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The degradation of concrete tunnel wall panels: a case study

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ABSTRACT

Concrete panels are often used along tunnel walls for technical and aesthetic purposes. Generally, the environment in contact with such materials is aggressive. Emission gases from the vehicles, sulphates, chlorides coming from the winter salt spreading, high temperature and humidity promote an acceleration of the deterioration phenomena. In this work 30 years old concrete panels placed along a 16 km long highway tunnel across the Alps were investigated with respect to their durability. The focus was given to the tunnel entrance zone. This region of the tunnel exhibited a critical environment with respect to the durability of the cementitious material and the steel rebar. An asymmetrical physical leaching caused by the water droplets transported by the vehicles was observed for the cementitious binder along the wall panels on the entrance lane of the tunnel. The concrete panels placed more inside the tunnel were less prone to degradation because of the higher temperature and reduced humidity. The lower part of the panels were susceptible to chloride degradation and rebar corrosion because of the presence of humidity from the splash zone. The upper part of the panels were more exposed to carbonation degradation and induced rebar corrosion caused by the increased dry atmosphere. The sulphate content slightly increased on the surface. This derived from the tunnel atmosphere in addition to the sulphate present within the cementitious material. The degradation type, the intensity and the distribution contributed to plan reasonable restoration and material replacement with a limited closing time of the important and busy roadway.

1. INTRODUCTION

Concrete tunnel linings are used since decades as a finishing coating [1]. Pre-cast concrete segments interact with the ground and the rocks and must assure an appropriate structural behavior [2]. The bending moment, strength and stiffness have to be designed to accomplish the structural requirements and the interactions with the ground [3, 4]. Concrete slabs cover the tunnel walls and are put in place with fixing systems. They are usually bolted on rigid supports. Cracks are often observed near the bolt holes negatively affecting the joint performance [5]. Movements and stresses along tunnels are continuously measured [6-8] and represent a major issue for linings. In addition pre-cast concrete slabs are often inserted and bolted to the underground for architectural geometry purposes to further protect the traffic movements, to ensure a reliable light reflection and sufficient brightness within the tunnel. Not at least, important safety concerns must also be attained. A continuous evolution of the safety norms takes place. Some tunnels are equipped with thermographic element to measure the vehicles temperature to prevent fire. Therefore, in particular the fire resistance of the concrete elements must be under control [9, 10]. The tunnel atmosphere exhibits severe environmental conditions. High humidity alternated by dry periods, wetted sections, frequent exposition to high amount of deicing salts, in particular where tunnel are present along cold climate regions significantly influence the durability aspects. Chlorides are usually detected within the cement-based matrix of the concrete slabs. They promote localized corrosion phenomena, thus reducing the diameter of the steel rebars and causing expansion and spalling of the cementitious cover [1]. In addition, the interaction with the CO2, i. e. the concrete carbonation and pH reduction and the exposition to exhausting gases negatively affect the service live of the lining elements.

The aim of the work is to assess the degradation of concrete lining rectangular slabs of a 16 km long highway tunnel, in particular the first 900 meters from the tunnel entrance. The tunnel is generally trafficked with around 7 milions of vehicles per year. Chloride concentration, corrosion phenomena, presence of Sulphates, carbonation, leaching and the air permeability have been investigated to determine the degree of deterioration and the influence of such aggressive environments on concrete linings.

2. EXPERIMENTAL

Pre-cast concrete panels 240 cm in height and 200 cm wide placed on both side of the tunnel in 1980 were investigated in the entrance region (Fig. 1 left). The slabs were 30 years old. Visual inspection and thermography were used to map the humidity distribution along the tunnel and leaching. The air permeability was measured with a Torrent permeability Tester. A rapid non-destructive method to measure the quality of the concrete cover. A test chamber with an external ring was applied on concrete surface. Underpressure was created. During the measurement, the external ring pressure maintained the same as the pressure in the internal test chamber. Within the test chamber the pressure variation with time was measured. An air flux from concrete to the test chamber was registered. The air permeability was calculated from the pressure change with time. The electric specific resistance of the concrete was also measured [11]. The carbonation front was determined on drilling concrete cores by using a basicity indicator, i. e. Phenolphtalein [12]. Concrete cylinders were cut on 10 mm disks and pulverized and the Chloride content was determined to a depth of 30 mm [13]. The core drilling and the air permeability measurements (Torrent) were done on wall panels 50 m and 150 m from the South entrance, along the car exit side (Fig. 1 right). The specimens for the determination of carbonation, Chloride and Sulphate contents as well as for the air permeability measurements were taken only on panels along the North-South lane, without mechanical leaching. More reliable data could be obtained.

