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Deep Underground Engineering Working Face Deformation Mechanism

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Abstract

With the excavation of many deep underground projects, it is very important to study the deformation of the working face, so the numerical model is established by FLAC3D software, and the extrusion displacement, working face plasticity zone, and working face pre-convergence displacement of the palm surface of the deep underground project are analyzed with the help of Origin data software. The results show that the extrusion displacement of the working face and the pre-convergence in front of the working face can be determined by numerical simulation with the decrease of the surrounding rock level, the increase of burial depth, the increase of lateral pressure coefficient and the increase of moisture content. The surrounding rock only has tensile damage or pull shear damage in the arch waist and the local area of the working face, and the tensile damage and pull shear damage area of the surrounding rock are mainly concentrated in the arch shoulder, arch foot, and working face edge part, and most of the working face is subject to shear stress.

Keywords

Working Face; Extrusion Displacement; Preconvergent Displacement.

1. Introduction

With the excavation of many high-altitude stresses, large burial depths, and underground projects, the inevitable soft rock formations put forward more requirements for the control of extrusion displacement and pre-convergence displacement of the working face, and the study of the deformation law and control of the working face in the construction project is very important for the excavation of deep underground engineering. Zheng L et al. [1] analyzed the stability of the surrounding rock of a deeply buried soft rock tunnel. The influence of different factors on the stability of deep buried tunnels was studied. Jiannan L et al.[2] Constructed a numerical calculation model of the tunnel by FLAC3D to study the variation characteristics of the extrusion displacement of the working face and the pre-convergent displacement in front of the working face during the tunnel arch effect. Jun D[3] Based on the strength reduction theory, the stability discrimination process of the palm face is established, and the stability safety factor of the palm face can be solved, and Zhongsheng T [4] studied the strength of the surrounding rock mass and the distribution law of the ground stress field through indoor and outdoor tests and numerical simulations. Bo T et al. [5] built deep buried long tunnels in the weak surrounding rock under the stress environment of the highland, and the deformation law of the surrounding rock of the sheling W Tunnel was analyzed. Zhijie W et al. [6] relying on the kun C Complex Line Jixin Tunnel Project, numerical simulation was used to analyze the whole process of instability of the working face of the tunnel. Aoxiang N[7] explored the failure characteristics and development laws of different surrounding rock levels, different buried working face, and the stress changes of the surrounding rocks in front of the working face.

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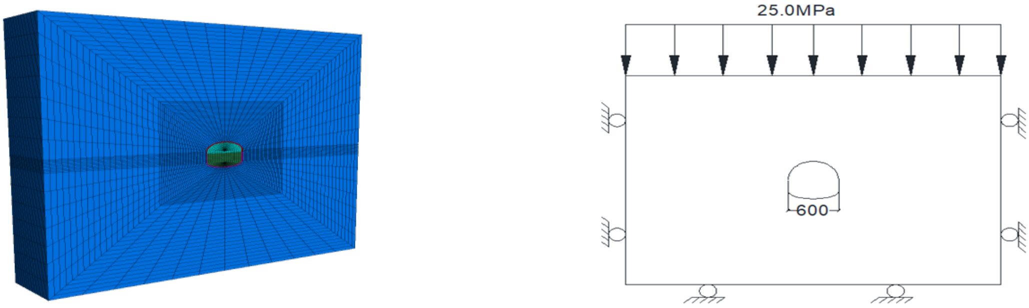
2. Numerical Model and Parameters

2.1 Numerical Model

The numerical calculation model is shown in Figure 1



(a)Numerical model (b) Boundary conditions (in cm)

