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Numerical analysis of DRC segment under inner water pressure based on full-scale test verification for shield tunnel

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ABSTRACT

Shield tunnel subjected to high inner water pressure is used to prevent waterlogging, and DRC (Ductile cast iron segment and Reinforced Concrete) segment has been developed for obtaining high loading capacity in the linings of underground drain shield tunnel. In general, tunnel linings resist bending moment, hoop and shear forces. Cracks will occur in tunnel linings under high inner water pressure during operating period, while tensile stress will appear at member section. On the basis of the existing experimental results, the crack pattern, relative slip, contact stress, strain distribution, and relationship between deflection and load of DRC segment were investigated by finite element method. A three-dimensional finite element model of DRC segment was proposed to simulate its nonlinear behaviors by applying MSC.Marc software package. Taking the three sources of nonlinearity into account, the proposed numerical model fully presented the complicated behaviors of DRC segment during the whole loading process. Results indicated that the numerical studies agreed well with the experimental tests, and comparisons between them demonstrated that the proposed numerical model could excellently analyze the nonlinear behaviors of DRC segment under combined hoop and bending loads.

1. Introduction

Composite structures have been widely used and studied over last few decades since they can take the advantages of constituent materials. For instance, Steel-Concrete-Steel (SCS) sandwich structure is one of important composite structures because of its outstanding property of bearing the extreme blast loadings. However, it is also because composite structures consist of two or more constituent materials that the holistic behaviors are quite different from those single structures, which attracts researchers and engineers' attention. A great number of analytical, experimental and numerical research works have been carried out worldwide to investigate and model the behaviors of composite structures.

Thomsen and Rits (1998) dealt with the local stress concentration of sandwich plates and then proposed a high-order theory. Extensive works were devoted to sandwich plates by Sahoo and Singh (2014). Qin and Wang (2009) and Alfredsson et al. (2012) derived theoretical solutions to sandwich beam under impulsive and flexure loading respectively. Hu et al. (2014) developed an analytical program to study the behaviors of concrete-filled steel plate composite shear walls. Experiment has always played a significant part in analyzing the behaviors of composite structures. The deformation of sandwich beam became complicated under flexure loadings (Minakuchi et al., 2007; Manalo and Aravinthan, 2012; Leng et al., 2015), and this can cause severe damage at different locations on beam during experiments. Sandwich panel was found to have various characteristics during different phases under impulsive or blast loadings (Nurick et al., 2009; Shen et al., 2010; Manes et al., 2013). Shear connectors can affect the strength and stiffness of sandwich panels by producing different degrees of composite action (Chen et al., 2015) and can dissipate dynamic pressure (Sohel et al., 2012), but more energy is absorbed by steel in sandwich panels (Y.H. Wang et al., 2015; J.H. Wang et al., 2015). The behaviors of composite columns (Nie et al., 2013a, 2013b), composite walls (Nie et al., 2013a, 2013b), and other composite structures (Nanayakkara et al., 2011; Haldar et al., 2015; Jover et al., 2014) were also described. Therefore, Zhang and Koizumi (2009, 2010) and Zhang et al. (2014) carried out 14 groups of experiments of closed-composite segment to systematically investigate their mechanical behaviors and to analyze the effects of

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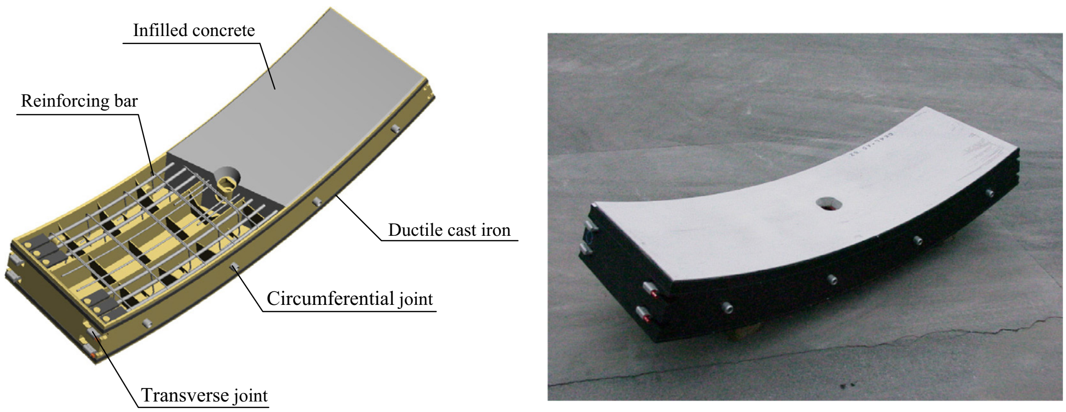

Fig. 1. DRC segment.

