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Influence of Groundwater Level Rise on The Geomechanical Changing Process in The Tunnel Surrounding Jointed Rock Mass and in The Tunnel Support Structure

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Abstract. In the practical construction of underground excavations, the groundwater level in the surrounding rock masses can fluctuate due to water accumulation (reservoirs), water abstraction and, in particular, due to the consequences of climate change. This fluctuation causes changes in the geomechanical state of the rock mass and effects on the support structure. This phenomenon and its effects must be predicted in order to get appropriate suggestion for the design and construction measures. The article presents some simulation results that analyse the redistribution of geomechanical processes in the jointed rock mass around a tunnel with and without support as well as the rule of the changes of the internal forces in the support structure when the groundwater level changes by using UDEC.

INTRODUCTION

Underground construction always faces a series of problems related to groundwater. Until now, research works mainly focus on forecasting the amount of water that can flow into underground excavation (Kochina 1962; Godman 1965; Lei 1999; El Tani 2003; Hyung Ho Park 2008; Homayoon Katibehl and Ali Aalianvari 2012), as well as the impact of groundwater reducing rock strength, friction and adhesion force of the interface, lead to unstable states of the rock mass (Nguyen Quang Phich et al. 2013). Obviously, when the groundwater level in the rock mass fluctuates, the impact range of the water in the rock mass also changes and leads to fluctuations in the geo-mechanical state. In addition, if the underground excavated opening has a supporting structure, so under the effect of water pressure (crevice water pressure or pore water pressure), the internal force in the supporting structure also changes. This is a practical issue, but so far has not received adequate attention, it needs to be studied in order to be able to analyze more accurately the types of geo-natural hazards, from which it can be proposed adequate solutions and reasonable design of underground support, as well as other geotechnical works.

Based on the above comment and on the basis of the development of powerful numerical simulation tools such as finite difference programs UDEC (Universal Distinct Element Code), FLAC (Fast Langarian Analysis of Continua), finite difference and meshless PFC (Particle Flow Code) and finite element programs such as PLAXIS (Nguyen Quang Phich et al. 2007, Nguyen Quang Phich et al. 2016), it can certainly research to identify general laws, as well as specific rules for each actual case. This article introduces some typical results obtained from a real-life case: a shallow underground structure in a rock mass with two joint systems affected by groundwater level fluctuations from a reservoir, using UDEC.

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NUMERICAL SIMULATION MODEL

The actual case of the problem is outlined in Fig. 1. The rock mass consists of weathered basalt with an average density of 2.5g/cm^3, bulk modulus K = 16.667GPa and shear modulus G = 10GPa. In the rock mass, there is existing two penetrating joints sets with deep angles of 20^0 and -80^0 compared to the horizontal. The 20^0 joint set has a distance of 2m ±0.3m. The joint set with plug angle -80^0 has an average distance of 1.5m±0.2m. The two joint sets have similar characteristics in terms of surface state with the aperture of 2×10^{-4} m, friction angle of 30^0, normal stiffness of 20GPa/m, and shear stiffness of 10GPa/m. The friction angle at the joint surface will decrease and has the value of 25^0 when water is flowed in to rock mass.

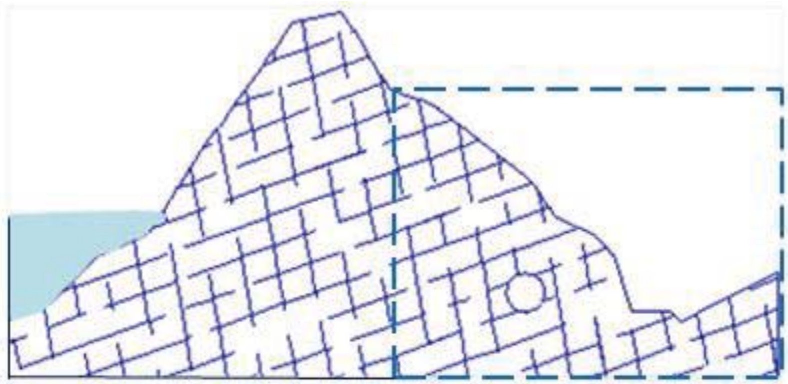

FIGURE 1. Rock mass area with tunnel and traffic road

The problem to be solved is a combining mechanics with hydrodynamics, which is solved by the distinct element method using UDEC program. The flow in the joints is assumed to be laminar and stable in the presence of rising water. The Darcy's law for water flowing as:

$$q = -k_J . a^3 . \frac{\Delta p}{l} \tag{1}$$

where q is the water flow rate through a unit cross-sectional area per unit time; a is the contact hydraulic aperture of the joint set (or joint width); k_J is the permeability coefficient of the joint sets; Δp/l is the hydraulic pressure gradient (Δp is the differential pressure and l is the distance). The permeability coefficient of the joint sets is determined according to the dynamic viscosity of water μ. In fact $k_J = 1/12\mu = 0.833.102$ Pa^{-1}s^{-1} with $\mu = 10^{-3}$Pa.s.

