WEP Warwick Evans Publishing

International Journal of Natural Resources and Environmental Studies

ISSN: 3006-2012 (Print), ISSN: 3006-0834 (Online) | Volume 2, Number 1, Year 2024
DOI: https://doi.org/10.62051/ijnres.v2n1.08
Journal homepage: https://wepub.org/index.php/IJNRES/index

The Influence of Underground Cavity on The Stability of Tunnel Excavation

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ABSTRACT

In order to study the influence of cavity on surrounding rock stability,a tunnel in Yunnan Province was taken as the research object,and the problem of voids in the tunnel was qualitatively analyzed and evaluated.FLAC3D was used to simulate and analyze the distribution location of voids,the number of voids,and the influence of voids in the excavation process.The influence of plastic zone,stress field and displacement field on the stability of surrounding rock was evaluated.The results showed that the onsite measured data were consistent with the simulation results.When the cavity existed at the top and side,bottom and side,the cavity at the side had a greater impact on the tunnel than the cavity at the bottom and top,and the cavity at the bottom had a greater impact than the cavity at the top.When the annular cavity was encountered in the excavation process,the displacement value of surrounding rock decreased under the support of primary lining and bolt,and the reduction range of arch bottom was greater than that of arch top.This study can provide a certain reference for the excavation stability of similar tunnel projects with cavities.

KEYWORDS

Cavity; numerical simulation; excavation stability; bad geology.

1. INTRODUCTION

With the implementation of the "Belt and Road Initiative",tunnel engineering has developed to large diameter,large depth and long distance,and underground engineering has developed to large area,large depth and comprehensive.In the construction process of tunnel and underground engineering,it is always faced with four high risks of karst,fault,gas and surrounding rock breakage,and four problems of high ground stress of soft rock,water-bearing sand layer,shallow burial and high ground temperature[1].In the process of tunnel excavation and underground engineering in karst area,the surrounding rock is disturbed by cavities,and the distribution of karst holes has a significant impact on tunnel excavation,which may produce a large settlement and seriously threaten the safety of construction and the surrounding environment[2-3].With the implementation of the "Belt and Road Initiative",tunnel engineering has developed to large diameter,large depth and long distance,and underground engineering has developed to large area,large depth and comprehensive.In the construction process of tunnel and underground engineering,it is always faced with four high risks of karst,fault,gas and surrounding rock breakage,and four problems of high ground stress of soft rock,water-bearing sand layer,shallow burial and high ground temperature[1].In the process of tunnel excavation and underground engineering in karst area,the surrounding rock is disturbed by cavities,and the distribution of karst holes has a significant impact on tunnel excavation,which may produce a large settlement and seriously threaten the safety of construction and the surrounding environment[2-3].

In southwest China,due to the particularity of karst landform,cavitation is relatively developed,the geological conditions are complicated,and the construction is difficult,and the development of cavitation is often accompanied by the enrichment of karst water,which is easy to cause water gusher accidents.When tunnels pass through karst areas,they are prone to encountering voids and underground rivers,resulting in geological disasters such as water inrush,mud outburst and collapse[4-6].Especially in stratified karst areas,the occurrence probability of these geological disasters is greater[7].However,for tunnel construction in karst areas in China,most scholars only consider the displacement generated by excavation and monitor the displacement,which ignores the influence of karst water in rock mass on the tunnel.After the karst water is discharged,the influence of pore water pressure change on the elastic-plastic deformation of solid particles and the stress around the tunnel should be analyzed[8-9].

2. RESEARCH BACKGROUND AND MODEL ESTABLISHMENT

2.1. Research background

Previous scholars have conducted a lot of studies on the influence of karst cavities.Zhang Feng et al.[10] believed that side cavities would have a great impact on the stability of surrounding rock during tunnel excavation.Shi Shiyong et al.[11],aiming at the influence of the top cavity on the tunnel,used ANSYS software to change the size and distance of the cavity and found that the principal stress of the tunnel top and bottom plate would change significantly after the change of the cavity parameters,which means that the parameters of the cavity have a significant influence on the subsidence of the tunnel surrounding rock arch.When the cavity is relatively water-rich,Mu LAN et al.[12] believe that when high water pressure accumulation occurs in the surrounding rock in front of the palm face,drilling should be carried out 1D in advance (D is the tunnel span) to drain water and reduce the water pressure accumulation in front of the palm face.The effective distance of extrusion deformation in front of the palm surface is 0.5D.Xu Jianguo et al.[13] believe that the seepage field is disturbed after tunnel excavation,and pore water flows towards the tunnel excavation surface under the action of water head difference,forming an inverted conical pore water pressure distribution,and the disturbance range gradually expands with the increase of buried depth.The maximum principal stress around the tunnel is concentrated and the minimum principal stress is relaxed after tunnel excavation.After tunnel excavation,the overall deformation of surrounding rock is the largest vertically,and the vertical displacement increases with the buried depth,and the maximum vertical displacement occurs in the vault.It is of guiding significance to discuss the influence of underground cavities on the surrounding rock during tunnel excavation.

2.2. Engineering overview

Because the lithology of a tunnel in Yunnan is mainly sandstone and its interlayer with mudstone,conglomerate,etc.,the cracks in the surrounding rock of the tunnel are relatively developed,resulting in water inrush in the tunnel.In addition,the groundwater in this area is dissolved,and there are voids in the surrounding rock of the tunnel,which is a high risk for the tunnel construction.With the help of FLAC3D numerical simulation software,this study analyzed and evaluated the adverse geological factors such as voids in the current survey results,and found out the law of their influence on the stability of surrounding rock,so as to provide technical suggestions for the further construction of the tunnel and ensure the safe construction of the tunnel.

