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Experimental investigation on precast tunnel segments under TBM thrust action

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ABSTRACT

An experimental procedure, useful for the evaluation of the structural behaviour of lining segments subjected to the Tunnel Boring Machine (TBM) thrust is presented in the paper. The study rises from the need to face the practical and rather frequent problem of cracks patterns in tunnels, occurring during the ring installation and in the first following phases of the TBM advance. This phenomenon, generally considered unavoidable, has a strong impact on the tunnel builder both in the economical and policy fields.

The proposed set-up allows testing single segments under different loads, applied in different zones, in order to simulate the TBM thrusts, also in the curved stretch of the tunnel. Furthermore, different support conditions can be simulated, in order to account for the frequent situation of imperfect contact between the segments of two next rings.

The experimental outcomes allow highlighting the different crack patterns related to the different support conditions, and appear useful for a deeper understanding of the segment behaviour under the TBM thrust.

1. Introduction

The Tunnel Boring Machine (TBM) and the EPB (Earth Pressure Balance) are nowadays the most extensively adopted systems for the tunnel construction, allowing the excavation in hard rock and soft soil, respectively. In particular, a distinction can be drawn between tunnel boring machines without shield body and those with ones. In the following, the term TBM will be adopted for indicating both the shielded TBM and the EPB machines, as suggested in ITA guidelines [10,11].

The tunnel lining is usually made with precast segment elements in reinforced concrete, when shielded TBM machines are adopted. In these structures the lining task is twofold: it has to resist the ground pressure and it is used as reaction element for the TBM advance. Furthermore, the single precast segments have to be designed for actions that can occur during the construction phase, i.e. demoulding, handling, storage and transportation [8].

The forces due to the TBM thrust on the lining can lead to a severe stress field on the element that has to be properly taken into account, since this condition can be the most severe in the segment design. As a matter of fact, the TBM thrust, even if transitional action, can cause cracking on the segment that can jeopardize the structural durability [6].

In order to study the problem of the TBM thrust effect on the precast segment, an experimental programme was defined and a proper loading system was designed and constructed.

Test set-ups able to provide a single load to the segment and then to simulate the effect of a single TBM pad are available in literature [18,3,22]. Nevertheless, the actual stress field is far away from this simplified scheme, as more loads (thrusting pads) are present on the segment, and their relatively small spacing implies a reciprocal interaction. Furthermore, for allowing the digging and the segment placement in the curved stretch of the tunnel, different hydraulic systems control the TBM thrust cylinders, in order to provide different forces on them.

Numerical analyses demonstrated that the simplified loading scheme can give very different results, both in terms of strength and crack pattern, with respect to the real situation [2,12,16]. Finally, another significant design aspect can be represented by the imperfect contact between the segments of two next rings [4,5]. This variable, neglected during the design phase, can lead to unavoidable and unexpected crack patterns, during the ring installation.

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The paper presents the results of an extensive testing program, developed with a testing set-up that allows simulating the TBM thrusts on a segment. In particular, the actual number of load pads can be placed on the segment, i.e. different forces can be applied in different zones of the structural element. Furthermore, different support conditions can be provided, in order to account for imperfect contacts. Particular attention was paid to the evolution of the crack pattern. Finally numerical analyses were performed in order to confirm the obtained results.

2. Testing set-up

During the excavation process, the TBM uses the already placed lining, made with precast segments (Fig. 1), as a reacting element for the advancing thrust.

The TBM acts on the lining by means of several hydraulic jacks whose force is applied on the segments with steel pads (Fig. 2a). In a traditional field set-up, two jacks act on a single pad and a Teflon layer is present between the steel pad and the segment.

In the case-study herein considered, three pads are present in every segment, with the exception of the key one, loaded through one pad, only (Fig. 1).

In order to perform full-scale tests simulating the actual condition, a suitable testing system has been designed and constructed (Fig. 3).

In the adopted configuration, the system is able to apply up to 4000 kN on a single pad. Since three pads are placed on a single segment, the total loading capacity is equal to 12,000 kN.

In order to reproduce the field condition, in the experimental set-up two hydraulic jacks act on every steel pad. Every jack, having a loading capacity of 2000 kN, is inserted in a close ring frame made with HEM 360 steel beams and 50 mm diameter Dywidag bars.

The precast segment is placed on a R/C beam having a 800 × 800 mm cross section, internal to the close ring frames (Fig. 3), suitably designed in order to simulate the stiffness of the already placed ring. A hydraulic control system has been adopted with the aim of applying the loads similarly to what happens with the TBM. In particular it is possible to control the load on a single couple of jackets acting on a single pad. Furthermore, valves able to maintain a constant value of the oil pressure in the circuits have been used.

