Analysis on construction deformation characteristics of Da-Puling tunnel by monitoring measurement

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Abstract: Tunnel monitoring and measurement is the guarantee of tunnel construction safety and implementation of dynamic parameter design; relying on the surface settlement, vault settlement and convergence deformation in the tunnel during the construction of Da-Puling tunnel on Guangxi expressway, based on the monitoring data, the stress situation and deformation characteristics of the tunnel are analyzed; the results show that the construction parameters of Da-Puling tunnel are basically reasonable, and the portal section is the key to the control of the whole construction parameters, the settlement of the tunnel vault in the V-Class surrounding rock of the portal section is about 4 times of the convergence deformation, which is mainly caused by the gravity of the overlying soil layer. The settlement of the tunnel vault in the IV-class surrounding rock is close to the convergence deformation, and the stress release deformation in the loose area of the tunnel surrounding rock is the main one. The monitoring and analysis in the construction process provides reliable data for design and construction in time, and ensures the smooth progress of tunnel construction.

1. Preface
Tunnel monitoring and measurement work is an important part of tunnel construction[1], which can timely reflect the impact of tunnel construction on the ground and the stable state of the tunnel support structure, so as to ensure the safety of tunnel construction; at the same time, it is necessary to tunnels constructed by the principles of new Austrian method, the rationality supporting parameters determined and the reserved deformation of the tunnel controlled by monitoring and measurement data which supports for dynamic design[2]. The basic monitoring and measurement items include surface settlement observation, vault settlement observation, and tunnel convergence and deformation observation, which was carried out during the initial support of the tunnel. For tunnel monitoring and measurement, related scholars have carried out a lot of research. An Yonglin[3] and others have found that the harder the surrounding rock, the smaller the span, and the smaller the height of the side wall. The smaller the displacement, the larger the other way; the main influencing factor of the allowable deformation control standard is the conditions of the surrounding rock, followed by conclusions such as the span of the tunnel.

Jiang Kun[4] et al. carried out relevant monitoring and measurement research on large-span tunnels with small clear distances, and obtained the distribution characteristics and change rules of
surrounding rock and initial support pressure; Wuke[5] et al. aimed at the left of Fu Jiachong Tunnel. Two typical landslides occurred during the construction of the ZK26+081 section of the tunnel and the YK25+547 section of the right tunnel. By monitoring the convergence displacement of the tunnel and the regression analysis of the vault subsidence, the stable state of the surrounding rock of the tunnel is reflected and compared with the actual Comparative demonstration of working conditions. The results show that for the V-class weakly weathered shale tunnel construction process, collapse accidents are extremely likely to occur, and it is necessary to combine the tunnel monitoring and measurement technology to promptly raise the collapse warning and guide the construction. Related research has accumulated rich experience and data analysis methods for tunnel monitoring and measurement.

The Da-Puling Tunnel is the first tunnel to be constructed on the Puqing Expressway. It is located in a mountainous and hilly basin. The mountain is low, the tunnel entrance section is shallowly buried, and the geological conditions are poor. In order to test whether the tunnel excavation method and support parameters are reasonable, it is necessary to monitor and measure the Da-Puling Tunnel to further optimize the design parameters and guide the construction.

2. Engineering Background
Da-Puling Tunnel is located in the TJ-3 contract section of Guangxi Puqing Expressway. It has a design speed of 120km/h. It is asplit two-way four-lane and a composite lining structure. The left tunnel is 2175m long, the right tunnel is 2155m, the maximum excavation span of a single tunnel is 14.11m, the maximum excavation height is 10.51m, and the standard section inner contour area is 121m². V-class surrounding rock is excavated by the three-step reserved core soil method, and the designed reserved deformation is 12cm; IV-class surrounding rock is excavated by the two-step method, and the designed reserved deformation is 8cm[6].

The tunnel site area is mainly the Indosinian intrusive rock area, the geological structure is not developed, but the weathered layer is thick. The grade V surrounding rock accounts for about 12.6%, the grade IV surrounding rock accounts for about 18.3%, and the grade III surrounding rock accounts for about 69.1%. Groundwater is mainly Quaternary loose void water and bedrock fissure water. The main forms of advanced support for tunnel excavation include large pipe sheds, small pipes, and bolts. The initial support structure includes I-steel arches, φ25 system bolts, φ8 double-layer steel mesh, and C25 strength sprayed concrete.

