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COMPUTATIONAL ASPECTS IN UNDERGROUND ENGINEERING

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Currently, underground engineering takes a key part in the construction of modern high-rise building, metro networks, as well as tunnel crossing straits. Nevertheless, these remarkable constructions are the foundations of infrastructures of human society. They should provide convenient transportation, fascinating living and working environments. Lists of the examples are Hongkong-Zhuhai-Macau Bridge and Shanghai Centre.

The bridge consists of actual bridges and an immsersed tunnel, Fig. 1. The length of the bridge and the tunnel, measured from point A to point B in Fig. 1(a), is approximately 35.6km. The tunnel is about 6.7km long. Its two ends are situated on artificial islands, the West Artificial Island and the East Artificial Island. Fig. 2 refers to the tunnel, connecting the two parts of the HZMB (Fig.1, Fig.2(a)). The segments of the tunnel elements (Fig.2(b)) are prefabricated on Niutou Island (point C in Fig.1). They have two bores and a middle gallery (Fig.2(c)).

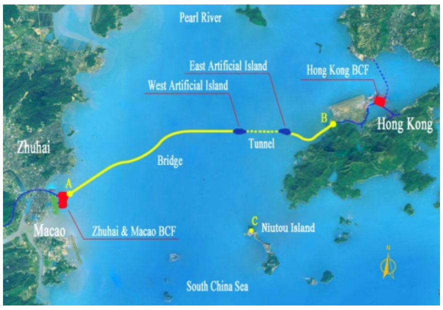


Fig.1: Course of the Bridge

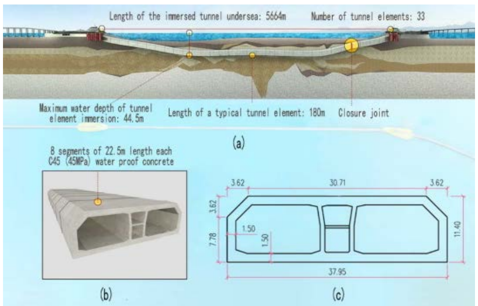
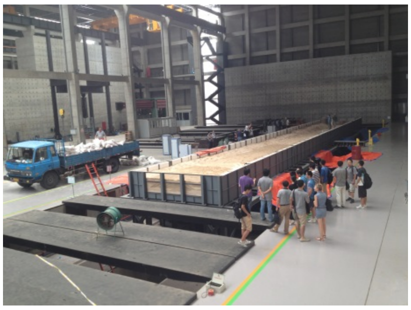


Fig.2 Profiles of the tunnel

The challenge is from the extreme condition of the tunnel located. Apart from load and erosion from sea water, seismic response of the tunnel invokes the needs for large scale computing compared with multi-shaking table tests, Fig.3. It is obvious that simplified structural analysis can not provide the whole understandings of its dynamic performance. A multiscale approach is developed to analysis the dynamic properties of both experiment and in-site tunnel.
The multiscale approach couples FEM calculations with coarse and fine meshes. The coarse-scale mesh is employed to capture seismic response characteristics of the integral system,

whereas the fine-scale mesh describes in detail the dynamic response in positions of potential damage or interest. An overlapping subdomain (Fig. 4) is created between the refined and the coarse meshes, where Lagrange multipliers are used to enforce kinematic constraints. The coupling method bridging domain is implemented to minimize, or at least reduce, spurious wave reflections at the coarse-fine mesh interface. This multiscale modeling method can significantly reduce the computational load. It adequately covers wide simulation areas of the entire tunnel-soil system but may also include details in key locations of the tunnel. Furthermore, the total number of finite elements can be kept within the range of computation capacity of the supercomputer used for the simulations.

(a) Layout of Model Tunnel



(b) Overall View

Fig.3 Multi-shaking-table Test

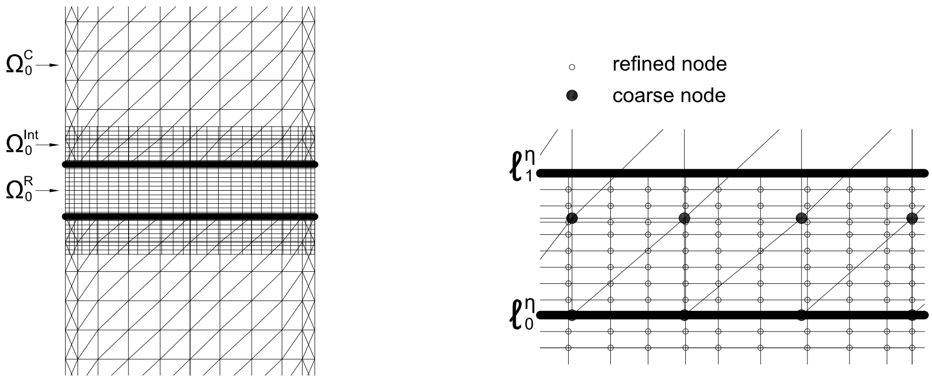


Fig. 4. Bridging domain model for long tunnels.

Mass concreting is the requirement of sound foundation for super-highrise building, Fig.5. The heat released from hydration of cement, pressure of thick concrete more than 10 meters, as well as transporting of water within concrete mass is a sophisticated process. Moisture content, thermal gradient, and stresses will vary with time. Theoretically, the process can be modelled as a multifields phenomenon.


(a) Profile


(b) Pouring concrete

Fig.5 Shanghai Centre

The heat accumulated by hydration of cementitious materials will diffuse through massive concrete structures, which is a classical heat-transfer problem. Meanwhile, the moisture transport near surfaces of structures belongs to the moisture-transfer problem, which will lead to the drying-shrinkage of early-age concrete especially in high-performance or high-strength concrete structures. In terms of massive structures themselves, the structural system will 'grow' with the process of fabrication, which is a typical mechanical problem in variable-structure system. All these are joined together and turn to a coupled-field system in massive concrete structures.

To understand the performance of massive concrete structures, a constitutive model for early-age materials should be employed, in which the elastic strain caused by load, thermal strain related to temperature variation, shrinkage strain and creep should be taken into account together. These components can be obtained by means of experiments or precisely by multiscale modelling and computations.

After defining the materials' early-age behavior, the structures' behavior can be modeled through the process of heat transfer, moisture transfer and the stress growing caused by different volume changes, or the coupled thermo-hydro-mechanical analysis.

Considering the evolution of the hydration reaction or movement of moisture is practically independent of the strains and stresses that develop in concrete, it is usual to consider a unidirectional coupling in which the mechanical analyses are performed after the thermal or hydro computations. With such an option, the thermal or hydro problem is assumed to be independent from the mechanical one.

As far as the mechanical analysis is concerned, it can be activated after the thermal or hydro modeling, from which it receives the local temperatures or moisture content indispensable for computing the thermal strain or shrinkage together with creep strain, as well as proper allowance for the external and internal restraints.

The above thermo-hydro-mechanical analysis can be solved with the help of the finite element method. The structural behavior or early-age performance can thus be predicted within the whole growing period.

The paper does not intend to present all points in computation of underground structures, but key aspects that would hinder its construction. The examples will also give discussion on the needs of nova algorithm on multiscale simulation and multifields for engineering usage.

REFERENCES