Outline of "Railway Tunnel Crossing the Bosphorus Strait to Connect Asia and Europe — Structure to Provide the Strength, Durability, and Waterproofness for a 100-year Service Life"

「アジアとヨーロッパをつなぐ「ボスポラス海峡横断鉄道トンネル」ー100年の耐用年数を保証する強度，耐久性と止水性能を備えた構造物ー[1]」の概要




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1. Introduction

The Bosphorus tunnel is a 13.6-km-long railway tunnel connecting Asia and Europe. People in Turkey have been very interested in this tunnel project since it was first conceived more than 150 years ago. This report gives an outline of the project and introduces structural features of the tunnel, especially from the materials perspectives of concrete and cement. The tunnel is of several types, being an immersed tunnel constructed both using a tunnel-boring machine (TBM) and the new Austrian tunneling method (NATM) (i.e., non-TBM tunnels).

2. Features of Each Type of Tunnel

(1) Immersed Tunnel

The immersed tunnel lies just beneath the Bosphorus strait. The tunnel is 1,387m long, consists of 11 elements, and has a rectangular cross section with two cells made of reinforced concrete. It is 15.3m wide and 8.6m tall, and the longest element is 135m.

The lower half of each element was constructed in a dry dock, and the concrete for the upper half was poured under floating conditions at sea (**Fig.1**). Because of such unstable pouring conditions, the three-dimensional finite-element method (3D FEM) was used to analyze temperature and stress in order to evaluate the risks of cracks occurring during construction; this led to crack inducers being installed in the side wall every 12m in the longitudinal direction (**Fig.2**).

The analyses and the use of crack inducers were verified by conducting full-scale mock-up tests (**Fig.3**). Core samples were extracted from the mock-up specimen for immersion testing to measure the coefficient of chloride ion diffusion, which is used to predict the durability of the concrete.

Fig.1 Construction of an element of the immersed tunnel (L: dry dock, R : floating)

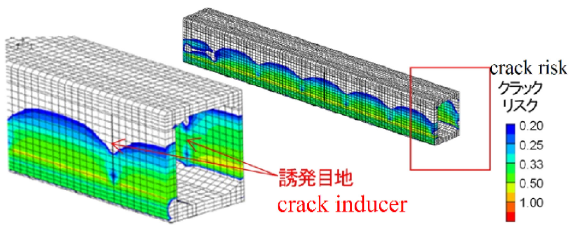

Fig.2 Results of 3D temperature and stress analyses

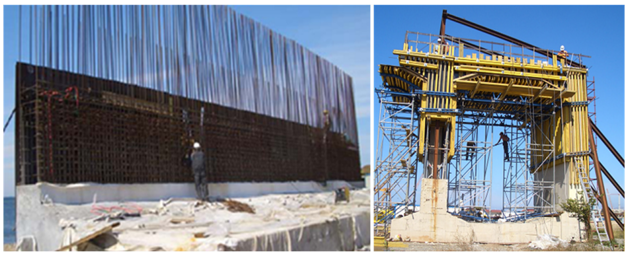

Fig.3 Mock-up tests

So-called "sandwich" structures were placed at either end of each element to connect neighboring elements. Each of these sandwich structures has internal and external surface steel plates connected by internal steel diaphragms, and the space between the surface plates is filled with non-shrink self-compacting concrete.

(2) TBM Tunnel

TBM tunnels were excavated from the ground surface to either end of the immersed tunnel. Their inner diameter is 7.04m, and precast reinforced concrete segments were used for the tunnel lining. These segments are 300mm thick and 1.5m wide.
The total excavation length was 18,720m, and approximately 13,000 segmental rings were required. Because there was no precast-concrete factory in the vicinity that could handle the volume of production, a purpose-built segment factory was established. This factory handled material procurement, rebar assembly, concrete production and pouring, steam curing, and quality control (**Figs.4**, **5**). In the steam curing, the temperature was highly controlled to prevent delayed ettringite formation and to maintain an appropriate production speed.
The TBM tunnels were connected directly to the immersed tunnel without using vertical shafts. Therefore, the end portions of the immersed tunnel were filled with artificial backfill soil (cement-soil mortar) containing anti-washout admixture. Because the stiffness of the ground changes drastically, seismic joints were also installed at these locations.

(3) NATM Tunnel

NATM tunnels were used wherever the tunnel sectional dimension varied, such as at stations, cross passages, and cross-over tunnels (**Fig.6**). In particular, Sirkeci station has a complicated spatial configuration involving connections among the main tunnel, a passenger walkway tunnel, ventilation shafts, and an escape shaft. Therefore, 3D FEM analyses were required to design the concrete linings and internal structures.

3. Conclusion

Various concrete practices including design and construction were incorporated to connect Asia and Europe. The railway service through the Bosphorus tunnel began on October 29, 2013 and is now an indispensable part of public transportation in Istanbul.
The paper was honored with Award of the Japan Concrete Institute in 2015.

Fig.4 Segment factory for TBM tunnel

Fig.5 Segment production process

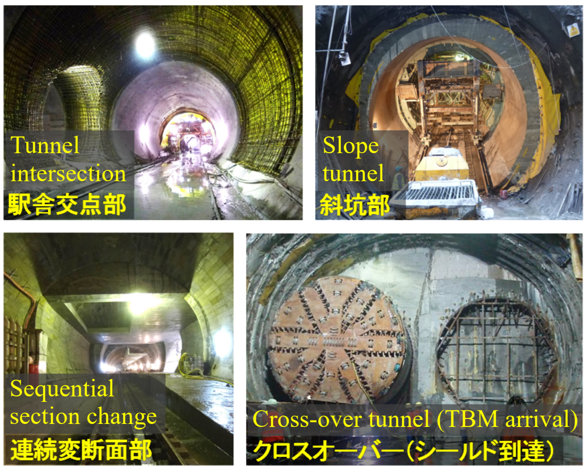

Fig.6 NATM construction

Reference

[1] Yamamoto, T., Yokota, K., Koyanagi, T. and Shimizu, Y.: *Railway Tunnel Crossing the Bosphorus Strait to Connect Asia and Europe –Structures Provided the Strength, Durability and Waterproofness of 100 Year Service Life–*, Concrete Journal, Vol.52, No.11, JCI, Tokyo, pp. 1007-1012, Nov. 2014. (in Japanese)