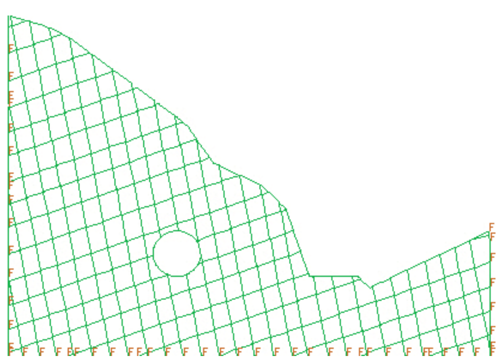

FIGURE 2. Unsupported tunnel

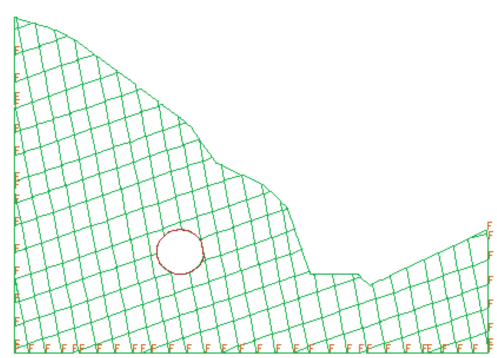

FIGURE 3. Supported tunnel

From the specific geometric conditions, based on the constraints on the boundary conditions of the investigation area in rock mechanics, the diagrams of the investigated problems are shown in Fig. 2 for the case of the unsupported tunnel and in Fig. 3 for the supported tunnel, in this case with concrete lining. The study area is 40 m wide and 30m height; the tunnel has a radius of 2m, with the bottom of the tunnel at the same level as the traffic road; The tunnel roof is 10 m vertically below the surface.

The tunnel stability analysis results show that if the tunnel is not supported immediately after excavation, the rock blocks on the roof of the tunnel slide along two joint faces of the joint set with deep angle of -80^0 in direction to the tunnel as illustrating in Fig. 4. To keep stability of a tunnel, preliminary support chosen is sprayed concrete of 10cm thick. The shotcrete has a density of 2.5g/cm^3, elastic modulus of 21GPa, Poisson coefficient of 0.15 and the tensile strength of 2MPa. After support, although new sliding surfaces appeared, but the rock mass and the supported tunnel were both stable in general, as shown in Fig. 5.

In order to analyze the effecting of water level rise on the stability of unsupported and supported tunnel, the water level at the left boundary was 0m, 2m, 3m, 6m and 10m in compared to the top of the tunnel. The objective of this investigation is estimated the stability of unsupported tunnel and the internal forces in the supported structure.

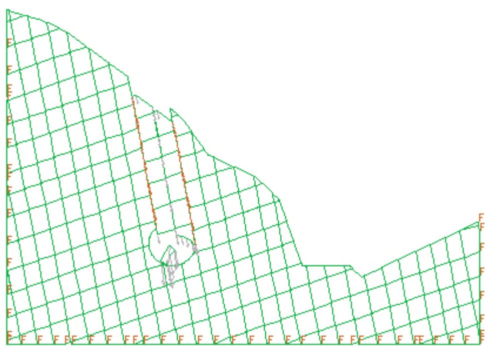

FIGURE 4. Rock Failure in unsupported tunnel

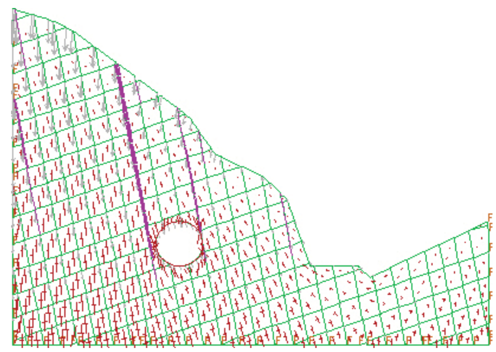

FIGURE 5. Displacement and stress in supported tunnel

SIMULATION RESULTS AND DISCUSSION

The results of the numerical simulation for unsupported and supported tunnel with different water level at the height of 0m; 2m; 3m; 4m and 10m to the tunnel crown are shown in Fig. 6.