Figure 1. Numerical model and boundary conditions

In order to ensure the realistic and reliable simulation results, based on the St. Venant's principle and the influence range of the excavation of underground works, while fully considering the engineering section, as well as eliminating the boundary effects generated by the simulation calculation, the calculation model established is 50m long horizontally, 30m high vertically and 10m long vertically, i.e. the left and right boundaries are 5 times the width of the excavation section of underground works, the upper and lower boundaries are 7 times the total height of the left and right excavation sections, the model See Figure 3-1. The cross section of the cavern is a straight wall arch (slightly with bottom arch), with a width of 6.0m and a total section height of 5.3m, of which the top of the arch is an arc with a radius of 3.0m and a vector height of 1.9m, the height of the straight wall of the section is 2.3m and the height of the bottom arch is 1.1m. The vertical load is applied to the top surface of the model to simulate vertical ground stress, and the side and bottom displacements are locked, and the boundary constraints are schematically shown in Figure 1.

2.2 Mechanical Parameters of Surrounding Rock

The mechanical parameters of the surrounding rock are selected according to the "Engineering Rock Mass Grading Standard" GBT50218-2014 (as shown in Figure 1), The simulations in this report make the following assumptions about the lithology of the rock: the rock is a homogeneous, isotropic continuum that meets the Mohr-Coulomb strength criterion, and the material parameters meet the Mohr-Coulomb constitutive model relationship.

Table 1. Mechanical parameters of surrounding rock.

Surrounding rock grade	density kg/m^3	Modulus of elasticity/GPa	Poisson's ratio	Cohesion/ MPa
IIIsurrounding rock	2500	6.265	0.312	0.78
IVsurrounding rock	2000	5.289	0.271	0.56

2.3 Determine the Simulation Scheme

The numerical simulation test scheme adopts the burial depth, side pressure coefficient, water-bearing state and surrounding rock grade to excavate the working face of the tunnel, and the specific simulated working conditions are shown in Table 2 below.

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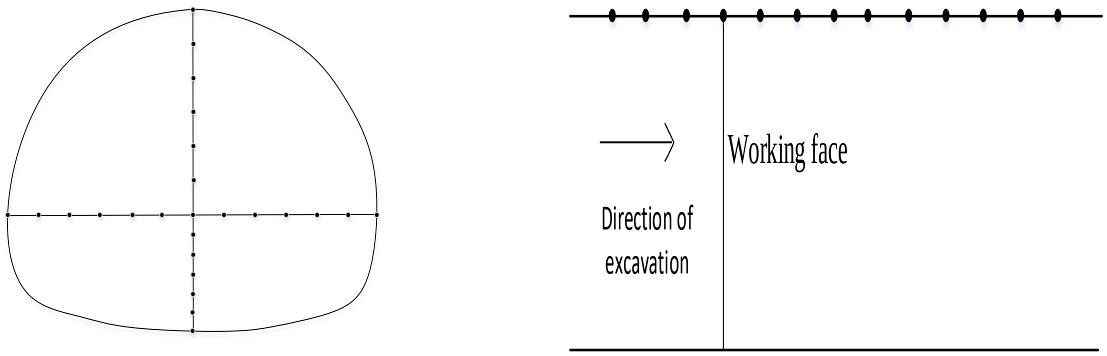
Table 2. Numerical simulation conditions

working condition	Content of numerical simulation
1	The buried depth of the cavern is 1200m and the lateral pressure coefficient is 1.5; Water bearing state is natural state; The grade of surrounding rock is grade III; The excavation method is full face excavation, and the excavation footage is 2m;
2	The buried depth of the cavern is 1200m and the lateral pressure coefficient is 1.5; Water bearing state is natural state; The grade of surrounding rock is grade IV; The excavation method is full face excavation, and the excavation footage is 2m
3	The buried depth of the cavern is 1200m and the lateral pressure coefficient is 0.9; Water bearing state is natural state; The grade of surrounding rock is grade III; The excavation method is full face excavation, and the excavation footage is 2m;
4	The buried depth of the cavern is 1200m and the lateral pressure coefficient is 1.2; Water bearing state is natural state; The grade of surrounding rock is grade III; The excavation method is full face excavation, and the excavation footage is 2m;
5	The buried depth of the cavern is 600m and the lateral pressure coefficient is 1.5; Water bearing state is natural state; The grade of surrounding rock is grade III; The excavation method is full face excavation, and the excavation footage is 2m;

