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Tunnel excavation based on FLAC3d numerical simulation

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Abstract: A semi-circular arch straight wall tunnel with a span of 10m, a side wall height of 5m and a buried depth of 500m is excavated in a class IV surrounding rock. Assuming that the surrounding rock is an ideal elastoplastic material, the following problems are analyzed by using finite element or finite difference method: the arch roof subsidence and the horizontal convergence of the side wall after tunnel excavation under the action of gravity stress field and the size of the plastic zone in the surrounding rock. If the lateral pressure coefficient is 0.5-3, the effects of structural stress on the subsidence of the tunnel arch, the horizontal convergence of the side wall and the plastic zone are analyzed. If the bolt support is adopted after excavation, the system bolt shall be laid on the tunnel arch and side wall. The bolt shall be a full-length metal bolt, perpendicular to the tunnel wall, with a spacing of 1.5m, a length of 3.0m, and a diameter of 25mm. The thickness of shotcrete is 100mm, the number is C20, and the supporting effect is analyzed.

Keywords: Numerical simulation; FLAC3d; Tunnel excavation.

1. Introduction

The finite element calculation method is often used in the numerical analysis of engineering structures, and FLAC3D is different from other finite element programs in that it uses the finite difference method [1-4]. In the finite difference method, the system of fundamental equations and boundary conditions (generally differential equations) are approximately expressed by difference equations (algebraic equations), i.e., they are replaced by algebraic expressions of field variables (stress, displacement) at discrete points in space [5-9]. These variables are non-deterministic within the unit, so that the problem of solving differential equations can be replaced by solving algebraic equations, and the finite difference equation can be regenerated relatively efficiently at each calculation step [10-13]. In the finite element method, implicit and matrix solutions are often used, while the finite difference method is usually used to solve algebraic equations using explicit and time-recurring methods [14,15]. The FLAC3D program has powerful post-processing capabilities that allow users to create and output multiple forms of graphics directly on the screen or as files, as well as to combine several variables in the same graph for research and analysis as needed [16].

2. Modeling

Since the radius of the tunnel is 5m, and the radius of the tunnel is 6 times as the affected area of the surrounding rock according to experience, so 30m is taken as the boundary, and the side length of the mesh is 0.5m, so we only need to analyze the force and displacement on the x-z plane, and the specific model is shown in the figure.

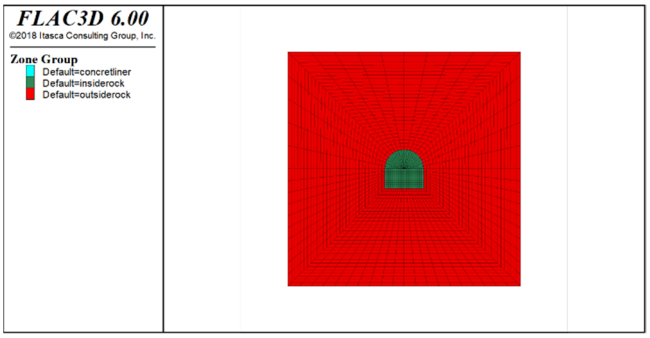

Figure 1. Model of the tunnel before excavation

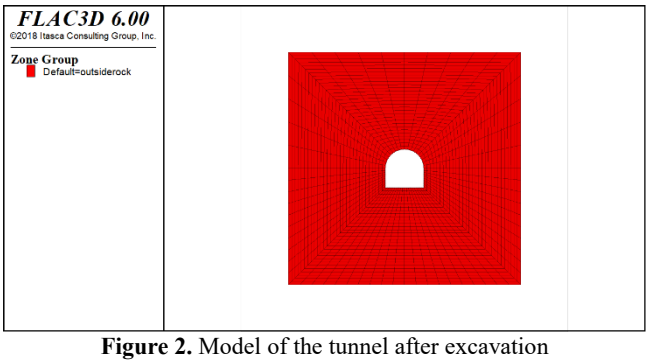

Figure 2. Model of the tunnel after excavation

3. Tunnel Excavation

Format and save your graphic images using a suitable graphics processing program that will allow you to create the images as PostScript (PS), Encapsulated PostScript (EPS), or Tagged Image File Format (TIFF), sizes them, and adjusts the resolution settings. If you created your source files in one of the following you will be able to submit the graphics without converting to a PS, EPS, or TIFF file: Microsoft Word, Microsoft PowerPoint, Microsoft Excel, or Portable Document Format (PDF).

The M-C model was used for surrounding rock, and the

parameters were selected as follows: rock density (kg/m^3) =2200; Acceleration of gravity (kg/N) =10; Volume modulus (Pa)=5e10; Shear modulus (Pa)= le10; Friction Angle =30°; Cohesion (N)=18e7; Tensile strength (N/m^2) =1e7. The stress applied at the Z=30m plane is y_h=22000x(500-30)=10.34e6N/m².