The length of a tunnel in Yunnan province is 13 018 m,and the numerical simulation can not simulate the actual situation of the whole tunnel,so the D1K467-D1K468 cavity section is selected for analysis and research.The lithology of this section is mainly mudstone with conglomerate,quartz sandstone with gypsum,which provides the congenital conditions for the formation of cavity.Because the tunnel body contains soft soil rock,the joint cracks are relatively developed,the rock mass is relatively broken,and the chemical erosion environment makes the cavity appear in the tunnel section.

2.3. Model establishment

According to the survey data,there are many voids in this section,and even 2~3 voids appear in the same section of the tunnel,most of which are 2~4m in diameter.The maximum value of the voids is 4m in diameter.However,the hole is too far away from the tunnel excavation face,which has little influence and low research value.Therefore,the distance d between the cavity and the tunnel is set at different distances of 1.4,2.4,3.4,4.4m,etc.,and the influence of multiple cavities on tunnel excavation is studied at different distances.In view of this situation,it is necessary to consider the influence of multiple cavities on the tunnel excavation process when establishing the model[14].

According to Saint-Venant's principle[15],the influence range of stress after tunnel excavation is 6 times the tunnel radius.The radius of a tunnel in Yunnan is 4.2m,that is,the minimum distance between the model boundary and the tunnel is 25.2m.The size of the mesh is different in the difference.In the range of 7 m around the tunnel,the mesh is denser,which can display the range and volume of the plastic zone more accurately.As shown in FIGURE1,the boundary conditions take the center of the tunnel as the center of the entire model,and the positive and negative directions of X and Z are 50 m.A cross-sectional model is established with the extension direction of the tunnel as the Y direction,and the Y direction is 3 m.The whole model has a total of 30924 units and 41924 nodes.

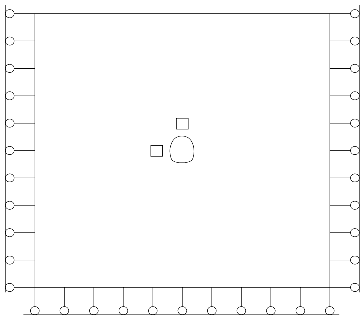


Figure 1. Multi cavity tunnel model

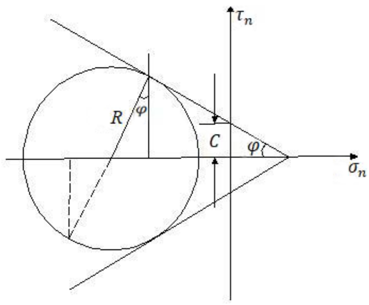


Figure 2. Molar stress circle

The tunnel solid element constitutive model adopts the Moore-Coulomb model,which is an ideal elastic-plastic model,applicableto soil,rock,concrete and other material types,and has a wide application range,and is a general geotechnical mechanics model,such as slope stability and underground excavation.The More-Coulomb failure criterion is widely used,and the Mohr stress circle is shown in Figure2.

The excavation method is two steps method.When the model is built,the position of the cavity should be holed out first,the equilibrium should be reached under the self-weight stress,and then all the anisotropic displacements should be reduced to 0.After returning to zero,excavate the upper step and calculate to balance,and continue to excavate the lower step and calculate to balance.So the cycle until the end of the excavation cycle.

In order to get closer to the actual situation,the physical and mechanical parameters of surrounding rock are obtained by numerical simulation considering the situation of field test and laboratory test,as shown in Table1.

Table 1. Mechanical parameters of surrounding rock

type	density $\rho[g\cdot cm^{-3}]$	Modulus of elasticity E[GPa]	Angle of internal friction φ[°]	Cohesive force C[MPa]	Poisson's ratio μ	Tensile strength [MPa]
Sandstone mixed with mudstone	2.79	2.54	30	1.3	0.27	1.25

FLAC3D software uses bulk modulus and shear modulus instead of elastic modulus for both solid and structural units.When conducting numerical simulation,elastic modulus and Poisson's ratio should be used first to convert into bulk modulus K and shear modulus G:

$$K=\frac{E}{3(1-2\mu)} \quad , \quad G=\frac{E}{2(1+\mu)} \tag{1}$$

Other adverse geological factors are not considered in the simulation process.Under ideal circumstances,there are 5 monitoring points for tunnel sections, namely,arch top,spinner,waist,arch foot and arch bottom.The stress and displacement of each monitoring point in the tunnel are shown in Table2.

Table 2. Displacement and stress values of monitoring points

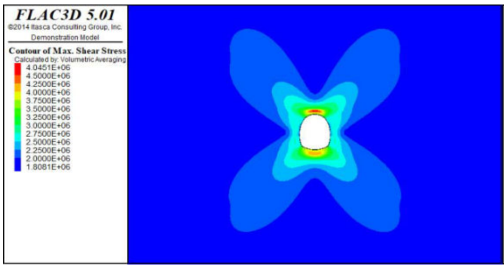
position	Vertical displacement [mm]	Horizontal displacement [mm]	Maximum principal stress [MPa]	Mean stress [MPa]
vault	5.95	0.13	11.18	5.92
spandrel	5.04	6.81	7.26	3.18
hogging	2.23	14.85	3.92	1.13
spandrel	1.74	10.6	6.69	3.37
Arch bottom	3.34	-1.27	9.72	5.83

