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LYON 13.14.15
OCTOBRE 2014

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Precast tunnel segments reinforced with fiber glass bars

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ABSTRACT

The possibility of substituting the traditional steel reinforcement with fiber glass bars in precast tunnel segments is investigated herein. Precast segments are traditionally used for the lining of tunnels excavated with a Tunnel Boring Machine (TBM). The use of fiber glass reinforcement in tunnel segments allows several advantages, mainly related to the durability aspects. In particular, it is of great interest the possibility of reduce the concrete cover that is usually a weak point for this kind of structure (concrete cover can crash during handling of the segments or due to TBM thrusts). Furthermore the use of fiber glass bars is suitable in tunnel where the aspect cycle life is equal or higher than 100 years. In addition the proposed solution is suitable in the part of the tunnel that have to be eventually removed (typical problem in TBM tunnel). In this case, segments reinforced with fiber bars can easily demolish and disposed. Full scale bending tests have been performed on precast segments in order to compare the structural performance of fiber glass reinforced concrete with respect to traditional steel reinforced concrete. Furthermore, consideration on the design procedure for the proposed solution are highlighted.

Keywords: fiber glass rebars, precast tunnel segments

INTRODUCTION

The use of fiber glass rebars in substitution of traditional steel reinforcement allows a series of advantages and it could be a innovative solution in a some of application. One of the main advantages linked to the use of fiber glass bars is related to the avoidance of corrosion problem.

It has to remark that this type of reinforcement is not suitable for all the applications for two main reason: the cost of the fiber glass reinforcement is generally higher respect to the traditional steel ones and the problem related to static fatigue when the fiber glass bar is subjected to a constant tensile load over time. In relation to static fatigue problem, the use of fiber glass reinforcement is suggested in structures that are mainly in compression under the serviceability load conditions or in temporary structures.

The possibility of use a fiber glass reinforcement in precast tunnel segments is investigated herein. These elements are used in mechanical excavated tunnel (generally excavated with a Tunnel Boring Machine, TBM). The tunnel lining is made with these precast elements placed by the TBM during the excavation process and it is used as reaction element from the TBM during the advancing. Segments are subjected to tensile actions (due to bending moment or to the TBM thrusts) only during the transitional phases, while are often mainly in compression at the final stage (soil or rock pressure).

The use of precast segments reinforced with fiber glass rebars is suitable when durability problems could jeopardize the tunnel integrity. Furthermore the possibility of using non-metallic reinforcement allows a strong reduction in the concrete cover, avoiding problem of crushing during the segments handling. The use of fiber glass reinforcement is also suitable in parts of the tunnel that have to be eventually demolish (typically in metro line when the station is build after the tunnel excavation or when the section of the tunnel has to be modified for safety areas). Finally, the use of this technology is suitable for create dielectric joint in the tunnel.

The use of fiber glass rebars in substitution to traditional steel cage can be proposed in a series of tunnel where the aforementioned problems are present. The higher cost of the fiber glass material can be balanced by the difficulties encountered in the use of a traditional steel reinforcement. By accounting for the overall costs related to the tunnel construction and maintenance, the fiber glass solution could be proposed.

On the structural point of view it is important to demonstrate to the designer that the behaviour of precast tunnel segments reinforced with fiber glass rebars is comparable (or even better) respect to the traditional

steel reinforcement. With this purpose, full scale tests on precast segments have been performed in order to compare the structural behaviour of elements reinforced with fiber glass bars or traditional steel bars. Furthermore some considerations on the design of precast segments with fiber glass reinforcement are presented

EXPERIMENTAL PROGRAM

The full scale segments considered in the research program are characterized by a thickness of 400mm, a length of about 4150 mm and a width of about 1483 mm (Figure 1).