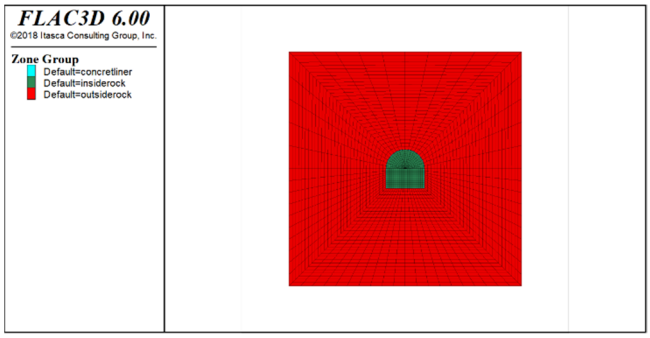

Figure 3. Model of the tunnel when it is not excavated

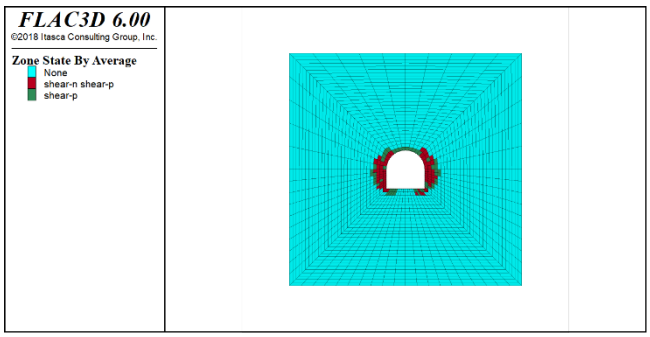

Figure 4. The plastic zone of the cavity after excavation

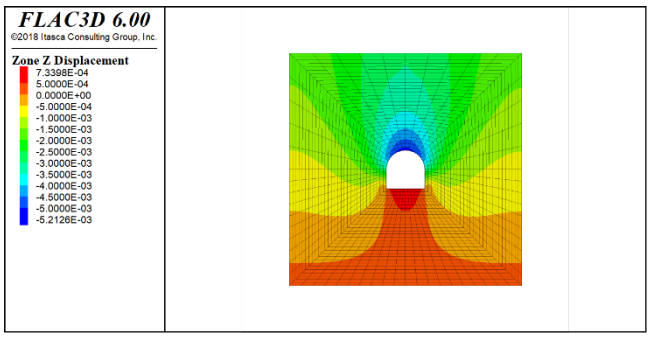

Figure 5. Displacement contour in the Z direction after excavation

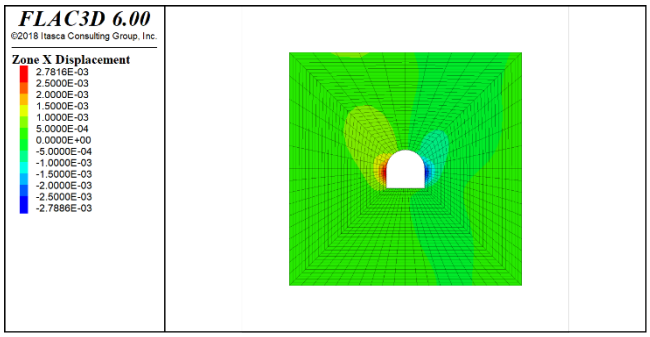

Figure 6. Displacement contour in the X direction after excavation

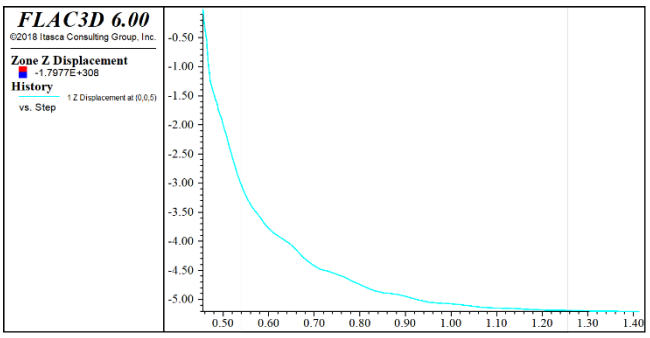

Figure 7. Displacement curve in the Z direction after excavation

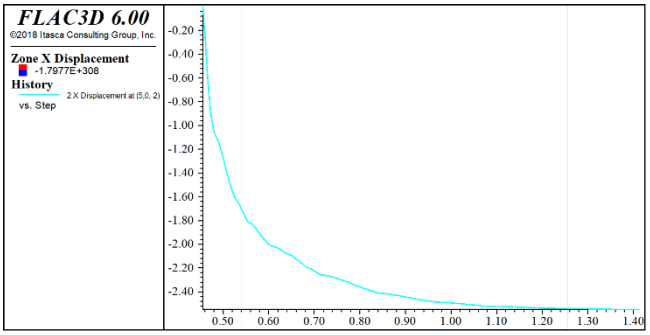

Figure 8. Displacement curve in the X direction after excavation

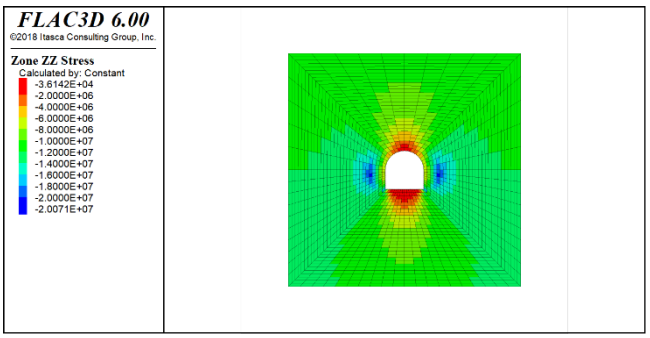

Figure 9. Stress in the Z direction after excavation

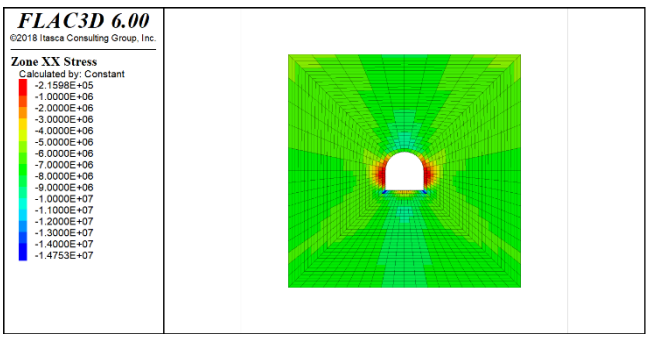

Figure 10. Stress in the X direction after excavation

It can be seen that the vault sinks 4.775mm without support after excavation, the horizontal convergence of the side wall is 2.996mm, and the plastic zone of the surrounding rock is shown in the figure above.

4. The Influence of Side Pressure Coefficient

The plastic zones after excavation with different side pressure coefficients are shown in the figure below:

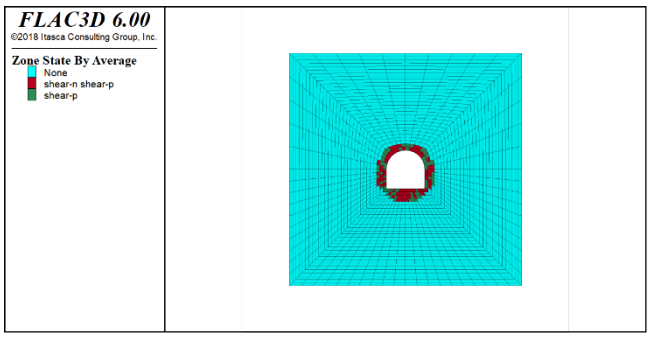

Figure 11. λ=0.5

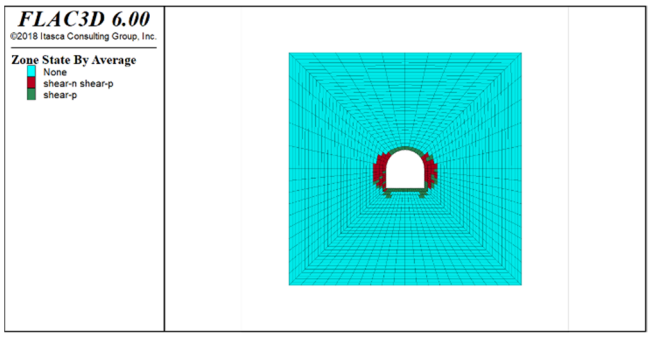

Figure 12. λ=1

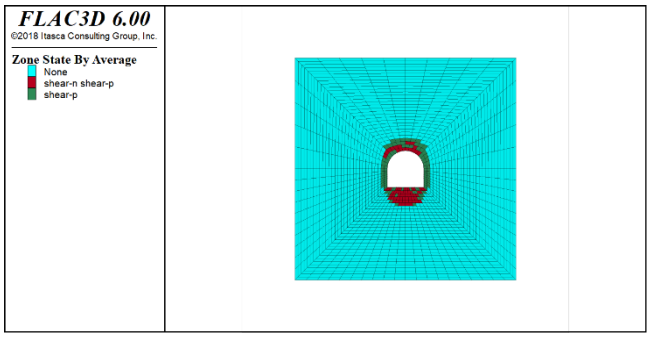

Figure 13. λ=1.5

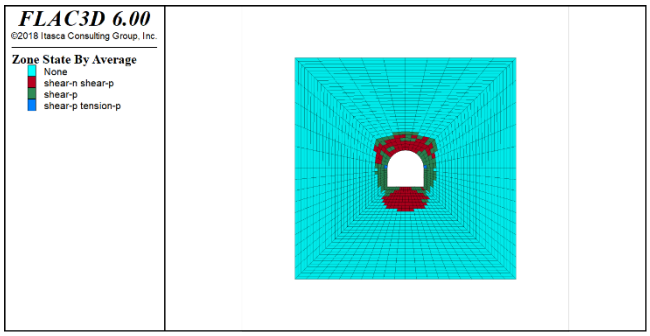

Figure 14. λ=2

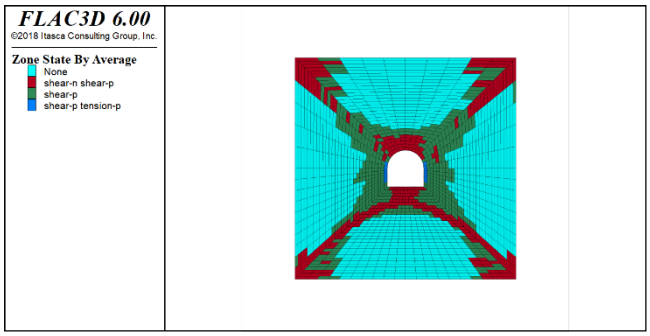

Figure 15. λ=2.5

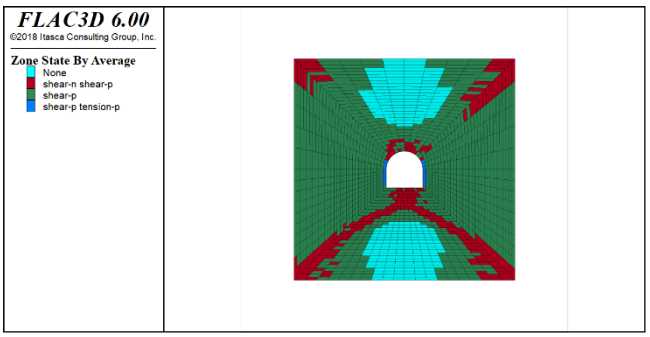

Figure 16. λ=3

With the increase of the lateral pressure coefficient, the plastic zone of the tunnel top and the side wall is gradually increasing, and the vault expands more, when the lateral pressure coefficient is 2.5, the plastic zone expands sharply and cannot be self-stable.

The displacement contours in the Z direction after excavation with different lateral pressure coefficients are shown in the figure below:

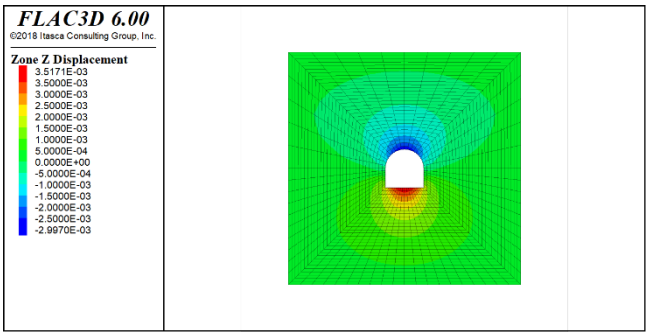

Figure 17. λ=1.5

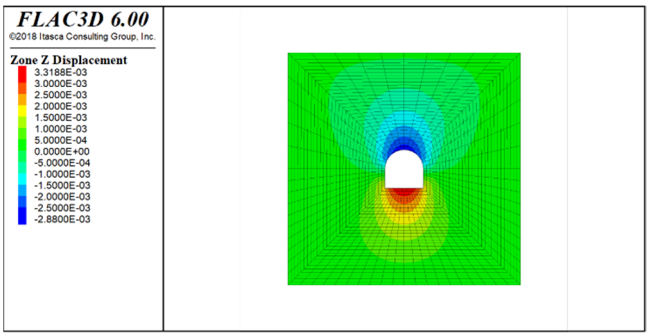

Figure 18. λ=2

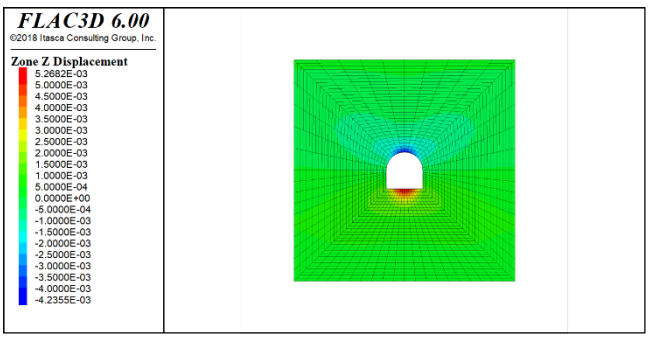

Figure 19. λ=1.5

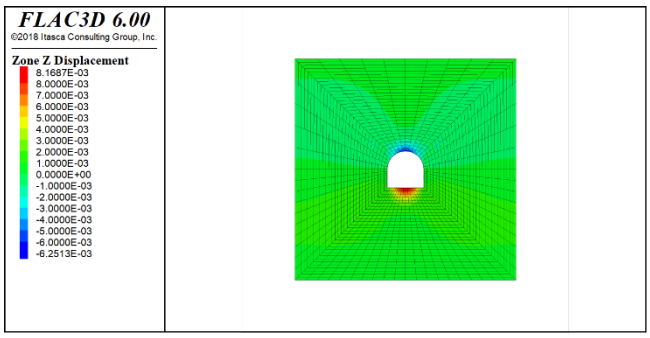

Figure 20. λ=2

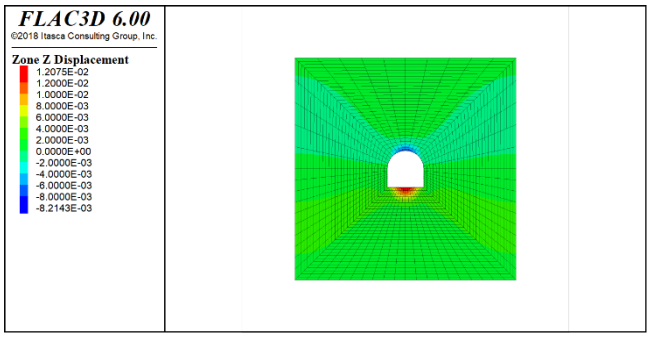

Figure 21. λ=2.5

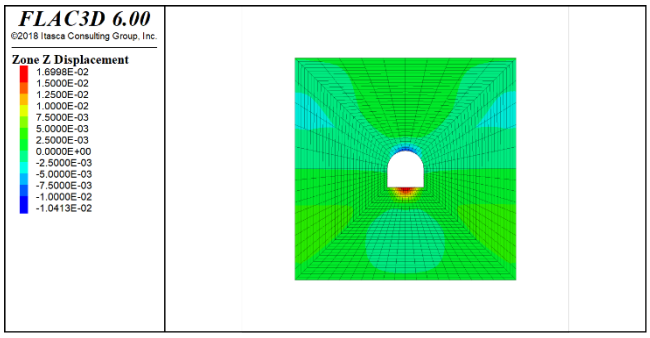

Figure 22. λ=3

The displacement curves in the Z direction of the vault after excavation with different lateral pressure coefficients are shown in the following figure:

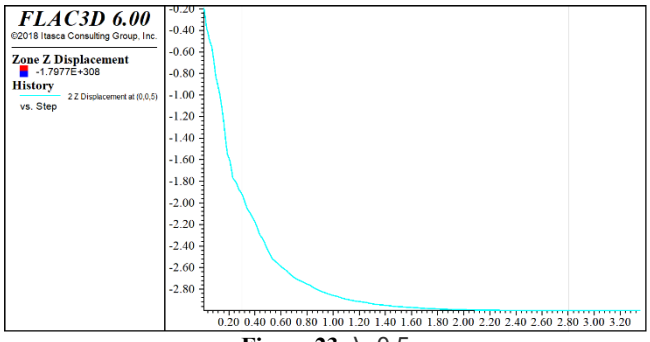

Figure 23. λ=0.5

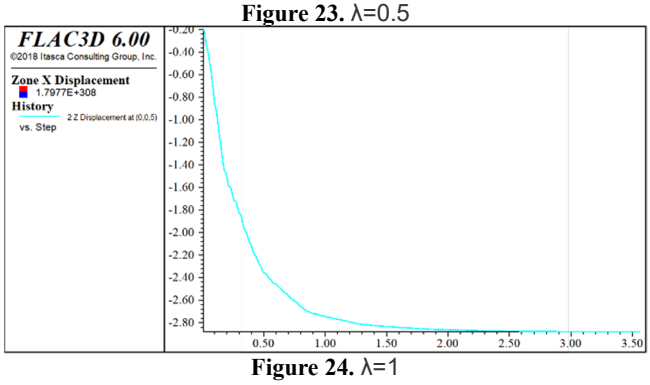

Figure 24. λ=1

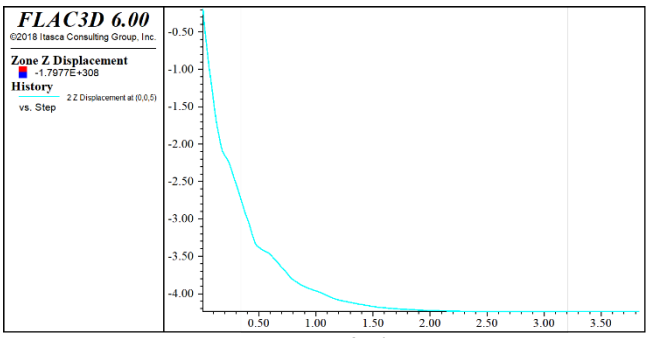

Figure 25. λ=1.5

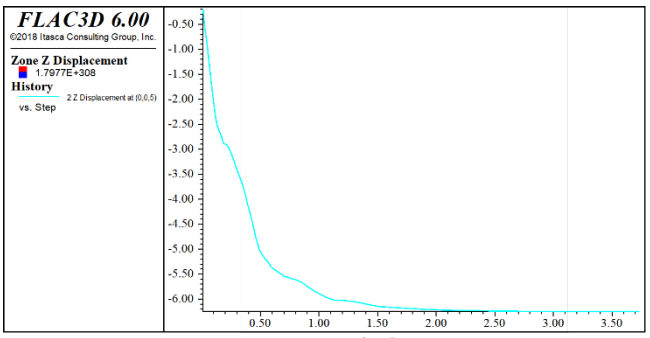

Figure 26. λ=2

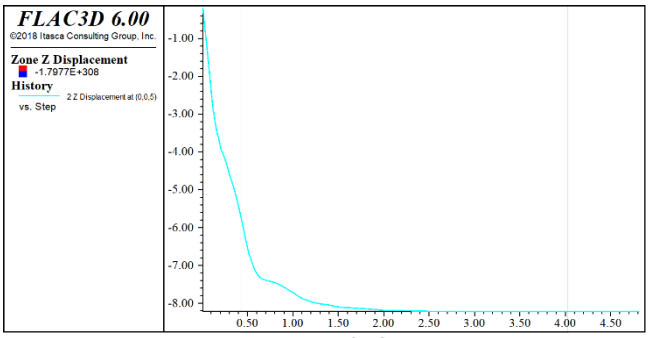

Figure 27. λ=2.5

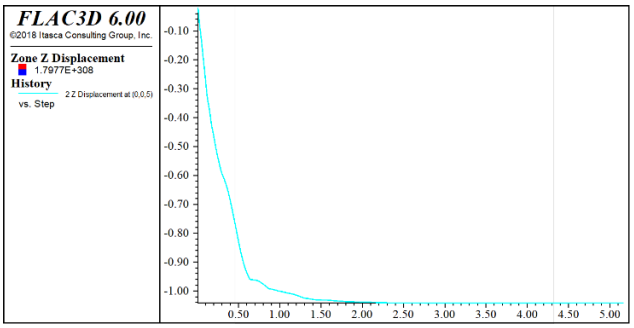

Figure 28. λ=3

The stress contour diagram in the Z direction after excavation with different lateral pressure coefficients is shown in the figure below:

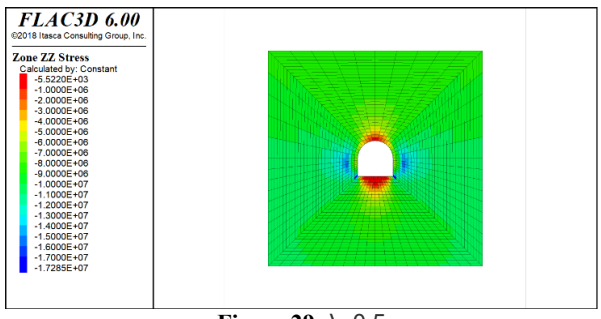

Figure 29. λ=0.5

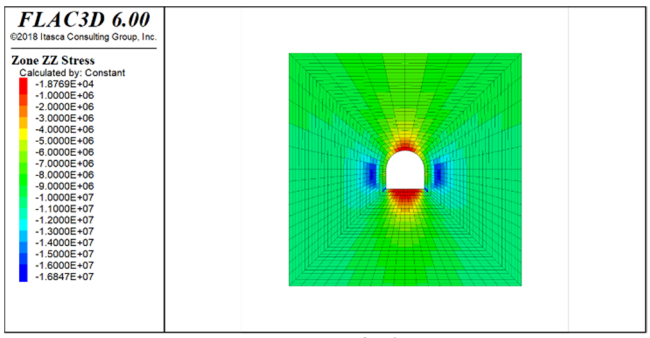

Figure 30. λ=1

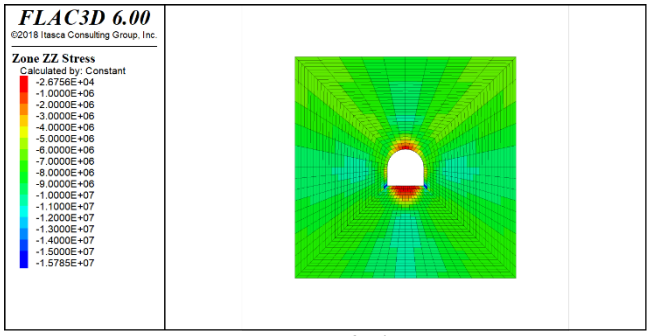

Figure 31. λ=1.5

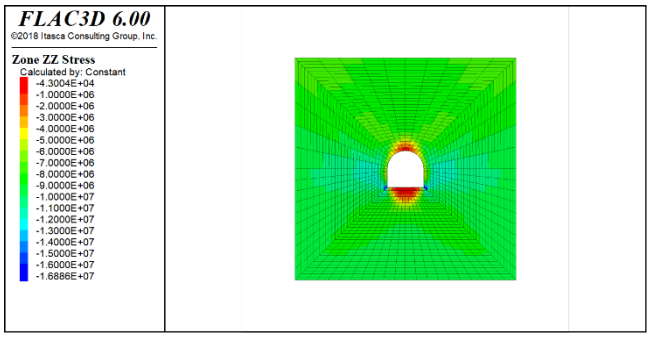

Figure 32. λ=2

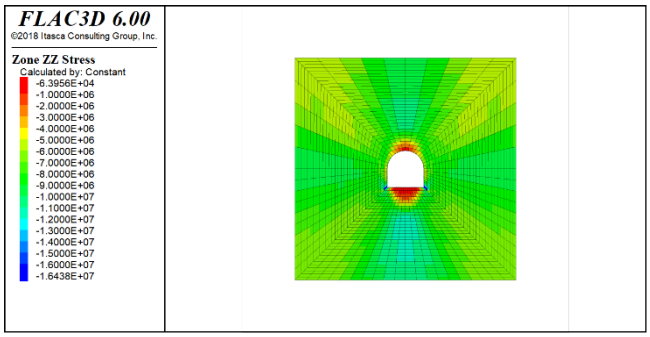

Figure 33. λ=2.5

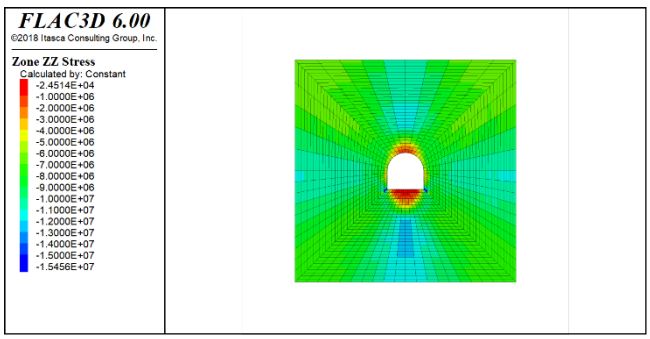

Figure 34. λ=3

The displacement contours in the X direction after excavation with different lateral pressure coefficients are shown in the figure below:

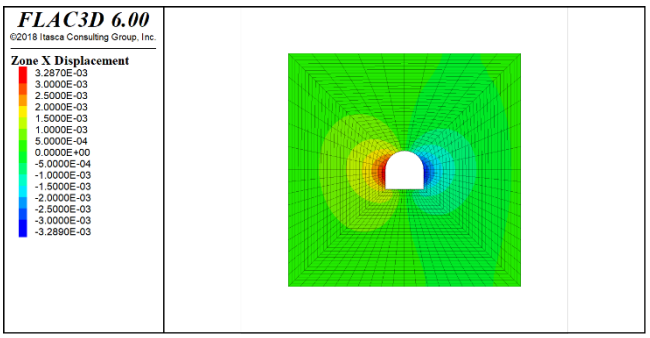

Figure 35. λ=0.5

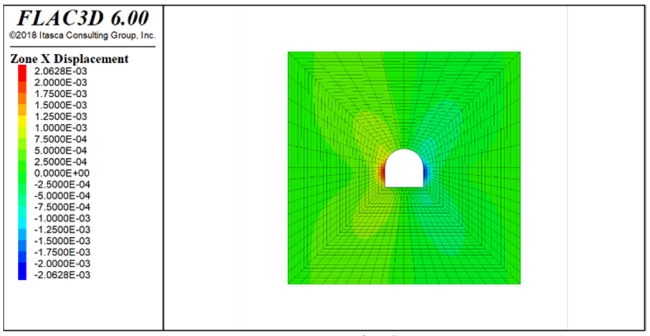

Figure 36. λ=1

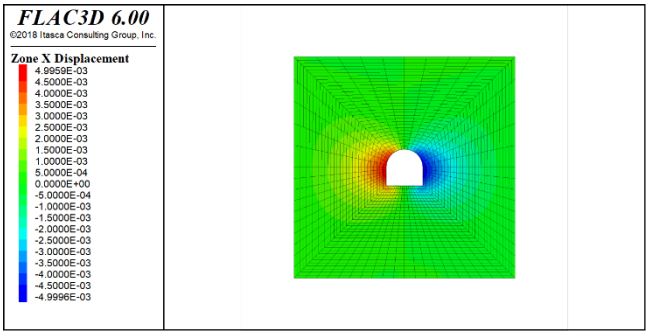

Figure 37. λ=1.5

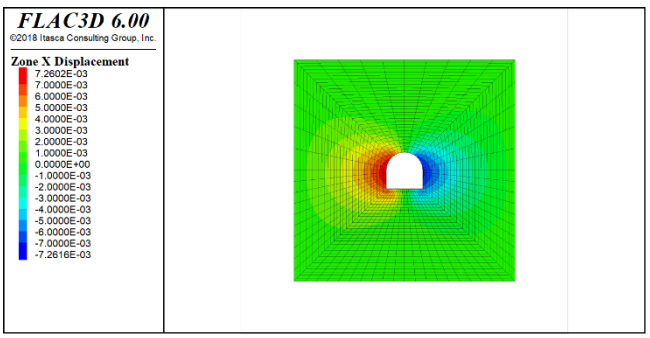

Figure 38. λ=2

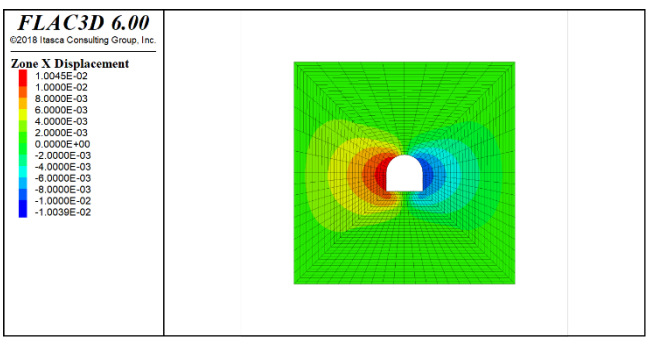

Figure 39. λ=2.5

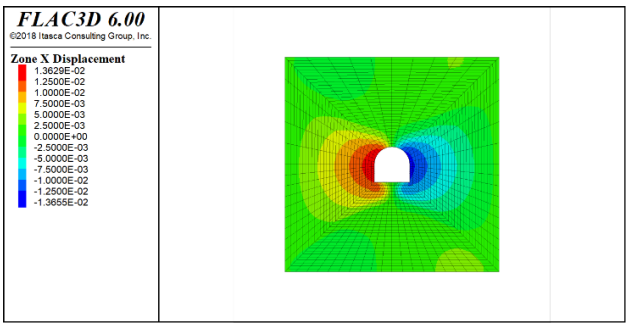

Figure 40. λ=3

The displacement curves in the X direction of the vault after excavation with different lateral pressure coefficients are shown in the figure below:

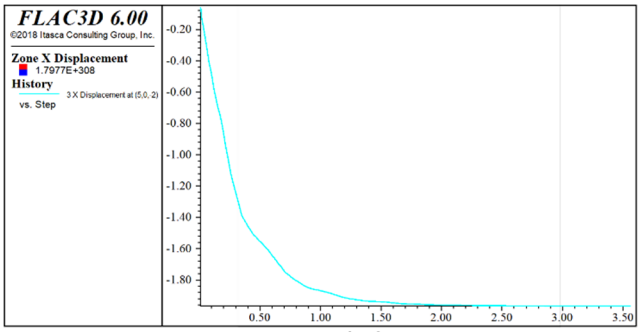

Figure 41. λ=0.5

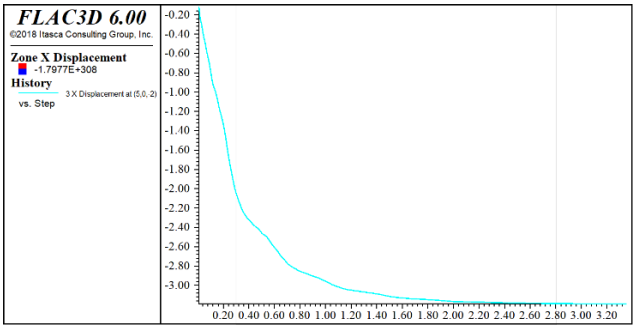

Figure 42. λ=1

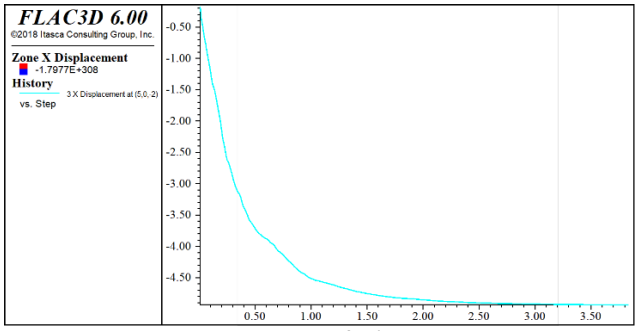

Figure 43. λ=1.5

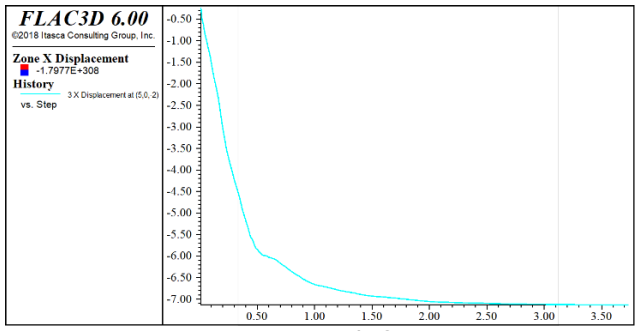

Figure 44. λ=2

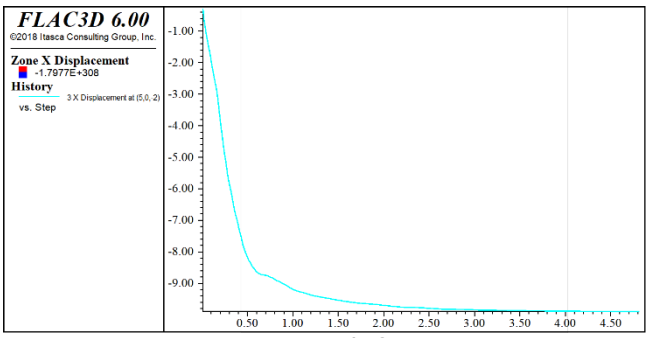

Figure 45. λ=2.5

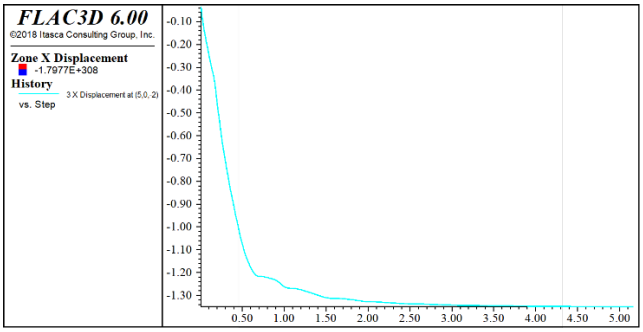

Figure 46. λ=3

The stress contour diagram in the X direction after excavation with different lateral pressure coefficients is shown in the following figure:

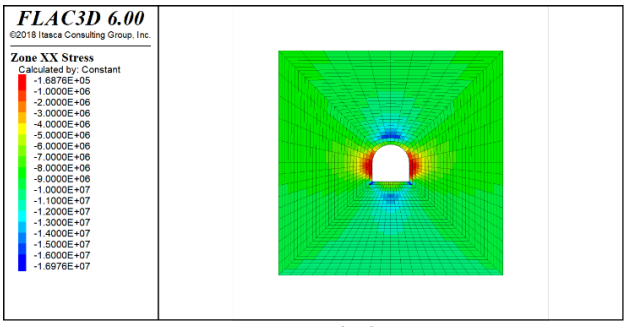

Figure 47. λ=0.5

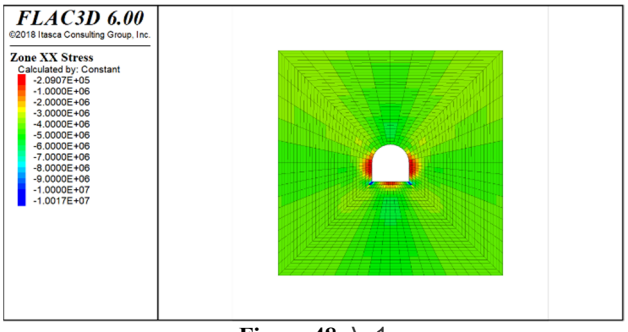

Figure 48. λ=1

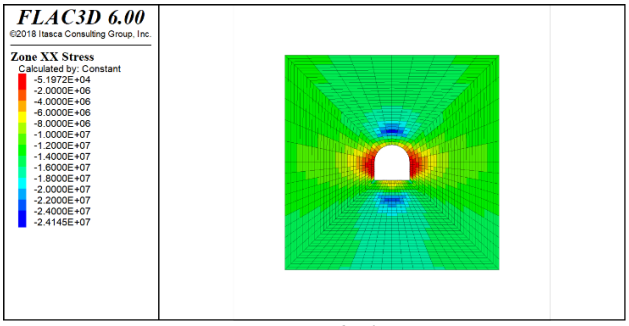

Figure 49. λ=1.5

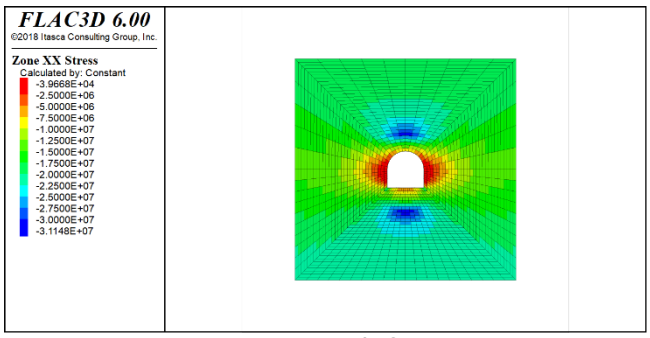

Figure 50. λ=2

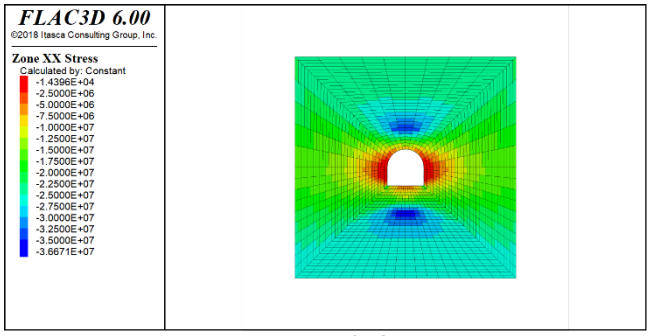

Figure 51. λ=2.5

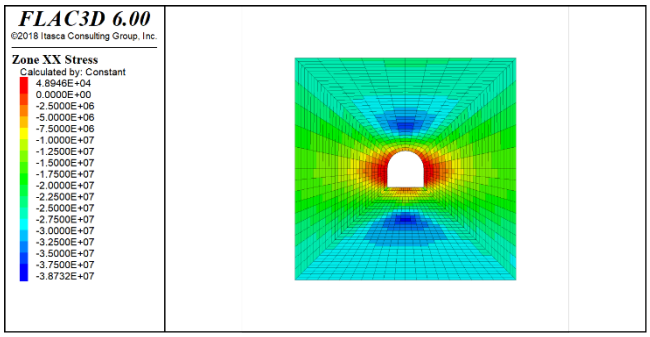

Figure 52. λ=3

It can be seen that with the increase of the lateral pressure coefficient, the vertical displacement of the vault and the horizontal displacement of the side wall increase correspondingly, and the horizontal displacement increases faster than the vertical displacement. The plastic zone increases with the increase of the lateral pressure coefficient, and the plastic zone at the vault increases more. This indicates that the horizontal tectonic stress has a great influence on the horizontal displacement of the side wall and the plastic zone of the vault.

Table 1. Statistical table

Lateral pressure coefficient (λ)	0.5	1	1.5	2	2.5	3
Vault vertical displacement (mm)	2.861	2.988	4.217	6.222	8.142	1.198
Horizontal displacement of side wall (mm)	2.052	3.253	4.949	7.200	9.963	1.319

5. Bolt Support After Tunnel Excavation

The calculation result after support is as follows:

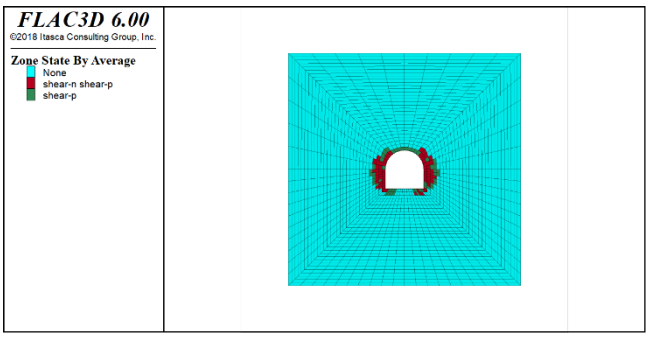

Figure 53. Plastic zone before support

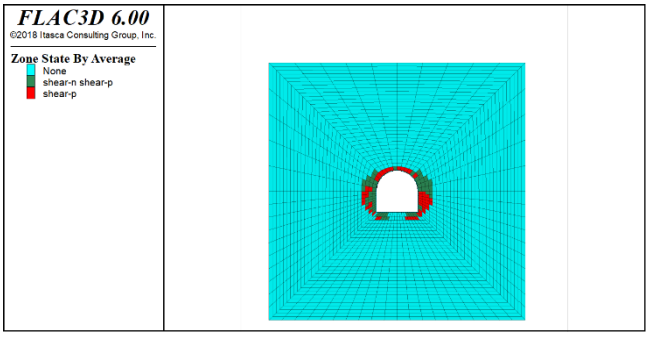

Figure 54. Plastic zone after support

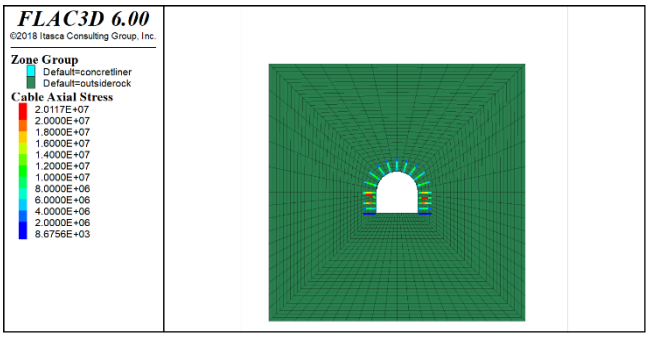

Figure 55. Stress of the bolt

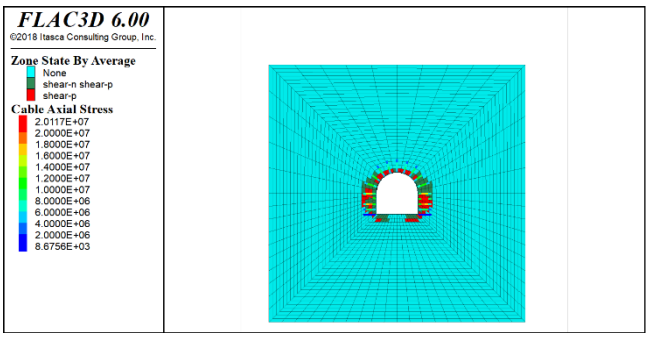

Figure 56. Relative position of the bolt and the plastic zone

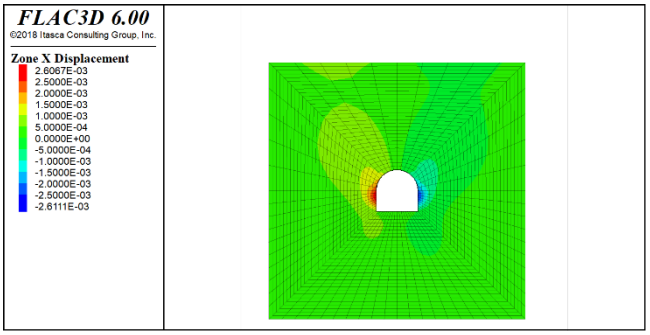

Figure 57. X-direction displacement contour after support

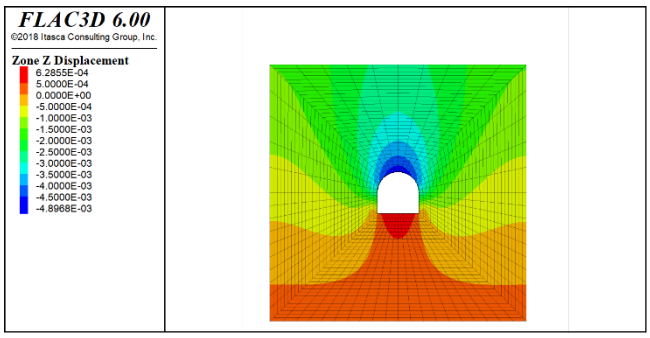

Figure 58. Z-direction displacement contour after support

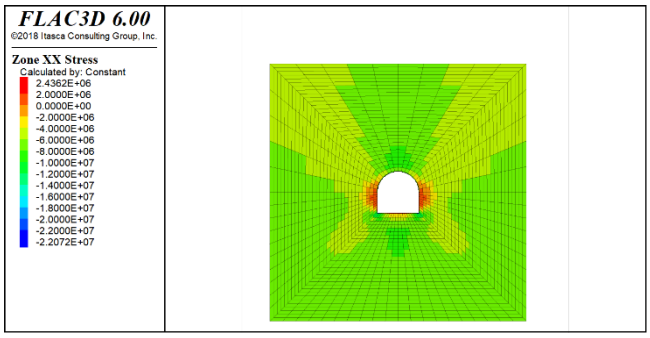

Figure 59. Stress contour in the X direction after support

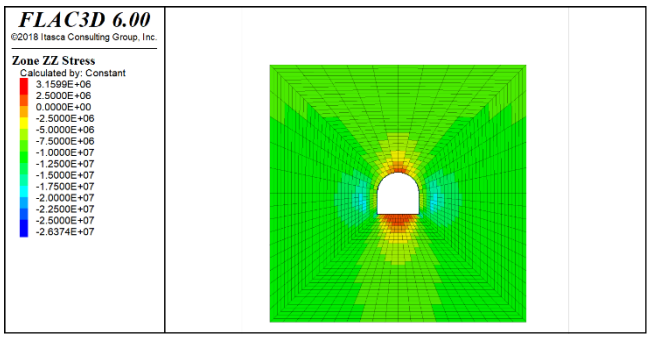

Figure 60. Stress contour in the Z direction after support

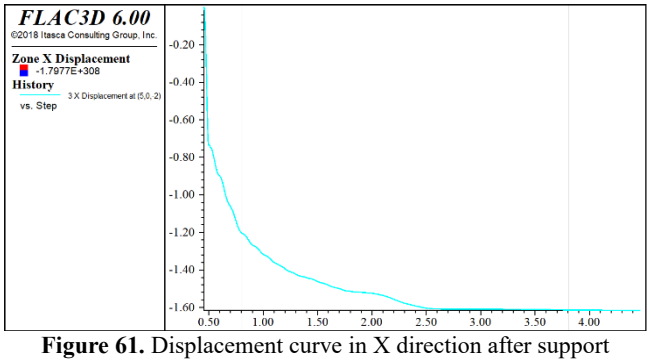

Figure 61. Displacement curve in X direction after support

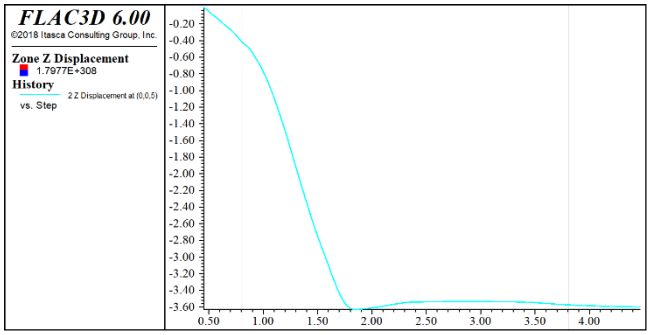

Figure 61. Displacement curve in Z direction after support

As can be seen from the figure, the plastic zone after support is obviously much smaller than that without support, and the stress of the surrounding rock after support is improved, and the vertical displacement and horizontal displacement are reduced. A turning point can be clearly seen in the displacement curve, which is caused by the restriction of the deformation of the surrounding rock after the application of the initial support, which prevents the further deformation of the surrounding rock.

Table 2 Comparison table before and after support

	Vault vertical displacement X0 (mm)	Horizontal displacement of side wall Z0 (mm)
Pre-support	3.181	5.199
After supporting	1.622	3.625

6. Conclusion

After in-depth study of FLAC3D numerical simulation of tunnel excavation process, we draw the following conclusions:

(1) During tunnel excavation, the stress distribution of surrounding rock changes significantly. At the beginning of excavation, the stress concentration around the tunnel is obvious, especially at the top and bottom of the tunnel, there are relatively concentrated tensile stress and compressive stress. With the progress of excavation, the stress gradually tends to be stable, but there is still a phenomenon of stress concentration in some areas, and special attention should be paid to the support design in these areas.

(2) FLAC3D simulation results show that the surrounding rock has obvious displacement and deformation after tunnel excavation. Among them, the subsidence deformation at the top and bottom of the tunnel and the convergence deformation of the side wall are the main deformation forms. These deformations are affected by many factors, including geological conditions, excavation methods, support measures, etc. Through reasonable support design and construction scheme, the displacement and deformation of surrounding rock can be effectively controlled.

(3) Numerical simulation results show that the stress and displacement deformation of surrounding rock are effectively controlled after adopting reasonable support measures. The supporting structure can effectively share the stress of surrounding rock, reduce the phenomenon of stress concentration, and limit the displacement and deformation of surrounding rock. Therefore, in the process of tunnel excavation, it is very important to select the appropriate supporting structure types and parameters.

Based on the above conclusions, we suggest that geological conditions and construction conditions should be fully considered in the process of tunnel excavation, and appropriate excavation methods and support measures should be selected. At the same time, on-site monitoring and data analysis should be strengthened to discover and deal with possible safety hazards in a timely manner. In addition, the construction scheme and support design should be continuously optimized to improve the safety and economy of tunnel excavation.

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