2.4 Layout of Monitoring Points

In the numerical simulation calculation, the monitoring points of several points are arranged on the excavation surface vault and the palm surface, and the pre-convergence displacement in front of the working face and the extrusion displacement of the palm face are monitored in time. Monitoring is carried out in the direction of excavation (monitoring points are shown in Figure 2). In order to analyze the variation characteristics of the pre-convergent displacement and extrusion displacement in front of the excavated working face, a monitoring line was set up in the vertical direction of the top plate, and the monitoring points were evenly arranged in the vertical and horizontal directions at 0.5 meters intervals on the working face.



(a) working face monitoring point (b) working face vault monitoring point

Figure 2. Layout of monitoring points

3. Analysis of Simulation Results

3.1 Analysis of the Evolution Law of Different Surrounding Rock Levels of the Working Face

3.1.1 Analysis of the Law of Extrusion Displacement and Plastic Zone Change of Working Face

In all underground engineering design and construction, the surrounding rock level directly determines the support method and construction method of the underground engineering. The surrounding rocks of Class III and IV. were selected for numerical simulation calculation, and the

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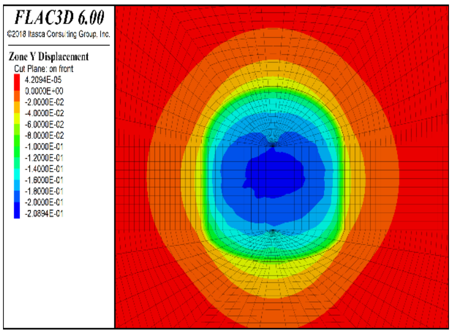
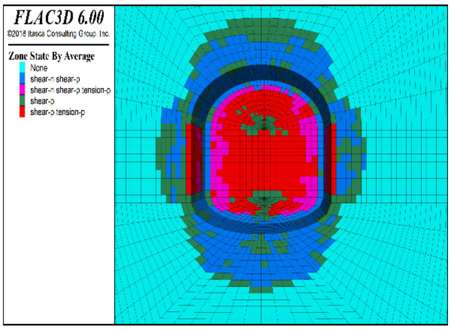
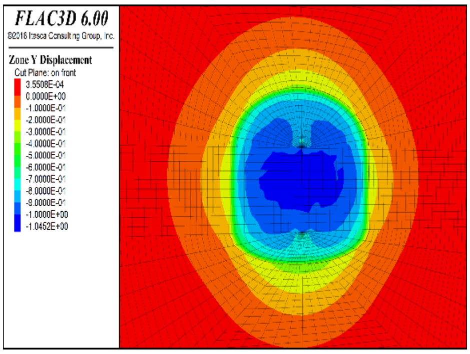
extrusion deformation and plasticity state of the palm surface changed with the level of the surrounding rock, as shown in Figure 3.



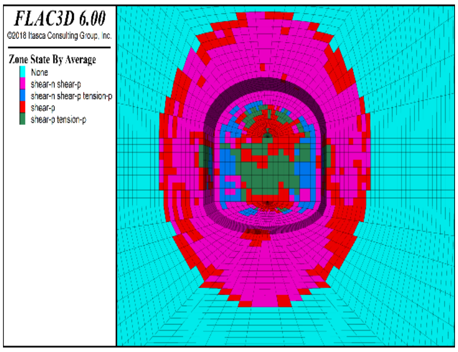
(a) Class III. Perident Rock working face Displacement Cloud Map



(b) Grade III surrounding rock working face plastic area



(c) Class IV. Surrounding Rock working face Displacement Cloud Map



(d) Grade IV. surrounding rock working face plastic zone

Figure 3. Slice of tunnel face and plastic zone at different surrounding rock levels