The blue color is indicated the water pressure in joints and the magnitude changes with the dark and light color respectively. The red crosses represent the strengths of the maximum and minimum stress components. Their lying position indicates the direction of action. The sepia color represents possible sliding surfaces in the rock mass, and the white (gray) arrows are displacement vectors. The relative length represents the magnitude of the displacement.

Fig. 6 indicate that: if the support structure has not yet been added during the excavation, the rock mass is unstable. The rising water level in the reservoir forms two sliding surfaces at the above of the roof of the tunnel. The jointed rock mass on above of the roof of tunnel is horizontal sliding and the rock mass is completely failured when the water level at 10m from top of the tunnel.

It can be observed in Fig. 6 that many small sliding surfaces occur along the joint sets and that the displacement parallel to the joint set of 20^0 is also with greater magnitude as the water level rises. Although it has not led to failure state but it is necessary to reinforced for the rock mass at the above of tunnel to prevent rock slope failure.

The Illustration of the law of transverse displacement and joint water pressure (or pore water pressure) (blue line) is shown in Fig. 7. It shows that when water pressure increases, due to rising water level up, the horizontal displacement amplitude also increases. Therefore, the increase in water level will cause landslide failure in the face of the crack system with an inclination angle of 20^0.

Fig.8 introduces the results of axial force and moment in the supporting structure of tunnel. The maximum value of axial force and moment in the supporting structure are summarized in the table 1 in different cases of water level.

TABLE 1. Maximum values of axial force and moment in supported structure

Internal force	No groundwater	Groundwater level (m)				
		0	2	3	6	10
N_{max} (MN/m)	0.648	0.625	0.609	0.600	0.596	0.851
M_{max} (10^2 MNm/m)	3.887	-4.980	-5.593	-6.008	-6.297	-6.920

