW/km	Energy saving
Standard *R2* table (reference)	0.070	54.7	1.89	0 %
R2 table rescaled with a classical bituminous pavement	0.054	70.6	2.43	-29 %
R2 table rescaled with Sinard T30 concrete pavement	0.092	38	1.31	31 %

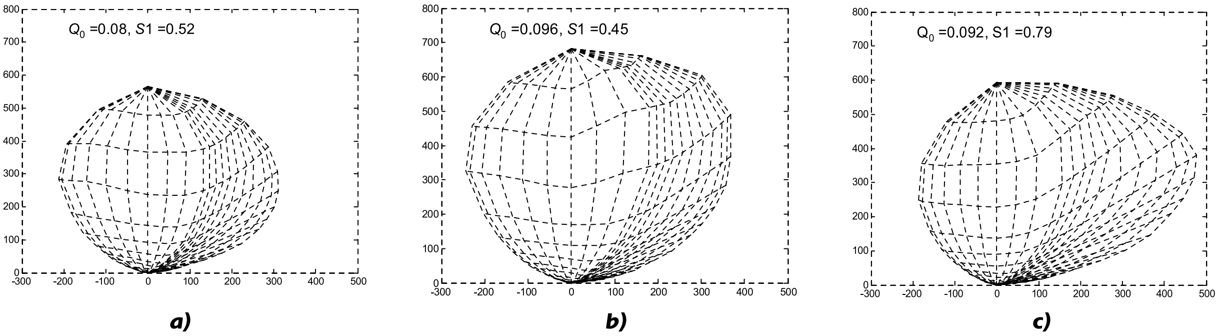


Fig.8. Photometric solids of the road surface in the Sinard tunnel, measured using COLUROUTE on new pavement (a), on a wheel track after 6 months (b) and 30 months (c) of traffic

er than typical *R2* pavements (the average brightness was 0.10 at 18 months and 0.09 at 30 months).

The energetic impact of the choice of such a concrete pavement is analysed with DIALUX software on a classical road installation with *Philips Iridium gen3 Led* and a lantern spacing of 29m (height 8m). Calculations were made in three conditions: using the standard *R2* table, using the standard *R2* table rescaled according to a 3 years old classical French black pavement from [5], and with a rescaling according to Q_0 obtained after 30 months with COLUROUTE. To achieve the class M3 requirement [11], 54.7W lantern are necessary for the standard *R2* table, 70.6W for the classical bituminous pavement and 38W for the Sinard concrete (Table 3.). The corresponding electrical consumption confirms that using a lighter pavement generates substantial energy saving.

3. CONCLUSION

The pilot study was used to choose between different surface treatments of concrete. An accordance with the results measured on core samples in laboratory and the portable device COLUROUTE was there. Differences are sometimes due to the process of sampling. In the pilot study located near a cement plant, there was residual dust that was removed during the extraction. Whatever of the type of measures, the broomed surface is always less specula than the scrubbed concrete. The results obtained in the pilot study and on the circulated tunnel were consistent. The broomed concrete pavement is and remains bright and its specularity stays moderate, despite the effect of traffic.

The energy consumption study has shown that taking into account the real characteristics of the concrete pavement used in the Sinard Tunnel, the lighting electric power could be reduced by 46 % compared to a classical French bituminous pavement. This emphasises the importance for the project owner to properly take into account the choice of pavement characteristics regarding its photometry when defining tunnel and road specifications.

With on site measurements, more measurements are done and the mean result is more representative than just one or two core sample. There is still necessity to define how many measurements shall be done and how to handle them. These aspects will be addressed during the European Empir project called SURFACE which is beginning.