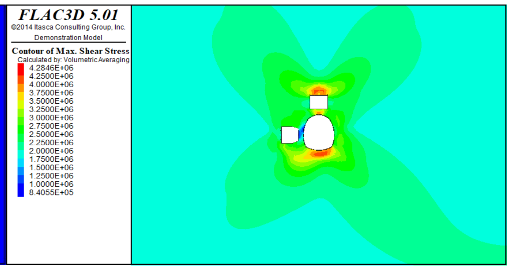
3. INFLUENCE OF CAVITIES ON TUNNEL SURROUNDING ROCK

3.1. Numerical analysis of stress,displacement,and plastic zone of circular multiple cavities on tunnel surrounding rock

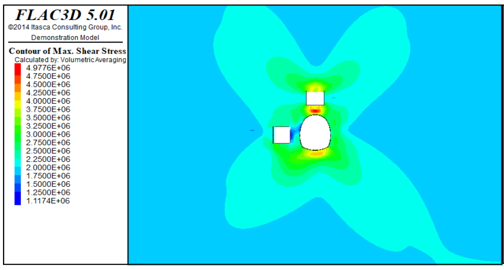
In the process of tunneling,the plastic zone of the tunnel surrounding rock will be connected as a whole,resulting in the stability of the tunnel surrounding rock will be greatly reduced,and even collapse accidents will occur.As shown in FIGURE3,when there is no cavity,the maximum shear stress is 4.04MPa,and cavities appear at the side and top of the tunnel during tunneling.When the cavity is 1.4m away from the tunnel,the top and bottom of the tunnel obviously bear a large shear stress,and the maximum shear stress is 4.16MPa,and the bottom area is larger than the top area.However,the lateral cavity has little influence on the stress distribution of the tunnel,only affecting the maximum shear stress at the shoulder of the tunnel arch.

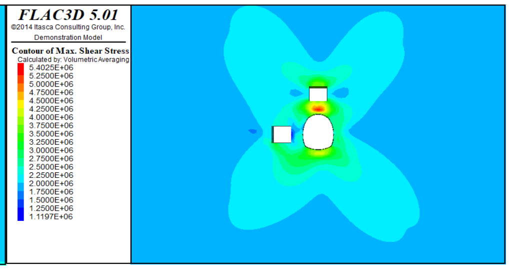
As can be seen from Figure3,when there are cavities at the top and side of the tunnel at the same time,the stress distribution of the vault is greatly affected,and the influence area of the stress distribution at the side is small,and the stress change is small.As can be seen from FIGURE3,when the distance between the cavity and the tunnel is less than the radius of the tunnel,the increase of stress value decreases by 28.6% every time the distance increases by 1 m.From the distance of 1.4m to 3.4m,the maximum shear stress increases from 4.2MPa to 5.4MPa.



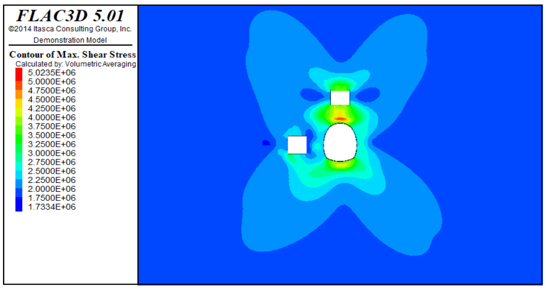


(a)d=0m (b)d=1.4m





(c)d=2.4m (d)d=3.4m

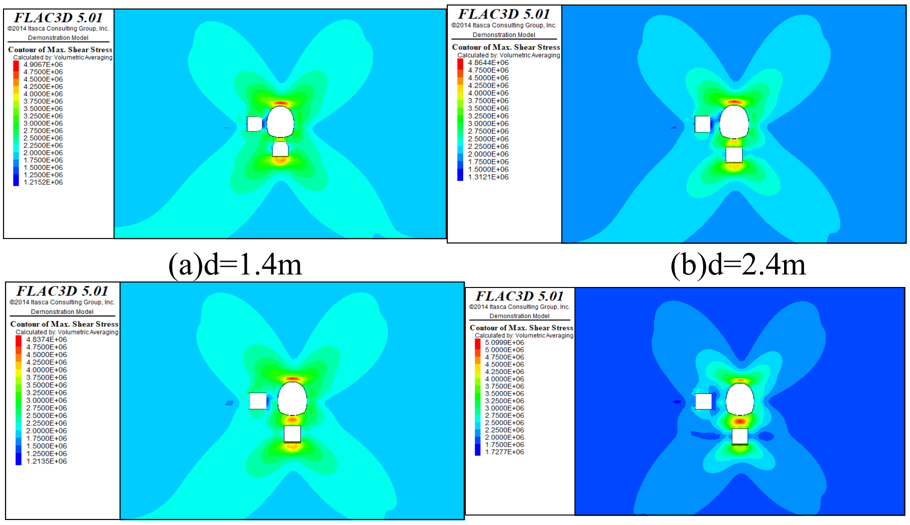


(e)d=4.4m

Figure 3. Nephogram of maximum shear stress of top and side cavities

Then the distance increases again,and the stress decreases to 5.0MPa,indicating that under the condition of large cavity size,the boundary line of distance influence on the stress field of tunnel surrounding rock is the tunnel radius.

However,when there are cavities at the bottom and side of the tunnel at the same time,the influence on the tunnel is greater,and the cloud diagram of the maximum shear stress at the bottom and side is shown in Figure4.



