Karstification of Limestone Around the Tunnels

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Abstract— **Karst is a phenomenon formed due to the dissolution of soluble rocks such as limestone. Karstification of limestone around of tunnels can have effects on the lining of tunnels. This paper presents numerical analysis of the effect of karstification on the forces of lining in tunnels formerly excavated in the limestone. The circular tunnels are modeled with diameter of 6, 8, 10, 12 and 14 meters and reinforced with lining and the effect of circular karsts is investigated on the forces of lining. The results of the evaluations show that by increasing ratio of karstification to tunnel surface, the changes of axial force and bending moment of lining have increased but changes in shear force associated with fluctuations. Percentage change of axial force is less than the bending moment and shear force and percentage change of shear force is highest. Moreover, by increasing distance of karst from the tunnel, the changes of axial force, bending moment and shear forces of lining have decreased.**

Keywords— Karstification; Tunnel; Lining; Axial force; Bending moment; Shear force

1. Introduction

Karstification of limestone may be characterized by sinkholes, sinking streams, closed depressions, subterranean drainage, and caves [1]. Waters from rainfall infiltrates into the ground and flows into the subsurface and often toward a stream at a lower elevation. Weak acids found naturally in rain slowly dissolve the tiny fractures in the limestone, enlarging the joints and bedding planes and karst forms. Many underground rivers are part of a karst landscape, where eroded limestone often creates caves. Conditions that promulgate karst formation are well-jointed, dense limestone near the surface; a moderate to heavy rainfall; and good groundwater circulation.

The study of the mechanism of formation of fractures by [2, 3] shows which the vertical tensional and shear fractures and faults are formed as a result of residual elastic stresses during the post-tectonic uplifting of terrains. These structures can be formed only if horizontal tectonic extension exists.

During the lifetime of tunnels, many failures happened as a result of the instability in the surrounding rock mass. All of these problems will generate considerations on the safety of the tunnel engineering [4]. Tunneling is associated with problems such as dissolution of the rock around the tunnel or karstification of them. Therefore, prediction of karstification and influence it on the lining of tunnels is considered as highly significant in the maintenance of tunnels.

This paper attempts to evaluate the effect of karstification on the forces of lining in tunnels formerly excavated in the limestone.

2. Geomechanical Properties of the Rock Masses

The rock mass properties such as the rock mass strength (σcm), the rock mass deformation modulus (Em) and the rock mass constants (mb, s and a) are calculated by the Rock-Lab program defined by [5]. This program has been developed to provide a convenient means of solving and plotting the equations presented by [5]. The geomechanical parameters of limestone rock masses is obtained and presented in Fig. 1.

