Research on Large Deformation Mechanism and Countermeasures of Shallow Buried Soft Rock Tunnel with Abundant Water

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Abstract: In view of the obvious deformation characteristics of shallow buried soft surrounding rock tunnels affected by excavation disturbance, this article takes a Tunnel as the engineering background and combines the geological conditions of the tunnel to carry out on-site monitoring and analysis of surrounding rock deformation after tunnel excavation. The deformation after excavation has the characteristics of fast deformation speed, long duration and large deformation. In addition, the excavation position and step have an important influence on the settlement of the vault and the convergence of the surrounding rock. The settlement of the vault and the convergence of the surrounding rock caused by the excavation of the upper and middle steps account for 61.16% and 63.34% of the total deformation respectively. Through the analysis of large deformation and collapse phenomenon, it is known that the large deformation mechanism in the cave mainly includes soft rock plastic flow and progressive loosening expansion. The soft rock plastic flow caused phenomena such as side wall bulging, top pressure and steel arch distortion, and the progressive loosening and expansion caused the collapse of the tunnel face and surface cracks. Finally, according to the principles of the New Austrian Method, temporary support (transverse bracing + vertical bracing) + grouting anchor pipe + spray-mixing coordinated support was used to construct the pipe shed at the same time, and the support was optimized, the leading small conduit was encrypted, and added Measures such as temporary invert and lock-foot anchor pipe have successfully dealt with the large deformation section of the collapse, and the treatment effect is good, which can provide reference and reference for similar projects.

1.Introduction
With the rapid development of my country's economic construction, the number of tunnels constructed in the fields of highways, railways, urban rail transit and municipal engineering in China has shown a geometric growth trend, especially the number and mileage of extra-long tunnels have also shown a rapid development trend. At present, my country's tunnel construction technology has made considerable progress, but tunnel construction still faces severe challenges. Especially for
shallow-buried tunnels with weak surrounding rock, such as large deformation, long deformation time, surface collapse, tunnel face instability collapse, etc., which not only affect the safety, quality, and construction period of the tunnel construction itself \cite{1} \cite{2} \cite{3}, and even cause greater economic losses and casualties. Therefore, studying the deformation law and construction technology of shallow-buried soft surrounding rock tunnels has significant engineering significance and practical value.

In recent years, scholars have continuously carried out a large number of field test studies on shallow-buried and weak surrounding rock tunnels, and have also achieved certain research results. Guo J \cite{4} analyzed the monitoring data of the Haibaluo tunnel on the Xiangli Expressway and pointed out that the excavation of the upper step is the main stage of surrounding rock deformation. Ren Y \cite{5} took Xiamen Lianyue Tunnel A ramp tunnel as the engineering background, through numerical simulation, pointed out that for shallow-buried soft surrounding rock tunnels, whether full-face excavation or bench excavation, the displacement of the tunnel face is the largest, and the vault is the largest. Subsidence and surface subsidence are the second, and the cave has the smallest convergence. Xu G \cite{6} analyzed the large deformation of soft rock that has occurred many times in the Zhegushan soft rock tunnel, and divided the large deformation of surrounding rock into three types: soft rock plastic flow, plate beam bending deformation and structural surface slip. In summary, there is still a lack of research on deformation monitoring data and large deformation mechanisms of fully weathered tuff lava tunnels at this stage, and there are few studies on large deformation treatment measures for water-rich shallow buried soft fully weathered tuff lava tunnels. Results are difficult to use to guide engineering practice.

In view of this, this article uses a typical fully weathered tuff lava large deformation section of a tunnel as the engineering background to discuss the surrounding rock deformation characteristics, influencing factors, large deformation mechanism and treatment measures during the construction process of the water-rich shallow fully weathered tuff lava tunnel. The research results are expected to guide engineering practice.

2. Project Overview
The tunnel is designed as a 4-hole separated tunnel with a double-hole two-way eight-lane main road tunnel in the middle. The overburden is mainly Quaternary slope silty clay and earthy yellow fully weathered tuff lava; the underlying bedrock is blue-gray mid-weathered and slightly weathered tuff lava of Jurassic Nanyuan Formation. The site construction revealed that the surrounding rock in the shallow buried section of the tunnel is fully weathered tuff lava, the original rock structure is basically retained, the mineral composition has been completely weathered into secondary minerals, the core is extremely broken, sandy, easy to be softened by water, and easy to pinch. The rock hardness is extremely soft, and the rock mass is extremely broken.

