The Effect Of Ground Surface Dip On The Variations Of Rock Bolts' Axial Forces In Seismic Mode

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***Abstract*— In this study, through Pseudo-static analysis with the help of finite element modeling software phase², effect the ground surface dip on the axial force of rock bolts and it variations in seismic mode evaluated. The circular tunnels are modeled with a diameter of 8 meters and in depth of 10 meters in the shale rocks. The tunnels are supported by end anchored rock bolts. The ground surface modeled in flat mode and also with the dips of 5, 10, 15, 20 and 25 degrees and the earthquake magnitudes of 6.5, 7, 7.5 and 8 on the Richter scale considered. The results of evaluations show that, with increasing the ground surface dip, the variations of axial forces have increased because it forces the tunnel to have more movements and in this condition, rock bolts are under higher tensile stresses. Furthermore, in greater earthquake magnitudes, the axial force of rock bolts variations has increased because of increasing the total displacements around the tunnel. Moreover, in steep surfaces, the alignment of horizontal acceleration of seismic coefficient with steep direction and the same direction of vertical seismic coefficient with gravitational force had resulted in the highest variance of rock bolts' axial force but in flat surfaces, the direction of horizontal seismic coefficient is ineffective.**

Keywords*— *Axial force, Rock bolt, Steep ground, Tunnel, Phase2

I. INTRODUCTION

Tunnels are vital underground structures that can withstand earthquakes. Although underground structures, in comparison to surface structures are of high safety regarding seismic waves, historical evidence and earthquake reports show that these structures are vulnerable to waves which result from earthquake and outbreak of damage and destruction is possible.

One of the ways to stabilizing of tunnels is application of rock bolts. A rock bolt is a long anchor bolt, for stabilizing rock excavations, which may be used in tunnels or rock slopes. It transfers load from the unstable exterior to the confined interior of the rock mass. The rock bolts are almost always installed in a pattern, the design of which depends on the rock quality designation and the type of excavation [1].

Rock bolts have been used for years to reinforce the surface and near surface rock of excavated or natural slopes. They are used to improve the stability and load bearing characteristics of a rock mass. When rock bolts are used to reinforce a fractured rock mass, the rock bolts will be subjected to tension, shear and compressive forces. The studies have been done by researchers [2, 3, 4] to reinforce the slopes with rock anchoring. A general rule for rock bolts is that the distance between rock bolts should be approximately equal to three times the average spacing of the planes of weakness in the rock mass, and the bolt length should be twice the bolt spacing [5].

Tunnels excavate in various rock masses and ground conditions with different modes of behavior. The way the rock masses surrounding a tunnel behave is very important. The behavior of steep ground largely depends on the degree of surface dip and the shape and size of underground excavation. The ground behavior can be assessed via ground conditions with various project features. The rock masses whose strength is lower than the surrounding stress can be considered as weak rocks. The behavior of weak rocks in tunnels has led to problems during the construction of a number of projects. The ratio of rock mass strength to the in situ stress value specifies that deformations induce stability problems in the tunnel. The analysis of circular tunnels excavated in weak rocks under hydrostatic stress fields has been one of the principal sources of knowledge.

Due to excavation of tunnel in weak rocks, the surface settlement of ground could be occurred. The displacements at the surface of ground and the displacement distributions around tunnels varying in the plastic zone. In this matter, the theories are investigated by [6] and [7].

Furthermore, excavating underground structures in rock mass, causes stress changes in the underground environment and this phenomenon can cause displacements in these areas. Also the displacements caused by excavation may cause induced stress on the support system of the tunnels and finally can end with instability of the tunnel surrounding area [8].

Moreover, applying the earthquake to the tunnel can cause compressive and tensile stresses which can leads to the destruction of a temporary tunnel supporting system or even to a complete closure of the tunnel cross section [9].

In this research in order to study the ground surface dip and the effect of seismic coefficients direction on the variations of rock bolts' axial forces, the circular tunnel with a diameter of 8 meters and in depth of 10 meters is modeled and the ground surface dips of 0, 5, 10, 15, 20 and 25 degrees are considered.

