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EVALUATION OF SHOTCRETE QUALITY USING DIFFERENT METHODS

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Abstract:

In this paper, a presentation is given of destructive and non-destructive test methods for evaluating the shotcrete strength and quality of a tunnel primary lining. The research was conducted in the tunnels that are under construction on the Zagreb - Rijeka highway in Croatia. Testing was carried out on site and in a laboratory on specimens taken from the tunnels. The non-destructive methods included an ultrasonic pulse velocity method and a hammer test.

The results of this research work show the relation between shotcrete properties (compressive strength, modulus of elasticity, and homogeneity) measured across the tunnel profile and along the whole tunnel by applying the destructive and non-destructive methods.

The main purpose of this experiment is the development of a method that evaluates the quality of shotcrete in underground structures during and after the construction work. Through the application of non-destructive and destructive test methods it is possible to assess the state of a tunnel in order to improve construction work. This will result in the higher quality of the tunnel lining and durability of the tunnel as a whole and cut remediation and maintenance costs.

Keywords:
compressive strength, homogeneity, modulus of elasticity, non-destructive and destructive test methods, tunnel primary lining

1. INTRODUCTION

A Croatian strategy to develop traffic system defines basic traffic routes and roads that should be given priority in construction of the network of roads in Croatia. Attention should also be drawn to the fact that the basic system of highways constitues also a part of major European road routes. In Croatia, the works on the construction of a modern road network, which also includes the motorway between Zagreb and Rijeka, are in full swing. One of the sub-sections of the said road route includes also three tunnels whose construction has been stopped due to the dispute arisen between the investor and contractor over the quality of the works executed until that time.

In order to assess the current state of the said tunnels, among other tests, in-place test methods were employed in order to estimate the quality of the concrete used for the tunnel primary lining. [1] The said methods, which were aimed at the determination of concrete quality, involved visual inspection of the tunnels as well as non-destructive and destructive methods for testing the primary concrete lining. This paper presents an analysis of the results of tests performed on the largest tunnel of the three tunnels tested. This tunnel had, at the time when the testing was carried out, the lengths of 822 and 338 m respectively. Namely, the tunnel construction had started from two tunnel ends and, at the time of testing, the excavation of the tunnel was fully completed.

The results obtained show that the quality of the tunnel primary lining varies both along the tunnel itself and within specific profiles of the tunnel. In addition, on the basis of the test results, a comparison was made of the measurements obtained by using the non-destructive and destructive test methods for determining the concrete quality. Also, the empirical formulae, which are generally applied for plain concrete, were used for the case of shotcrete placed in the tunnel primary lining, and their applicability to such a case examined.

The use of the combination of the destructive and non-destructive test methods for determining the quality of concrete of the already constructed tunnel primary lining can give satisfactory results as regards the properties which are tested.

2. APPLIED TEST METHODS

In order to assess the state of the built tunnel structure, the quality of concrete of the tunnel primary support was tested after it had been constructed by using the combination of the destructive and non-destructive methods according to the Croatian HRN.U.M1.048 Standard. [2] The test methods employed were the following:

- Non-destructive methods (testing of compressive strength of concrete by using a hammer test method), and
- Destructive methods (determination of concrete compressive strength and modulus of elasticity on drilling cores taken out of the structure, testing of concrete strength and homogeneity on drilling cores taken out of the structure by using an ultrasonic pulse velocity method).

Besides the above-mentioned test methods, the dimensions of the built primary concrete lining were measured and visual inspection of the whole tunnel made.

Testing by the non-destructive test methods were done on representative profiles along the tunnel spaced about 25 metres apart. In each profile there were 4 to 5 measuring points at the tunnel sides and the cap. The destructive tests were performed, i.e. the drilling cores were taken out of the tunnel primary lining at about each 50 metres of the tunnel length at the same measuring points at which the non-destructive testing of strength was carried out by means of a test hammer. The representative profiles for testing were selected based on visual inspection of the tunnel and the condition that there was at least one profile in each particular category of the rock mass along the tunnel. [1]

The non-destructive test method involving the use of digital test hammer was employed to determine the surface strength of shotcrete of the tunnel primary lining on the basis of a rebound value. As the hammer test was carried out on shotcrete placed in the tunnel structure, prior to this testing each measuring point had to be prepared in the manner as to have ground, clean and dry surface, which was a very complex and hard work. [3] The number of impacts by the test hammer on each individual measuring point was 30. The hammer tests were carried out at 198 measuring points along the tunnel. By comparing these results with those of the destructive testing on drilling cores it was possible to estimate the strength and homogeneity of concrete in the tunnel primary support. Since the age of the tested concrete did not exceed one year, it is safe to say that the influence of carbonisation on the obtained test results was negligible.