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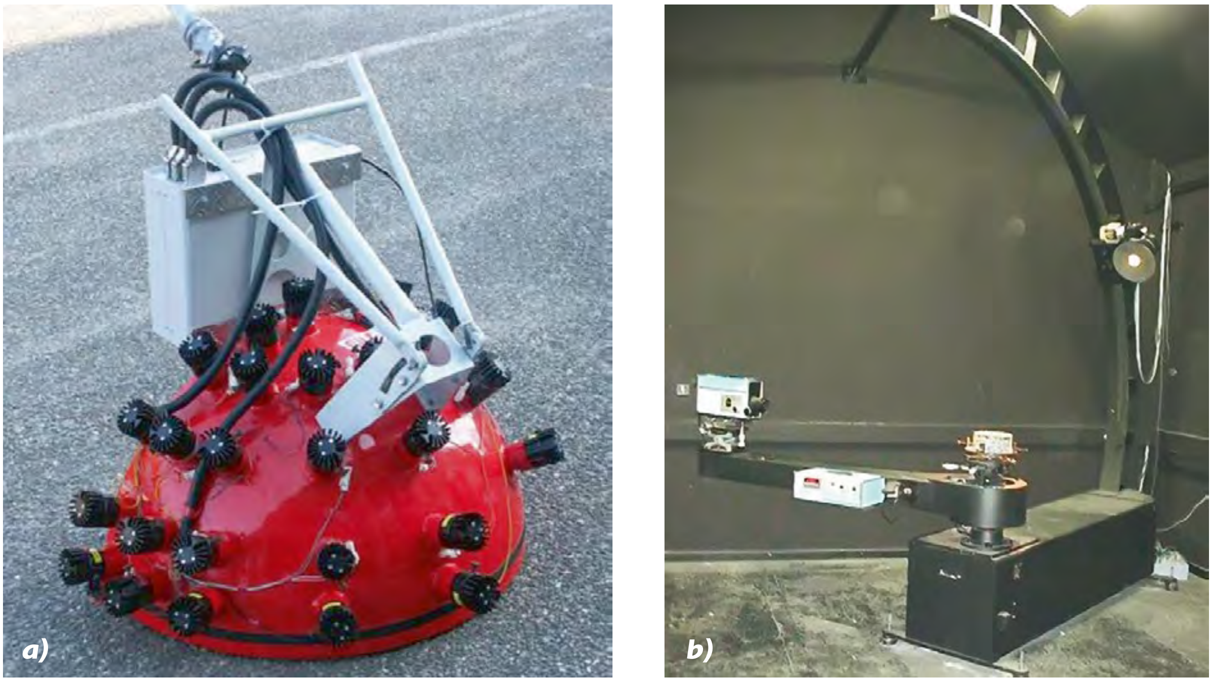

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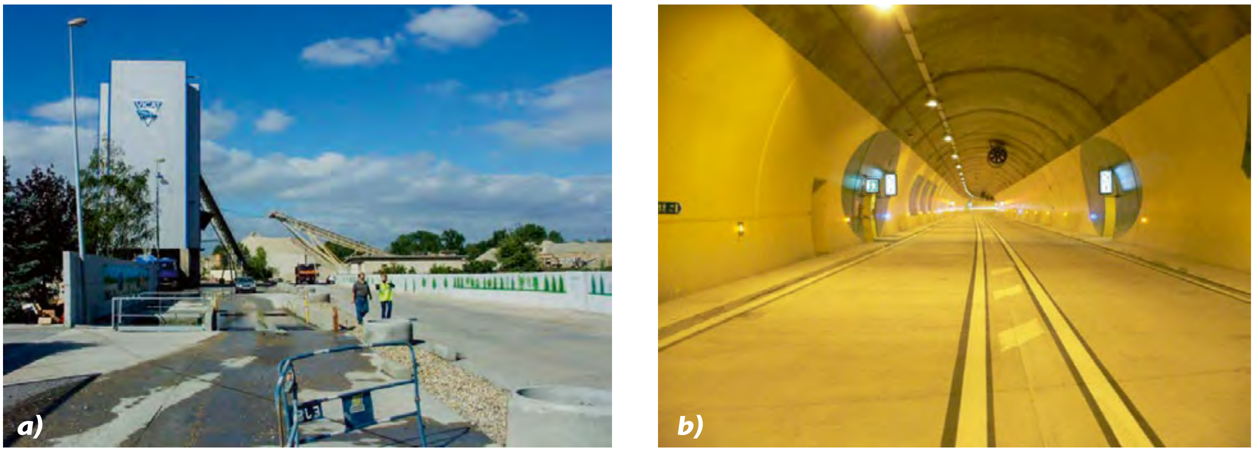

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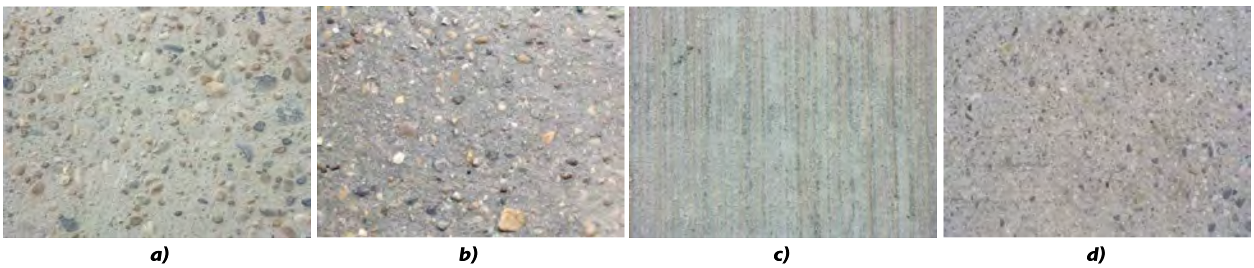

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