It can be seen from the extrusion displacement cloud diagram of the palm face in Figure 3 that under the conditions of class III surrounding rock, the maximum extrusion displacement of the working face after the excavation of the underground project is only 20cm, and most of the working face is shear damage, the vault and arch bottom are shear damage, and the arch waist appears as pull shear damage. With the reduction of the level of surrounding rock, the self-stability ability of the rock is getting worse and worse, especially for soft rock, excavated under the conditions of the IV. surrounding rock, with the excavation of the underground engineering, the maximum extrusion displacement of the working face of the IV. surrounding rock after the excavation of the underground engineering is 104.5cm, which is 5 times that of the III. surrounding rock, which can not ensure the stability of the working face itself and the surrounding rock, and the plastic area of the IV. surrounding rock is manifested as the central area of the working face and the left and right sides for shear destruction, and the upper and lower parts of the working face are only manifested as shear damage, vault and arch bottom , the arch shoulders, arch feet and the surrounding area of the tunnel excavation are all shear damaged, and only a little pull shear damage occurs in the arch waist part, so as the level of the surrounding rock decreases, the extrusion displacement of the working face becomes larger and larger. With the reduction of the level of the surrounding rock, the surrounding rock will be seriously deformed after the excavation of the underground project, and the working face is particularly prone to large collapses.

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3.1.2 Extrusion Displacement Analysis of Working Face of Different Surrounding Rock Levels

The extrusion displacement analysis of working face of different surrounding rock levels is shown in Figure 4.

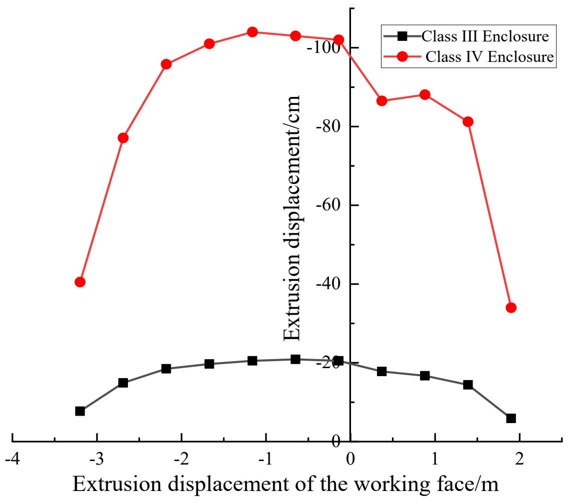

Figure 4. Comparative analysis of palm face extrusion displacement at different surrounding rock levels

From Figure 4, it can be seen that the extrusion displacement at the working face is extruded inward in an arc-shaped shape, after the excavation of the local underground project, there is no surrounding rock at the working face to constrain the working face , so that the working face undergoes longitudinal extrusion deformation, and the surrounding rock at the edge of the working face still has a certain constraint effect around the working face , so the extrusion deformation at the edge of the working face is relatively small, so the extrusion displacement of the working face shows a small trend of small on both sides and a large middle, and the strength of the core soil at the working face also determines the size of the extrusion displacement of the working face . When the surrounding rock level is grade III surrounding rock, the maximum extrusion displacement at the working face is 21cm at this time, and when the working face is the IV. surrounding rock, the maximum extrusion displacement of the palm surface is 101cm, which is 90cm (an increase of 89%) compared with the III surrounding rock, and the extrusion displacement of the working face of the ivy surrounding rock at this time is very large, and it is difficult to maintain the stability of the working face itself. The extrusion displacement of the palm face increases as the level of the surrounding rock decreases. III. The maximum extrusion displacement of the working face is 2.55m from the edge of the working face , and the maximum extrusion displacement of the working face is 3.06m from the edge of the working face , that is, about 0.6H (H is the height of the working face).