The drilling cores were taken out of the structure by means of a drilling machine with diamond crown of 95-mm diameter. The cores were prepared for testing and then hammer tested to obtain average correction factor between the core compressive strength and mean compressive strength obtained by non-destructive tests performed by using the test hammer in the tunnel. After that compressive strength of the drilling cores was determined according to established standard procedures. Since the cores taken out of the structure were of various lengths their compressive strength was calculated as for a cube of 200-mm side according to BS 1881 (Part 120, 1983). A total number of drilling cores taken out of the structure was 112.

Each profile of the tunnel in which the destructive tests on one of the samples were performed was also tested by using an ultrasonic pulse velocity test method. This is a non-destructive test method involving the measuring of the time required for the impulse of longitudinal oscillations to be sent from the probe of a transmitter to that of a receiver. [3] By using this method it is possible to determine a number of different concrete properties, and for this research the most important ones were concrete homogeneity (uniformity) and the strength of concrete within the structure. Due to the very unfavourable climatic conditions in the tunnel, field-testing could not be carried out by using the ultrasonic pulse method. Considering that the ultrasound test method is a non-destructive method, the same sample was after that tested for static modulus of elasticity (according to the Croatian HRN.U.M1.025 Standard) and compressive strength.

3. ANALYSIS OF THE RESULTS OBTAINED

In the case when a modulus of elasticity is not determined experimentally, the Croatian Regulations on Concrete and Reinforced Concrete Structures [2] specify that the modulus of elasticity may be determined based on the known compressive strength of concrete according to the following empirical formula:

$$E_{cs} = 9.25 \cdot \sqrt[3]{f_c + 10} \quad \text{(GPa)}$$

This formula was verified on the basis of the values of the modulus of elasticity and compressive strength determined for the drilling cores, and the results obtained are presented in the graph drawn in Figure 1. It is evident from the graph that the values of modulus of elasticity obtained experimentally and the values of those calculated from the known value of compressive strength by using the above-mentioned empirical formula do not match. Namely, the modulus of elasticity of the tested shotcrete obtained experimentally are in average 20 % lower than those obtained empirically. Such a result can be partially explained by the differences in the composition of shotcrete and plain concrete.

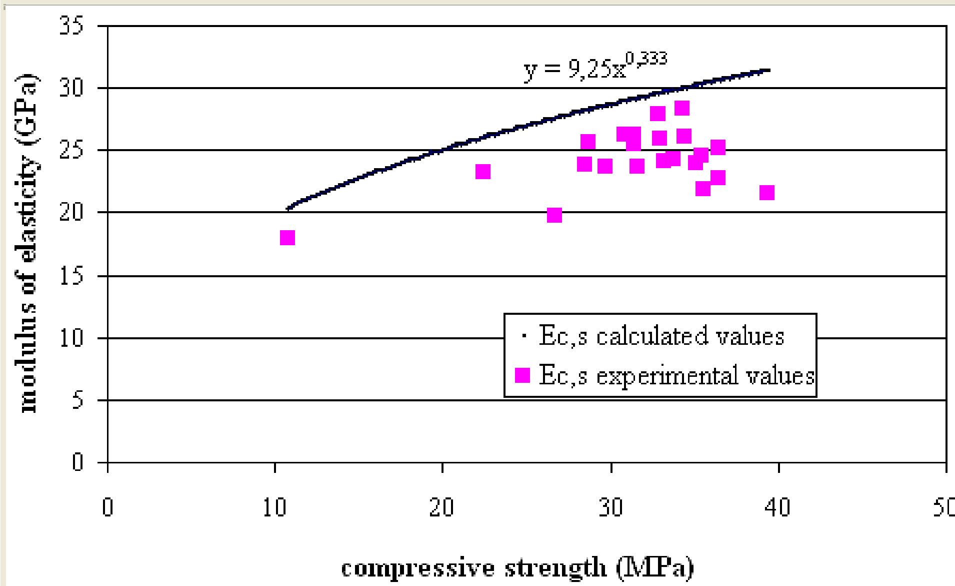

Fig 1: Relation between compressive strength and modulus of elasticity (theoretical and experimental values).

The measurements of ultrasonic pulse velocity obtained on the drilling cores taken out of the tunnel structure can be used to calculate dynamic modulus of elasticity of concrete. The dynamic modulus of elasticity depends on the ultrasonic pulse velocity (v), concrete density (ρ) and Poisson's coefficient (μ) according to the following formula:

$$E_{C,D} = \frac{v^2 \cdot \rho \cdot (1+\mu) \cdot (1-2\cdot\mu)}{1-\mu} \quad \text{(GPa)}$$

Figure 2 shows the dependence of the ratio between static and dynamic modulus of elasticity on concrete compressive strength. The obtained values of the dynamic modulus of elasticity of concrete are, on average, about 50% higher than the values of the static modulus of elasticity calculated experimentally. The values of the dynamic modulus of elasticity of shotcrete that were obtained are higher in average by about 50 % than the static modulus of elasticity calculated experimentally.

