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Numerical Analysis of Lining Hinge in Tunnels

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Abstract- Design of support system in weak rocks has some special challenges to the geotechnical engineer because in these rocks very large forces will be applied to support systems of tunnels. The form and function of the support will vary according to a wide range of factors and it would seem that for every different tunnel there is a different lining solution. Using the lining hinge, the lining will be free to rotate about the hinge, and a zero bending moment condition will be enforced at that point, but axial force and shear force in the lining can be transmitted across the hinge location. The lining hinge can be added to the beam elements. The effect of the lining hinge on the lining of tunnels was analyzed by means of modeling the circular and horseshoe tunnels in shale rocks using the finite element program Phase2. The results of the evaluations show that lining hinge has no effect on the axial force of lining of tunnels, but it cause the shear force and bending moment of lining to be reduced. Furthermore, in horseshoe tunnels the effect of lining hinge in reducing loads on the lining is more specific than circular tunnels.

Keywords- *Lining hinge; Circular tunnel; Horseshoe tunnel; Beam elements*

I. INTRODUCTION

Tunneling in weak rocks presents difficulties in predicting tunnel performance [1]. Overcoming instability problems in these tunnels require the use of new methods in design of support systems. Such problems are widely reported in the literature [2, 3, 4]. The stability of these tunnels can be carried out by either numerical or empirical procedures. In numerical methods, the basic input parameters for a safe tunnel design are characteristics of the rocks surrounding the tunnel, the tunnel size, geometry and properties of the support system.

The effect of tunnel size on stability problems is usually analyzed through the estimation of rock support pressures. It is apparent that the size of tunnel has a significant influence on the rock support pressures in the weak rocks. The rock support pressure increases with the size of the tunnel for the elastic case, and the maximum axial force of lining increases significantly with increase in diameter of the tunnel for the plastic case [5].

It is difficult to estimate ground movement and tunnel support pressures in weak and squeezing rocks. Many researchers used measured ground deformations around tunnels to determine ground squeezing and contact pressures [6, 7, 8]. When designing support system in weak and squeezing rocks, time dependent deformations should be highly considered because large amount of deformation and contact pressure may take place with time [9].

The lining hinge can be used to reduce tunnel support pressures because the lining will be free to rotate about the hinge, and a zero bending moment condition will be enforced at hinge point, so the support pressure decreases significantly. In this paper numerical analysis are conducted to investigate the effect of lining hinge on the support pressures in tunnels with different size and form.

II. THE PHYSICAL AND MECHANICAL CHARACTERISTICS OF THE SHALE ROCKS

The physical and mechanical properties of the shale rocks are determined from cores obtained of boreholes in a tunnel. The specific gravity of these rocks is equal to 2.65 and the minimum and maximum of UCS varies from 35 to 41 MPa, respectively, and the average value is equal to 38 MPa.

The rock mass properties such as the rock mass strength (σ_{cm}), the rock mass deformation modulus (Em) and the rock mass constants (mb, s and a) were calculated by the RocLab program defined by [10] (Fig. 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 method of excavation, was considered zero for the shale rocks, it means these rocks would not be disturbed more than this during blasting.

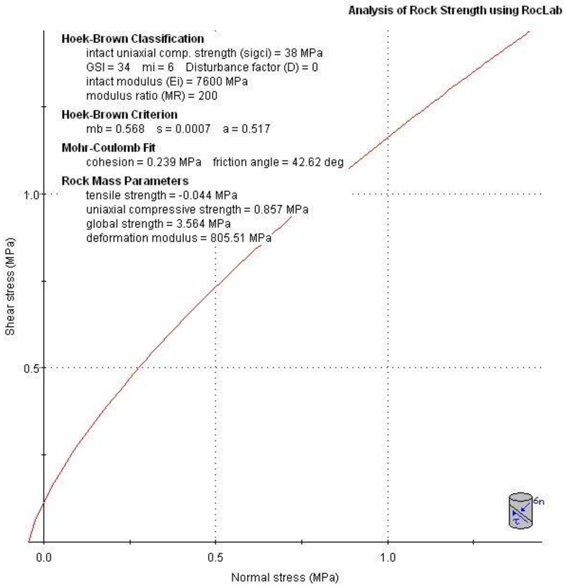

Fig.1. The geomechanical parameters of shale rock masses

III. THE CIRCULAR TUNNELS MODELING

For modeling of tunnels in shale rock masses a finite element model for circular tunnels with diameters of 4, 6, 8, 10, 12 and 14 meters are used. The external boundary of models is located in distance 5 times of tunnel diameter and graded meshes with 6 nodes are used in finite element meshing (Fig. 2).