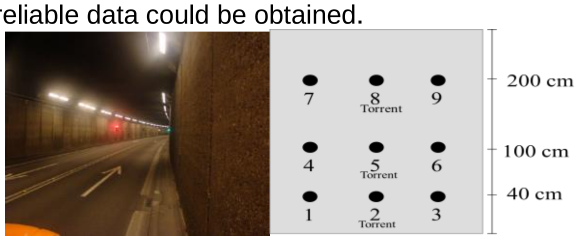

Fig. 1. South entrance of the tunnel (left) and sample location and measurement (right).

3. RESULT AND DISCUSSION

The use of thermography allowed to determine the humidity distribution along the South entrance of the tunnel. The measurements were taken during a rainy night outside the infrastructure. The temperature outside the tunnel was close to 0 ºC. Along the South-North lane the lower temperature indicated the presence of humidity and water on the lane and in the middle-lower parts of the wall panels. The water was transported by the wet vehicles inside the tunnel. Along the North-South lane the more intense orange coloration indicated a higher temperature and a reduced humidity. In fact, on this lane, the vehicles came from the North entrance and traveled more than 16 kilometers inside the tunnel with peak temperatures close to 30 ºC in the middle part. Consequently, they exit the tunnel in a dry condition (Fig. 2 left). The South-North lane wall panels were subjected to mechanical and physical degradation. They suffered from leaching caused by the water droplet transported from cars and trucks. Exposition of the stone aggregates due to the leaching of the cementitious fine material was observed. This phenomena was strongly seen up to 2 meters height and until 900 m inside the tunnel on the entrance side. With time, starting from 1980, corrosion and exposition of the rebar took place (Fig. 2 right).

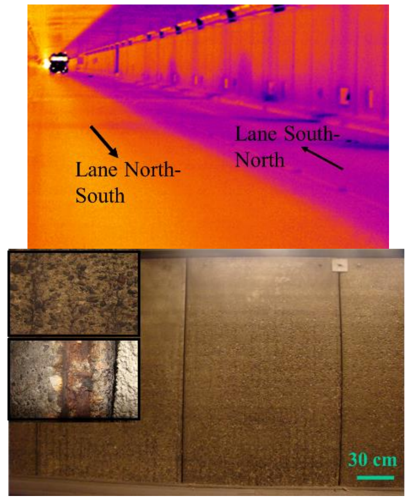

Fig. 2 Thermography and humidity distribution on the South entrance on the tunnel (left) and leaching as well as rebar corrosion of the wall panels (right).

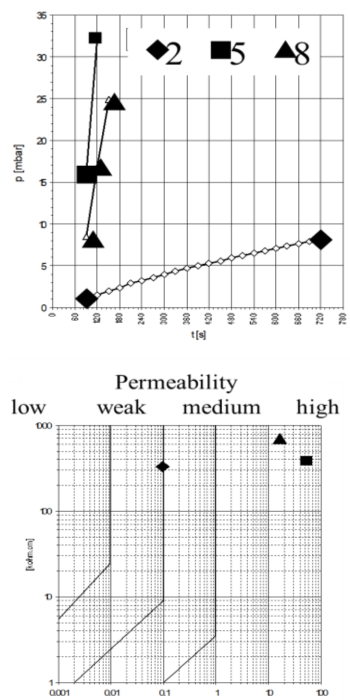

Fig. 3. Air permeability of the panel 50 meters from the South entrance.

The air permeability and the electrical resistivity of the panels was measured in the points 2 (lower part), 5, 8 (higher part) after 50 meters from the South entrance. A higher air permeability in the upper parts of the panels was seen as compared to the lower parts, that showed a more frequent presence of humidity and water (Fig. 3).