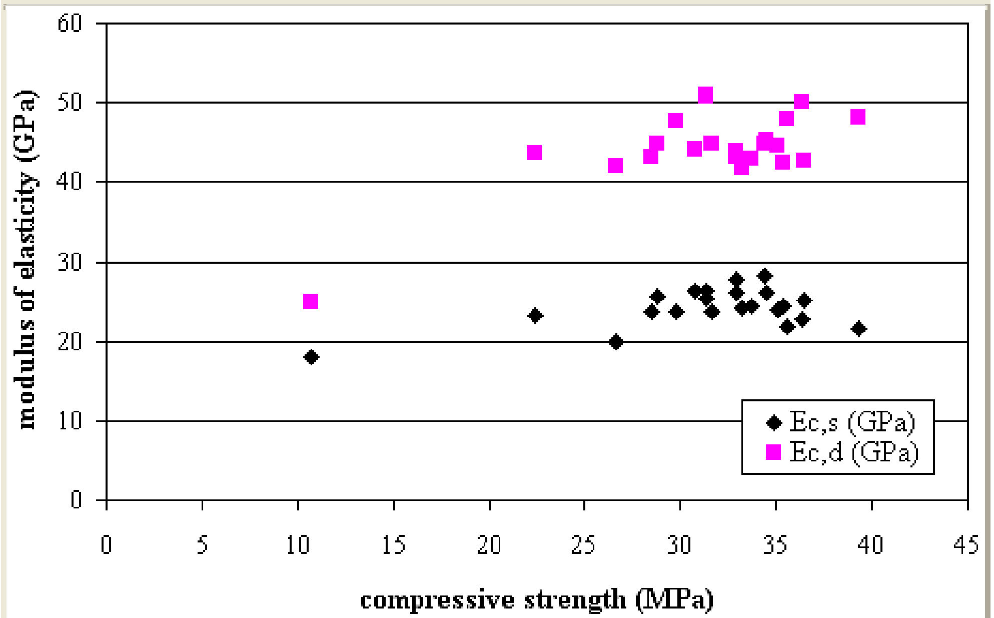

Fig 2: Correlation between compressive strength and modulus of elasticity (static and dynamic).

The diagrams in Figures 3 and 4 show average values of compressive strength at the sides and cap along the tunnel obtained by using the hammer test method in the tunnel, by using the same method on the drilling cores, and by determining compressive strength on the drilling cores.

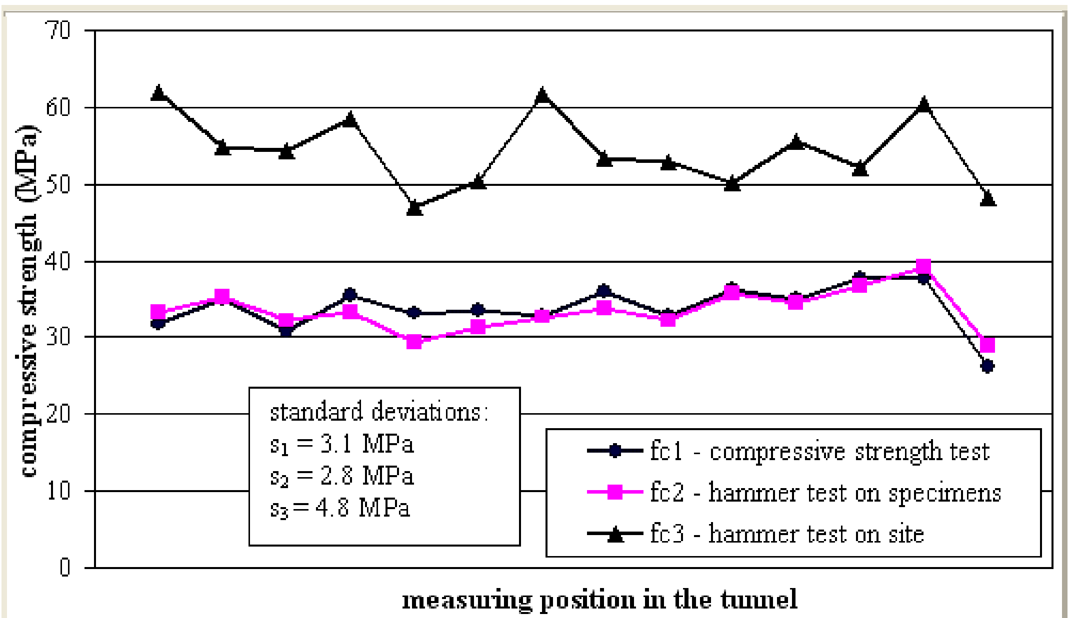

Fig 3: Comparison of destructive and non-destructive testing of compressive strength, performed on specimens and on-site (position - sides of the tunnel).