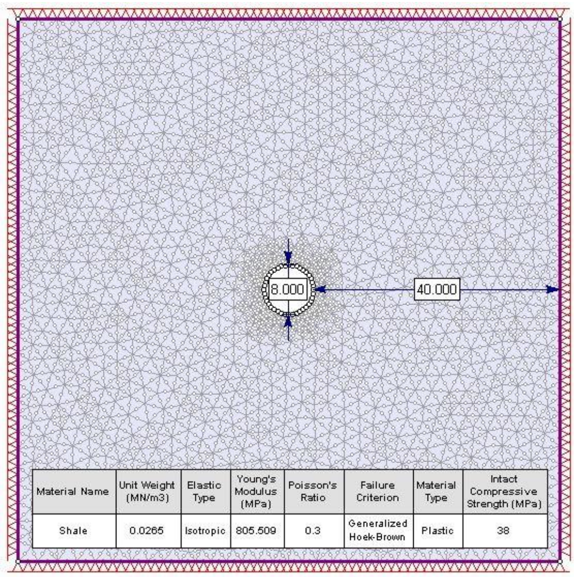

Fig. 2. The modeling of circular tunnel with diameter of 8 m

Numerical analysis of lining hinge in tunnels include analysis of amount of axial force, shear force and bending moment in the lining of tunnels. These analyses are accomplished for 2 modes: without lining hinge and with lining hinge.

IV. NUMERICAL ANALYSIS OF LINING HINGE IN CIRCULAR TUNNELS

This analysis about the tunnel with diameter of 4 m is as follows:

A. Modeling of Tunnel in the Case of Lining Without Hinge

In this case, a lining composed of beam elements with Young's modulus of 30000 Mpa and Poisson's ratio of 0.2 and thickness of 0.2 m is installed in the tunnel. This lining is without hinge and is constructed from integrated beam. The maximum axial force and shear force in the lining of tunnel is equal to 4.52 and 0.200 MN respectively (Figs. 3 and 4). Furthermore, the mean bending moment in the lining of tunnel is equal to 0.088 MNm (Fig. 5).

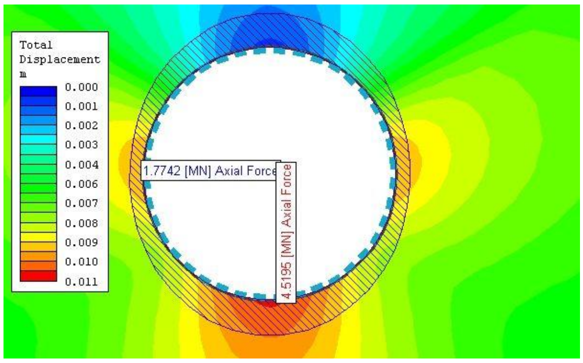

Fig. 3. The maximum axial force in the lining of tunnel (diameter of 4 m) in the case of lining without hinge

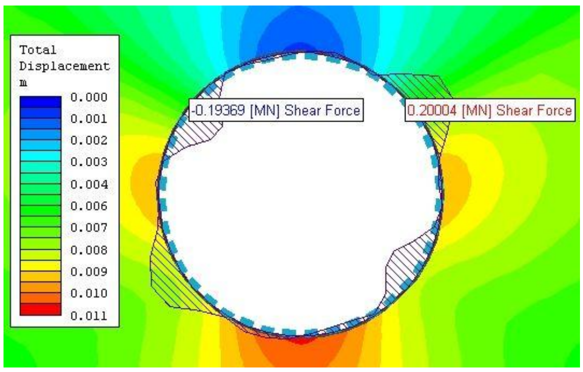

Fig. 4. The maximum shear force in the lining of tunnel (diameter of 4 m) in the case of lining without hinge

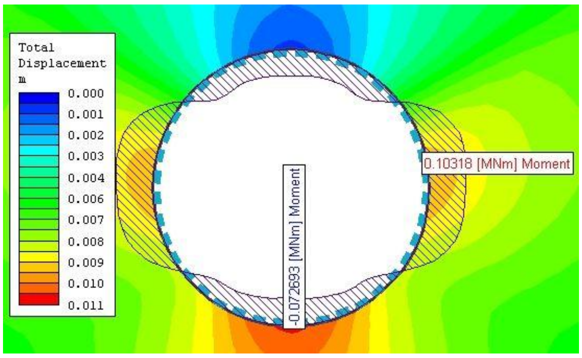

Fig. 5. The mean bending moment in the lining of tunnel (diameter of 4 m) in the case of lining without hinge

