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The Effect Of Rock Mass Locked-in Stresses On The Axial Force Of Rock Bolts

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***Abstract*— In this study, through Pseudo-static analysis with the help of finite element modeling software phase2, effect size of factors such as tunnel depth, dip of ground surface and rock mass locked-in stresses on axial force of rock bolts installed in the tunnel and it changes in different conditions evaluated. The circular tunnels are modeled with diameters of 4, 6, 8, 10 and 12 meters and in depths of 5, 10, 25 and 35 meters in the shale rocks. The tunnels are supported by end anchored rock bolts with length of 3 meters and spacing of 2 meters. Also the ground surface modeled with dip of 0, 5, 10, 15, 20, 25 and 30 degrees and the earthquake magnitude of 8 on the Richter scale is considered. The results of the evaluations show that locked-in stresses in rock mass cause the increase of rock bolts' axial force, but the amount of axial force variations is less when compared to the non-existential condition of locked-in stresses.**

Keywords*— *Axial force; Rock bolt; Locked-in stress; Tunnel; Phase2

I. INTRODUCTION

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 work by knitting the rock mass together sufficiently before it can move enough to loosen and fail by unravelling. The rock bolts can become seized throughout their length by small shears in the rock mass, so they are not fully dependent on their pull-out strength.

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].

Locked-in stresses are stresses inside a rock mass body, or in parts of it, that's in equilibrium after all boundary loads have been removed. An example of locked-in stresses are sedimentary multilayer rock masses consisting of intermittent weak and stiff layers that firmly welded together (Fig.1). After uplifting, multilayered rocks are cut out of the sequence while completely unloaded layers in an opposite sign of normal stresses remain locked in nearby layers by the interlayer joining [6].

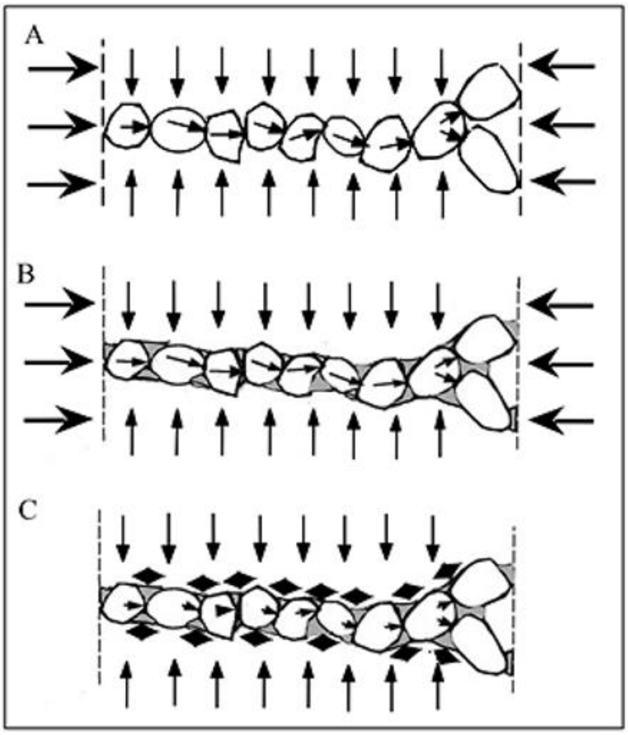

Fig. 1. Locked-in stresses of a granular material. Stages of formation: A) Before cementation; B) After cementation; C) Stress transfer after unloading (vertical arrows indicates tensions in the cemented material) [7].

Higher locked-in stresses can exist on a micro scale. These stresses in sedimentary rock masses may usually derive from the rock formation processes [7].

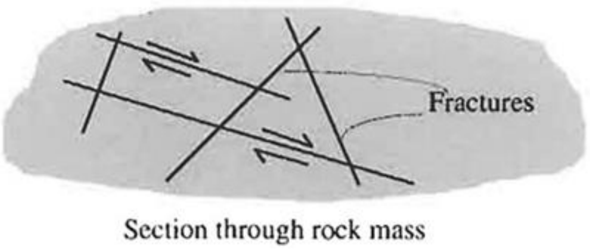

Fig. 2. The concept of locked-in stresses, in a rock mass [7].