II. THE PHYSICAL AND MECHANICAL CHARACTERISTICS OF THE SHALE ROCKS

The rock mass properties such as the rock mass strength (σ_{cm}), the rock mass deformation modulus (E_m) and the rock mass constants (mb, s and a) were calculated by the RocLab program defined by [10] (Table 1). This program has been developed to provide a convenient means of solving and plotting the equations presented by [10].

In RocLab program, both the rock mass strength and deformation modulus were calculated using equations of [10]. In addition, the rock mass constants were estimated using equations of Geological Strength Index (GSI) [10] together with the value of the shale material constant (mi). Also, the value of disturbance factor (D) that depends on the amount of disturbance in the rock mass associated with the excavation method was considered equal to 0.2 for the shale rocks in Table 1.

Table 1. Geomechanical parameters of shale rock mass obtained by using RocLab software.

Input and output of Roclab software						
Hoek-Brown classification				**Heok-Brown criterion**		
σ_{ci} (Mpa)	GSI	m_i	D	M_b	s	a
Intact Uniaxial compres-sive strength	Geologi-cal strengt-h index	Constant Hoek-Brown criterion for intact rock	Disturb-ance Factor	Heok-Brown criterion		
35	**32**	**6**	**0.2**	**0.404**	**0.0003**	**0.520**

Parameters of the Mohr-Coulomb equivalent		Rock mass Parameters			
Mohr-Coulomb Fit		**Rock Mass Parameters**			
C (Mpa)	φ (degree)	σ_t (Mpa)	σ_c (Mpa)	σ_{cm} (Mpa)	E_{rm} (Mpa)
Cohe-sion	Friction angle	Tensile strength	Uniaxial compress-ive strength	Global strengt-h	Deformati-on modulus
0.079	**54.04**	**-0.026**	**0.522**	**2.700**	**495**

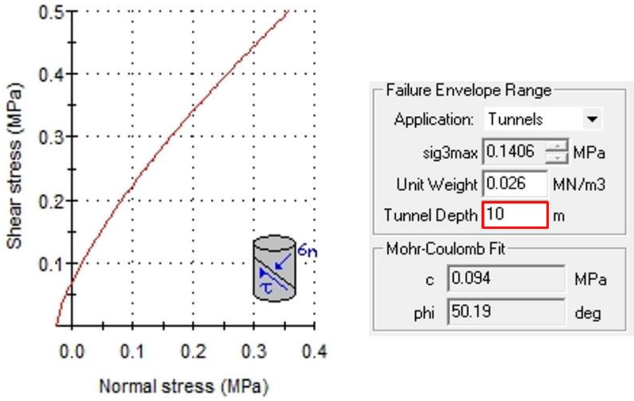


Fig. 1. The Hoek-Brown failure envelope of shale rock masses in the depth of 10 meters.

The Hoek-Brown failure envelope of shale rock masses for depth of 10 meters is obtained and presented in Fig. 1.

III. NUMERICAL ANALYSIS

Numerical analyses are done using a two-dimensional hybrid element model, called Phase^2 Finite Element Program [11]. This software is used to simulate the two-dimensional excavation of a tunnel. In this finite element simulation, based on the elasto-plastic analysis, deformations and stresses are computed. These analyses used for evaluations of the tunnel stability in the rock masses. The geomechanical properties for these analyses are extracted from Table 1. The generalized Hoek and Brown failure criterion is used to identify elements undergoing yielding and the displacements of the rock masses in the tunnel surrounding.

To simulate the excavation of tunnels in the shale rock masses, a finite element model is generated for circular tunnels with a diameter of 8 meters and in depth of 10 meters. Also the dips of 0, 5, 10, 15, 20 and 25 degrees to the horizon are considered as the ground surface dips. The six-nodded triangular elements are used in the finite element mesh. The end anchored bolts with length of 3 meters and spacing of 2 meters are used for reinforcement of tunnels. Figs. 2 and 3. show the different ground surface dips which considered in tunnels modeling.