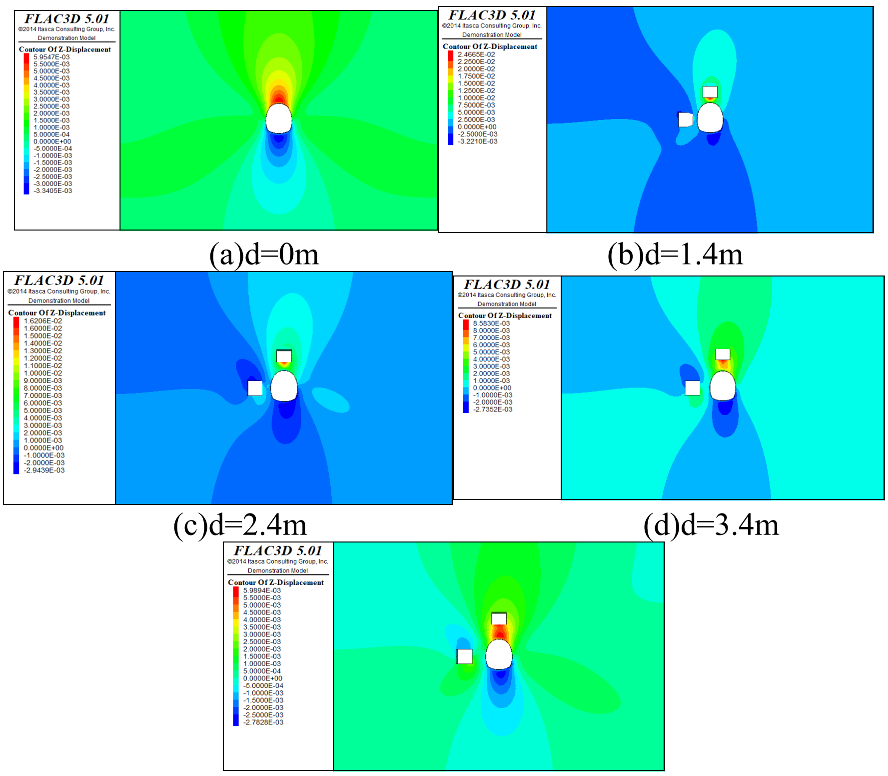
(a)d=1.4m (b)d=2.4m

(c)d=3.4m (d)d=4.4m

Figure 4. Nephogram of maximum shear stress at bottom and side

As can be seen from Figure4,the distance between the tunnel and the cavity ranges from 1.4m to 4.4m,and the maximum shear stress on the rock mass between the cavity and the tunnel does not decrease all the time,but increases from 2.5MPa to 5.1MPa.When the distance is the radius of the tunnel,the stress distribution at the bottom of the tunnel arch tends to increase because of the cavity at the bottom.When the cavity at the side is 4.4m,it is not completely disconnected from the shear stress nephogram of the tunnel.Compared with the cavity at the top,the cavity at the bottom has a wider influence on the cavity at the side.

In the process of tunnel excavation,its stress state affects its displacement to some extent.The displacement cloud map during excavation is shown in Figure 5 and Figure 6.



(a)d=0m (b)d=1.4m

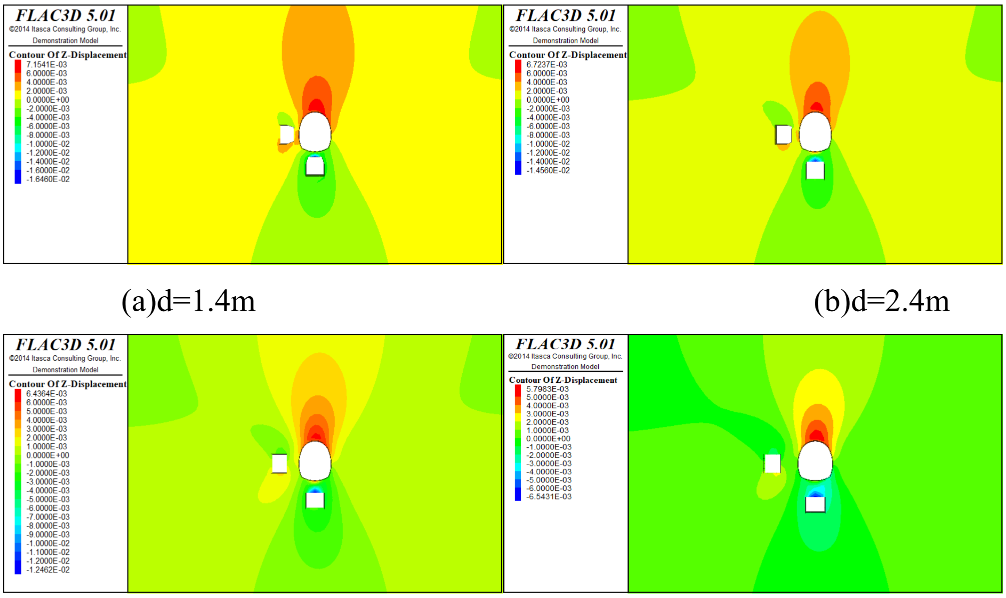
(c)d=2.4m (d)d=3.4m

(e)d=4.4m

Figure 5. Nephogram of vertical displacement of top and side cavities

As can be seen from FIGURE5,when the distance between the tunnel and the cavity is 1.4m,the maximum displacement of the tunnel vault reaches 24.67mm,which is a large displacement.At this time,the stability of surrounding rock between tunnel vault and cavity is poor,and the possibility of vault collapse is greater.With the cavity distance increasing by 1 m,the displacement of the tunnel vault decreases rapidly,and the maximum displacement is 16.2 mm.With the further increase of 1 m,the maximum vertical displacement of tunnel vault decreases to 8.58 mm.When the distance reaches 3.4m,the vertical displacement decreases as the distance continues to increase by 1m.When the distance is 4.4m,the vertical displacement decreases by 2.59mm to 5.99mm.

At this time,the surrounding rock of the tunnel is less affected by the cavity,and the effect of the cavity can hardly be considered any more.In other words,when the cavity diameter is 4m and the cavity distance is close to the tunnel radius,the tunnel excavation stability is small,and the influence of the cavity on the stability of the tunnel surrounding rock can be ignored as long as the support is proper.