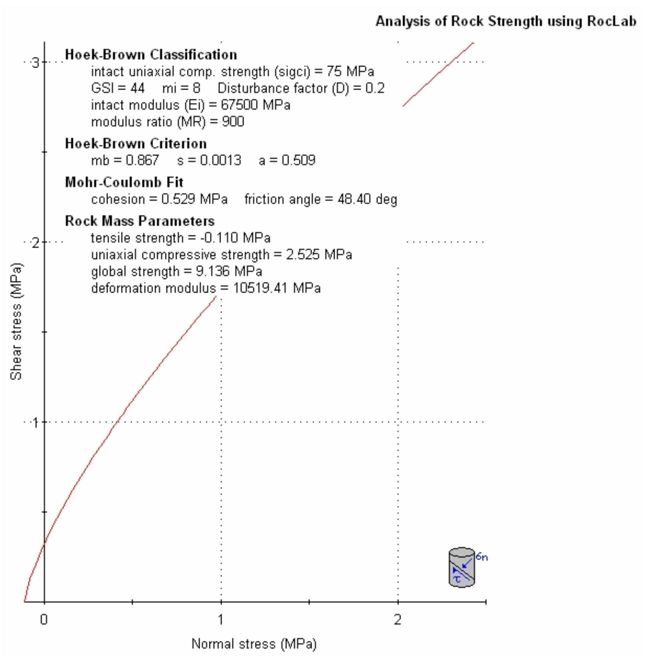

Fig. 1. The geomechanical parameters of limestone rock masses

3. Numerical analysis of the karstification around the tunnels

Numerical analyses of the karstification around tunnels are done using a two-dimensional hybrid element model, called Phase2 Finite Element Program [6]. This software is used to simulate the three-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 Fig. 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 limestone rock masses, a finite element models is generated for circular tunnels with diameter of 6, 8, 10, 12 and 14 meters that reinforced with lining (for example Fig. 2). The outer model boundary is set at distances of 7 times the tunnel radius and six-nodded triangular elements are used in the finite element mesh.

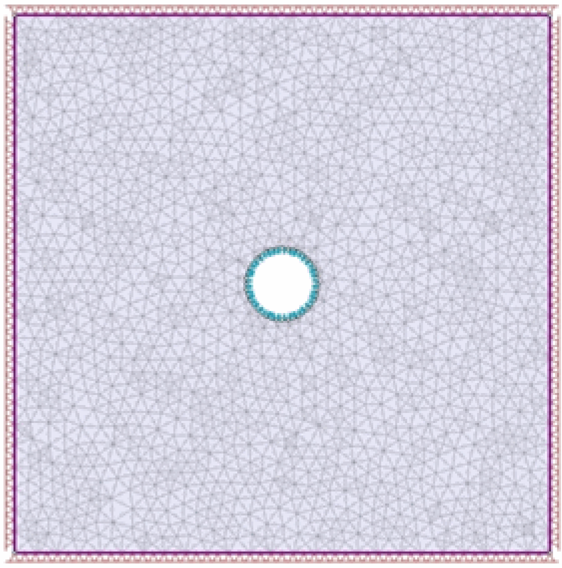

Fig. 2. The modeling of circular tunnel with diameter of 8 meters that reinforced with lining

By run of models, the value of axial force, bending moment and shear force in the lining of tunnels is determined (for example Fig. 3). Then, the circular karsts are modeled around tunnels (for example Fig. 4) and again the value of axial force, bending moment and shear force in the lining of tunnels is measured and it changes is shown in Figs. 5 to 13.

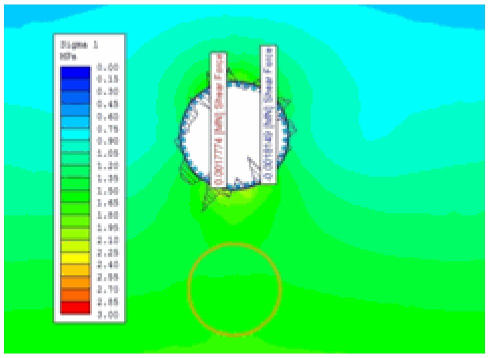

Fig. 3. The values of shear force in the lining of circular tunnel with diameter of 8 meters

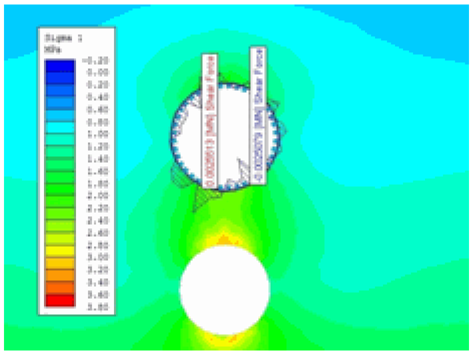

Fig. 4. The values of shear force in the lining of circular tunnel with diameter of 8 meters in the case of circular karstification at the bottom of the tunnel

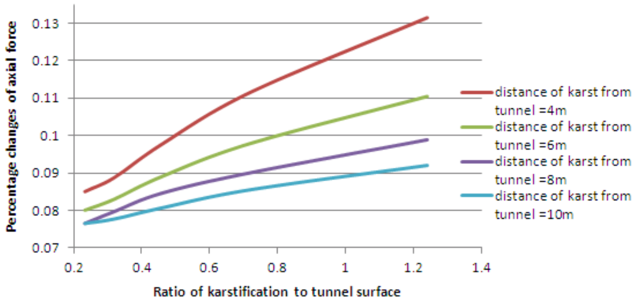

Fig. 5. The diagram shows the percentage changes of lining axial force in terms of ratio of karstification to tunnel surface (karstification at the top of tunnel)