B. Modeling of Tunnel in the Case of Lining with Hinge

In this case, the lining with formerly characteristics is installed in the tunnel with the exception that the lining have hinges which enable it to rotate about the hinges (Fig. 6). In this case, the maximum axial force and shear force in the lining of tunnel is equal to 4.52 and 0.150 MN respectively (Figs. 7 and 8). Also, the mean bending moment in the lining of tunnel is equal to 0.040 MNm (Fig. 9). As can be seen in this case, the axial force has not changed but, the shear force and bending moment due to rotation lining about the hinges has considerably decreased.

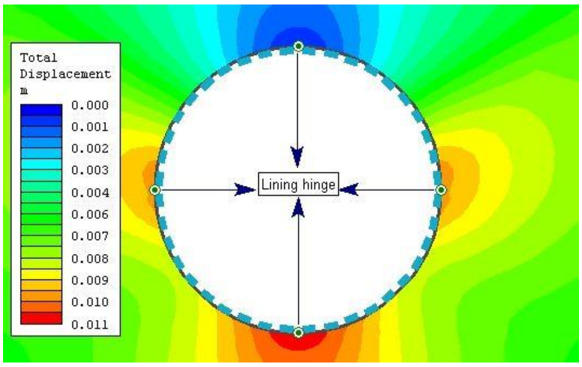

Fig. 6. The position of lining hinges in the tunnel with diameter of 4 m

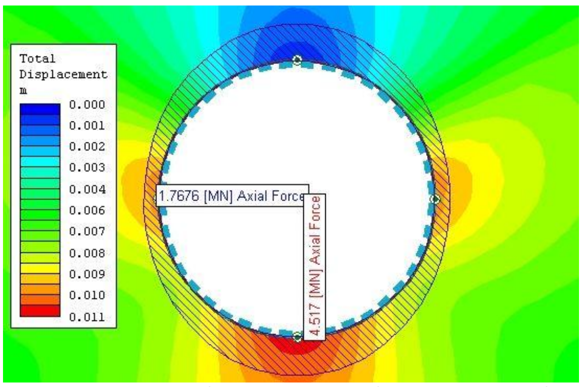

Fig. 7. The maximum axial force in the lining of tunnel (diameter of 4 m) in the case of lining with hinge

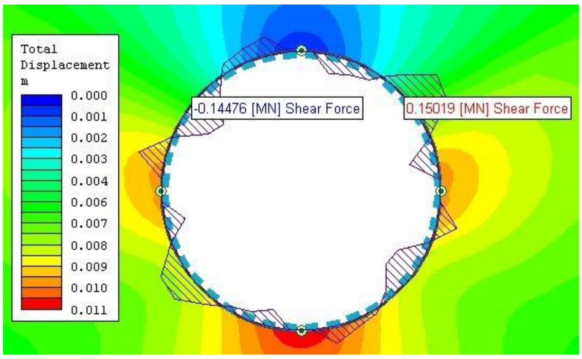

Fig. 8. The maximum shear force in the lining of tunnel (diameter of 4 m) in the case of lining with hinge

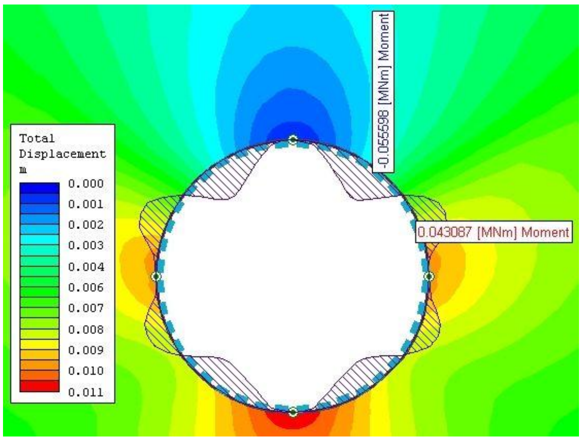

Fig. 9. The mean bending moment in the lining of tunnel (diameter of 4 m) in the case of lining with hinge

The numerical analysis in the other circular tunnels is done similarly and the obtained results are shown in diagrams presented in Figs. 18 to 20.