![Figure 1. Tunnel design section](image-url)
3. Monitoring and measurement methods

Based on the comprehensive analysis of hydrological, topographic and geological information, the monitoring and measurement of the Da-Puling Tunnel mainly focused on the deformation monitoring of the tunnel. The shallow buried section of the entrance of the tunnel was observed for surface settlement, vault settlement, and peripheral convergence observations[7]. The horizontal measurement range of ground settlement is larger than the influence range of tunnel excavation. The monitoring points are separated by 2m~5m. The measurement points near the center line of the tunnel are appropriately encrypted and numbered one by one from left to right, as shown in figure 2(a). The measurement range covers the entire shallow buried section of the tunnel. The monitoring section spacing is 5m, and the topography is flexibly arranged according to the side of the entrance. The monitoring section spacing in the tunnel is 5m~10m (V-class) and 20m~30m (IV-class). When monitoring sections are buried, the spacing between different grades of surrounding rock is adjusted according to the type of tunnel support, as shown in table 1. Each monitoring section contains one vault settlement monitoring point, 2 or 3 convergence deformation monitoring points, and one convergence point for each excavation step. The deformation monitoring points are shown in figure 2(b).

| Lining support parameters | Section spacing (m) |
|---------------------------|---------------------|
| Va                        | 5                   |
| Vb                        | 8                   |
| Vc                        | 10                  |
| IVa                       | 20                  |
| IVb                       | 25                  |
| IVc                       | 30                  |

Da-Puling tunnel monitoring measurement adopts total station non-contact measurement method[8]. The total station is Leica TS50 type, with angle measurement accuracy of 0.5", and ranging accuracy of 0.6 mm+1 ppm; the monitoring point adopts the form of embedded parts and reflective diaphragm, and the embedded parts are made of 14mm diameter reinforced bar, and the steel bar is buried in the surrounding rock depth of about 20cm. When the surrounding rock is broken and soft, the embedded depth of reinforcement should be appropriately increased Stability is the principle. Considering the thickness of the initial support of the tunnel, about 23cm, the length of embedded reinforcement is 50cm. The exposed part of the reinforcement is welded with 4cm × 4cm iron sheet for pasting the reflective diaphragm. The embedded parts are shown in fig. 3 (a). The reflective diaphragm pasted on the surface of embedded parts embedded in the surrounding rock is taken as the monitoring point. The monitoring points embedded on site are shown in fig. 3 (b).
Total station non-contact measurement technology can well meet the requirements of tunnel measurement accuracy. Compared with the traditional contact measurement, it is more suitable for tunnel construction environment, efficient and fast, and will become the mainstream way of tunnel monitoring and measurement in the future.

![Schematic diagram of embedded parts](image1)

![Tunnel monitoring points](image2)

Figure 3 Schematic diagram of on-site monitoring points of tunnel

4. Analysis on deformation characteristics of Tunnel

During the construction of Da-Puling tunnel, a lot of monitoring and measurement work has been carried out, and abundant data have been obtained. Generally, the surrounding rock conditions of grade V and IV are poor and the construction uncertainty is large. In this paper, typical monitoring sections YK26+412 and ZK26+340 are selected for deformation data analysis to study the deformation characteristics of tunnel construction.

The right exit section of Da-Puling tunnel is located on one side of mountain slope with thin overburden layer, belonging to shallow buried section of portal. YK26+412 monitoring section is the first group of monitoring sections buried after tunnel entering. Surrounding rock is mainly grade V sandy strongly weathered granite, which is easy to soften when encountering water. When the tunnel had turned to the construction, it is rainy season in Guangxi area, and precipitation will have adverse effect on the deformation of shallow buried section of tunnel[9]. The deformation of surface settlement trough of YK26+412 mileage is shown in Fig. 4. Three bench method is adopted in this area.
Figure 4. Timedependent relationship of sedimentation tank in YK26+412 cross section

It can be seen from Fig. 4 that the maximum surface settlement is located near the middle line of the tunnel and gradually decreases to both sides, and the maximum settlement value reaches 165.3mm. The time-dependent curve of settlement at each monitoring point is shown in Fig. 5. The proportion of deformation in each stage of tunnel construction at this section is counted. The settlement deformation of upper bench excavation construction accounts for 31% of the total deformation, the deformation during middle bench excavation construction accounts for 45% and the construction of lower bench and inverted arch accounts for 20%. It can be seen that most of the settlement deformation occurs during the construction of middle bench tunnel, and the middle bench construction is a tunnel at the same time, due to the size effect of the excavation face, the settlement rate of the upper bench construction is less than that of the middle bench construction.