Similar measurements were carried out on the wall panel 150 meters from the South entrance. The panel placed in a higher distance from the entrance exhibited a reduced difference in the air permeability between the upper and the lower parts of the panel (Fig. 4). Generally, a more dry atmosphere was present inside the tunnel.

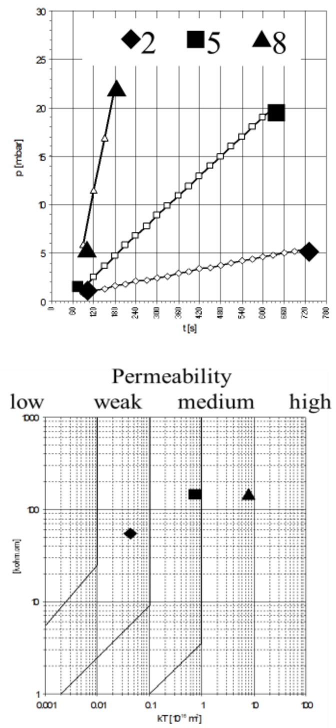

Fig. 4. Air permeability of the panel 150 meters from the South entrance.

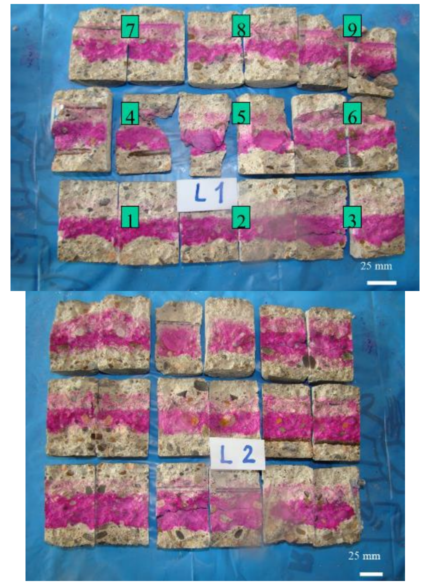

Fig.5. Carbonation depth on cylinders 50 meters (left) and 150 meters (right) from the South entrance.

The carbonation depth was measured on cylinders ∅ 50 mm from the panel 50 m away from the exit. Each specimen taken from the points 1-9 was broken into two halves. The lower part of the cylinders corresponded to the road side. The higher part of the cylinders was the internal side, facing the rocks. The middle and lower parts of the panel exhibited a redu-

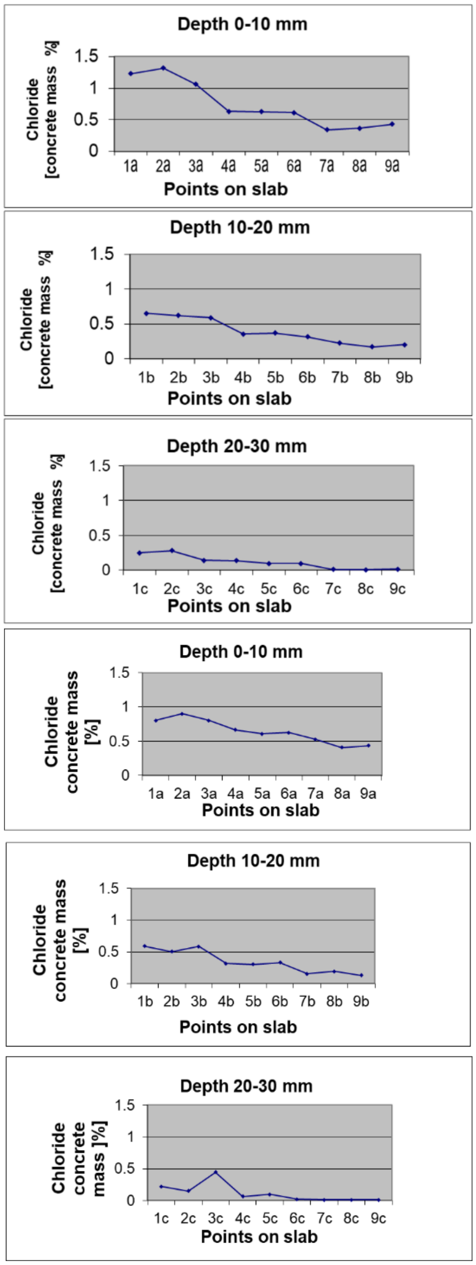

Fig. 6. Chloride content on the 50 meters (left) and 150 meters (right) wall panels at different depths.