These stresses typically have small values in rock masses, so in this study 0.1 Mpa intended for them in numerical modeling.

Also in order to study the effect of rock mass locked-in stresses on the axial force of rock bolts, the circular tunnels with different depth and diameter are modeled in static & dynamic conditions and the effect of ground surface dip evaluated in analysis processes.

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 [8] (Table 1). This program has been developed to provide a convenient means of solving and plotting the equations presented by [8].

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**

The Hoek-Brown failure envelope of shale rock masses for different depths is obtained and presented in Figs. 3 to 6.

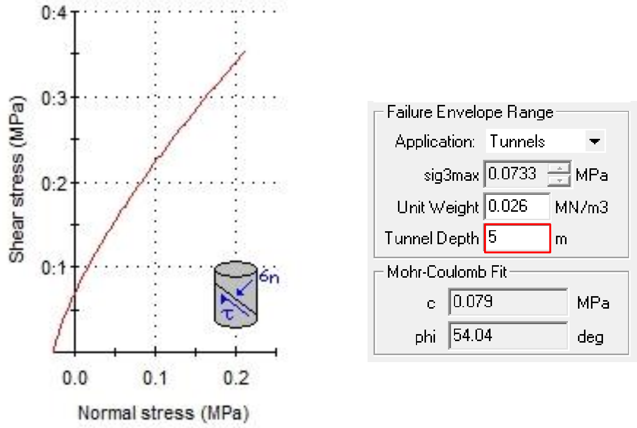

Fig. 3. The Hoek-Brown failure envelope of shale rock masses in the depth of 5 meters.

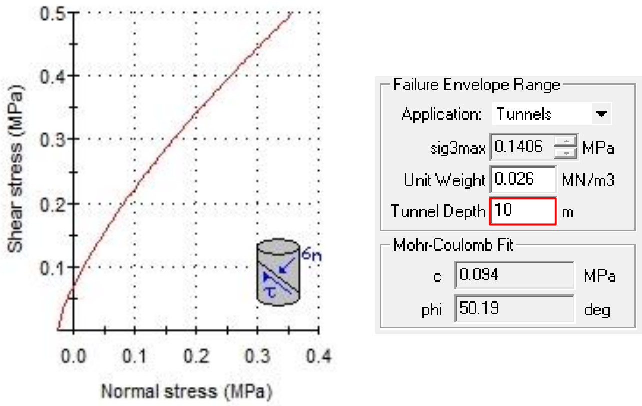

Fig. 4. The Hoek-Brown failure envelope of shale rock masses in the depth of 10 meters.

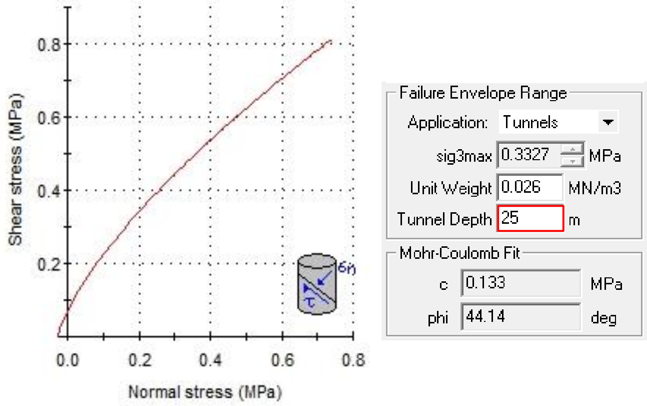

Fig. 5. The Hoek-Brown failure envelope of shale rock masses in the depth of 25 meters.

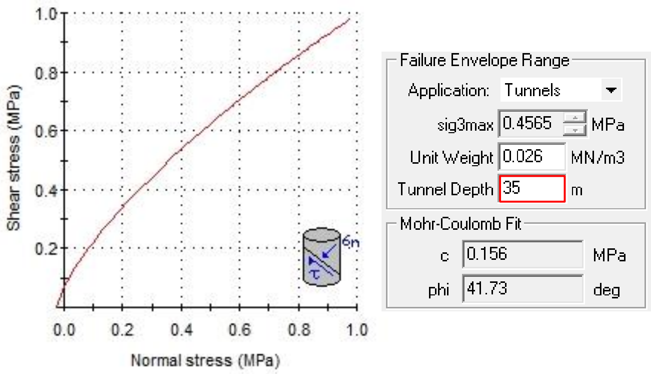

Fig. 6. The Hoek-Brown failure envelope of shale rock masses in the depth of 35 meters.