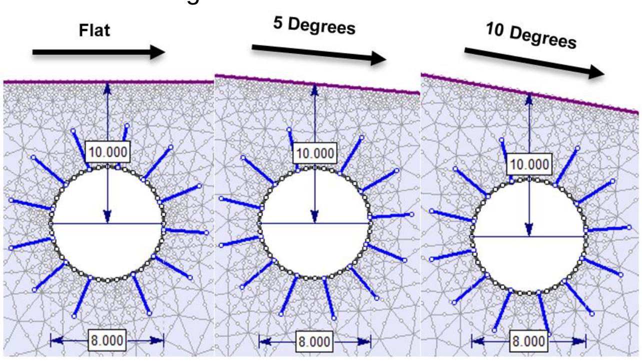


Fig. 2. The modeling of circular tunnels with a diameter of 8 meters and in depth 10 meters. The dips of ground surface are 0, 5 and 10 degrees to the horizon.

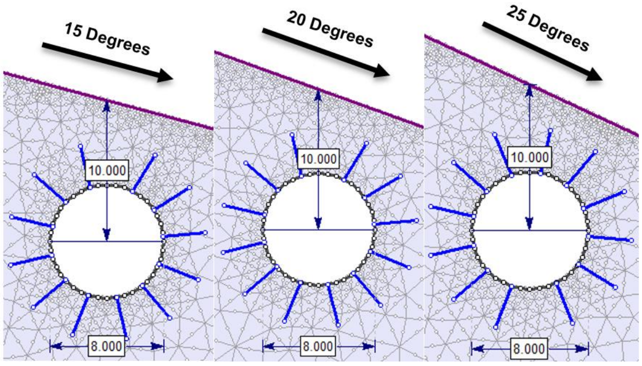


Fig. 3. The modeling of circular tunnels with a diameter of 8 meters and in depth 10 meters. The dips of ground surface are 15, 20 and 25 degrees to the horizon.

Figs. 4 to 9. show the results of rock bolts' axial forces and tunnel displacements in different dips of ground surface and in static mode.

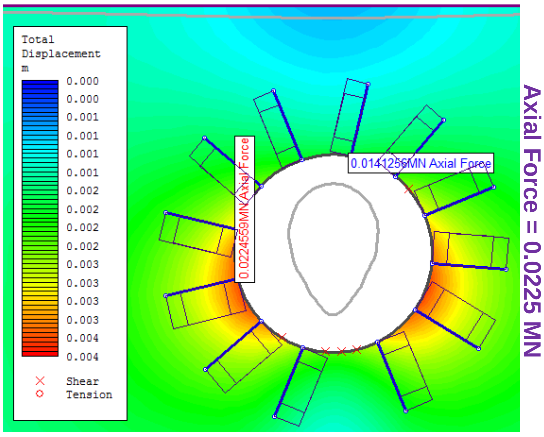


Fig. 4. The axial force of rock bolts and tunnel displacements in static mode. The ground surface is flat.

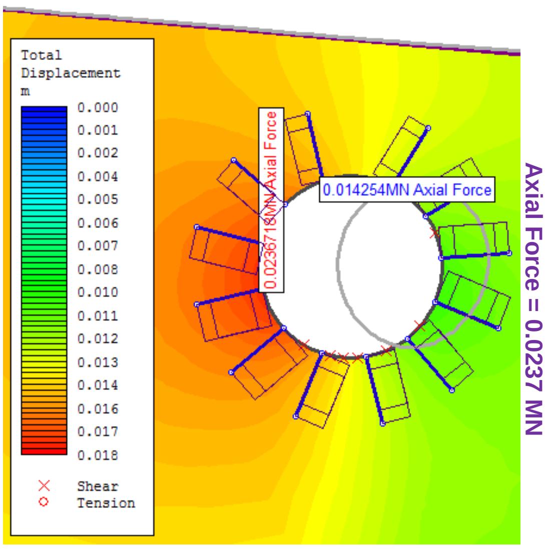


Fig. 5. The axial force of rock bolts and tunnel displacements in static mode. The dip of ground surface is 5 degrees to the horizon.