The reference segment (SR – steel reinforcement) is characterized by a traditional steel cage made of 12+12Ø12 bars, placed in the intrados and extrados surfaces, with minimum cover of 50 mm (Fig. 2a) while the reinforcement of the segment with fiberglass bars (FGR – fiber glass reinforcement) is made of 12Ø12 +12Ø14 longitudinal bars (Fig. 2b) with minimum cover of 50 mm (in these tests the same detailing for both the reinforcement was considered). Figure 3 shows the fiber glass cage. The reinforcement were designed in order to have the same bending resistance according to the codes indications.

The segments were cast with concrete coming from the same batch and characterized by a cubic strength equal to 61 MPa.



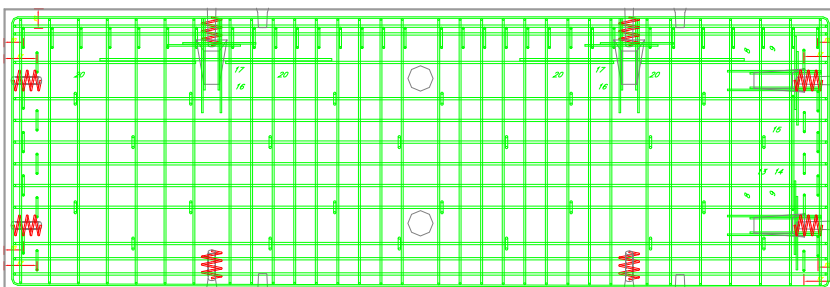
Figure 1 - Tunnel segment.

The segments were tested in bending, since this is the principal lading condition in transient stages (demoulding, storage, handling...). The segments have been placed on rolling support with a span of 3m a loaded in the centre by means of a frame system able to transversally distributed the action, as shown in Figure 4a.

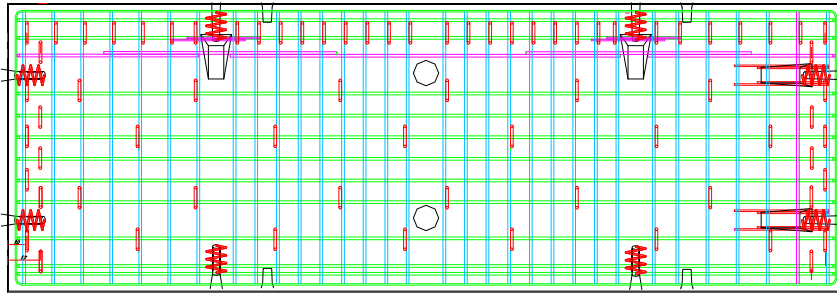
The segment was loaded by means of a electromechanical close loop jacket having a maximum capacity of 1000 kN. During the test, the following measures were continuously registered:

- the load measured by means of a 1000kN load cell with a precision of 0.2%;
- the midspan displacement measured by means of three potentiometer wire transducers placed along the transverse line (Fig. 4b);
- the crack opening at midspan, measured by means of two LVDTs (Fig. 4b).

Furthermore, the crack pattern was recorded at different step, with the help of a grid plotted on the intrados surface (100x100mm).



(a)



(b)

Figure 2 - Detailing for the traditional reinforcement (a) and the fiber glass reinforcement (b).



Figure 3 - Fiber glass cage.



(a)



(b)

Figure 4 - Bending tests (a). Displacement measuring (b).

TESTS RESULTS

Figure 5 shows the results of the full scale tests as load versus midspan displacement. The first crack occurred at a load level of 175 kN for SR segment and of 130 kN for the FGR segment. Eventually, in both the segments several cracks developed. It can be noticed that the SR segment showed a more stiff behaviour respect to FGR segment. This was mainly due to the higher bond of traditional rebars respect the fiber glass ones. This aspect is also confirmed by the crack pattern for different load level (Fig. 6) where more cracks are present in the FGR segment.

Looking at the maximum bearing capacity, it can be noticed a higher failure load for the FGR segment respect to the SR segments. This is justified by considering that both the segments were designed according

to the codes: thus a safety coefficient of 1.15 is used for the steel reinforcement while a 1.5 safety coefficient is adopted for the fiber glass rebars.