3.1.3 Analysis of Working Face Vault Displacement at Different Surrounding Rock Levels

In the process of excavation of underground engineering, the vault displacement of the working face also has a significant impact on the excavation of the underground engineering, and the numerical simulation calculation of the level III and IV surrounding rocks is carried out to focus on the analysis of the impact of the pre-convergent displacement in front of the working face on the excavation of the underground engineering with the decrease of the surrounding rock level. This is shown in Figure 5.

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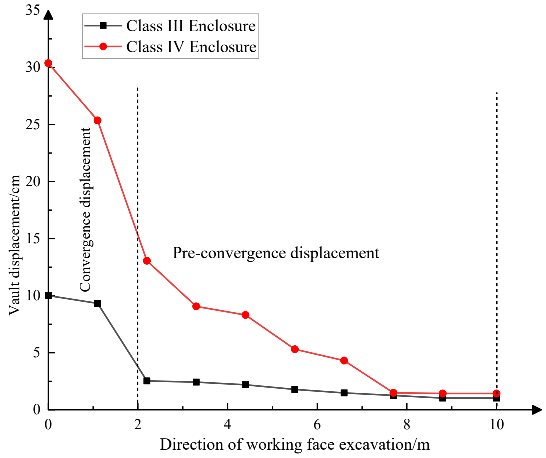


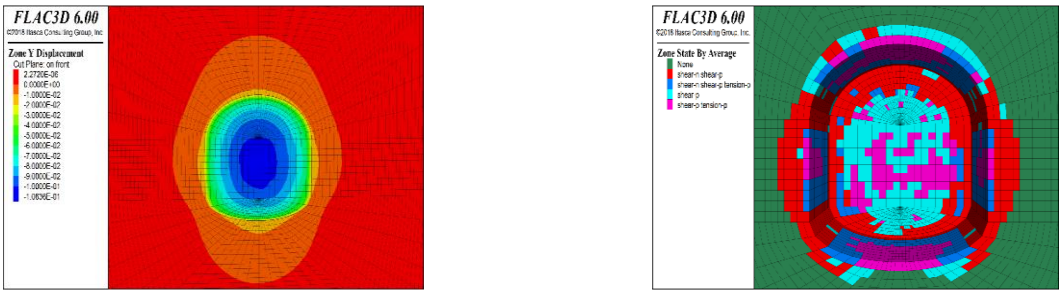
Figure 5. Comparative analysis of vault displacement of tunnel face at different surrounding rock levels

It can be seen from Figure 5 that under different surrounding rock levels, the settlement of the working face vault increases with the increase of the surrounding rock level, and the vault settlement gradually decreases from the front of the palm in the direction behind the working face , which is in line with the trend of underground engineering convergence, and with the decrease of the surrounding rock level, the vault displacement of the working face gradually increases. In the process of underground engineering, the vault displacement can be divided into pre-convergent displacement in front of the working face (the unexplored has been deformed) and the palm face convergence displacement (the excavated part). At 2 m behind the working face , the vault displacement (convergence displacement) of the working face of the IV. surrounding rock has reached 30 cm, while the preconvergence displacement near the working face is 17 cm, accounting for 56.7% of the entire vault displacement, and it is difficult to ensure the stability of the working face itself. However, the pre-convergent displacement near the working face of the grade III surrounding rock is 2.5cm, accounting for 25% of the entire vault displacement, and the III grade can maintain its own stability well in the unsupported state because of the high level of the surrounding rock.

3.2 Analysis of the Evolution Law of Pressure Coefficients on Different Sides of the Working Face

3.2.1 Working Face Extrusion Displacement and Plastic Zone Analysis

Taking the class III surrounding rock as the benchmark, the extrusion deformation of the working surface under different lateral pressure coefficients and the distribution of the plastic zone under the condition of burial depth of 1200m were discussed, and the extrusion deformation and the distribution of the plastic zone of the working surface under different lateral pressure coefficients were discussed under the conditions of 0.9, 1.2 and 1.5, respectively, as shown in Figure 6.