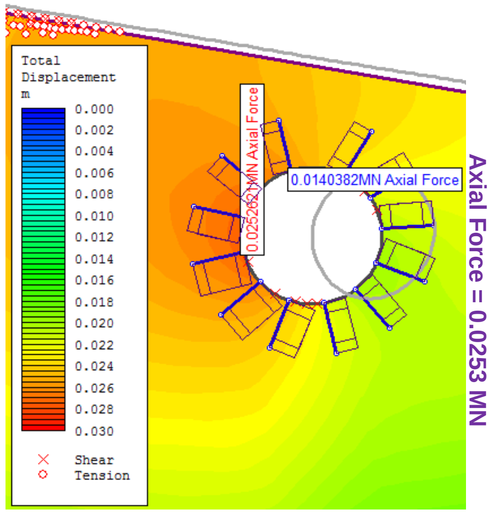


Fig. 6. The axial force of rock bolts and tunnel displacements in static mode. The dip of ground surface is 10 degrees to the horizon.

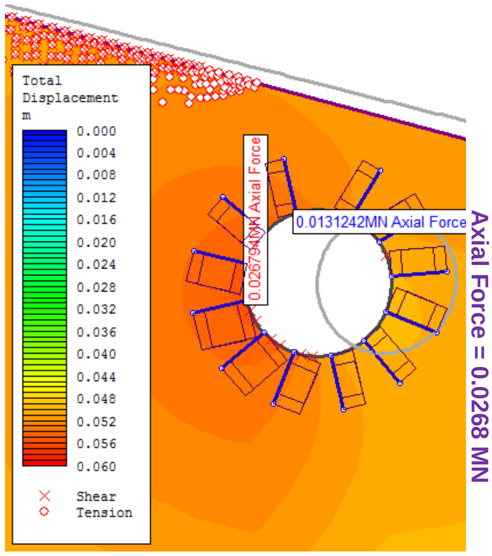


Fig. 7. The axial force of rock bolts and tunnel displacements in static mode. The dip of ground surface is 15 degrees to the horizon.

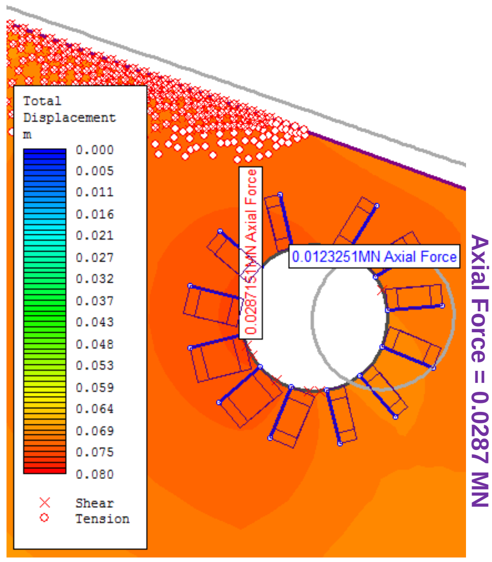


Fig. 8. The axial force of rock bolts and tunnel displacements in static mode. The dip of ground surface is 20 degrees to the horizon.

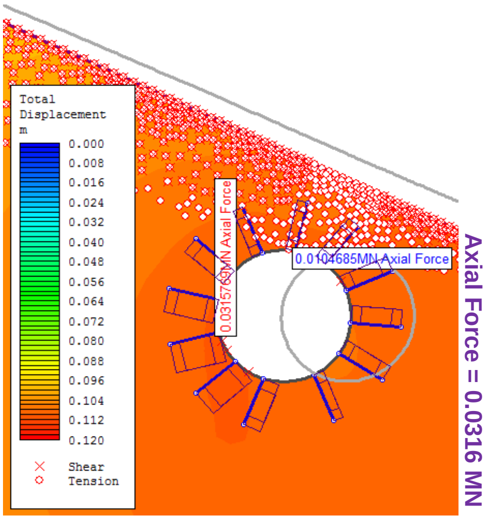
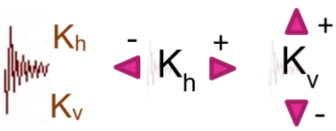


Fig. 9. The axial force of rock bolts and tunnel displacements in static mode. The dip of ground surface is 25 degrees to the horizon.