(a)d=1.4m (b)d=2.4m

(c)d=3.4m (d)d=4.4m

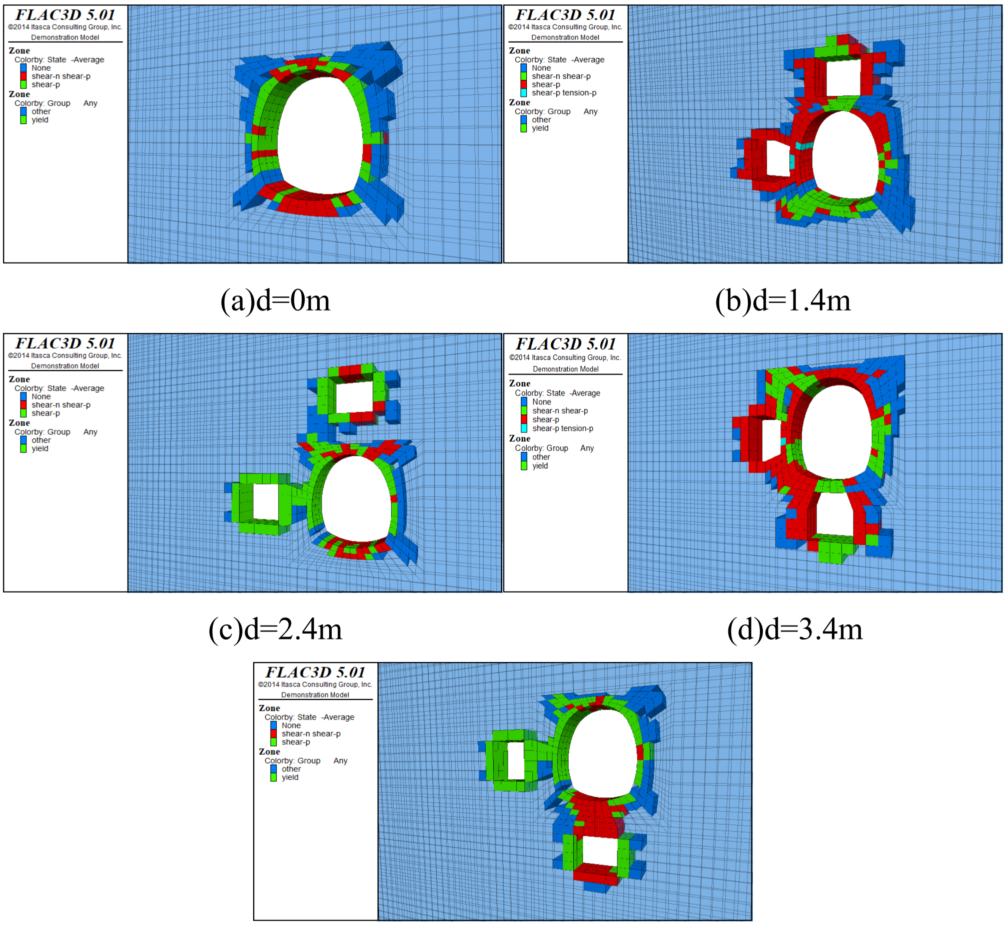
Figure 6. Nephogram of vertical displacement of bottom and side cavities

When there are cavities at the bottom and side of the tunnel,the vertical displacement of the tunnel vault,arch waist and arch bottom decreases further with the increase of the cavity distance.Similarly,when the distance is increased to about the tunnel radius,that is,after the distance is 4.4m,the maximum displacement is about 5.79 mm for the tunnel vault,while the maximum displacement is reduced from 16.4mm to 6.5 mm for the lower cavity top.The vertical displacement cloud map of the bottom and side caverns is shown in Figure6.It can be seen from Figure6 that the side and bottom caverns have little influence on the displacement value of the tunnel surrounding rock.In the tunnel surrounding rock plastic zone,the fish statement written in advance is used to carry out accurate statistics on the surrounding rock plastic zone,and the results are shown in Table3.At the same time,another fish statement is used to display the plastic zone of surrounding rock with three-dimensional 3D effect,as shown in Figure7.

Table 3. Volume statistics of plastic zone

Distance [m]	Top and side plastic zone volume [m^3]	Plastic zone volume at bottom and side [m^3]
d=1.4	569.16	626.72
d=2.4	519.19	601.13
d=3.4	523.31	530.7884
d=4.4	488.152	519.21

It can be intuitively seen from Table3 that when the cavity is at the top and side,the plastic zone volume of the tunnel decreases as a whole with the increase of the cavity distance.The plastic zone volume of the tunnel surrounding rock is relatively small compared to the cavity at the bottom and the cavity at the top.Especially when the void distance is close,the plastic zone volume difference between the two is obvious.With the increase of void distance,the plastic zone volume tends to a stablevalue.When there is a cavity at the top and side,the plastic zone volume reaches the maximum at the cavity distance of 1.4m,reaching 569.16m3,and decreases slowly.When the cavity distance is 4.4m,the plastic zone volume reaches 488.15m3.When there are cavities at the bottom and side of the tunnel,the plastic zone volume of the surrounding rock is 626.72m3 and 519.21m3 respectively.The presence of voids at the bottom has a greater effect than the presence of voids at the top,and the effect diminishes rapidly as the distance increases.



(a)d=0m (b)d=1.4m

(c)d=2.4m (d)d=3.4m

(e)d=4.4m

Figure 8. 3D display of plastic zone

As can be seen from Figure7,when there is no cavity,the plastic zone is mainly concentrated at the bottom,which has basically no impact on the safety of the entire tunnel.Taking the cavity distance of 1.4m and 4.4m as an example,when the distance is 1.4m,the tunnel plastic zone is connected to the cavity,and when there is a cavity at the bottom,the plastic zone has a wide expansion range.When the distance is 4.4m,the plastic zone of the top cavity is basically separated from the plastic zone of the tunnel,and the plastic zone of the two continuously decreases greatly,which basically can not cause the collapse zone anymore.