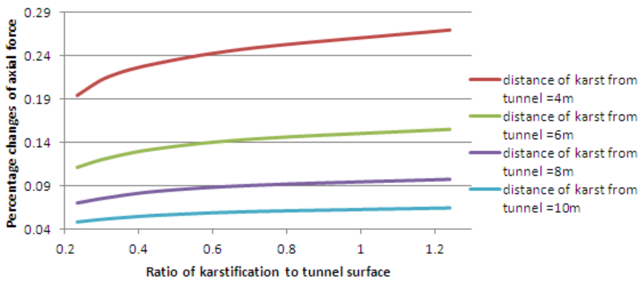

Fig. 6. The diagram shows the percentage changes of lining axial force in terms of ratio of karstification to tunnel surface (karstification at the bottom of tunnel)

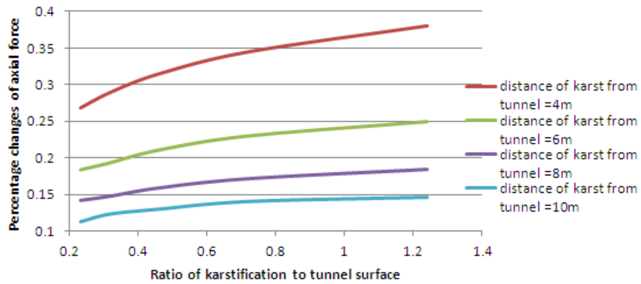

Fig. 7. The diagram shows the percentage changes of lining axial force in terms of ratio of karstification to tunnel surface (karstification both the top and bottom of tunnel)

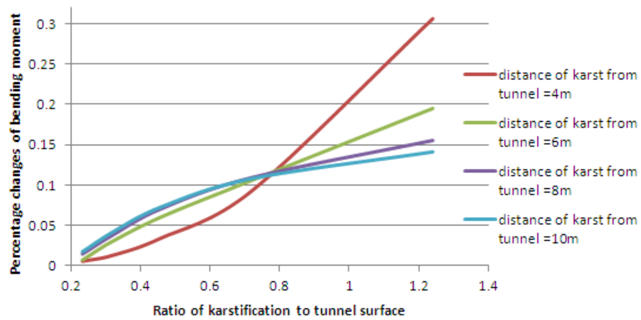

Fig. 8. The diagram shows the percentage changes of lining bending moment in terms of ratio of karstification to tunnel surface (karstification at the top of tunnel)

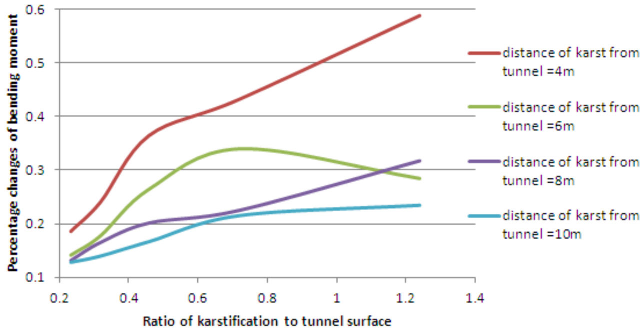

Fig. 9. The diagram shows the percentage changes of lining bending moment in terms of ratio of karstification to tunnel surface (karstification at the bottom of tunnel)