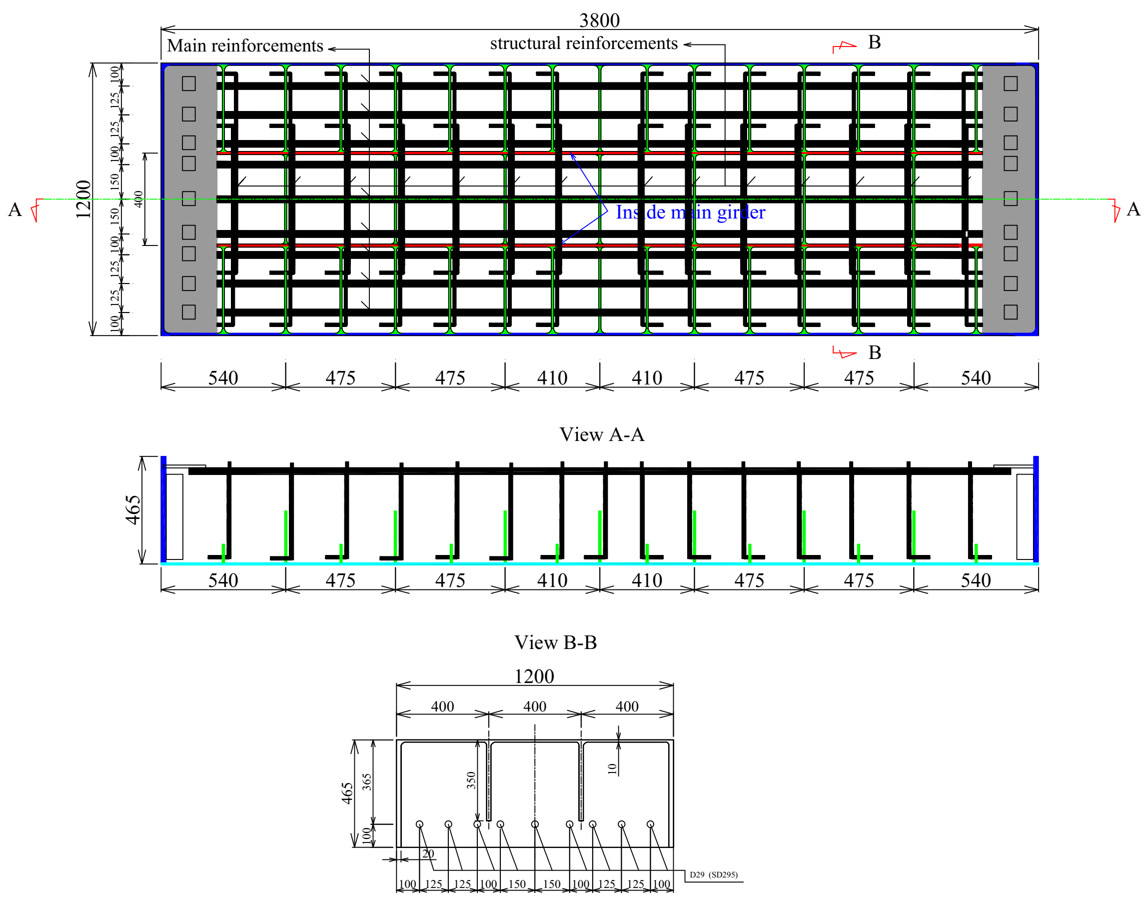

Fig. 2. Configuration and reinforcing bar layout of DRC segment specimens (Unit: mm).

influencing factors on segment. Finite element method (FEM) has also been introduced to evaluate composite structures because of its advantages of convenience and low cost. By using FEM, Smidt (1996) demonstrated a 2D plane strain analysis for sandwich beams. Hou et al. (2013) performed a parametric analysis to simulate the flexural and failure behaviors of sandwich structures. Menna et al. (2013) calculated the plastic deformation of sandwich structures. Based on these experimental and FEM results, corresponding models have been presented for composite beams (Minakuchi et al., 2008; Beheshti-Aval et al., 2013; Qin et al., 2014; Sohel et al., 2015), composite panels (Burton and Noor, 1995; Etemadi et al., 2009; Zhu et al., 2009; Hou et al., 2015), and composite columns (Parel et al., 2014), respectively. Liang (2014) summarized the previous studies on analysis and design of steel and composite structures.

On the other hand, frequent waterlogging in cities is becoming a hard problem to solve in the management of urban construction. Waterlogging not only threatens the safety of urban residents, but also seriously affects the normal development of urban economy. Building large cross-section underground drain shield tunnels and underground reservoirs becomes a powerful solution to solve the problem (Lei, 1999; Feng et al., 2012) because it can make rainwater draining and storing rapid. However, rapid drainage can lead the inner water pressure acting on tunnel linings