III. NUMMERICAL ANALYSIS

Numerical analyses are done using a two-dimensional hybrid element model, called Phase2 Finite Element Program [9]. 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 models is generated for circular tunnels with diameter of 4, 6, 8, 10 and 12 meters and in depth of 5, 10, 25 and 35 meters. Also the dip of ground surface is between 0 to 30 degrees which Increased 5 degrees at any stage of modeling. 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 is used for reinforcement of tunnels. Fig. 7. Shows an example of tunnels modeling with diameter of 10 meters and in different depths. This fig. shows 10 degrees of ground surface dip.

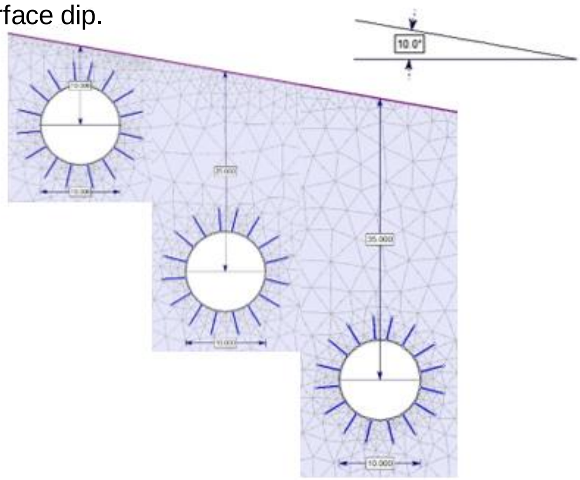

Fig. 7. The modeling of the circular tunnel with a diameter of 10 meters, in depths of 10, 25 and 35 meters. Ground surface dip is 10 degrees.

By run the models in static mode, the axial force of rock bolts is determined in existence and non-existence condition of locked-in stresses which shown in Figs 8 and 9.

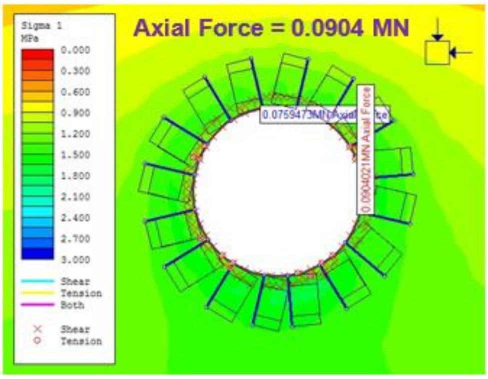

Fig. 8. The axial force of rock bolts installed in circular tunnel with a diameter of 10 meters, in depth of 35 meters in static mode. Ground surface is flat and locked-in stresses not applied in the rock mass.

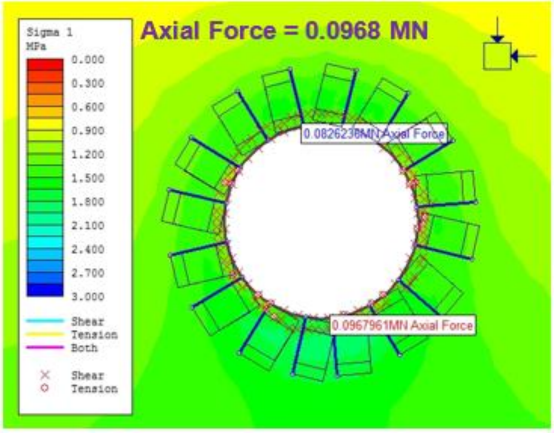

Fig. 9. The axial force of rock bolts installed in circular tunnel with a diameter of 10 meters, in depth of 35 meters in static mode. Ground surface is flat and 0.1 Mpa locked-in stresses applied in the rock mass.