3.2. Influence of annular cavity on surrounding rock of tunnel during excavation

In the process of tunnel excavation,due to the large displacement value of the surrounding rock of the tunnel,the support system will be applied to the tunnel during the excavation,of which the anchoring and lining system is the most common.The supporting measures of D1K467-D1K468 cavity section of a tunnel in Yunnan province are also used by anchoring and lining.The anchoring method is full length anchoring,and the bolt layout method is plum pile distribution.The results of the triaxial compression test were analyzed,and the anchorage parameters in the numerical simulation were shown in Table 4.

Table 4. Simulated anchor cableparameters

category	Elastic modulus [GPa]	Poisson's ratio μ	Density P[g·cm^{-3}]	Tensile strength [MPa]	Bond force per unit length of cement paste [MPa]	Unit length cement stiffness [MPa]
Bolt diameter 22mm	450	0.31	0.81	0.28	1.60	150
Prelining C25	24	0.20	0.27			

According to the actual situation of the site,in the process of subsequent tunnel excavation,it is very likely to appear on the tunnel section,and there are multiple voids in a ring around the tunnel.Figure8 shows that the tunnel center is the center of the entire model,and the positive and negative directions of X and Z are both 50 m.A cross-section model is established with the tunnel extension direction as Y direction.The Y direction is 15 m,the depth of each excavation is 3 m,and the excavation method is two steps up and down.The whole model has 141380 units and 161040 nodes.

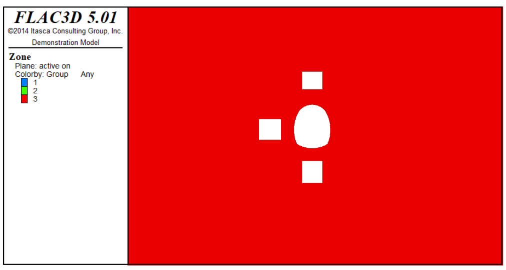


Figure 8. Simulation diagram of multiple cavities with circular distribution in tunnel surrounding rock

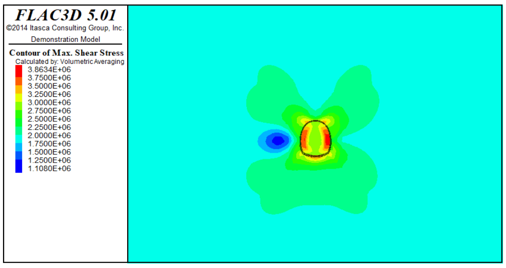
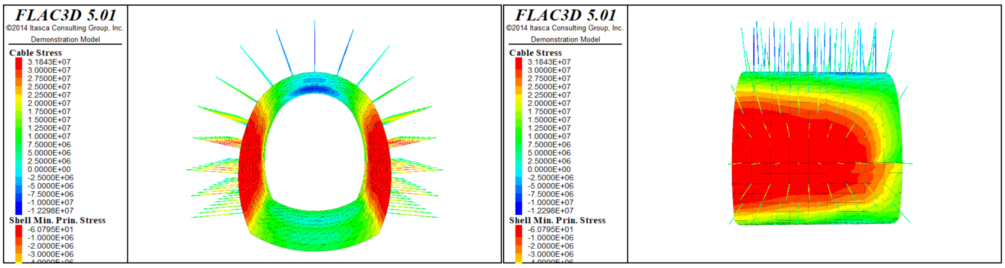


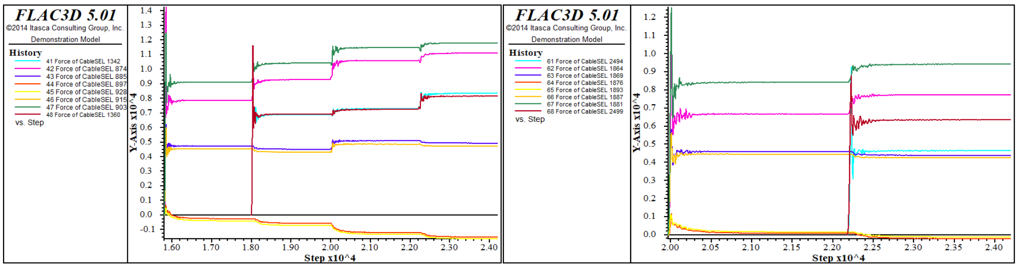
Figure 9. Cloud diagram of maximum shear stress in surrounding rock

For normal constraints on other surfaces except the top surface,the surrounding rock constitutive model adopts the Moore-Coulomb elastoplastic model widely used in tunnel simulation[16].

At the same time,the actual application of the support system improves the stability of the surrounding rock of the tunnel.From the stress field of the surrounding rock,after the cavity appears in the tunnel excavation process,the left cavity shows a circular stress field distribution in the front view.The left cavity causes the maximum shear stress around the cavity to be larger,while the shear stress of the surrounding rock of the tunnel is not affected,and the maximum shear stress is small.When the distance between the tunnel and the cavity on the left is 3.4m,it can be seen that the stress fields of the two are independent of each other and do not affect each other under the application of the supporting system.At the same time,the maximum shear stress at the arch waist of the tunnel is 3.86 MPa,and the maximum shear stress at the arch roof is 2.25 ~2.50 MPa.It can be seen from FIGURE9 that the cavity at the bottom of the tunnel is closely related to the stress field of the tunnel and influences each other.The cavity size of the bottom of the arch is also larger,3 m×4 m×5 m.