Due to weak lithology, broken rock mass, and development of groundwater, landslides frequently occurred during tunnel excavation. The deformation after initial support was large and it was difficult to control. Many large deformations occurred and the limit was severe. The construction progress of the four tunnels was slow. Table 1 shows the statistics of landslides, large deformations, lateral displacements and distortions of arches.

It can be seen from Table 1 that during the excavation of the tunnel, the surrounding rock collapse, large deformation, cracking of the initial support, and intrusion limits are very prominent. Among them, there were 3 caves in the surrounding rock vault, 6 large deformations, 6 water leakage at the initial branch, and the total length of the invasion limit reached 100.6m. Therefore, it is necessary to carry out systematic and comprehensive field tests on tunnels, conduct in-depth analysis of monitoring data, and grasp the temporal and spatial evolution laws and characteristics of surrounding rock deformation and supporting forces after tunnel excavation, so as to provide science for the initial support and secondary lining in accordance with. A typical photo of tunnel diseases is shown in Figure 1.
### Table 1. Statistics of landslide, large deformation and initial branch cracking

| Tunnel number | Type of surrounding rock | Destroy mileage | Damage location | Disease description |
|---------------|--------------------------|-----------------|-----------------|---------------------|
| Right auxiliary hole | Fully Weathered Tuff Lava (V) | FYK6+163.6-176.8 | vault | Large deformation, invasion limit of the first branch, 1 circumferential crack, water seepage at the first branch |
| Right main hole | Fully Weathered Tuff Lava (V) | FYK6+240 | vault | Large deformation, invasion limit of the first branch, 1 circumferential crack, water seepage at the first branch |
| | | FYK6+245.8 | vault | Collapse (20 m3), 1 circumferential crack Landslide (25 m3) |
| | | FYK6+250 | vault | Large deformation, longitudinal cracks, water seepage in the first branch |
| Right auxiliary hole | Fully Weathered Tuff Lava (V) | YK12+269-285 | Left spandrel | Large deformation, longitudinal cracks, water seepage in the first branch |
| Left auxiliary hole | Fully Weathered Tuff Lava (V) | FZK6+105-139 | vault, Left spandrel | Large deformation, invasion limit of first branch, seepage of first branch Landslide (18 m3) |
| Left main hole | Fully Weathered Tuff Lava (V) | ZK12+220-235 | Left spandrel | Large deformation, invasion limit of first branch, seepage of first branch |

Figure 1. Collapse, ring-direction cracks of initial support, water seepage at arch foot

### 3. Analysis of influence factors of surrounding rock deformation

(1) The influence of construction procedure on the settlement of vault

Select a typical monitoring section and summarize the monitoring data. The curve of the vault settlement of the FYK6+200 monitoring section of the right auxiliary tunnel over time is shown in Figure 2. The weights of the settlement and deformation of the vault caused by the excavation of each part are shown in Figure 3.

It can be seen from Figure 2 that the excavation of each part will have an impact on the settlement of the vault. After the excavation of the upper arc-shaped pilot tunnel, there is a sudden change in the settlement of the vault, about 20mm; after the excavation on the left side of the middle step, the settlement of the vault has a smaller amplitude. After the excavation on the right side of the middle step, the vault settlement increased significantly, and the maximum deformation rate reached 36.3mm/d. After 8th day of excavation on the right side of the middle step, the settlement and deformation of the vault tended to stabilize; subsequent excavations After excavation on the left and right sides of the step, the maximum deformation rate of the dome settlement after excavation is 12.2mm/d; after excavation on the left and right sides of the step, the invert is excavated after 7 days, and the maximum deformation rate of the dome settlement after the excavation of the invert is 4.4mm/d; Invert arch excavation and invert pouring and backfilling are carried out after 4 days. After invert arch pouring and backfilling, the settlement rate decreases after the section is closed into a ring, and the settlement deformation tends to stabilize, with a maximum deformation rate of 1mm/d.