Based on the results obtained in static mode for flat and steep grounds, the axial force of rock bolts increases with applying the locked-in stresses in rock mass. Furthermore, these stresses may increase the major principal stress (σ_1) around the tunnel at least 0.01 Mpa and maximum of 0.035 Mpa that causes stress concentration around the tunnel increased with, and number of yielded rock bolts in this condition increase too.

Figs. 10 and 11. represents difference of major principal stress (σ_1), axial force of rock bolts and number of yielded rock bolts (yellow colored rock bolts) between existence and non-existence of locked-in stresses in dynamic mode for circular tunnel with diameter of 10 meters and in depth of 35 meters. The earthquake applied to model with a magnitude of 8 on the Richter scale.

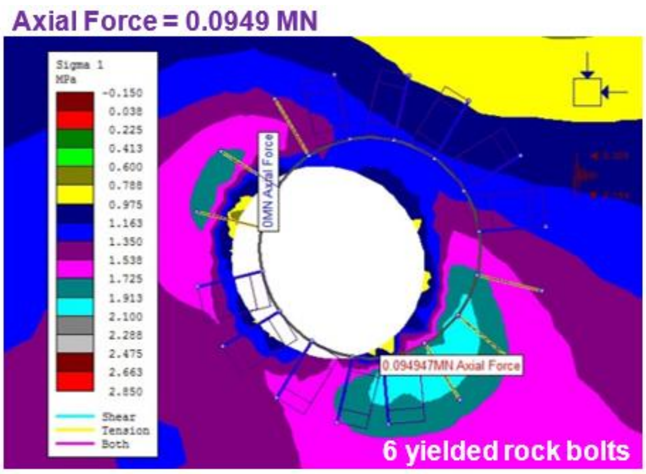

Fig. 10. The axial force of rock bolts installed in circular tunnel with diameter of 10 meters, in depth of 35 meters in dynamic mode. Ground surface is flat and locked-in stresses not applied in the rock mass.

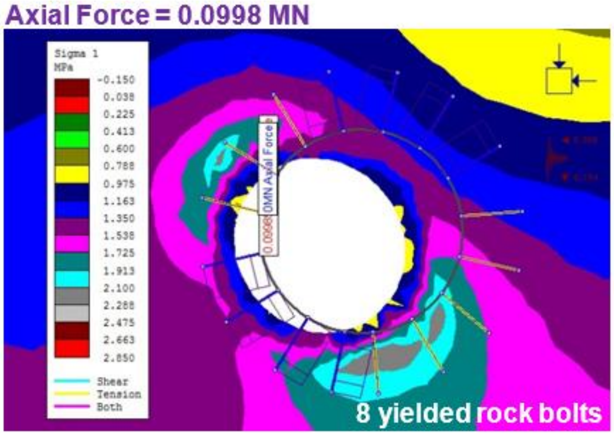

Fig. 11. The axial force of rock bolts installed in circular tunnel with diameter of 10 meters, in depth of 35 meters in dynamic mode. Ground surface is flat and locked-in stresses applied in the rock mass.

By studying the yielded elements of rock mass around the tunnels, following results were obtained. Figs. 12 and 13. show the axial force of rock bolts and yielded elements for a tunnel with diameter of 8 meters and in depth of 25 meters in dynamic mode. In this model, ground surface tilt is 25 degrees to the horizon.

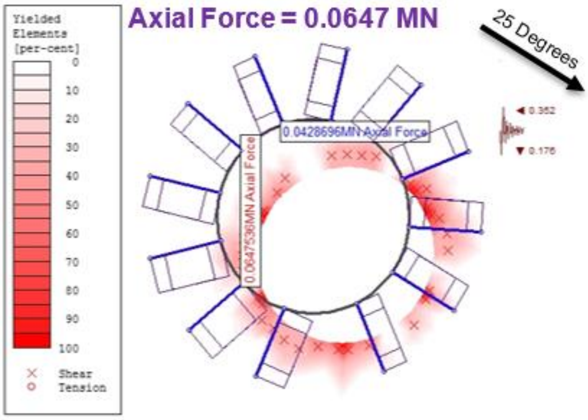

Fig. 12. The axial force of rock bolts and yielded elements around the circular tunnel with diameter of 8 meters, in depth of 25 meters in dynamic mode. The dip of ground surface is 25 degrees and locked-in stresses not applied in the rock mass.

