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Fire Thermal Stress and Its Damage to Subsea Immersed Tunnel

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Abstract

Relying on subsea immersed tunnel of the Hong Kong-Zhuhai-Macau Bridge (HZMB) project, this paper studies thermal stress redistribution and fire damage of twin-tube structure for achieving a quantitative assessment to thermal stress damage of tunnel linings in fired condition. Being different from classical static analysis method used for tunnel structure, a modified calculation method is proposed for building thermal-mechanical coupled model of twin-tube structure with basic temperature rise curve of fire as thermal boundary input. In this coupled model, thermal and mechanical parameters used to reinforced concrete structure could change over time. By means of the analysis of transient heat conduction, temperature gradient inside tube structure is obtained. On this basis, heat and outer loads' combined effect on twin-tube is carried out to solve the stress redistribution in the direction of tube depth. At last, this paper focus on the effect of having or note fireproof board on tube damage depth. The results show that the temperature inside tube would rise and bring down rapidly, and that tube surface stress induced by heat would exceed concrete compressive strength and lead to disruption. Having or not thermal insulation is a key to tube structure. The depth of heat stress damage would reduce 58.3 percent under the condition of laying fireproof board.

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Keywords: Immersed Tunnel; Tube Structure; Fire Damage; Temperature Field; Thermal-mechanical Coupled; Reinforced Concrete Structure.

1. Introduction

Subsea immersed tunnel belongs to linear structure. Due to its long shape and closed feature, smoke and heat emission are difficult. Therefore, damage caused by fire is severer than that of other structures. Unprotected concrete will burst within 5~30min at high temperature or under flame action. Fire in tunnel not only causes physical and

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chemical damage to immersed tube, but also threatens safety and stability of tube system caused by reduction of mechanical property [1,2]. Besides, immersed tunnel is arranged in marine environment. On the top, water is unlimited. Water leakage caused by fire burst will generate adverse effect on traffic operation. How to diagnose and evaluate fire in immersed tunnel in marine environment is a key scientific problem.

At present, mechanical analysis of immersed tunnel is mainly centralized in static or dynamic calculation and analysis on thermal-mechanical coupling of fire is less. Wei Gang et al. [3] put forward calculation method of vertical uneven sedimentation of single tube or many tubes of subsea immersed tunnel; Liu Peng et al. [4] built a 3D nonlinear stiffness mechanical model for immersed tunnel joint based on static equilibrium relationship; Han Dajiang, based on time course response method and traveling wave method, put forward seismic analysis and design method for immersed tunnel in Zhujiang River [5-6]. Nestor et al. [7-8] and Jan et al. [9] mentioned fire prevention in operation in 40 years review of concrete immersed tunnel and structure design of immersed tunnel, but didn't mention fire prevention design and evaluation method.

This paper relies on immersed tunnel of the Hong Kong-Zhuhai-Macau Bridge, builds mixed thermal-mechanical analysis model based on load-structure (stratum) by utilization of modern finite element technology, puts forward temporal definition method of thermal parameters and mechanical parameters and analyzes temperature filed, thermal stress and damage of twin-tube in fire condition by taking fire temperature rise curve as thermal boundary input. Therefore, this paper can be regarded as reference basis for study in the field.

2. Engineering overview

Hong Kong-Zhuhai-Macau Bridge engineering is the century engineering in China, including three main projects, artificial island, cross sea bridge and subsea tunnel. The subsea immersed tunnel is built by immersed tube method. It is two-way six-lane with total length of 5664m. Thirty-three tubes (E1-E33) are immersed and continuously jointed. After completion, the tunnel will be the largest mid sea deep immersed tunnel in the world. Standard tube of the tunnel is composed of two holes and one corridor, as shown in figure 1. Length, width and height of single tube are 180m, 37.95m and 11.4m respectively. As above mentioned, as to two-way six-lane immersed tunnel of Hong Kong-Zhuhai-Macau Bridge, there is still no diagnosis and evaluation of fire safety for similar super-large wide structure.

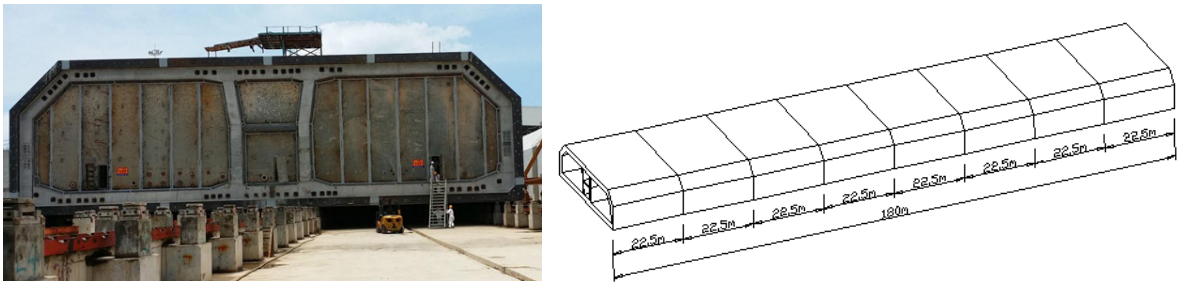

Fig. 1. Section of twin-tube and tube segments

3. Thermal-mechanical coupled finite element modeling method

In case of safety assessment of fire condition of tunnel structure, building proper physical model and selecting related thermal and mechanical parameters are key points. Thermal-mechanical coupled finite element modeling method suggested by the paper is significantly different from traditional load-structure method and stratum-structure method, as shown in fig. 2. There are three aspects: a. adopt mixed model, i.e. load-structure (stratum)-thermal (mechanical) boundary, including exterior load and foundation spring unit in load-structure method as well as stratum unit in stratum-structure method; the stratum unit belongs to thermal-mechanical coupled unit; b. thermal and force boundary includes soil pressure, water load and other static boundary, temperature boundary or heat conduction; c. because there is transient heat conduction of air temperature in tunnel to tube structure, thermal and mechanical