Temperature Control Simulation and Stability Analysis of Diversion Tunnel Plug for Hydropower Project

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Abstract

As permanent structure, the diversion tunnel plug often works in complicated condition. Its stability directly affects impoundment for power generation and safety operation of hydropower plants. In this paper, the simulation model considering temperature stress field of nonlinear contact is created by combining with typical engineering. Temperature stress field is calculated and analyzed by hybrid algorithm of interface element and partitioned finite element basing thermodynamic and contact theory during the construction of diversion tunnel plug. The main researches are carried out about the influence of different temperature control measures on the plug temperature stress and surrounding rock contact stability. The results show that: the simulation analysis considering temperature stress field of nonlinear contact can truly reflect the stress state during the construction of diversion tunnel plug. The hybrid algorithm of interface element and partitioned finite element can simulate the process from continuous to discontinuous between the plug and surrounding rock under temperature stress field and improves the computational efficiency for localized nonlinear problems. The research results provide analysis method and reference for the plug design and construction.

Keywords: diversion tunnel plug, mixed finite element method, nonlinear contact, temperature control and crack prevention, stability.

1. Mixed finite element method for contact problem

For two neighboring blocks with contact problem, the static equilibrium equation in the n+1$_{th}$ iteration can be formed as,

$$K\Delta u_n = (F_{n+1} + f_n - \int B^T \sigma_n d\Omega) + \Delta f_n \quad (1)$$

where K is the total stiffness matrix, Δu_n is the displacement vector increment; F_{n+1} is the exterior load vector; f_n is the contact force vector for the nth iteration; Δf_n is the contact force increment at the n+1th iteration; σ_n is the stress tensor. Eq.(1) can be rewritten as,

$$\Delta u_n = K^{-1}(F_{n+1} + f_n - \int B^T \sigma_n d\Omega) + K^{-1}\Delta f_n \quad (2)$$

Considering $\overline{\Delta u_n} = K^{-1}(F_{n+1} + f_n - \int B^T \sigma_n d\Omega)$, Eq.(2) can be changed after using the element flexibility matrix C defined on the possible contact boundaries,

$$\Delta u_n = \overline{\Delta u_n} + C\Delta f_n \quad (3)$$

For contact point pair (1, 2) on the contact surface of BlockΩ_1 and Ω_2, we have

$$\Delta u_n^1 = \Delta \overline{u}_n^1 + C^1 \Delta f_n^1 \quad (4)$$

$$\Delta u_n^2 = \Delta \overline{u}_n^2 + C^2 \Delta f_n^2 \quad (5)$$

Due to the relation between force and reaction $\Delta f_n = \Delta f_n^1 = -\Delta f_n^2$ and noting $C=C^1+C^2$, Eq.(4) minus Eq.(5) results in

$$C\Delta f_n = (\Delta u_n^1 - \Delta u_n^2) - (\Delta \bar{u}_n^1 - \Delta \bar{u}_n^2) \qquad (6)$$

In Eq. (6) above $(\Delta \bar{u}_n^1 - \Delta \bar{u}_n^2)$ is the displacement increment component caused by exterior load increment, which is independent of the contact state, so it can be calculated directly. $(\Delta u_n^1 - \Delta u_n^2)$ is the total displacement increment at this step and it's dependent on the contact state. Since both $(\Delta u_n^1 - \Delta u_n^2)$ and Δf_n in Eq. (6) are unknown, an iteration procedure is required considering the contact conditions.

2. Application

Problem description. The geometry model of the tunnel plug and its surrounding rock are shown as in Fig.1. The plug is built with 5 layers by steps. Due to the hydration of the cement and the water pipe cooling through embedded pipes, the concrete temperature rises at first and then decrease into the water temperature. Certain point values for different layers are plotted in Fig.2. The simulated displacements at the contact points on different layers and the resulting gaps are plotted in Fig.3 and Fig.4, respectively.

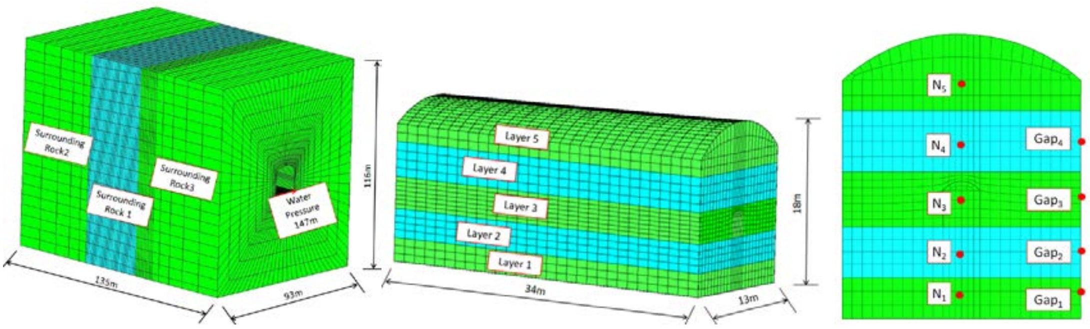

Fig. 1. FE model of the surrounding rocks, the tunnel plug and its cross section.