As the above figs. show, with increasing the dip of ground surface in static mode, the axial force of rock bolts increased too. Because the declivity of ground surface, forces the tunnel to have more displacement and in this condition, rock bolts are under higher tensile stresses which shown as the axial force of them.

Furthermore, a set of numerical analysis case studies were carried out to investigate the effect of horizontal and vertical seismic coefficient in steep ground, using the pseudo-static seismic loading procedure. Four seismic loading scenarios, as shown in below are applied to the models.

At first, it's necessary to mention that when horizontal seismic coefficient (K_h) is positive, it applies to right side and when it's negative, applies to left side. For vertical seismic coefficient (K_v), positive value means upward and negative value means downward.



1) K_h = **+** value and K_v = **0**. In this case the effect of vertical seismic coefficient ignored and equal to zero considered.

2) K_h = **+** value and K_v = **+** value too. This seismic loading scenario considers a positive horizontal and vertical seismic coefficient. In this case, the vertical seismic coefficient is adding an inertial force and in the opposite direction as the downward force due to gravity.

3) K_h = **+** value and K_v = **-** value. This loading case the sign of the vertical seismic coefficient is negative. Thus, the inertial force, simulating seismic loading, is in the same direction with gravitational force and therefore is added to the self weight.

4) K_h = **-** value and K_v = **-** value too. In this case the direction of horizontal seismic coefficient is in negative direction. This case was established to investigate the influence of direction of horizontal seismic coefficient on the axial force of rock bolts.

All the horizontal and vertical seismic coefficients are calculated for the earthquakes with magnitudes of 6.5, 7, 7.5 and 8 on the Richter scale, by equations presented in [12].

Figs. 10 to 15. show variations of axial force in terms of earthquake magnitudes for different dips of ground surface. The variations of axial force are difference between static and pseudo-static axial force values. The diameter of 8 meters and depth of 10 meters considered for tunnels in all cases.

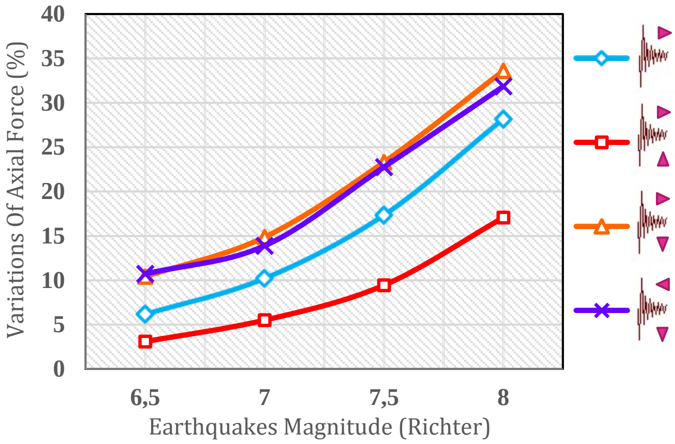


Fig. 10. Variations of axial force in terms of earthquake magnitudes. The ground surface is flat.

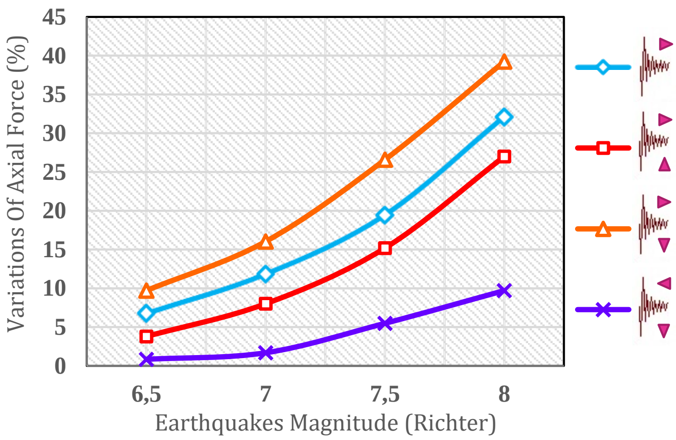


Fig. 11. Variations of axial force in terms of earthquake magnitudes. The dip of ground surface is 5 degrees to the horizon.