The loads applied on the segment are measured by means of three pressure transducers, each for every couple of jackets. The vertical displacements of the steel pads are measured with potentiometric wire transducers placed on the front side (intrados) and on the rear side (extrados) of the segment (Fig. 4). Furthermore, LVDTs are used for measuring the crack opening (Fig. 4). All the data are continuously recorded by an acquiring digital system and transmitted to a PC.

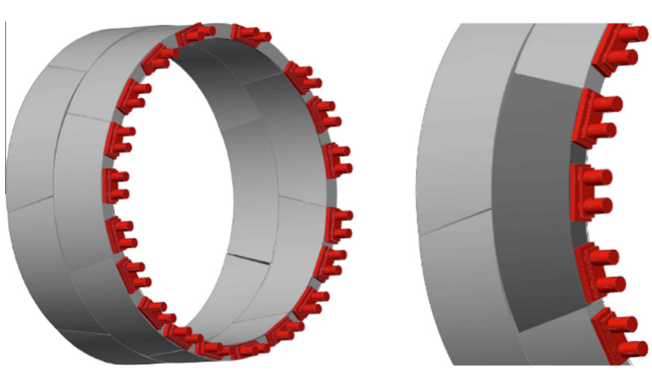

Fig. 1. Segmental lining scheme and loading shoes.

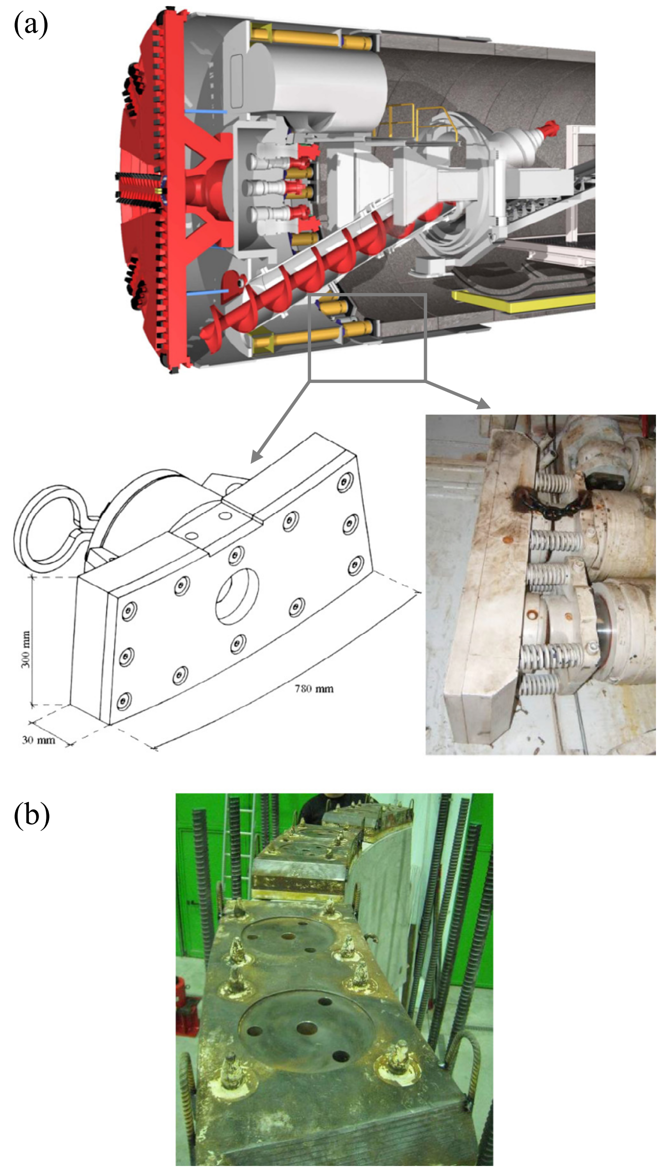

Fig. 2. Transversal section of TBM with shoe detailing (a) in situ; (b) in Lab.

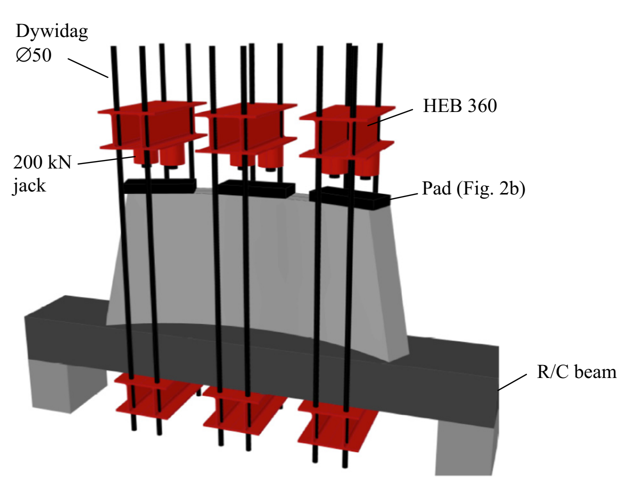

Fig. 3. Testing system.