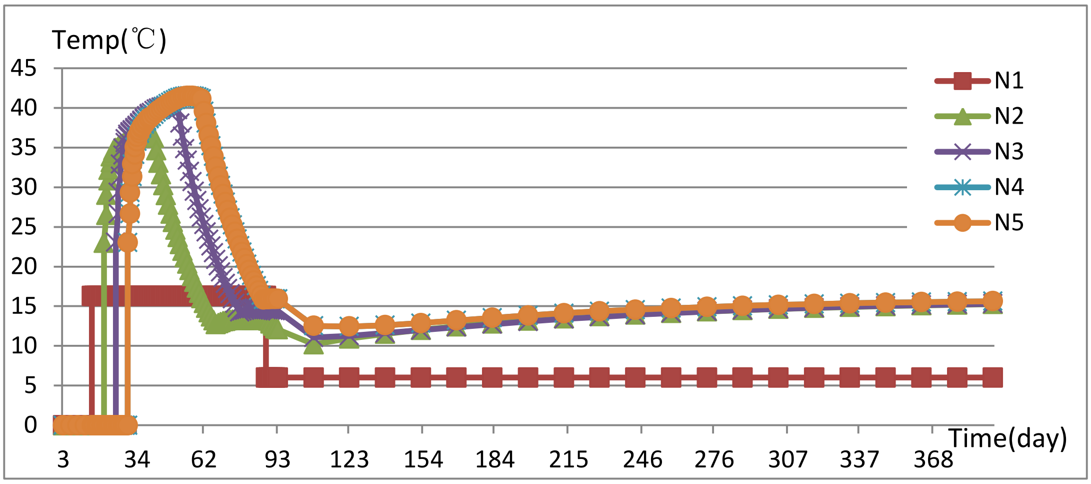

Fig. 2. Simulated temperature(℃) at the center points for different layers (mm)

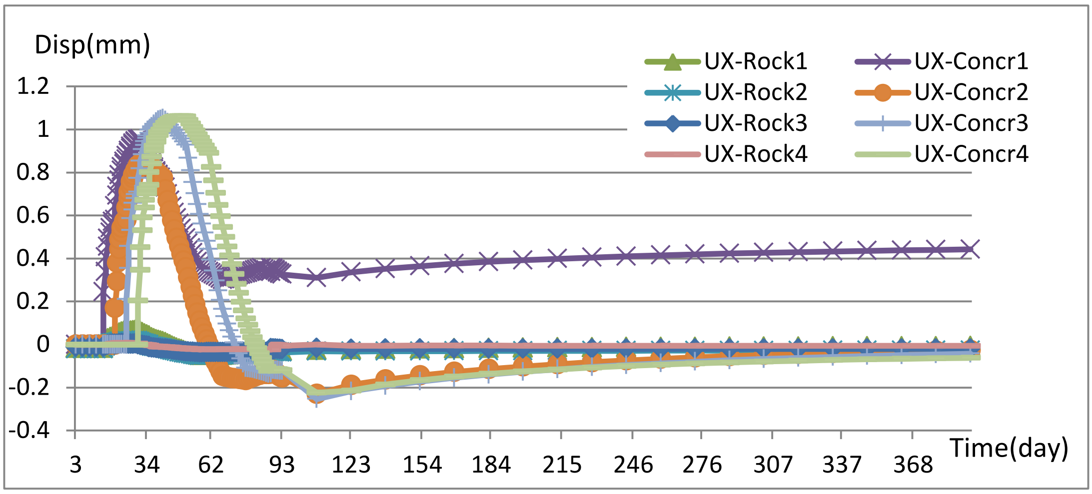

Fig. 2. Simulated displacements at the gap measuring points for different layers (mm)

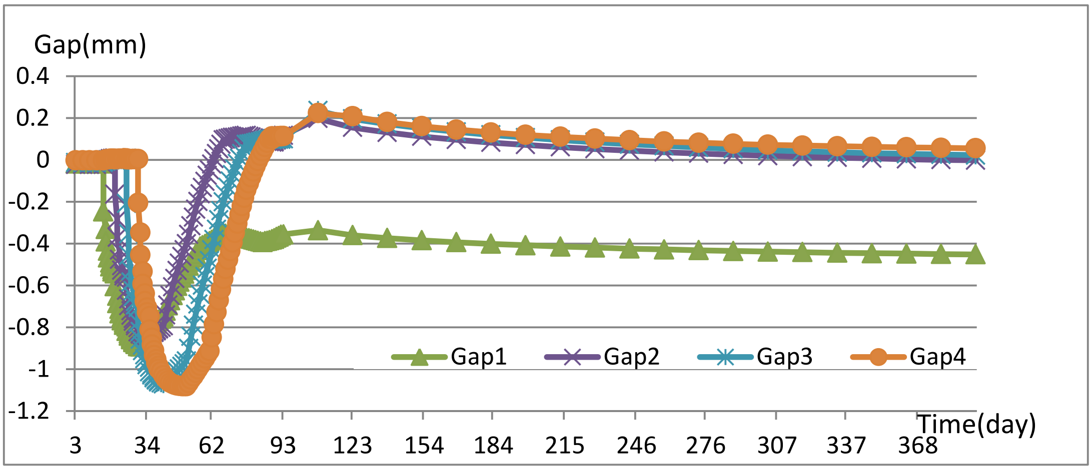

Fig. 3. Simulated gaps at the measuring points for different layers (mm)

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