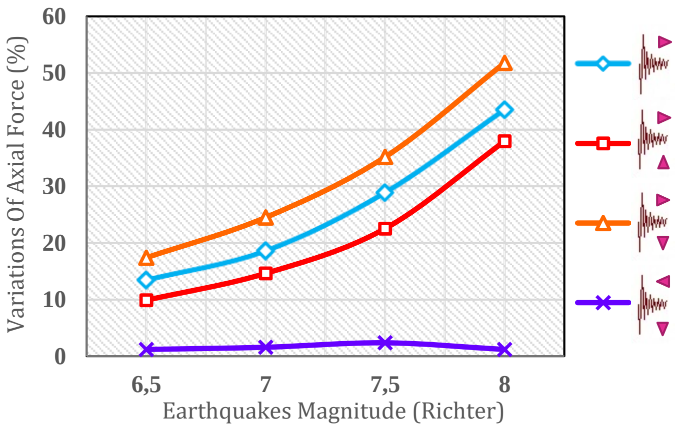


Fig. 12. Variations of axial force in terms of earthquake magnitudes. The dip of ground surface is 10 degrees to the horizon.

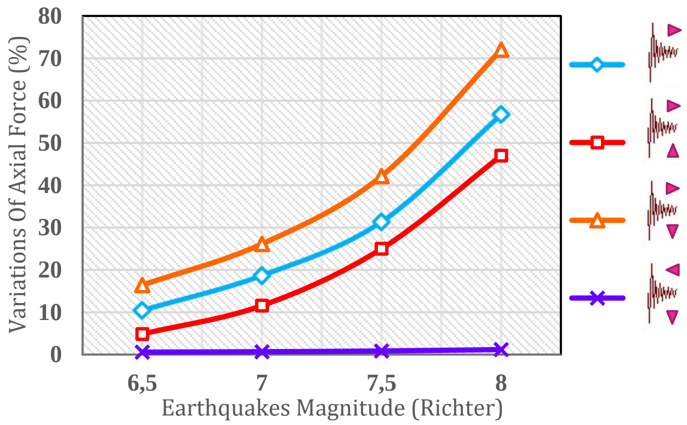


Fig. 13. Variations of axial force in terms of earthquake magnitudes. The dip of ground surface is 15 degrees to the horizon.

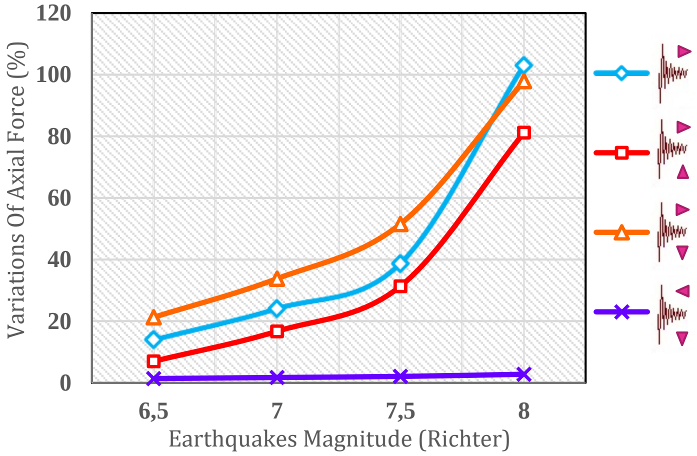


Fig. 14. Variations of axial force in terms of earthquake magnitudes. The dip of ground surface is 20 degrees to the horizon.