(a) Side pressure coefficient of 0.9 working face displacement cloud diagram

(b) The side pressure coefficient is 0.9 plastic zone

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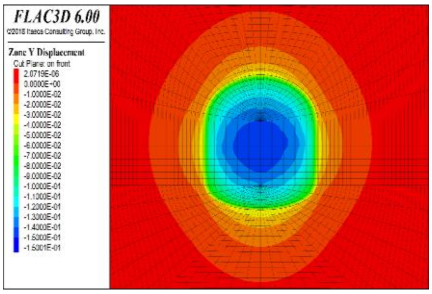
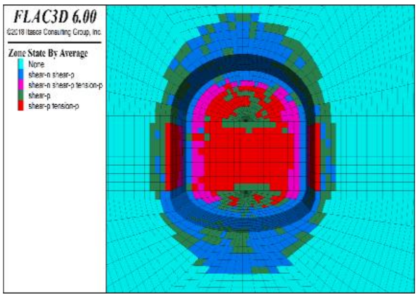
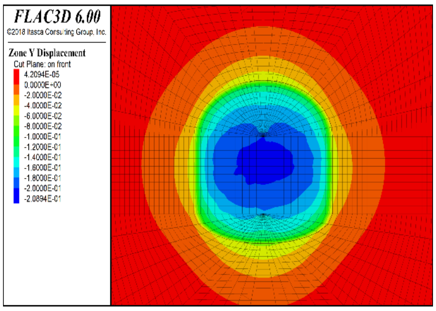


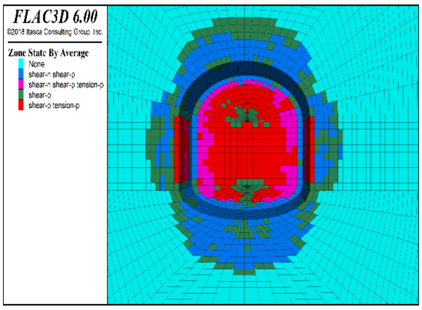
(c) Side pressure coefficient of 1.2 working face displacement cloud diagram



(d) The lateral pressure coefficient is 1.2 plastic zone



(f) Side pressure coefficient of 1.5 working face displacement cloud map



(g) The lateral pressure coefficient is 1.5 plastic zone

Figure 6. Slice of tunnel face and plastic zone with different lateral pressure coefficients

It can be seen from Figure 6 that with the grade III surrounding rock as the benchmark and the burial depth of 1200 meters, the numerical simulation calculations of the lateral pressure coefficients of 0.9, 1.2 and 1.5 are carried out respectively to explore the extrusion displacement of the working face and the change of the plastic zone with the lateral pressure coefficient. When the side pressure coefficient is 0.9, the maximum extrusion displacement of the palm face is 10 .6cm, because the side pressure coefficient is relatively small at this time, and the working face can basically maintain self-stability. At this time, most of the central area of the plastic area of the palm face is sheared, the edge and center area of the working face are mostly expressed as pull scissors, and most of the arch shoulders, arch waist, and arch feet are expressed as pull scissors.When the side pressure coefficient is 1.2, the maximum extrusion displacement of the palm surface is 15cm, compared with the side pressure coefficient of 0.9, the extrusion displacement of the working face increases by 5cm, and the plastic area on the working face is mostly realized as shear destruction, only the upper and lower parts appear a little shear damage, at this time, the vault, arch bottom, arch foot, and arch shoulder are shown to be shear damaged, and only the arch waist is pull shear damage. When the side pressure coefficient is 1.5, the maximum extrusion displacement of the palm surface after the excavation of the underground engineering is only 20cm, which is 10cm more than when the side pressure coefficient is 0.9, because the side pressure coefficient is relatively large, the working face is difficult to ensure its own stability, and most of the plastic areas on the working face are shear damage, the vault and arch bottom are shear damage, and the arch waist appears as pull shear damage. The extrusion displacement of the working face increases with the increase of the lateral pressure coefficient.