ced carbonation front (road side) as compared to the middle-higher parts. This was to correlate with the more frequent presence of humidity in the lower part of the panel and a decreased carbonation. This also correlated with the higher air permeability of the upper part of the panels, which were more dry, as compared to the lower parts (Fig. 5 left). Similar carbonation depth measurements were carried out on a panel 150 meters from the exit. The backside of the cylinders (rock side) generally exhibited a deeper carbonation front, because of the reduced humidity and water presence as compared to the side exposed towards the road (Fig. 5 right).

Chloride content profile were measured from 0 to 30 mm depth for the points 1-9 on the 50 m and 150 m wall panels. The presence of water in the lower part of the 50 meters panel also allowed an increased chloride migration. Therefore, a higher Chloride content in the lower parts (samples 1, 2, 3 a, b, c) as compared to the medium-upper parts of the panels (samples 4-9 a, b, c) were detected on the 50 meters panels (Fig. 6 left). Along the 150 meters wall panels the Chloride content lowered by the half by moving upward along the panel (Fig. 6 right). The values remained above the limit of 0.025 % referred to the concrete mass [13]. A reduction of the chloride content was observed by entering the tunnel. But detrimental agents such as Chlorides were transported by the vehicles and were also found for some kilometers inside the tunnel.

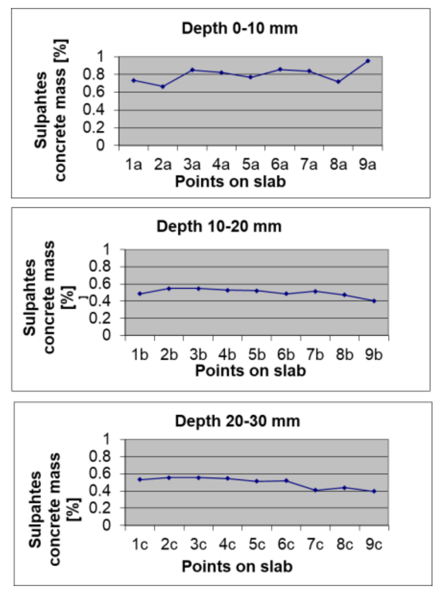

Fig. 7. Sulphate profiles on the concrete wall panel 50 meters inside the tunnel, measured down to a depth of 30 mm.

Considering the adverse chemical substances within the tunnel and the Sulfur dioxide present in the car exhaustion gases and in the atmosphere in the past, the Sulphate content from 0 to 30 mm depth for the points 1-9 on the 50 m wall panel was determined. The Sulphates slightly increased on the surface 0-10 mm (Fig. 7). This derived more from the tunnel atmosphere added to the Sulphates present within the cementitious material. They also had a detrimental effect because of the ettringite formation, causing expansion and cracking of the cementitious matrix.

4. CONCLUSIONS

The tunnel entrance for at least 900 meters inside was a critical environment with respect to the durability of cementitious material and steel rebar.

Asymmetrical physical leaching was caused by the water droplets transported by the vehicles. The cementitious binder along the wall panels on the entrance side of the tunnel was significantly leached. The concrete panels some kilometers inside the tunnel were less prone to degradation because of the higher temperature and the reduced humidity. At the entrance, the lower parts of the panels were susceptible to chloride degradation i. e. steel rebar corrosion because of the presence of humidity taken up from the splash zone. The Sulphate content slightly increased on the surface 0-10 mm. This derived more from the tunnel atmosphere added to the Sulphates present within the cementitious material. The main detrimental effect was cracks formation. The upper parts of the panels were susceptible to carbonation induced degradation which in turn caused steel rebar corrosion. This was caused by a more dry local atmosphere. Degradation type, intensity and distribution contributed to plan reasonable restoration and material replacement with a limited closing of an important busy roadway.

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