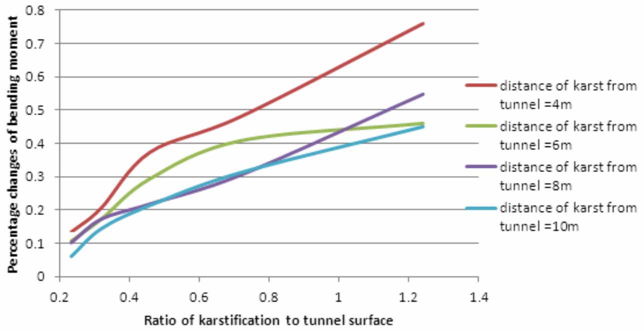

Fig. 10. The diagram shows the percentage changes of lining bending moment in terms of ratio of karstification to tunnel surface (karstification both the top and bottom of tunnel)

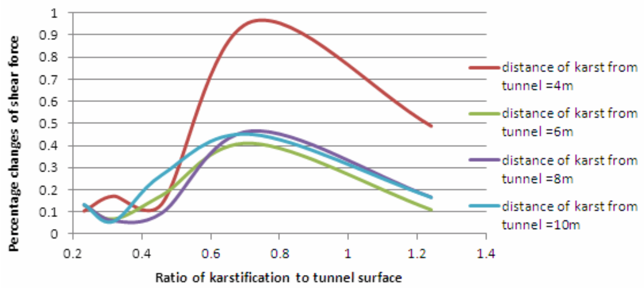

Fig. 11. The diagram shows the percentage changes of lining shear force in terms of ratio of karstification to tunnel surface (karstification at the top of tunnel)

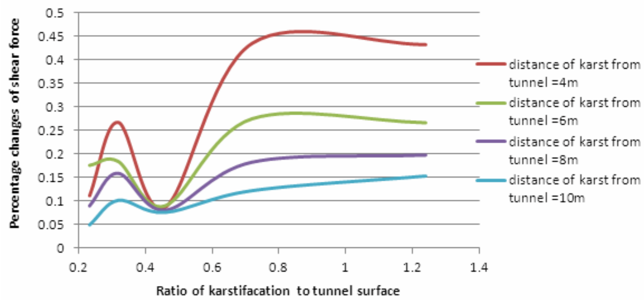

Fig. 12. The diagram shows the percentage changes of lining shear force in terms of ratio of karstification to tunnel surface (karstification at the bottom of tunnel)

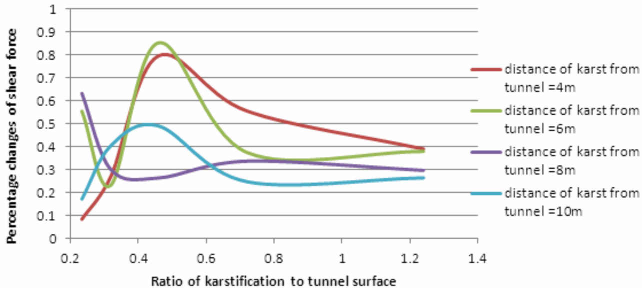

Fig. 13. The diagram shows the percentage changes of lining shear force in terms of ratio of karstification to tunnel surface (karstification both the top and bottom of tunnel)

As the above diagrams show, by increasing distance of karst from the tunnel, the changes of axial force, bending moment and shear forces of lining have decreased. Furthermore, by increasing ratio of karstification to tunnel surface, the changes of axial force and bending moment of lining have increased but changes in shear force associated with fluctuations. The diagrams show percentage change of axial force is less than the bending moment and shear force and percentage change of shear force is highest. Moreover, the karstification position relative to axis of tunnels is effective on the axial force, bending moment and shear forces of lining and the maximum changes of lining forces have happened by karstification at the bottom of tunnels.

4. CONCLUSION

This study provides an estimation of the effect of karstification on the axial force, bending moment and shear forces of lining in tunnels that formerly excavated in the limestone. The following conclusions could be noted:

- By increasing ratio of karstification to tunnel surface, the changes of axial force and bending moment of lining have increased but changes in shear force associated with fluctuations.
- Percentage change of axial force is less than the bending moment and shear force and percentage change of shear force is highest.
- By increasing distance of karst from the tunnel, the changes of axial force, bending moment and shear forces of lining have decreased.
- The maximum changes of axial force, bending moment and shear forces of lining have happened by karstification at the bottom of tunnels.

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