3.2.2 Extrusion Displacement Analysis of Working Face under Different Side Pressure Coefficients

A comparative analysis of the extrusion displacement of the working face under different lateral pressure coefficients is shown in Figure 7.

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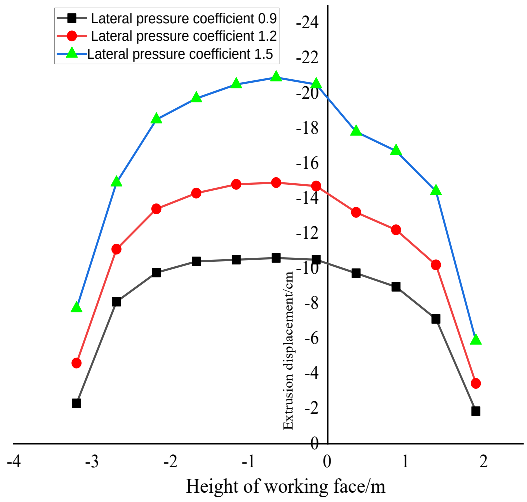

Figure 7. Comparative analysis of working face extrusion displacement under different side pressure coefficients

3.2.3 The Displacement Law of the Working Face Vault under Different Side Pressure Coefficients

Considering that the working face vault displacement also has an important impact on the excavation of underground engineering, taking the grade III surrounding rock as the standard and the burial depth of 1200m, to explore the variation law of the working face vault displacement change of the side pressure coefficients of 0.9, 1.2 and 1.5, as shown in Figure 8.

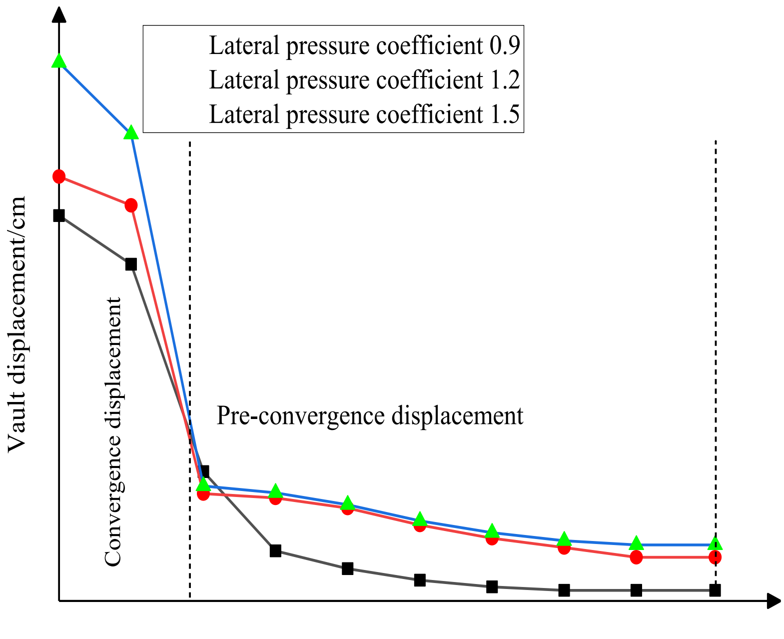

Figure 8. Comparative analysis of vault displacement of working face under different lateral pressure coefficients