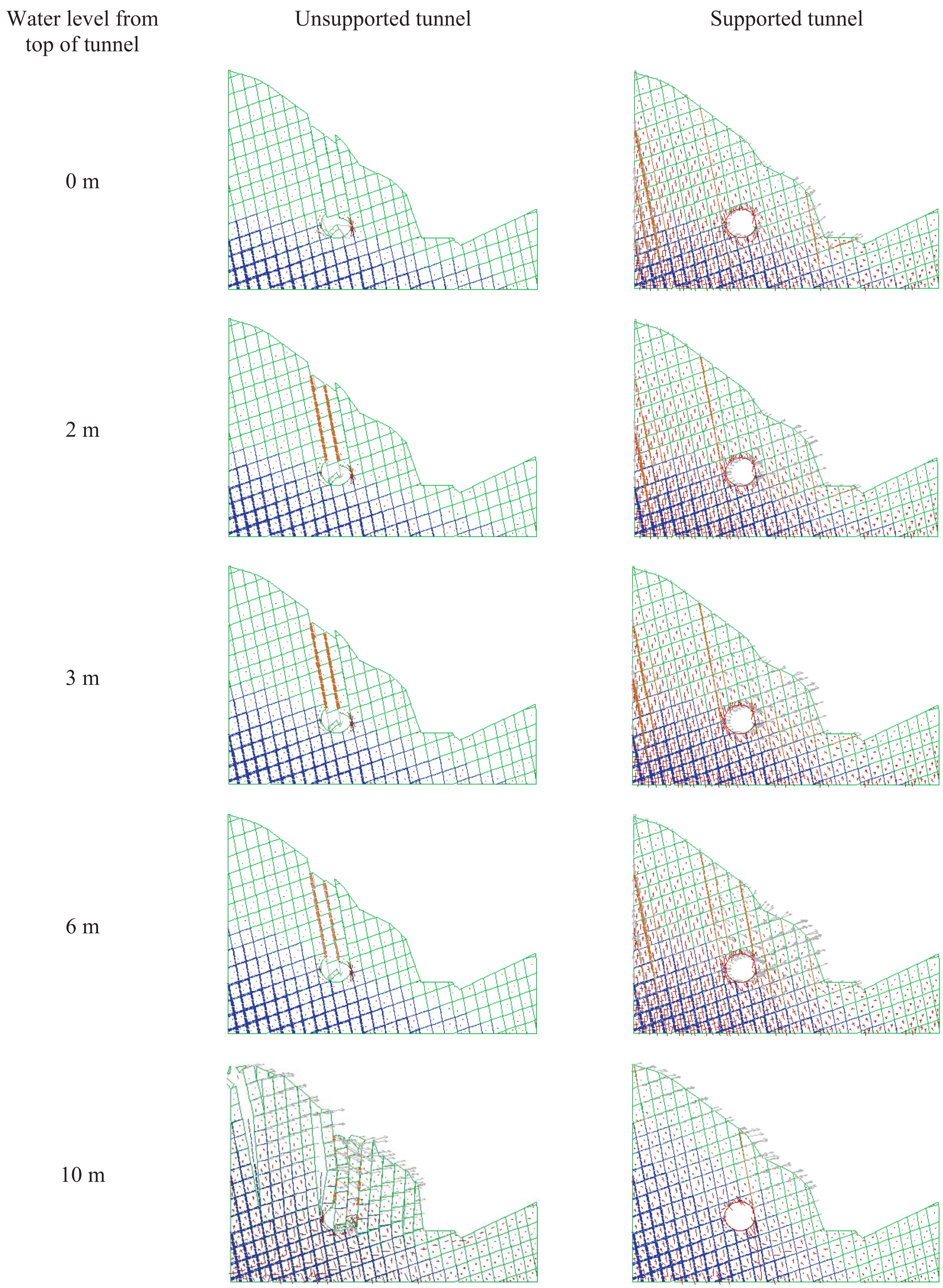

FIGURE 6. Behaviour of tunnel at different water level

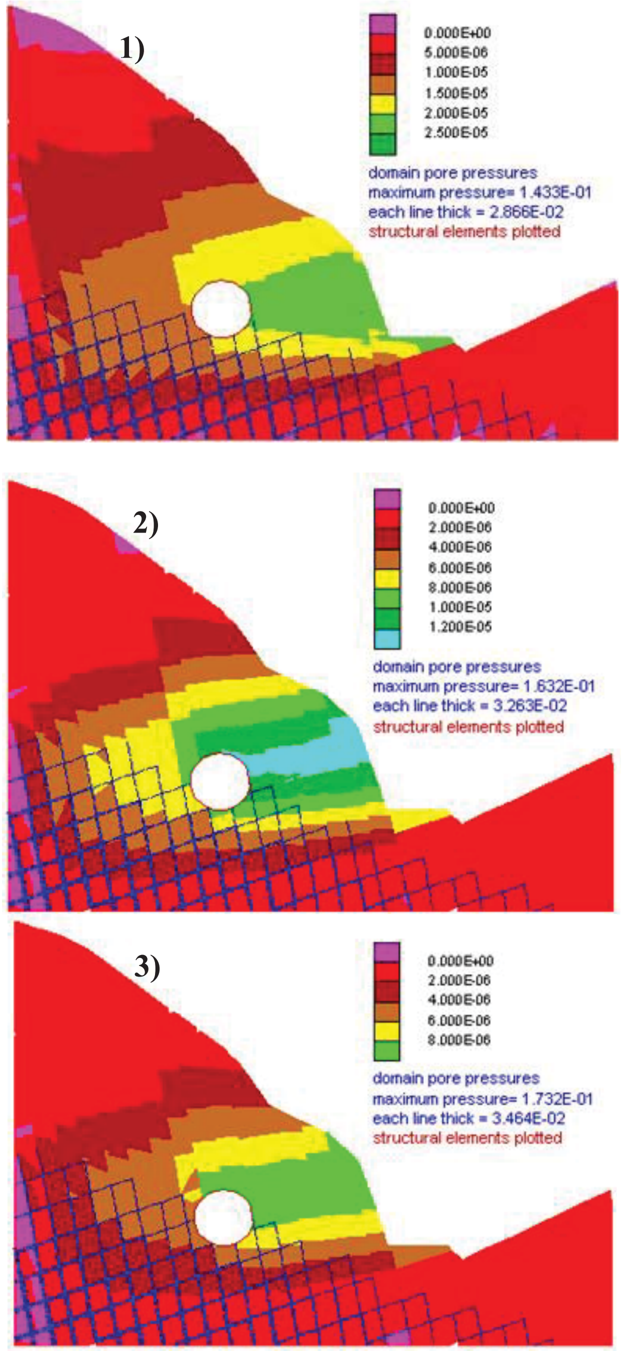

FIGURE 7. Dependent of horizontal Displacemennt and pore pressure on water level obove the top of the tunnel: 1) 0m; 2) 2m and 3) 3m.

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The results in table 1 and Fig.8 show that the axial force is decreased while the moment changes direction and increases when ground water level is at low levels (at 0m, 2m, 3m and 6m). This means that the groundwater level in the joints has not yet overflowed the top of the tunnel. When the groundwater level rises to 10m, it is appeared on the roof of the tunnel and axial force and moment change in the distribution and increase. This is a warning sign that needs attention to analyze the effects of climate change to groundwater level which cause to unstable of tunnel structure and can lead to rock mass failure.