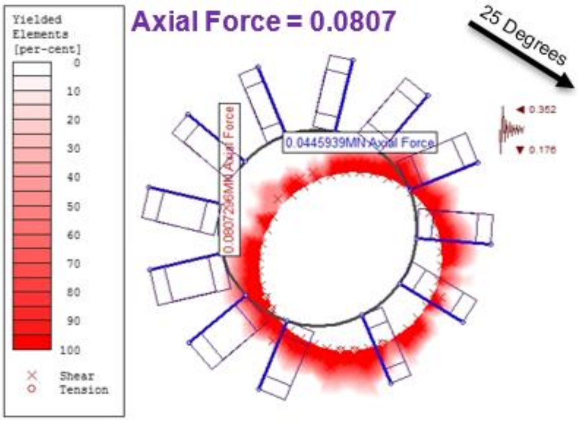

Fig. 13. The axial force of rock bolts and yielded elements around the circular tunnel with diameter of 8 meters, in depth of 25 meters in dynamic mode. The dip of ground surface is 25 degrees and locked-in stresses applied in the rock mass.

As you can see, by applying the locked-in stresses to the rock mass, the axial force of rock bolts, number of yielded rock bolts and percent of yielded elements around the tunnel increased. So these stresses can have a significant impact on the stability of tunnels.

Figs. 14 to 29. show the variations of axial forces and the result of comparison between existence and non-existence of locked-in stresses in the rock mass for different diameters and depths of tunnels.

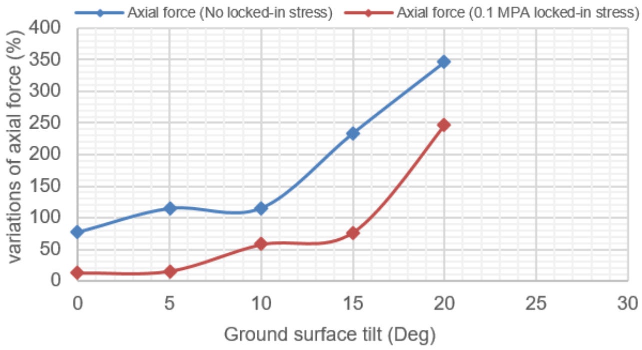

Fig. 14. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 4 meters, in depth of 5 meters.

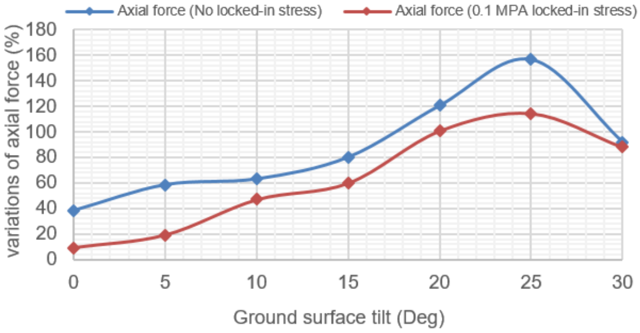

Fig. 15. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 4 meters, in depth of 10 meters.

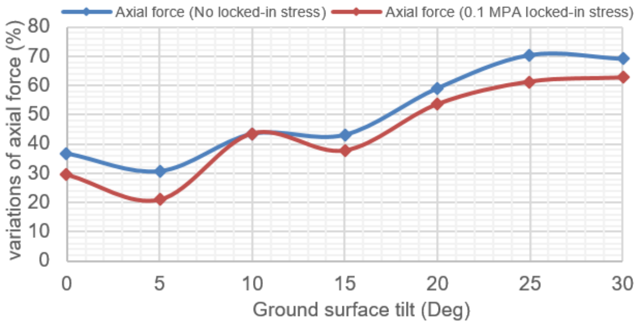

Fig. 16. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 4 meters, in depth of 25 meters.

