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TUNNEL PRECAST SEGMENTAL LINING WITH FIBER REINFORCED CONCRETE

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ABSTRACT

An experimental research on the possibility of using fiber reinforced concrete precast tunnel segments instead of traditional reinforced concrete (RC) elements is presented herein. This solution allows removing the traditional reinforcement with several advantages in terms of quality and cost reduction.

The case of precast elements used with a Tunnel Boring Machine (TBM) in the Brennero Base Tunnel has been considered Full-scale tests on both traditional reinforced concrete and fiber reinforced elements have been performed. In particular, bending tests were carried out in order to compare the behaviour of the segments under flexural actions, while point load tests were developed with the aim of simulating the thrust force induced by the Tunnel Boring Machine, and then the effect of load concentration and splitting phenomena. The tests results showed that, in this peculiar application, the fiber reinforced concrete can substitute the traditional reinforcement; in particular the segment performance is improved by the fiber presence, mainly in terms of cracking opening control.

I. INTRODUCTION

Fiber reinforced concrete (FRC) is nowadays extensively used in civil engineering due to theadvantage in reducing or substituting the traditional reinforcement. After the first applications inpavements , where the fiber presence allows removing totally the steel mesh reinforcement,several applications were developed, particularly in the precast industry. The use of FRCin substitutionof the traditional reinforcement allows obtaining several advantages in terms ofstructural performance and costs reduction. These advantages are particularly suitable in precastelements, where the industrialized process enhances the benefit of using such compositematerial.In terms of structural aspects, the fiber reinforcement improves the performance of the materialunder tensile actions, remarkably increasing the toughness and enhancing the cracking control Furthermore, the presence of fiber in the concrete matrix has an important effect in increasing the fatigue and the impact resistance All these aspects are boosting the interest in new applications in FRC. In the design process, thedefinition of the performance expected from the material is a key-factor. Different fiber reinforcedconcretes are available with different grade of performance and, as a consequence, at differentcost. Furthermore the mix-design of the material has to be optimized for the required structuralapplication. The sustainability of the choice of using FRC in substitution of the traditionalreinforcement has to be evaluated by considering different factors. Indeed, not only the cost ofthe bare materials (i.e. the cost of the removed reinforcement with respect to the cost of theFRC), but also the reduced labour cost or the enhanced quality of the structure has to beaccounted for.

In the last few years there is an interest in using FRC in precast tunnel segment particularly whenTunnel Boring Machine (TBM) machines are adopted [1]. The bended shape of these elementsleads to the use of ordinary reinforcement with complex detailing due to the embedded items. In addition, the structures are mainly stressed during the construction phases rather than in servicestage. Therefore, it is important to maintain the structural integrity - limiting the concrete cracking mainly in curing and assembly steps, when the segment can be subject to impact loads duringthe handling and it is usually subject to point loads from the TBM rams. The fiber reinforcement isparticularly suitable at this aim [8]. Other advantages in the use of FRC in tunnel segments arelinked to the possibility to remove the cathodic protection due to fact the fiber are dispersed in theconcrete matrix and the absence of contact between them does not allow the onset of current.Furthermore, the use of fiber reinforced concrete increases the fire protection performance of thematerial, limiting the spelling. Considering all these aspects, FRC seems to be a suitablematerial for the construction of tunnel precast segmental lining.In order to verify the effectiveness of the proposed solution a research program was developedby performing experimental tests on full scale specimens. The tunnel segments here analysed refer to the Brenner Base Tunnel, between Italy and Austria and they were designed for the application in mechanized tunnelling with a TBM doubled shield machine, Constructor SELI, Italy.

II. SEGMENT DESCRIPTION

The Brenner Base Tunnel is composed of six segments for a total circumference length of about 19 m (external diameter equals to 6 m). The segments considered in the study are shown in figure 1. The thickness is equals to 200 mm while the length and the width are 3640 mm and 1500 mm respectively.

Two types of elements have been considered: a segment in fiber reinforced concrete without any traditional reinforcement and a reference element in ordinary concrete (average cubic compressive strength of 50 MPa) reinforced with 8 mm rebars spaced of 200 mm (see figure 2). Open stirrups are used as splitting reinforcement as shown in figure .