From Figure 8, it can be seen that in the process of underground engineering construction, the vault displacement can be divided into pre-convergent displacement in front of the working face (the unexplored has been deformed) and the working face convergence displacement (the excavated part). At 2 m behind the working face , the surrounding rock with a lateral pressure coefficient of 1.5, the vault displacement (convergence displacement) of the working face has reached 12.9 cm, while the preconvergence displacement near the working face is 4 cm, accounting for 31% of the entire vault displacement, and it is difficult to ensure the stability of the working face itself. The surrounding rock with a lateral pressure coefficient of 1.2, at 2 m behind the working face , the vault displacement (convergence displacement) of the working face has reached 10 cm, while the preconvergence displacement near the working face is 3.8cm, accounting for 38% of the entire vault displacement, and the surrounding rock with a horizontal pressure coefficient of 0.9, at 2 m behind the working face , the vault displacement (convergence displacement) of the working face has reached 9 cm, and the preconversion displacement near the working face is 3.8cm, accounting for 42% of the entire vault displacement. As the pressure coefficient on the horizontal side increases, the preconvergent displacement of the working face increases.

4. Conclusion

This paper numerically simulates the deformation of the working face of the tunnel under different working conditions such as surrounding rock level, different lateral pressure coefficients analyzes the deformation of the working face of the tunnel from the extrusion displacement of the working face, the distribution of the vault displacement before and after the working face and the tensile shear stress in the plastic area, and draws the following conclusions:

(1) The preconvergence displacement and extrusion displacement of the working face will become larger with the decrease of the surrounding rock level, the improvement of the lateral pressure coefficient.

(2) With the reduction of the surrounding rock level, the extrusion displacement of the working face is extruded longitudinally to the rear of the palm surface, and the extrusion displacement at the working face is extruded inward in an arc-shaped shape, and after the excavation of the local underground project, there is no surrounding rock at the working face to constrain the working face, so that the working face is longitudinally extruded and deformed.

(3) With the deterioration of the quality of the surrounding rock, the vault behind the working face settles during the excavation of the underground project; The extrusion deformation and pre-deformation of the working face dough machine have similar rules. Class III surrounding rocks only have tensile damage or pull shear damage in the local area of the arch waist and working face of the underground engineering, and the tensile damage and pull shear damage area of class IV surrounding rock are mainly concentrated in the arch shoulders, arch feet, arch bottom and the edge of the working face, and most of the working face area is subjected to shear stress. With the increase of the moisture content of the surrounding rock, the extrusion deformation and pre-convergence deformation of the working face dough machine increased, and the range of plastic zone also increased; With the increase of moisture content, the maximum compressive stress of the surrounding rock increases.

References

[1] Zheng L , Zuo Y , Hu Y , et al. Deformation Mechanism and Support Technology of Deep and High-Stress Soft Rock Roadway[J]. Advances in Civil Engineering, 2021, 2021(4):1-14.

[2] Jianan L, Long C, Zhiyuan L. Study on palm surface deformation and control of soft rock tunnel based on incomplete arch effect[J].Chinese Journal of Geological Hazards and Prevention, 2019, 30(04):61-68.

[3] Jun D, Zhirong M, Lilei F, et al. Study on Palm Surface Stability of Shallow Buried Weak Surrounding Rock Tunnel Based on Strength Reduction Method[J]. Modern Tunnelling Technology, 2020, 57(01):51-57.

[4] Zhongsheng T, Songtao L, Jianjun W, et al. Experimental study on large deformation characteristics of weak surrounding rock in China-Laos railway tunnel[J]. China Railway Science, 2021, 42(04):98-106.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0089

[5] Bo T, Fa-quan W, Qi-liang G, et al. Study on the Rheological Law of Weak Surrounding Rock of Wusheling Deep Buried Long Tunnel under Highland Stress Environment and Numerical Analysis[J]. Chinese Journal of Rock Mechanics and Engineering, 2006(09):1828-1834.

[6] Zhijie W, Yiwen D, Yifan J, et al. Study on the mechanism of palm surface instability in sandy dolomite stratigraphic tunnels[J]. Chinese Journal of Rock Mechanics and Engineering, 2021, 40(S2):3118-3126.

[7] Aoxiang N. Study on palm surface stability and pre-reinforcement construction method of weak surrounding rock tunnel[D]. Beijing Jiaotong University, 2019, 30(3):34-37.