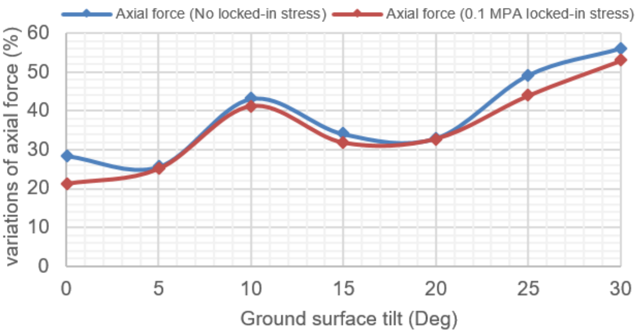

Fig. 17. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 4 meters, in depth of 35 meters.

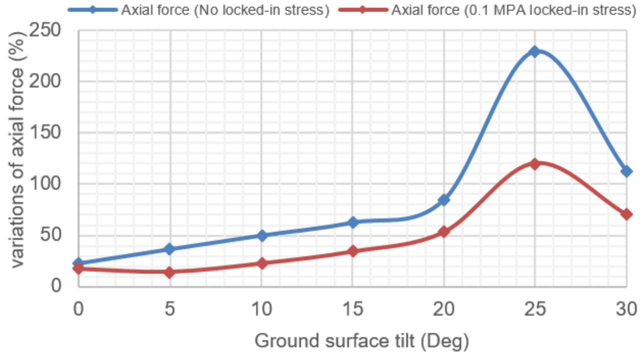

Fig. 18. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 6 meters, in depth of 10 meters.

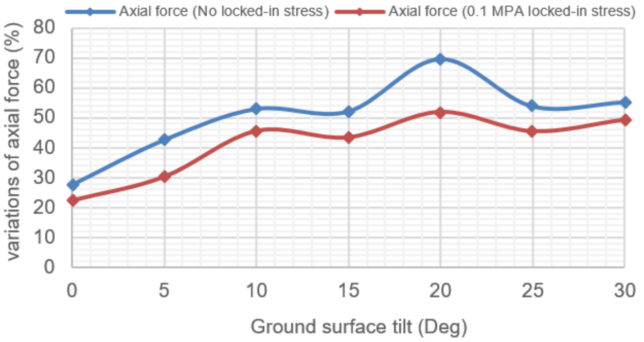

Fig. 19. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 6 meters, in depth of 25 meters.

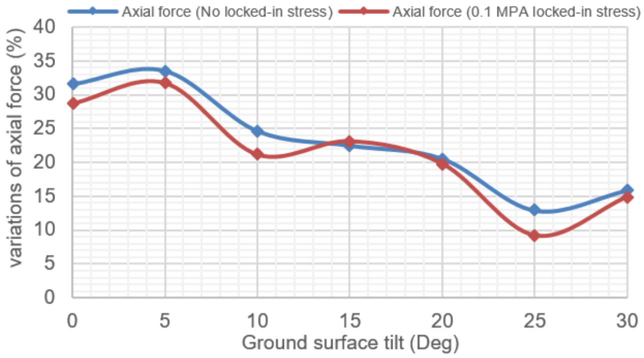

Fig. 20. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 6 meters, in depth of 35 meters.

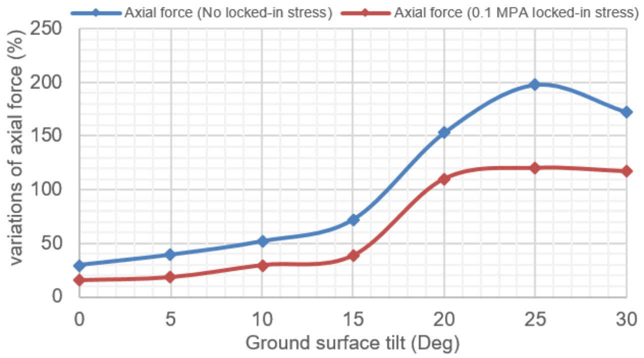

Fig. 21. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 8 meters, in depth of 10 meters.