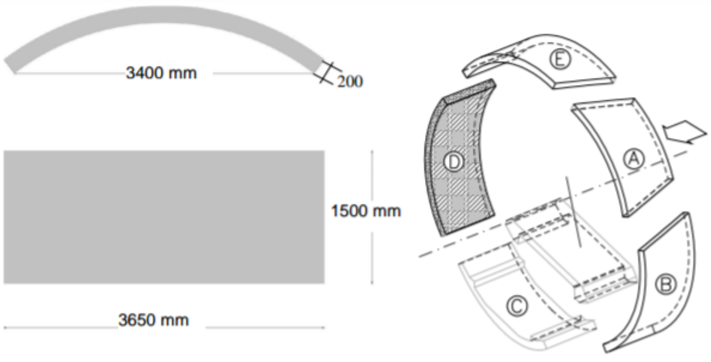


Fig. 1 - Tunnel segment geometry

Fig.1 Tunnel segment geometry

The average compressive strength of the fiber reinforced material, measured on cubes of 150mm edge, is equals to 75 MPa. The concrete mix was properly designed to enhance the performance of the adopted steel fibers. The tensile behaviour was characterized by performing bending tests on 150x150x600 mm notched specimens according to the Italian Standard [2], particular, the nominal stress versus the crack opening measured at the tip of the notch was considered. The equivalent strength, measured as the average of the stress for crack opening ranging between 0.6 and 3 mm resulted equals to 6.5 MPa. In the design, according to the Italian Guidelines for FRC structures , the value adopted for the tensile strength (considered uniform with a stress-block distribution) is 1/3 of the equivalent strength (i.e. 2.15 MPa).

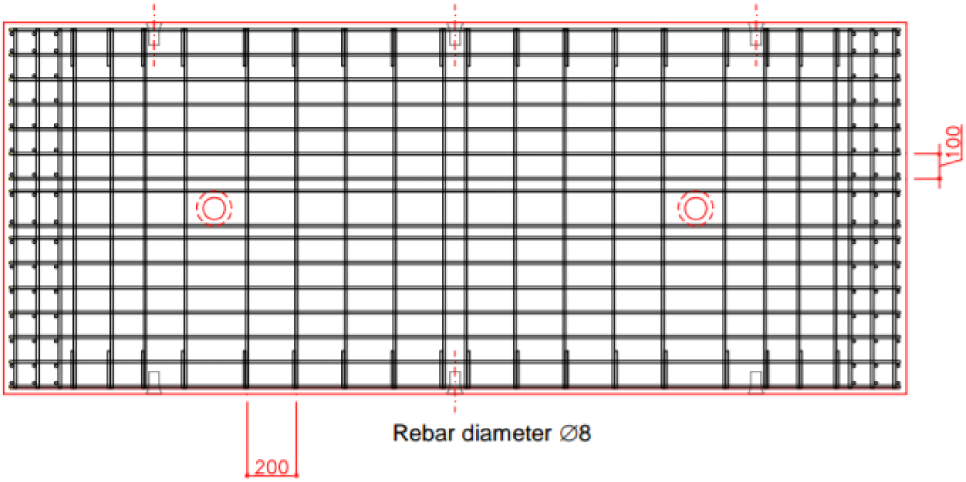
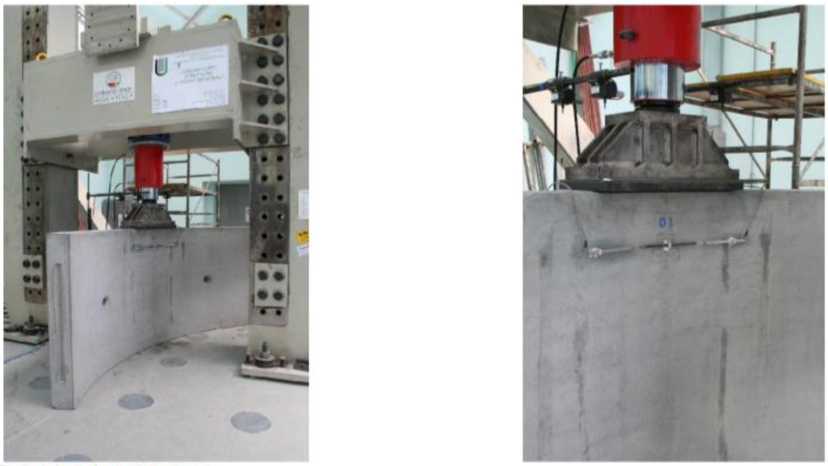


Fig. 2 – Tunnel segment reinforcement

For both the flexural and point load tests, a reacting frame, having a maximum bearing capacity equals to 4000 kN, has been adopted. The testing set-up adopted in the flexural test is illustrated in figure 4: the tunnel segment is placed on hinge supports with a span of 2040 mm. The load was applied by means of an electromechanical jacket with a PID control and a maximum load of 1000 kN. The tests were conducted by using the jacket displacement as control signal. In order to distribute the point load on the segment width, a frame system was used, as shown in figure . A load cell was placed between the jacket and the frame system. The vertical displacement was measured by means of three wire transducers, placed at midspan, in the segment intrados see figure. The crack openings were measured with two LVDTs placed in the central part of the segment intrados.

The point load tests were carried out through a hydraulic jacket with a maximum load of 4000 kN. The segment was placed on the laboratory floor, directly under the reacting frame (see figure 6). Due to the necessity of simulating, with this testing set-up, the load transmitted by the TBM machine on the segment, a rigid plate was placed between jacket and segment, obtaining the same loading of the actual situation (on site). Two LVDTs were placed in order to measure the splitting crack while three potentiometric wire transducers were adopted for measuring the displacement of the loading plate. The load was measured by means of a pressure sensor.