It can be seen from Figure 3 that the left and right sides of the steps in the excavation have the greatest impact on the settlement of the vault, with a weight accounting for 51.98%; the left and right sides of the steps under the excavation have the second largest impact on the settlement of the vault, accounting for 44.53%; The impact of the dome settlement is the smallest, accounting for only 4.16%.
The main reasons for the above phenomenon are: when excavating the arc-shaped pilot pit of the upper step, the upper part of the tunnel face is empty, the stress is suddenly released, the top surrounding rock suddenly changes from a three-dimensional stress state to a two-dimensional stress state, and the top surrounding rock is on the top. Due to the downward extrusion deformation under the action of the gravity stress of the overburden and the radial shear stress, the deformation of the dome has a sharp change value. When excavating the left side of the step, the vault deformation increased slightly, but when the right side of the step was excavated, the vault deformation increased sharply. This is because only a part of the core soil was excavated during the excavation of the left step. Most of the core soil remains, and the core soil can still bear most of the load. When the right side of the middle step is excavated, all the core soil on the upper part of the middle step is excavated, and the load is borne by the arch. Therefore, after the right side of the middle step is excavated, the vault settlement deformation increases sharply. The same is true after the excavation of the lower step. After the right side of the lower step is excavated, all the core soil of the lower step is excavated, and the deformation of the vault is also greatly increased. The deformation after invert excavation and initial support is small. On the one hand, it is because the deformation of the surrounding rock has a "creep" property. After the entire section has undergone the three stages of excavation of the upper, middle and lower steps (28d), most of the deformation has been completed Settlement deformation, the whole has become stable; on the other hand, because the entire arch is closed into a ring, the arch will completely distribute the force to the surrounding rock, and the deformation is completely stable.

(2) Convergent deformation in the hole

After sorting out the convergence data of FYK6+200 surrounding rock, the time history curve of surrounding rock convergence is shown in Figure 4. It can be seen from Fig. 4 that the maximum convergent displacement of surrounding rock is 83.2mm. In addition, the convergence of the surrounding rock will increase greatly each time the excavation of the upper arc-shaped pilot pit reaches the maximum rate of 19.4mm/d; the left and right sides of the middle step are excavated, and the left and right sides of the lower step are excavated. The influence of rock convergence rate is basically the same, the maximum wall rock convergence rate is 5.3mm/d; the inverted arch excavation and initial support have the least influence on the surrounding rock convergence rate, and the maximum wall rock convergence rate is 3.0mm/d. It can be seen from Figure 5 that the excavation of the upper arc-shaped pilot pit has the greatest impact on the convergence of the surrounding rock, with a weight ratio of 35.46%; the excavation of the invert has a smaller impact on the convergence of the surrounding rock, with a weight ratio of 10.94%; invert pouring Later, the surrounding rock still has convergent deformation, but the convergent deformation is basically stable, and the deformation only accounts for 5.05% of the total deformation. Therefore, in terms of controlling the convergent deformation of the surrounding rock, it is recommended to strengthen the support when excavating the upper arc-shaped pilot pit to reduce the convergent deformation of the surrounding rock.

4. Large deformation mechanism analysis

According to the records of multiple landslides and intrusion limits, there are two main types of tunnel surrounding rock deformation and failure: soft rock plastic flow and progressive loosening expansion [7][8][9][10].

(1) Soft rock plastic flow

The excavation of underground engineering leads to the adjustment of the surrounding rock stress. Before excavation, the soft rock is in a tight and dry state. After the excavation, the resilience caused by the stress release process and the expansion caused by the stress adjustment make the originally closed structure in the rock mass open and slippery. When the stress state and strength of the rock mass are changed, the groundwater in the surrounding rock seepage and soften along the open fissures, which further reduces the strength of the rock mass and leads to plastic flow, thus causing the surrounding rock mass to flow. The rock produces a large convergence displacement, and then the side wall bulge, top pressure, and the steel arch frame distortion caused by the excessive deformation of the initial support and other phenomena.
Progressive loosening expansion

The rock masses in superficial reformation zones that have been superficially reformed and relatively broken surrounding rock mass, and in-situ stress in surrounding rock is relatively small. When tunnel project passes through this type of surrounding rock, the surrounding rock mass is nearly scattered. Structural characteristics, expansion process of deformation and failure of surrounding rock is very fast, and can develop all the way to the surface.

