Tunnelling and Underground Space Technology 26 (2011) 284–291

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Structural behaviour of precast tunnel segments in fiber reinforced concrete

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ARTICLE INFO

Article history:
Received 23 February 2010
Received in revised form 14 October 2010
Accepted 19 October 2010
Available online 20 November 2010

Keywords:
Precast tunnel segment
Fiber reinforced concrete
Flexural experimental tests
Point load experimental tests

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.

1. Introduction

Fiber reinforced concrete (FRC) is nowadays extensively used in civil engineering, due to the possibility of reducing or substituting the traditional reinforcement. After the first uses in pavements (Falkner et al., 1995), where the fiber presence allows totally removing the steel mesh reinforcement, several applications were developed, particularly in the precast industry (di Prisco and Toniolo, 2000; Failla et al., 2002; Minelli et al., 2006). The use of FRC in substitution of the traditional reinforcement allows obtaining several advantages in terms of structural performance and cost reduction. These advantages are particularly suitable in precast elements, where the industrialized process enhances the benefit of using such composite material.

In terms of structural aspects, the fiber reinforcement improves the performance of the material under tensile actions, remarkably increasing the toughness and enhancing the cracking control (Romualdi and Batson, 1963; Walraven, 1999). Furthermore, the presence of fiber in the concrete matrix has important effect in increasing the fatigue and the impact resistance (di Prisco et al., 2004).

All these aspects are boosting the interest in new application in FRC. In the design process, the definition of the performance expected from the material is a key-factor. Different fiber reinforced concretes are available, with different grade of performance and, as a consequence, different cost. Furthermore the mix-design of the material has to be optimized for the required structural application. The sustainability of the choice of using FRC in substitution of the traditional reinforcement has to be evaluated by considering different factors. Indeed, not only the cost of the bare materials (i.e. the cost of the removed reinforcement with respect to the cost of the FRC), but also the reduced labour cost or the enhanced quality of the structure has to be accounted for. With particular reference to the tunnel segments, the cost of the adopted steel fibers (per unit of weight) is nowadays about the double with respect to the cost of the traditional steel rebars; nevertheless the necessary fibers amount in the segment is about the half of the rebars. As a consequence the costs of FRC and RC segments are comparable.

In the last few years there is an interest in using FRC in precast tunnel segment particularly when Tunnel Boring Machines (TBM) are adopted (Burgers et al., 2007). The bended shape of these elements leads to the use of ordinary reinforcement with complex detailing. In addition, these structures are mainly stressed during the construction phases rather than in serviceability stage. Therefore, it is important to maintain the structural integrity – limiting the concrete cracking – mainly in curing and assembly steps, when the segment can be subjected to impact loads during the handling and is usually subjected to point loads from the TBM rams. The fiber reinforcement is particularly suitable at this aim (Plizzari and Tiberti, 2006). Other advantages in the use of FRC in tunnel segments are linked to the possibility of removing the cathodic

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doi:10.1016/j.tust.2010.10.003

protection due to fact that fibers are dispersed in the concrete 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 performance of the material, limiting the concrete spalling (Chen and Liub, 2004). Considering all these aspects, FRC seems to be a suitable material for the construction of tunnel precast segmental lining.

The tunnel segments here analysed refer to the 55 km long Brennero Base Tunnel, between Italy and Austria, and they were designed for the application in mechanized tunnelling with a

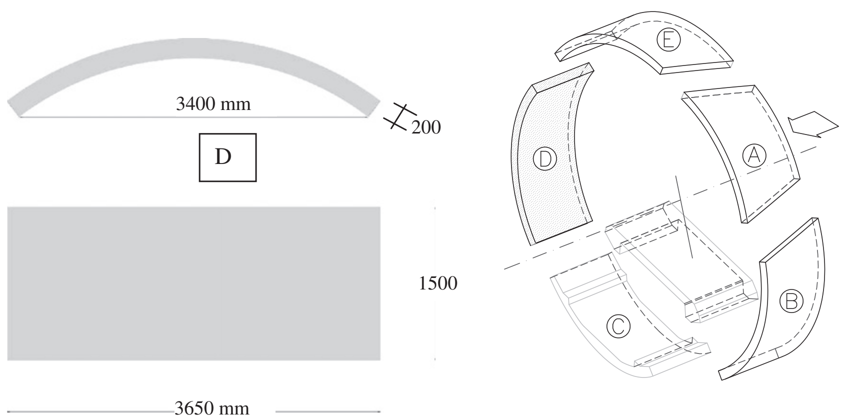

Fig. 1. Tunnel segment geometry.

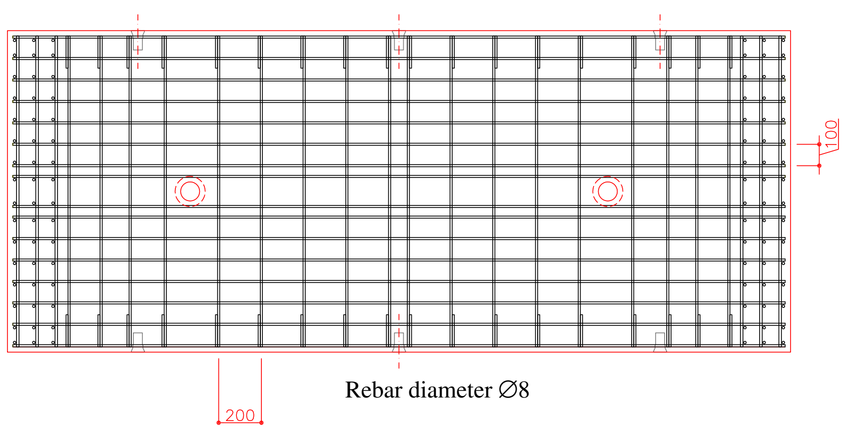

Fig. 2. Tunnel segment reinforcement.

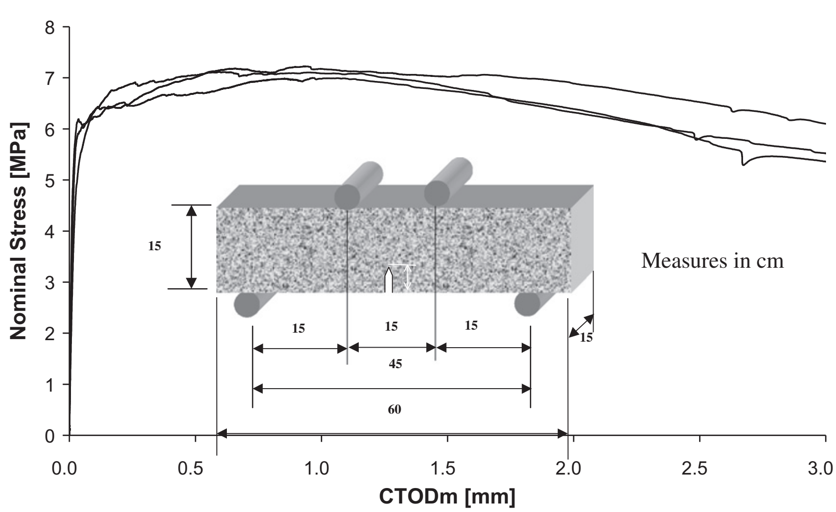

Fig. 3. FRC flexural behaviour in tension: nominal strength versus crack opening.