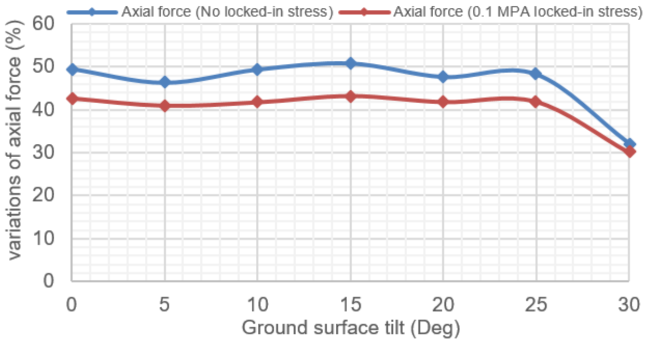

Fig. 22. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 8 meters, in depth of 25 meters.

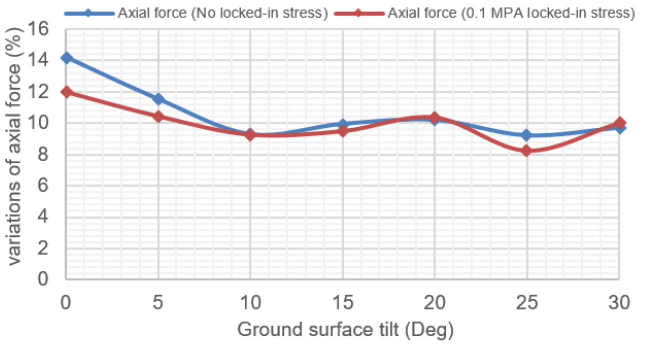

Fig. 23. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 8 meters, in depth of 35 meters.

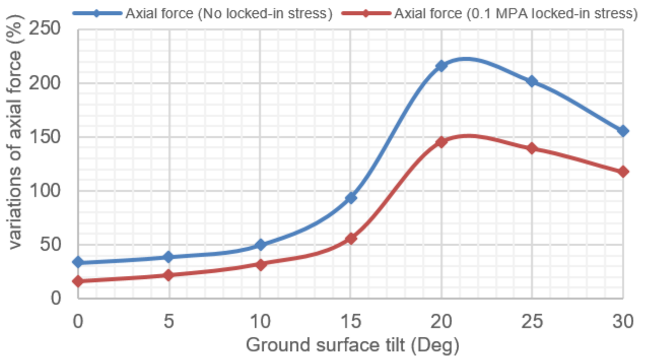

Fig. 24. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 10 meters, in depth of 10 meters.

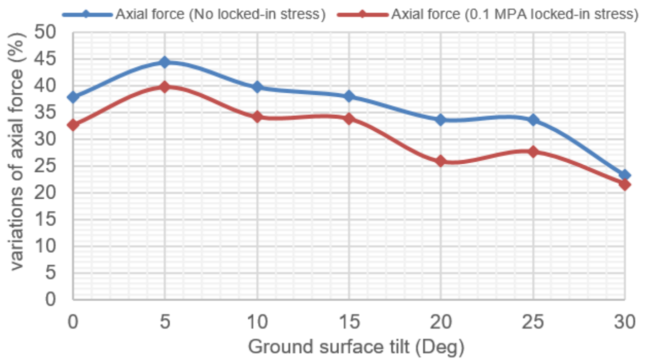

Fig. 25. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 10 meters, in depth of 25 meters.

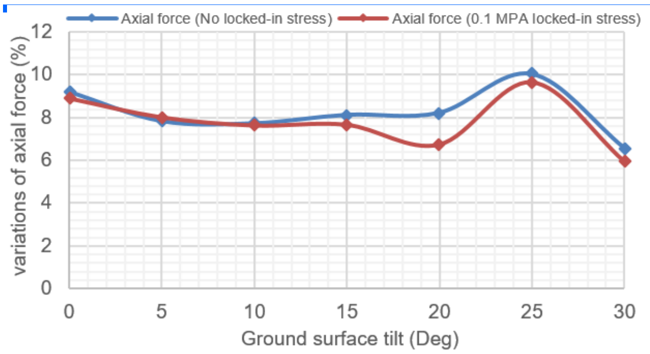

Fig. 26. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 10 meters, in depth of 35 meters.