V. The Horseshoe Tunnels Modeling

For horseshoe tunnels modeling in shale rock masses a finite element model for tunnels with span of 4, 6, 8, 10, 12 and 14 meters are used. The external boundary of models is located in distance 5 times of tunnel diameter and graded meshes with 6 nodes are used in finite element meshing (Fig. 10).

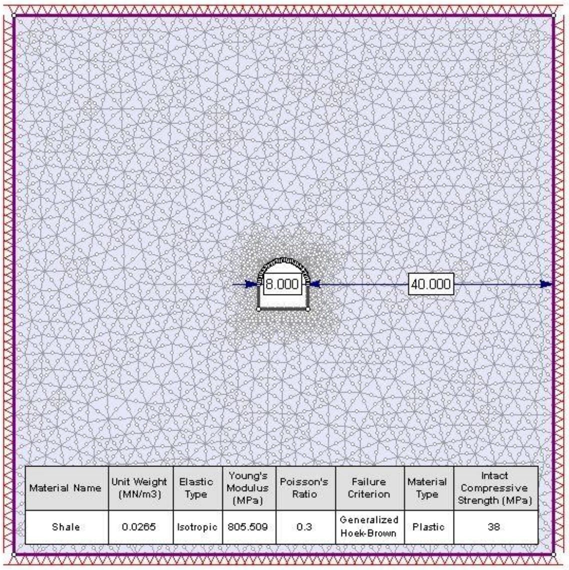

Fig. 10. The modeling of horseshoe tunnel with span of 8 m

VI. NUMERICAL ANALYSIS OF LINING HINGE IN HORSESHOE TUNNELS

This analysis about the tunnel with diameter of 4 m is as follows:

A. Modeling of Tunnel in the Case of Lining without Hinge

In this case, a lining composed of beam elements with Young's modulus of 30000 Mpa and Poisson's ratio of 0.2 and thickness of 0.2 m is installed in the tunnel. This lining is without hinge and is constructed from integrated beam. The maximum axial force and shear force in the lining of tunnel is equal to 3.43 and 0.278 MN respectively (Figs. 11 and 12). Furthermore, the mean bending moment in the lining of tunnel is equal to 0.191 MNm (Fig. 13).

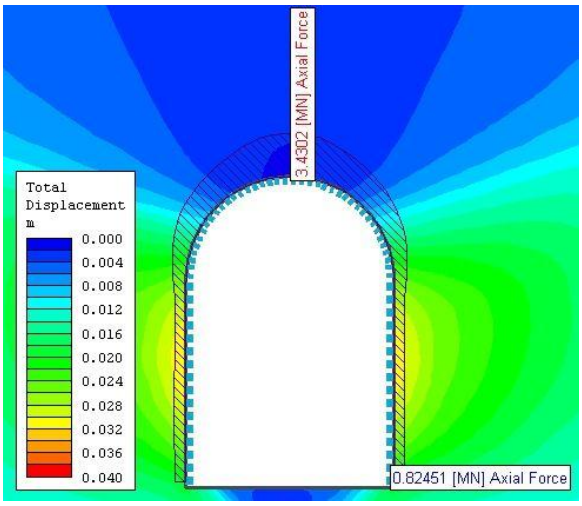

Fig. 11. The maximum axial force in the lining of tunnel (span of 4 m) in the case of lining without hinge

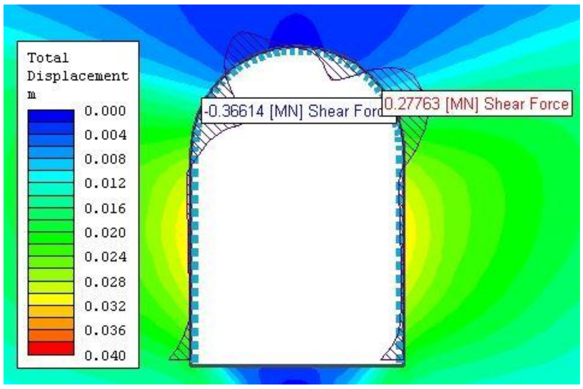

Fig. 12. The maximum shear force in the lining of tunnel (span of 4 m) in the case of lining without hinge