5. Treatment plan for tunnel face collapse and large deformation

After the tunnel face collapsed at FYK6+250 in the right auxiliary tunnel, the collapsed body was piled up in front of the tunnel. The collapsed body can not only block the collapse cavity, control the further loss of rock mass, but also restrain the extrusion deformation of the tunnel face. The degree of stress release of the surrounding rock, so after the collapsed body is stabilized, the collapsed body should be reinforced by spraying concrete to control the deformation of the tunnel face and control the loss of the surrounding rock mass. In addition, at the same time, temporary steel supports are used to strengthen the supporting structure in a certain range near the tunnel face. In view of this, the engineers used C25 shotcrete to spray 20cm thick concrete on the face of the face and the initial support surface, and then the collapsed body was temporarily stabilized. Within 10 meters behind the tunnel face, the engineers added one I18 cross brace and vertical brace per meter (Figure 6). After the
construction, C25 spray concrete was used to cover the cross brace steel arch.

According to the New Austrian Methodology theory, the surrounding rock is both the actor and the bearer of the underground engineering load. In order to give full play to the self-proclaimed ability of the surrounding rock, engineers set up a 5m radial hollow grouting small pipe and the hollow face grouting ahead Small pipes (φ42×4mm), arranged in a plum blossom shape with a spacing of 1m×1m, and then small pipes are injected with cement-water glass double liquid grout. The grouting is filled with multiple repeated injections to fill the collapsed cavity, so that the surrounding rock in the loosening ring is The surrounding rock outside the scope of the excavation is fully condensed into a whole, so as to maximize the self-proclaimed capacity of the surrounding rock and reduce the load borne by the arch.

After grouting reinforcement slurry has solidified and has a certain strength, the section adopts a 12m long φ127 pipe roof for overpassing, so as to continue tunneling. After inverted arch pouring and backfilling of the section is completed, the camera will change the arch.

Follow-up construction to strengthen the initial support: ① Add a temporary invert at the middle step (Figure 7) to close the arch as a ring as soon as possible. At the same time, set up a locking tube at the arch toe of the upper, middle and lower steps. Set up four lock-leg conduits (Figure 8), and grouting; ② The arch feet are connected by section steel between the front and rear arches to enhance the rigidity and integrity of the arches. ③ Encrypt the leading small ducts at the upper and middle steps, from the original 2.4m loop (54) to 1.2m loop. The models of the leading small catheter and the locking foot catheter are φ42×4mm, and the length is 3.5m. ④ Add dewatering wells in the cave, one every 10m, arranged along the left and right sides of the cave.

After the above measures are adopted for reinforcement, the settlement of the vault is controlled. From the monitoring and measurement data, the treatment effect is good. The settlement time history curve of the section after reinforcement is shown in Figure 9.
6. Summary
Based on the monitoring and measurement data of a shallow-buried soft rock tunnel with rich water, this paper discusses the law of surrounding rock deformation and its influencing factors, large deformation mechanism and disposal measures and effects. The results are as follows:

(1) For the fully weathered tuff lava section of the tunnel, the three-step reserved core soil excavation method is adopted. The mid-excavation and upper-step excavation have the greatest impact on the settlement and lateral convergence of the vault, accounting for 61.16% and 63.34 of the total deformation respectively. Is the main stage of large deformation. Therefore, during the excavation process, we should focus on the excavation of the upper and middle steps, and take targeted measures.

(2) The large deformation mechanisms of shallow buried weak surrounding rock with rich water mainly include soft rock plastic flow and progressive loosening expansion. Soft rock plastic flow mainly causes diseases such as bulging of side walls, initial support cracks, and distortion and deformation of arches; progressive loosening and expansion mainly cause tunnel face collapse, large deformation, and surface cracks.

(3) Through a series of measures, the collapse and large deformation of the tunnel face were dealt with. The effect is good, and it can provide reference and reference for the collapse and large deformation treatment of similar water-rich shallow fully weathered tuff lava tunnels.

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