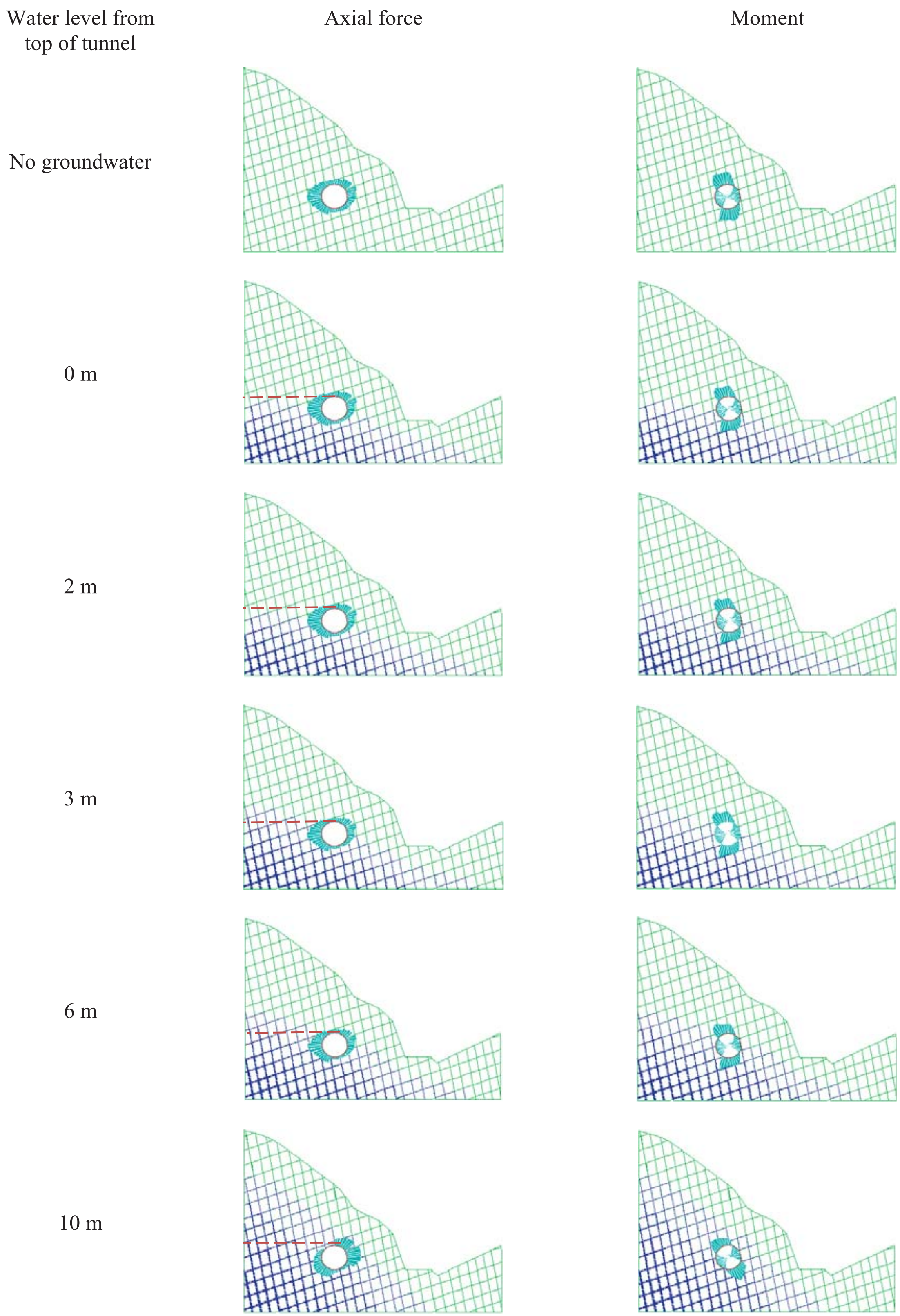

FIGURE 8. Axial force and moment in upporting structure of the tunnel

CONCLUSIONS

The groundwater level in the rock mass around the tunnel is one of the factors effecting to the instability of the rock mass and behavior of the supporting structure. Due to climate change, heavy raining, the groundwater level may rise suddenly. The analysis and simulation by using UDEC numerical model allows to predict the possible mechanical behavior of the rock mass and supporting structure. It is contributed to propose the adequate solutions to prevent geological disasters. The groundwater level also leads to a change in the joints water pressure, which leads to a change in both the magnitude and the direction of the internal forces in the supporting structure. In addition, the simulation results of the effects of groundwater level suddenly change will be indicated for selecting and designing more suitable type of support for underground structures to respond to heavy raining caused by climate change.

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