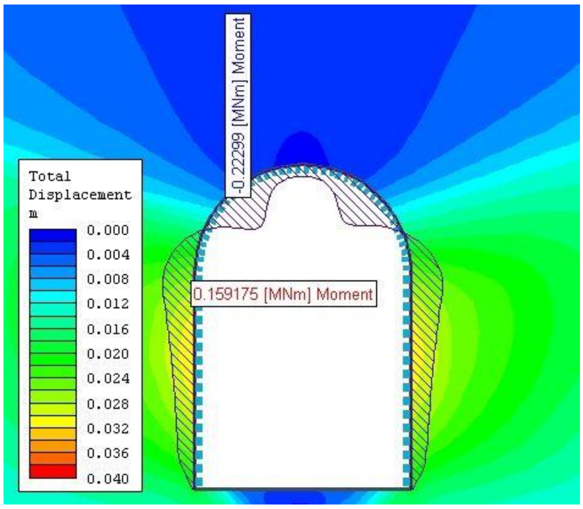

Fig. 13. The mean bending moment in the lining of tunnel (span of 4 m) in the case of lining without hinge

B. Modeling of Tunnel in the Case of Lining with Hinge

In this case, the lining with formerly characteristics is installed in the tunnel with the exception that the lining have hinges which enable it to rotate about the hinges (Fig. 14). In this case, the maximum axial force and shear force in the lining of tunnel is equal to 3.45 and 0.200 MN respectively (Figs. 15 and 16). Also, the mean bending moment in the lining of tunnel is equal to 0.106 MNm (Fig. 17). As can be seen in this case, the axial force has not changed nearly but, the shear force and bending moment due to rotation lining about the hinges has largely decreased.

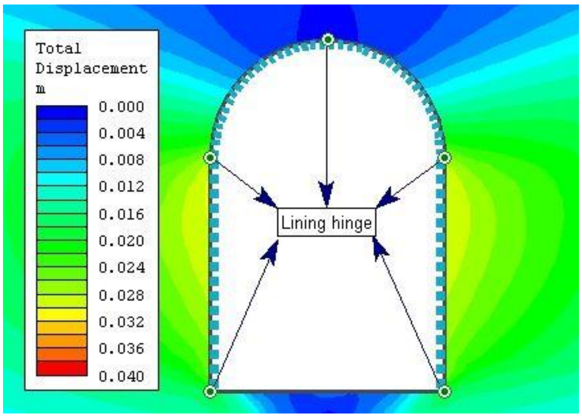

Fig. 14. The position of lining hinges in the tunnel with span of 4 m

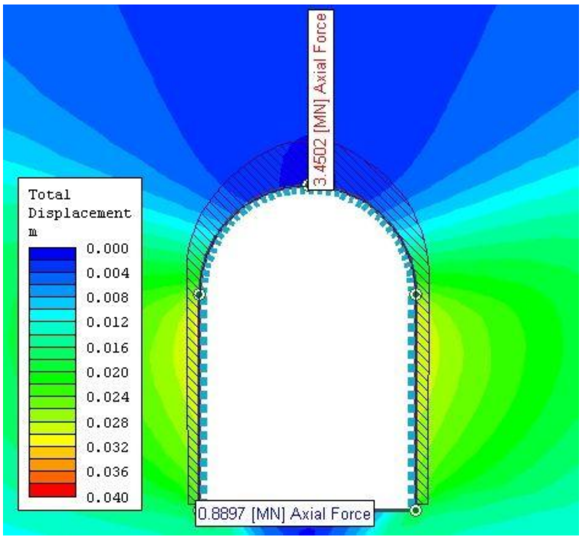

Fig. 15. The maximum axial force in the lining of tunnel (span of 4 m) in the case of lining with hinge

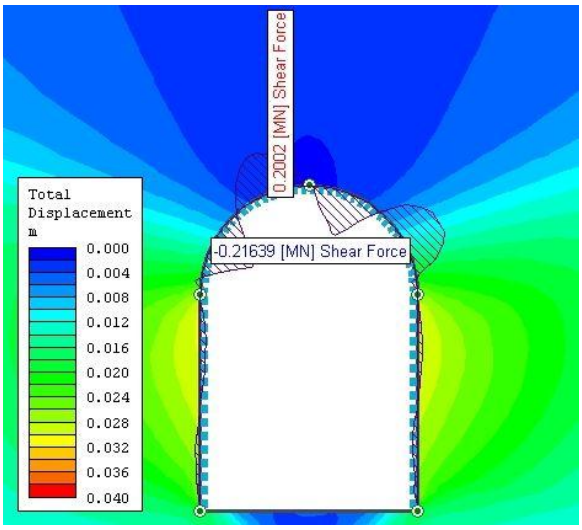

Fig. 16. The maximum shear force in the lining of tunnel (span of 4 m) in the case of lining with hinge