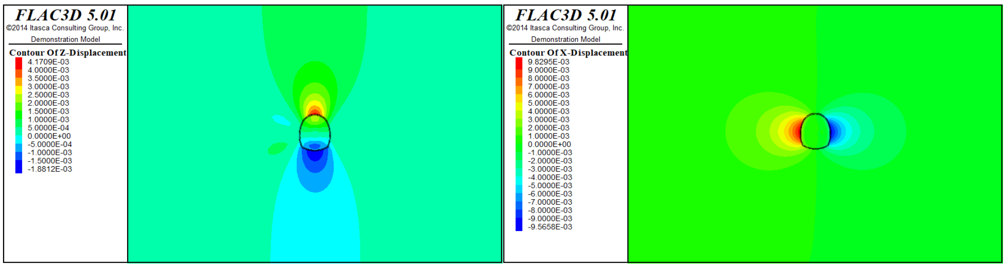
(a)Initial stress field nephogram (front) (b)Initial stress field nephogram (side)



(c)Axial force curve of bolt at 4m section (d)Axial force curve of bolt at 6m section

Figure 10. Stress field nephogram of anchor cableand initial lining and axial force curve of anchor cableat monitoring points

Figure10 shows that the maximum axial force of the bolt is 8.6MPa,the distribution position of the maximum axial force is that the bolt is in tension at the middle part of the bolt at the arch waist,and the maximum axial force of the bolt at the arch top is 12.3MPa,and the bolt is under pressure.As can be seen from FIGURE11,when the tunnel is driven to 6~9 m,the initial lining stress at the arch top of the tunnel is greater than the area with stablesupport at the entrance.At 9 m,the maximum value of the initial lining stress at the arch is 3.1 MPa,and the minimum value is 1~2 MPa at the arch waist.It shows that the surrounding rock is not stableafter the tunnel is just excavated.After the support,the range of stress field and stress value of the surrounding rock are reduced,but the stress value is still high on the new excavation surface.It can be seen from the curve of the monitoring point that each excavation will have an impact on the axial force of the bolt.After the axial force of the bolt is excavated at 4m and excavated at 6 m,the axial force of the bolt changes slightly,rising by about 2 kN.Compared with the case without support,the influence range of the cavity on the surrounding rock of the tunnel is significantly reduced.When the distance is 3.4m,the influence of the cavity on the stress field of the surrounding rock of the tunnel is not enough to threaten the further tunneling.



(a)Vertical displacement cloud image (b)Horizontal displacement cloud image

Figure 11. Nephogram of vertical and horizontal displacement of tunnel surrounding rock

The application of support system can reduce the displacement of tunnel surrounding rock.As shown in FIGURE11,according to the simulated situation,the vertical displacement of tunnel surrounding rock decreased from 5.95mm to 4.17mm in the absence of support,a decrease of 29.9%.The maximum vertical displacement of arch bottom decreased from 3.34mm to 1.88mm,a decrease of 43.7%.The maximum horizontal displacement of the vault is reduced from 14.8mm to 9.8mm,a reduction of 33.8%.The maximum horizontal displacement of the arch bottom was reduced from 14.8mm to 9.6mm,a reduction of 35.1%.It is obvious that the support system has a great effect on the stability of tunnel surrounding rock.

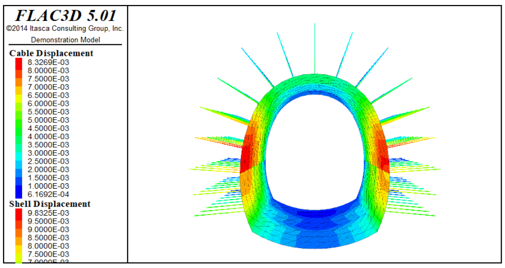


Figure 12. Anchor rod and initial lining total displacement cloud diagram

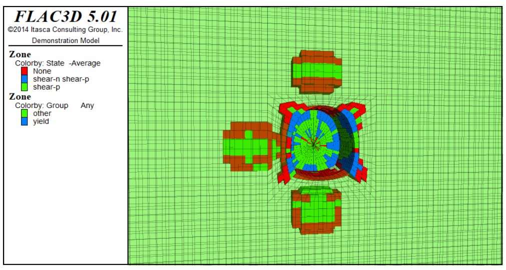


Figure 13. Distribution of plastic zone around the circular cavity

As can be seen from Figure12,the displacement value of the anchor rod is small in the newly excavated section,the surrounding rock gradually tends to be stablein the initial excavation,and the displacement value of the anchor rod is large,and the displacement value of the anchor rod at the arch waist reaches 8.3mm.Moreover,it can be seen that the excavation of the upper and lower steps leads to large jump changes in the displacement value of different parts of the same excavation section.

From the perspective of the plastic zone of the tunnel surrounding rock,there are 3 annular cavities with a plastic zone volume of 927 m^3.After the anchoring system is applied,the holes at the top and bottom of the tunnel produce plastic zones,but the plastic zone is no longer connected with the tunnel,and no collapse phenomenon will occur.However,the left cavity plastic zone is still connected with the tunnel,which affects the stress field of the tunnel surrounding rock.The application of the support system reduces the volume of the plastic zone of the tunnel,but the influence of the cavity on the stability of the tunnel surrounding rock,especially the side cavity,cannot be completely eliminated.The distribution of the plastic region of the annular cavity is shown in Figure13.

As can be seen from Figure13,when the cavity plastic zone at the tunnel side is relatively unsupported,the influence range gradually decreases in a conical shape near the tunnel side.The plastic zone generated by the cavity at the top and bottom is not a threat to the tunnel,and the supporting effect is remarkable

3.3. Comparison between actual engineering monitoring and simulation

The K1+ 440-K1 +460 mileage section of the right line of the tunnel was taken as the research section,and a 20 m model was established to carry out circular excavation of the whole section.In order to avoid the influence of the boundary,16 m of excavation was carried out for statistical analysis of displacement data.The comparison between the field actual monitoring and numerical simulation analysis is shown in Figure14.