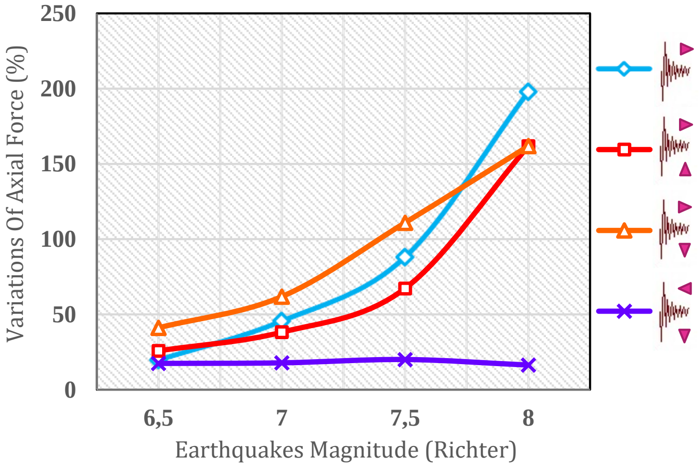


Fig. 15. Variations of axial force in terms of earthquake magnitudes. The dip of ground surface is 25 degrees to the horizon.

As the results show, when the ground surface is flat, with increasing the earthquake magnitude, the variations of axial forces have increased for all seismic loading scenarios because, the total displacements around the tunnels has been increased. Moreover, we can see the highest variations of axial forces for purple and orange curves in fig. 10 which is because of the same direction of vertical seismic coefficient (K_v) with the gravitational force in them. But unlike the previous case results (fig. 10), in steep grounds results (figs. 11 to 15.), we see the lowest variations of axial forces for purple curves and the highest results still related to the orange curves. In fact, in these cases, the alignment of horizontal acceleration of seismic coefficient (K_h) with steep direction and the same direction of the vertical seismic coefficient (K_v) with gravitational force had resulted in the highest axial force of rock bolts and it variations that shown with orange curves in Figs. 11 to 15. But when the horizontal seismic coefficient (K_h) is in opposite direction of ground surface dip, the lowest results, compared to the other modes have been obtained. Because it reduces the displacements of tunnel.

Furthermore, based on the above figs. we can see about 33 percent of variations as the maximum of axial forces variations in flat ground results (fig. 10). But in steep grounds, with increasing the dip of ground surface, the maximum variations of axial forces increased. Because the effect of ground surface dip, forces the tunnel to have more displacements in the same direction of ground surface dip and the seismic forces are also supplement it to make more movements. In this condition, rock bolts put under severe tensions to can control the displacements of tunnel and finally the growth rate of axial force variations has increased.

IV. Conclusions

The results of the evaluations show that, with increasing the dip of ground surface in static mode, the axial force of rock bolts increased. Also, when the ground surface is flat, with increasing the earthquake magnitude, the variations of axial forces have increased for all seismic loading scenarios. The highest variations of axial forces in flat grounds related to the purple and orange curves, because of the same direction of vertical seismic coefficient (K_v) with the gravitational force in them. But in steep surfaces, the alignment of horizontal acceleration of seismic coefficient (K_h) with the direction of ground surface dip and the same direction of vertical seismic coefficient (K_v) with the gravitational force, had resulted in the highest axial force of rock bolts and the opposite direction of horizontal seismic coefficient (K_h) with ground surface dip leads to obtaining the lowest axial force of rock bolts. Moreover, the effect of ground surface dip, forces the tunnel to have more displacements in the same direction of ground surface dip and the seismic forces are also supplement it for more movements and in this condition, rock bolts put under higher tensile stresses that leads to increasing the growth rate of axial force variations. It is important to note that in excessive tensile stresses, there is a possibility of yielding in rock bolts which can leads to the destruction of a temporary tunnel supporting system or even to a complete closure of the tunnel cross. So, design engineers have to pay special attention in variations of rock bolts' axial forces and tensile stresses which affect the tunnel and it supporting system, to prevent structural damages and casualties in underground structures during the earthquake.

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