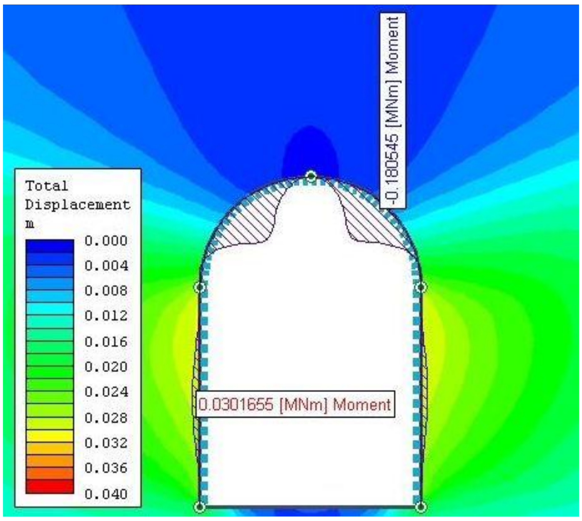

Fig. 17. The mean bending moment in the lining of tunnel (span of 4 m) in the case of lining with hinge

The numerical analysis in the other horseshoe tunnels is done similarly and the obtained results are shown in diagrams presented in Figs. 18 to 20.

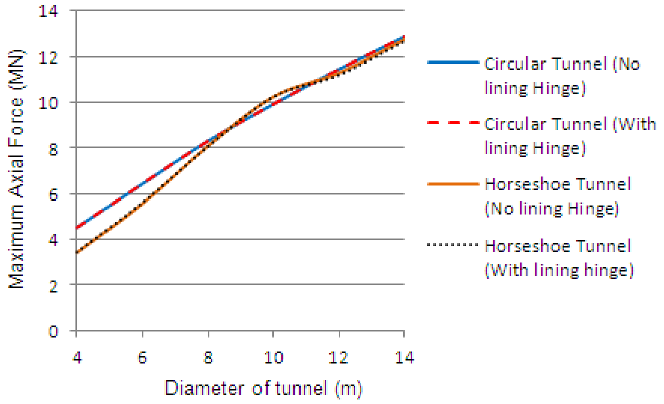

Fig. 18. The maximum axial force in the lining in circular and horseshoe tunnels in the cases: without lining hinge and with lining hinge

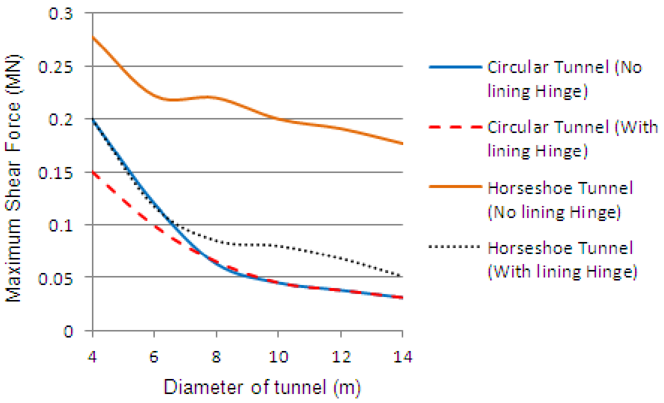

Fig. 19. The maximum shear force in the lining in circular and horseshoe tunnels in the cases: without lining hinge and with lining hinge

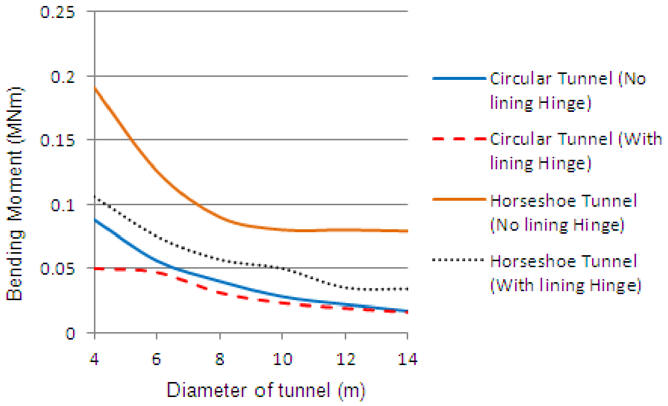

Fig. 20. The mean bending moment in the lining of circular and horseshoe tunnels in the cases: without lining hinge and with lining hinge