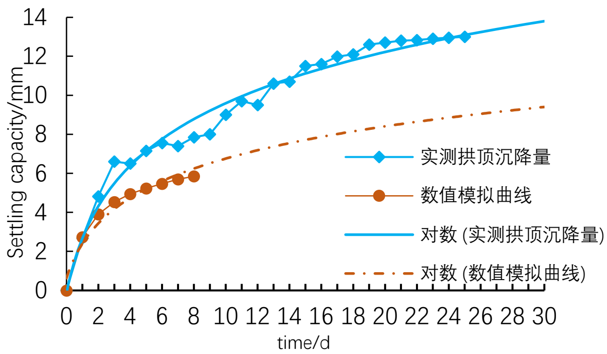


Figure 14. K1+440 Comparison analysis curve of arch top settlement displacement

According to the linear regression analysis of the monitoring curve and the simulation,it can be inferred that the maximum settlement of the arch is about 13.94mm,and the vertical displacement of the arch under the numerical simulation is 9.61mm.The results show that the numerical simulation results of the selected physical parameters are close to the field measured results,but because the model does not take into account the influencing factors such as joint fractures,rock formation,groundwater,and model construction process,the simulation results are relatively small.

4. CONCLUSION

Through the preliminary geological survey,section D1K467-D1K468 of a tunnel in Yunnan Province was selected as the research object,and numerical simulation software FLAC3D was used to analyze the annular multiple voids of the tunnel,including two states of voids at the top and side,and voids at the side and bottom.Considering the different distance between the voids and the tunnel,the study was conducted at different distances.The influence of cavity on tunnel surrounding rock.Through the analysis of the stress field,displacement field and plastic zone of the tunnel surrounding rock,the following conclusions are drawn.

(1)When there are cavities at the top and side of the tunnel,and at the bottom and side of the tunnel at the same time,it is found that the cavity at the top and bottom has less influence on the tunnel surrounding rock than the cavity at the side.The bottom cavity has more influence than the top cavity.According to the scope of the plastic zone,the influence range of the cavity on the tunnel surrounding rock is about the radius of the tunnel.When the distance exceeds the tunnel diameter,the influence of the cavity on the surrounding rock of the tunnel is greatly reduced.

(2)In the case of annular multiple voids on the excavation surface,according to the actual construction process of a tunnel in Yunnan Province,when voids are encountered in the excavation process,the displacement value of the tunnel surrounding rock becomes smaller due to the supporting effect of the primary lining and anchor rod,and the reduction of the arch bottom is greater than that of the vault when there is no support.Moreover,due to the supporting function of the anchor rod and the primary lining,the plastic zone of the cavity and the tunnel can no longer be connected at 2.4m,which greatly reduces the risk of water inrush and collapse accidents in the excavation process of the near-distance cavity.

(3)The comparison between the numerical simulation and the field actual project shows that there is a high coincidence between the two,indicating that it is feasible to study the stability of surrounding rock by using numerical simulation in this project.

REFERENCES

[1] HONG Kairong.Development and prospects of tunnels and underground works in China in recent two years[J].Tunnel Construction,2017,37(2):123-134.

[2] HU Gege.Research and application of injecting paste material in high-risk Karst tunnel[D].Wuhan: Wuhan Institute of Technology,2015.

[3] YANG Yi.Research on support control of soft-rock large deformation in thered stratum of mid-Yunnan Area[D].Chengdu:Southwest Jiaotong University,2018.

[4] ZHENG X,ZHANG B,DENG Z,et al.Stability analysis of surrounding rock mass of an underground cavern in Tibet[J].Yangtze River,2011,42(4):40-42.

[5] TONG W,WANG YH,LI X.Evaluation of underground cavern surrounding rock mass stability influencing factors based on AHP[J].Design of Hydroelectric Power Station,2008(2):10-13.

[6] PAN-FENG L I,LIU H,CUI C W,et al.Engineering geological assessment of rock mass stability surrounding a large-scale underground cavern swarm[J].Geology-Geochemistry,2005,33(3):90-94.

[7] Su Xiangwu. Analysis of influence of beaded karst caves on tunnel stability[J].Fujian Transportation Science and Technology, 2017(2):89-95.

[8] SHAO Yong, YAN Changhong, XU Baotian,et al.Analysis on the influence of small caves on stability of underground tunnel[J].Geological Review,2012,58(3):519-525.

[9] WANG Tao, CHEN Xiaoling,YU Lihong.Discrete element calculation of surround -ing rock mass stability of underground cavern group[J].Rock&Soil Mech-anics,2005,26(12):1936-1940.

[10] ZHANG Feng,JIN Xiaoguang,JIA Xueming.Analysis for influences of side caverns on stability of tunnel wall rock[J].Technology of Highway and Transport,2011,27(4):101-104.

[11] SHI Shiyong,MEI Shilong,YANG Zhigang.Research on the influence of Karst cave in the roof of tunnel on stability of surrounding rock[J].Chinese Journal of Underground Space and Engineering,2005,1(5):698-702.

[12] MU Lan,HU Yuting.Study on stability of surrounding rock due to tunnel passing across water-bearing fault utilizing fluid-mechanical coupling[J].Highway Engineering,2017,42(4):108-113.

[13] XU Jianguo,YU Songling,WANG Gang,et al.Stability analysis of tunnel surrounding rock based on fluid-solid coupling theory[J].Journal of Water Resources and Architectural Engineering,2018,16(4):62-67.

[14] TAN Daiming,QI Taiyue,MO Yangchun.Numerical analysis and research on surrounding rock stability of lateral Karst cave tunnel[J].Chinese Journal of Rock Mechanics and Engineering,2009,28(Suppl.2):3497-3503.

[15] XIE Xiaoli,PENG Wenli,QIN Rong.Application of SAINT-VENANT principle in analysis of CFST arch bridge[J].China Journal of Highway and Trans-port,2001,14(2):33-35.

[16] LÜ Wentao. Study on deformation mechanism of soft rock tunnel and support effect of cable[D]. Chongqing: Chongqing University,2018.