Despite the brittleness of the fiber glass reinforcement, the structural behaviour of FGR was anyway ductile, with a ultimate displacement even higher respect to what obtained for SR segment.

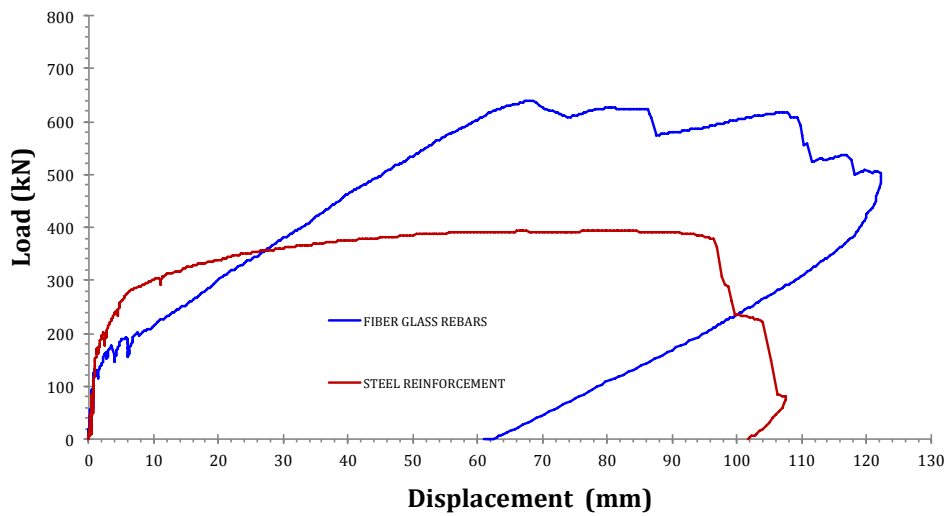


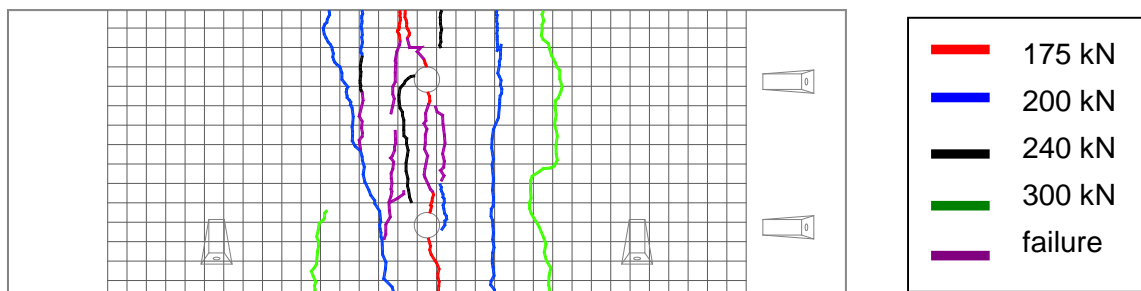
Figure 5 - Load versus midspan displacement curves.

DESIGN CONSIDERATIONS

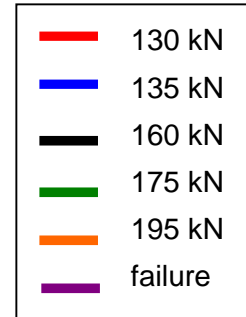
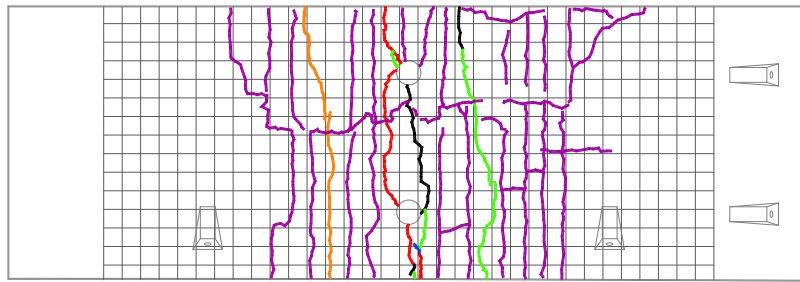
In order to better discuss the experimental results some considerations have to be done on the design aspect related to the use of fiber glass rebars respect to the traditional reinforcement.