The diagram in Fig. 18 shows the maximum axial force in the lining of circular and horseshoe tunnels in two case abovementioned. As can be seen in all tunnels by increasing the diameter of tunnel, the maximum axial force in the lining has considerably increased in the case of without lining hinge and with lining hinge. Furthermore, the lining hinges have no effect on the axial force of lining of tunnels and by increasing the diameter of tunnels, the effect of tunnel shape in the amount of axial force has also disappeared.

The diagram in Fig. 19 shows the maximum shear force in lining of circular and horseshoe tunnels. In all tunnels by increasing the diameter of tunnel, the maximum shear force in the lining has decreased in the case of without lining hinge and with lining hinge. In addition, in the horseshoe tunnels lining hinges have a significant role in reducing shear force in the lining but, in the circular tunnels lining hinges have low effect in reducing shear force in the lining so that, this effect is zero in the large diameter tunnels.

The diagram in Fig. 20 shows the mean bending moment in the lining of circular and horseshoe tunnels. As can be seen in all tunnels by increasing the diameter of tunnel, the mean bending moment in the lining has decreased in the case of without lining hinge and with lining hinge. Reduction of bending moment is more significant for small tunnels and also, this reduction is more specific in the horseshoe tunnels. Rotation of lining about the hinges causes the lining to sustain less bending moment and so the possibility of yielding support system reduces.

VII. CONCLUSIONS

This study is investigated effect lining hinges in circular and horseshoe tunnels. The lining hinges play an important role in reducing shear force and bending moment in the lining of tunnels and in such way the possibility of yielding support system reduces in the weak rocks. In this case, the following conclusions could be noted:

- The lining hinges have no effect on the axial force of lining of tunnels.

- In all tunnels, the lining hinge cause the shear force and bending moment of lining to be reduced.

- In circular tunnels, the effect of lining hinge in reducing loads on the lining is more significant for small tunnels.

- In horseshoe tunnels, the effect of lining hinge in reducing loads on the lining is more specific than circular tunnels.

- The axial force of lining increases significantly with increase in diameter of the tunnels and the effect of tunnel shape in the amount of axial force disappear in large tunnels.

REFERENCES

[1] A. Steindorfer, and W. Schubert, "Application of new methods of monitoring data analysis for short term prediction in tunneling". In: Tunnels for People, World Tunnel Congress, Vienna. Balkema, Rotterdam, 1997, 65-69.

[2] W. Schubert, and P. Schubert, "Tunnels in squeezing rock: failure phenomena and counter actions". In: Proc. ISRM Internat. Symposim on Assessment and Prevention of Failure Phenomena in Rock Engineering, Istanbul. Balkema, Rotterdam, 1993, 479-484.

[3] S. Klein, "An approach to the classification of weak rock for tunnel projects". In: Proc. 15th Rapid Excavation and Tunneling Conference. Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 2000, 793-805.

[4] D. Brox, and H. Hagedorn, "Extreme deformation and damage during the construction of large tunnels". Tunnelling and Underground Space Technology, 1991, 14, 23-28.

[5] R. Bhasin, A. W. Magnussen, and E. Grimstad, "The effect of tunnel size on stability problems in rock masses". Tunnelling and Underground Space Technology incorporating Trenchless Technology, 2006, 21, 405.

[6] N. Phien-wej, and E.J. Cording, "Sheared shale response to deep TBM excavation". Eng. Geol. 1991, 30, 371-391.

[7] M. Panet, "Two case histories of tunnels through squeezing rocks". Rock Mech. Rock Engng. 1996, 29 (3), 155-164.

[8] W. Steiner, "Tunneling in squeezing rock: case history". Rock Mech. Rock Engng. 1996, 29 (4), 211-246.

[9] F.I. Shalabi, "FE analysis of time-dependent behavior of tunneling in squeezing ground using two different creep models". Tunnelling and Underground Space Technology, 2005, 20, 271-279.

[10] E. Hoek, C. Carranza-Torres and B. Corkum, "Hoek-Brown Failure Criterion, 2002 Edition". Rocscience, 2002.