Figure 5. Curve of settlement with time at YK26+412 settlement point

The curve of settlement deformation with time of monitoring points in section YK26+412 is shown in Fig. 6, which shows that the settlement deformation mainly occurs within 40 days after tunnel
excavation, and then the stress redistribution of surrounding rock caused by excavation is basically completed, and the surrounding rock reaches a stable state. The cumulative settlement of tunnel vault is 129.6mm, which is close to the control value of construction reserved deformation by 200mm, exceeding the design reserved deformation of 120mm[10]. For the shallow buried section of tunnel portal with poor surrounding rock properties, it is suggested that the actual construction reserved deformation should be greater than 1.5 times of the design value to prevent the risk of invasion; the deformation modulus of steel arch and shotcrete is different, and the settlement of arch crown is large. Under the deformation, the synergistic deformation of the two is poor, resulting in slight cracks on the surface of the initial lining near the section YK26+412; the convergence deformation of the upper bench in the tunnel is 32mm, and that of the middle bench is 34mm. The convergence deformation of each step in the tunnel is close, and the numerical value is small, about 1/4 of the vault settlement, which is lower than the reserved deformation of the tunnel.

The ZK26+340 section on the left side of Da-Puling is located in grade IV surrounding rock. The settlement of arch crown is 17.0 mm, the convergence deformation of upper bench is 15.2 mm, and the
The convergence deformation of middle bench is 10.4 mm. The settlement deformation is small and the values are close.

The settlement deformation of YK26+412 section and ZK26+340 section is shown in Table 2.

| Monitoring items                  | YK26+412         | ZK26+340         |
|----------------------------------|------------------|------------------|
| Surface subsidence               | 13.0             | 165.3            | -                | -                |
| Vault settlement                 | 11.3             | 129.6            | 1.6              | 17.0             |
| Upper bench convergence value    | 2.2              | 32.0             | 1.5              | 15.2             |
| Middle bench convergence value   | 2.6              | 34.0             | 1.3              | 10.4             |

It can be seen from table 2 that the surface settlement of section YK26+412 consists of two parts, namely, the soil subsidence caused by tunnel excavation and the self-compression settlement of overburden, the former accounts for 80%, and is the main part of surface settlement; the maximum settlement rate of surface settlement monitoring point is 13mm/d, and the maximum settlement rate of arch crown is 11.3mm/d, which exceeds the deformation warning value by 5mm/d; when the rate is large, it is shortened in time excavation footage, even sealing the tunnel face, increasing the number of foot lock bolts of steel arch frame, grouting treatment on the surface slope, laying waterproof cloth and other measures can effectively reduce the settlement rate.

Based on the settlement deformation monitoring data of Da-Puling tunnel during the construction period, the stress analysis of YK26+412 section and ZK26+340 section is carried out. For the shallow buried section of V-Class surrounding rock, the flat tunnel shape determines that the tunnel deformation is mainly affected by the gravity of the overburden soil layer, as shown in Fig. 8 (a), resulting in the settlement deformation of the vault far greater than the surrounding convergence deformation of the tunnel. When the tunnel is excavated in grade IV surrounding rock, the surrounding rock has good properties and high strength. The surrounding rock loose zone with a certain thickness is formed along the tunnel excavation free face. The deformation in the tunnel is mainly the stress release deformation of surrounding rock, as shown in Fig. 8 (b).

![Diagram](image1)

(a) Stress diagram of V-Class shallow buried tunnel

![Diagram](image2)

(b) Schematic diagram of loose zone of tunnel surrounding rock

Figure 8. Schematic diagram of tunnel excavation under different surrounding rock conditions
5. Conclusion

(1) The monitoring data of surface settlement and deformation in the tunnel show that the construction parameters of Da-Puling tunnel are basically reasonable within the construction control value range of tunnel deformation;

(2) The tunnel entrance section is the key part of the whole tunnel. The initial deformation of Da-Puling tunnel is relatively large, and the deformation rate exceeds the warning value. Therefore, attention should be paid to the construction of portal section and temporary support should be added if necessary;

(3) For the portal section with poor surrounding rock properties, it is suggested that the actual construction reserved deformation should be greater than 1.5 times of the design value to prevent the risk of limit invasion, and dynamically adjust the construction parameters according to the monitoring results;

(4) The settlement of vault in shallow buried section of V-grade surrounding rock is about 4 times of surrounding convergence, which is mainly due to the gravity of overlying soil layer; in class IV surrounding rock, the deformation of the tunnel is small, and the settlement of arch crown is close to convergence deformation, and the stress release deformation of surrounding rock loose area is the main deformation.

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