Figure 3 and Figure 4 shows that the use of the hammer test method along the tunnel primary lining gave significantly higher values and higher standard deviations than the use of the same method along the drilling cores taken out of the structure. The analysis values are larger at the tunnel cap than at the tunnel sides, which is explained by more difficult working conditions when shotcrete is placed above head, i.e. at the tunnel cap. Based on the comparison of the values of compressive strength obtained by hammer testing and that of the drilling cores it is safe to conclude that the values obtained by hammer testing on the drilling cores correspond roughly to the real compressive strength of the tunnel primary support. Consequently, when estimating concrete quality after tunnel construction has been completed, it is necessary to use not only the non-destructive test methods (a test hammer) but also the destructive test method (drilling cores) to obtain the reliable values of compressive strength.

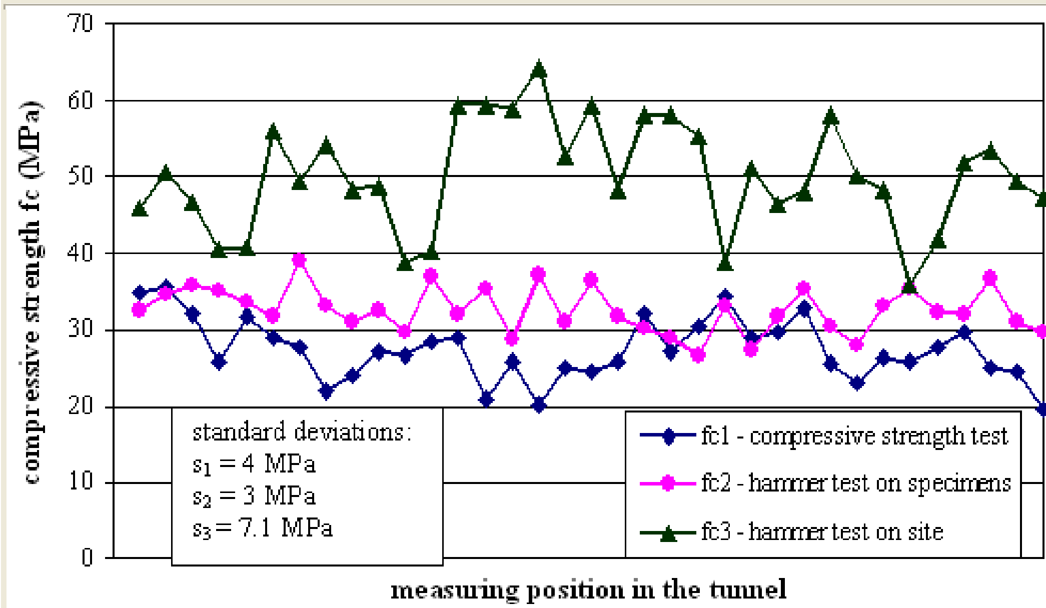

Fig 4: Comparison of destructive and non-destructive testing of compressive strength, performed on specimens and on-site (position - tunnel cap).

In conclusion, only the use of the non-destructive and destructive test methods for determining the quality of concrete makes it possible to estimate the quality of the built structure in a practical manner and with sufficient accuracy.

4. CONCLUSION

The tests carried out to estimate the quality of the tunnel primary support after the tunnel construction has been completed involved the non-destructive (the hammer test and ultrasonic pulse velocity methods) and destructive (the drilling cores taken out of the tunnel structure) test methods. On the basis of the results of the above tests, it can be concluded as follows:

- The modulus of elasticity of shotcrete determined experimentally are lower in average by 20 % than the same modulus determined by using compressive strength according to the empirical formula for plain concrete;
- The modulus of dynamic elasticity of shotcrete obtained by using the ultrasonic pulse velocity test method are higher by about 50% than the static modulus of elasticity determined experimentally;
- The values of surface compressive strength obtained by hammer testing in the tunnel demonstrate sharp departure from the compressive strength obtained on the drilling cores. This indicates that the combination of the destructive and non-destructive test methods should be used when estimating concrete quality after

the construction has been completed.

5. REFERENCES

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