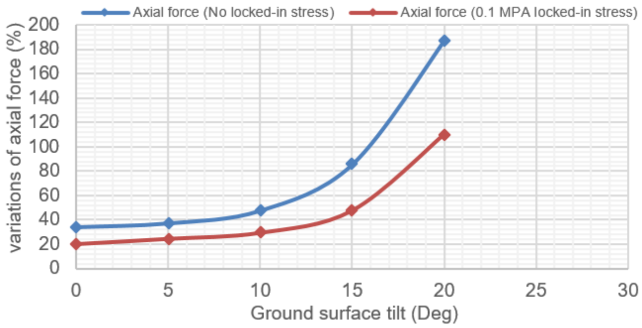

Fig. 27. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 12 meters, in depth of 10 meters.

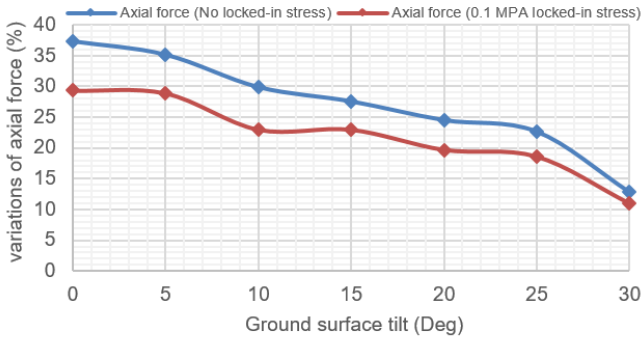

Fig. 28. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 12 meters, in depth of 25 meters.

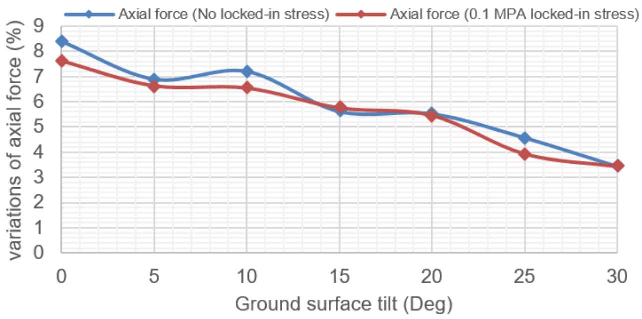

Fig. 29. Variations of axial force in terms of ground surface dip for a circular tunnel with diameter of 12 meters, in depth of 35 meters.

In top figs., blue curves represent axial force of rock bolts variations when locked-in stresses not applied to the rock mass and the red ones indicate result of axial force variations when locked-in stresses applied. As the result show, the blue curves in all figs. show more variations of axial force, in comparison to the red ones. So when locked-in stresses applied to the rock mass, the axial force of rock bolts increases in static and dynamic modes which leads to reducing variance of axial forces when compared to no locked-in stresses curves (blue curves). Furthermore, with increasing the tunnel depth, the variations of axial force and difference between two curves gradually reduced. In lower depths, curves are greatly coincident. In fact, increasing the tunnel depth can reduce the effect of earthquake on the tunnel that is appears with reduction of axial force variations and difference between curves.

IV. Conclusions

The results of the evaluations show that by applying the locked-in stresses to rock mass, axial force of rock bolts is increased. Also these stresses can increase the major principal stress (σ_1) around the tunnel at least 0.01 Mpa and maximum of 0.035 Mpa and It causes the stress concentration around the tunnel that leads to increasing the number of yielded rock bolts. Also the results represent more variations of axial force when locked-in stresses not applied to rock mass in comparison to existence of locked-in stresses. In fact, when locked-in stresses applied to rock mass, axial force of rock bolts increases in static and dynamic modes which leads to reducing variance of axial forces when compared to no locked-in stresses results. Furthermore, results show that with increasing the tunnel depth, variations of axial force and difference of results between applied and not applied locked-in stresses mode, gradually reduced and in lower depths, results are almost coincident. With increasing the tunnel depth, the effect of earthquake on the tunnel reduced and It appears with reduction of axial force variations in comparison to existence and non-existence of locked-in stresses results.

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