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Mechanical Properties of 30 Years Old Primary Lining Tunnel Concrete

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Abstract. This article shows the acquisition and testing of concrete from tunnel primary lining. The main objective of this article was to describe the mechanical properties of primary lining tunnel concrete at higher age. The primary lining was made from dry mixture sprayed concrete. The primary lining concrete was in contact with the surrounding rock continuously. The surrounding rock could be dry or with ground water. Some surrounding rocks could produce a highly aggressive environment for concrete. The question was, whether the sprayed concrete is still in service after 30 years in this environment.

Introduction

There is a tunnel in the Austrian Alps under the mountain massif of Bosruck. The Bosruck tunnel is thirty years old and nowadays it is undergoing the major reconstruction throughout its entire length. A part of the reconstruction is made in order to change the profile of the tunnel from parabolic to circle which is associated with demolition of the both primary and secondary linings. With this reconstruction it was possible to obtain samples of the concrete from the primary lining. Cylindrical samples were obtained in the side gallery by using concrete core drilling method. The mountain massif Bosruck is formed by the Alpine limestone. The Alpine limestone was very dry in this place, where testing samples were obtained. Testing samples were obtained from a side gallery as well as from the main tunnel tube. Large concrete blocks of the primary layer were obtained in a main tunnel tube. 13 cores with diameter of 94.5 mm and length of 250 – 370 mm were obtained in the side gallery. 12 concrete cubes were carved from the large blocks from the main tunnel tube. Several pieces of steel reinforcement of the primary lining were also obtained within larger concrete blocks. Cylindrical samples were cut into 12 long cylinders (94.5 x 190 mm) and 7 short cylinders (94.5 x 100 mm) in order to determine the compressive and splitting tensile strength, respectively.

Testing of Samples

Non-destructive Testing of Concrete

All samples were tested by non-destructive ultrasonic pulse method (Fig. 1). Ultrasonic pulse testing of concrete was used primarily to determine and roughly estimate the quality of concrete. It was possible to determine the dynamic modulus of elasticity using the CSN 731371 [1] and CSN EN 12504-4 [2]. All samples were tested by Proseq equipment. From measuring of the speed of longitudinal waves it was apparent that the tested concrete is of a very good quality. Dynamic modulus of elasticity was determined to be 52,0 MPa.

Fig. 1. Testing samples and ultrasonic equipment.

Destructive Testing of Samples

Destructive testing of samples was used for determining the real mechanical properties of the concrete. Compressive strength was determined on 12 cubes, 4 short and 12 long cylinders. Static modulus of elasticity was determined on 4 long cylinders together with Poisson's ratio. Tensile splitting strength was determined on 6 short cylinders. The steel reinforcement was in good quality and without any signs of corrosion.

Cubes – Compressive Strength

Large concrete blocks of the primary layer were obtained in a main tunnel tube. 12 concrete cubes were carved from the large blocks. The hydraulic machine EDB 400 was used for testing concrete cubes (Fig. 2, 3, 4). The speed of loading was 4,5 kN/s [3]. The compressive strength was determined to be 37.6 MPa from experimental destructive testing.

Figs. 2, 3, 4. Destructive testing of cube sample in compression.

Long Cylinders – Static Modulus of Elasticity and Poisson's Ratio

The static modulus of elasticity and the Poisson's ratio were determined on 4 long cylinders. Long cylinders were 200 mm long. Four foil strain gauges were installed on each cylinder (Fig. 5). Value of the load (force), the vertical deformation and the horizontal deformation of the sample were recorded during the experiment [5].

Long Cylinders – Compressive Strength

CSN EN 12504-1 Testing concrete in structures – Part 1: Cored specimens – Taking, examining and testing in compression [4] specifies the recommended ratio of the length to the diameter of the core. The compressive strength of the core, which had ratio of length to diameter equal to 1.0, was equal to the cube compressive strength. The compressive strength of the core, which had a ratio of length to diameter equal to 2.0, was equal to cylinder compressive strength. Total 9 long cylinders (ratio of length to diameter was 2.0) were tested to determine the cylinder compressive strength. The hydraulic machine EDB 400 was used for testing of long cylinders. The speed of loading was 4,5 kN/s [3]. The cylinder compressive strength was determined to be 22.5 MPa from destructive experimental testing.

Short Cylinders – Tensile Splitting Strength

The tensile splitting strength was determined on the 6 short cylinders. Standard CSN EN 12390-6 [6] was used for testing cylinders and for evaluation of the results. The hydraulic machine EDB 400 was used for testing short (Fig. 6) cylinders. The tensile splitting strength was determined to be 3.35 MPa.

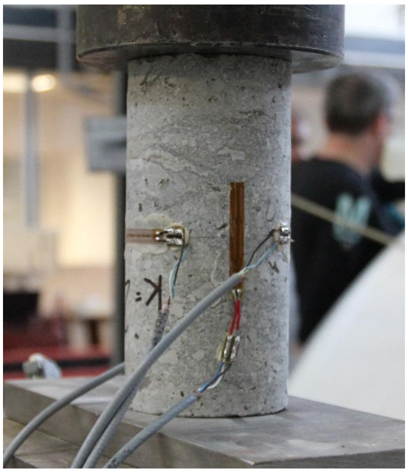

Fig. 5. Testing of the long cylinder.

Fig. 6. Testing of the short cylinder.

Steel Reinforcement – Yield Strength

Steel reinforcement was obtained from the primary lining. Steel reinforcement was found to be without any signs of corrosion after visual inspection (Fig. 7). Total 3 bars were obtained for determination of the Yield strength. Steel bars were 400 mm long and 6 mm in diameter. The yield strength of reinforcement was determined to be 695 MPa.

Overview of Results

Bulk density:	2,300 kg/m^3
Compressive strength – Cubes:	37.6 MPa
Compressive strength – Cylinders:	22.5 MPa
Tensile splitting strength:	3.35 MPa
Static modulus of elasticity:	26,500 MPa
Dynamic modulus of elasticity:	52,000 MPa
Poisson's ratio:	0.21
Yield strength of reinforcement:	695 MPa

Conclusions

The primary tunnel lining was made of several layers of sprayed concrete. Sprayed concrete in 80´s was most probably made of dry mix which was found to be inhomogeneous and porous. Inhomogeneity of sprayed concrete had a significant influence during experimental testing of samples which was indicated by a relatively large scatter of results. However, the sprayed concrete had a very good quality throughout its thickness. This claim was proven also by an ultrasonic pulse method and can be seen by a visual inspection (Fig. 7). The sprayed concrete from Bosruck tunnel is still in very good quality at the age of thirty years.

Fig. 7. Cut through the concrete and through the steel reinforcement.

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