Point load test set up

Fig.3 Point load test set up

III. FLEXURAL TEST RESULTS

The results of the bending test on both the segments in ordinary reinforced concrete and in fiber concrete are illustrated in figure 7 through a force versus midspan displacement diagram. No appreciable torsion was found, as the three wire transducers measured almost coincident displacements. For this reason only the central transducer is considered in figure. In the same figure a line corresponding to the load of the frame used for distributing the load along the width (8 KN) is reported. Looking at the response of the traditional RC segment, it can be noticed that the first cracking occurs at a load level of 70 kN while the yielding can be located at 125 kN. Eventually, a hardening branch develops up to a failure load of 175 kN.

The behaviour of FRC segment is remarkably different. The first recordable crack was detected at a load level of 95 kN. Following this stage, the stiffness remained almost constant up to 120 Kn thanks to the stress transmitted along the cracks by the fiber reinforcement. The maximum bearing capacity was equals to 140 kN. Afterwards a softening branch was developed. Figure shows the load versus crack opening displacement (average of the two LVDTs) curve for the two tested segments. It can be noticed the reduced crack opening for the fiber reinforced concrete with respect to the traditional reinforced concrete segment. Even if the total bearing capacity of the reinforced concrete segment resulted higher if compared with the fiber reinforced concrete, some considerations have to be done for the particular case of this kind of structures. In precast tunnel segment structures the heavier loads are developed in the construction phase. In this situation the cracking can represent an ultimate state. Also at service ability, the cracking control usually represents a limit for the acceptance of the structures. In the reinforced concrete the crack opening at yielding (125 kN) resulted equals to 0,5 mm; with this value, the structures cannot be considered able to satisfy the criteria of integrity.At the same load level, the crack opening in the fiber reinforced concrete segment was less than 0.2 mm. Figure shows the crack pattern at 125 kN for both the segments, with a remarkably better situation in the FRC segment. Summarizing, in the FRC segment it was noticed a lower number of cracks with a lower crack opening with respect to the RC segment. Furthermore if, as usual the design ultimate load is related to the yielding of the reinforcement (while the hardening branchis neglected), it is worth noting that the FRC element presents a higher bearing capacity withrespect to the traditional one (yielding force is about 140 and 125 kN for FRC and traditionalsegments respectively,

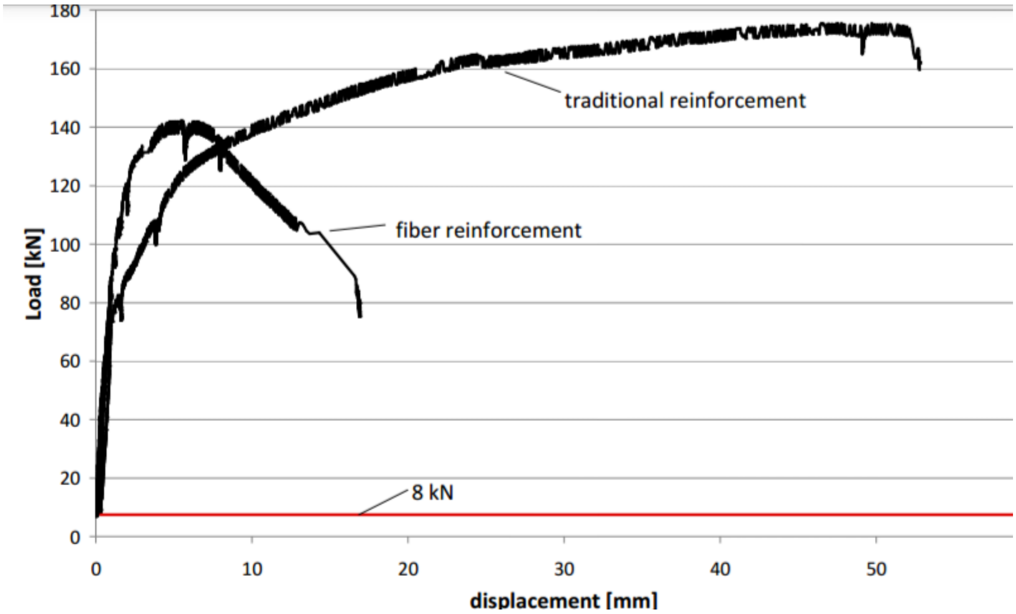


Fig.4Flexural test: Load .midspan displacement

IV. POINT LOAD TEST RESULTS

Both the segments were loaded up to the maximum bearing capacity of the system (4000 kN). Figure 10 shows the load versus point load displacement curves. It was not detected remarkable cracking either of the RC and the FRC segments and their behaviours were very similar.

V. CONCLUSIONS

The full-scale tests developed on concrete segments were really successful. The major finding is that the FRC elements show a more competent behaviour in terms of cracking control. This important feature is instrumental in tunnel lining where the serviceability limit is usually well far from the incipient cracked status of the structures. The presented results have been achieved with an accurate design of the concrete mixes and steel fiber materials. Nevertheless further goals may be accomplished through a more comprehensive optimization of the FRC segments. Eventually this process can lead to the final

choice of FRC structures thanks to both performance and cost aspects.

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