Design guidelines for fiber glass rebars [1-3] suggest to use elasto-brittle behaviour for the fiber glass rebars in tension and no resistance in compression. Furthermore, the material safety coefficient is usually taken as 1.5 [3] respect to 1.15 for the steel.

The reinforcement detail in the specimens was defined in order to have the same design bearing capacity for the two segments, at least in pure bending (Figure 7). If the average values of the material strength are considered (Figure 8), it is clear the higher bearing capacity exhibited by the segment with fiber glass rebars.



(a)



(b)

Figure 6 - Crack pattern at different loading stage for traditional reinforcement (a) and fiber glass reinforcement (b).

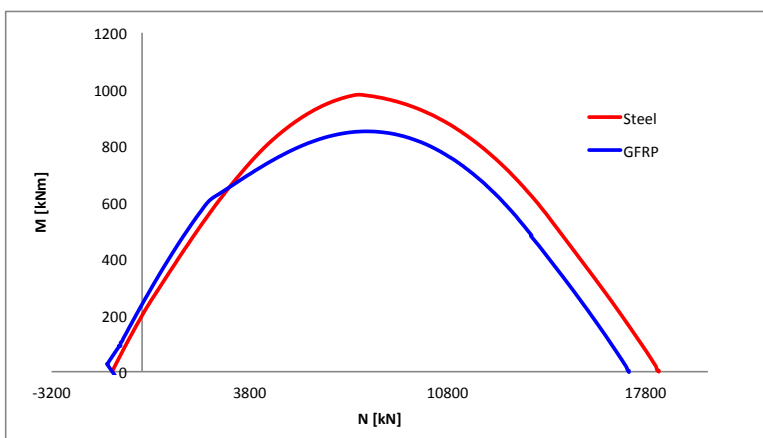


Figure 7 - Bending moment versus axial force envelope for the two testes segment, evaluated considering the design strength of the materials

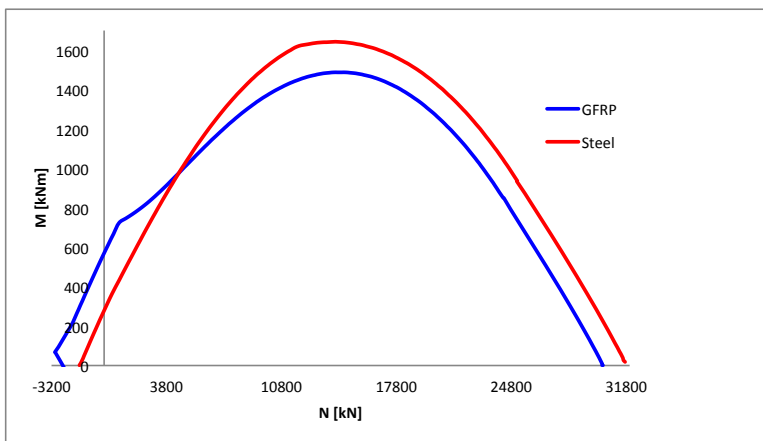


Figure 8 - Bending moment versus axial force envelope for the two testes segment, evaluated considering the average strength of the materials

CONCLUSIONS

Fiber glass rebars can be a solution in some problems that can arise in the segmental lining construction. On the point of view of the structural behaviour, there are not significant difference when the steel reinforcement is substituted with a fiber glass reinforcement. In fact, despite the brittleness of the fiber glass

rebars, the structural behaviour exhibited not only a significant strength but also an adequate ductility. On the base of the obtained results, fiber glass rebars can substitute the steel reinforcement in this kind of application.

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