The Research into Quality Control over Bolt Support for High Slopes

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Abstract. The height of slope has a significant impact on its safety and stability, for which an effective quality control enforced over the course of construction is essential to ensure the safety of construction works. In this paper, the high-slope bolt involved in a specific engineering project is exemplified to analyze the quality-related issues, based on which the major influencing factors in construction quality are identified as the techniques and environment of construction. Further with this, an analytical research is conducted into the quality of construction with three priority procedures, including the construction of latticed girder, bolt and slope concrete spraying. The construction environment shall be subjected to effective control and the ultimate quality of construction shall be inspected as compliant. In doing so, valuable reference could be provided for the engineering works of the same category in terms of construction.

1. Introduction
High slope is common in deep foundation pit engineering, traffic engineering, water conservancy engineering and other fields. It has prominent impact about stability problem and belongs to the dangerous sub-projects. In recent years, many engineering accidents have occurred during the construction, excavation and support of high slopes. This is mainly due to the overall instability of slopes and the destruction of supporting structures. Based on the engineering background of high rock slope, this paper focuses on the quality problems in the construction process of high slope support, and puts forward the measures which have been successfully applied in practical projects.

2. The general state of high-slope engineering works
High slopes are commonly seen in a variety of different engineering works, such as deep foundation pit, transport and water infrastructures. One prominent issue with high slopes lies in their stability, for which they are classed as highly dangerous partial engineering works. In recent years, there have been a large number of accidents occurring due to the high slope-related construction works, especially during the excavation and support process. This is primarily attributed to the instability of the high slope as a whole and the damage caused to the support structure. This paper takes the rock-based high slope as its engineering background to conduct a prioritized in-depth research into the quality-related issues arising from the construction of high-slope support, based on which the measures that have been verified as successful in practical applications are recommended[1].

The engineering project named as “Chunxiao Garden of Fusheng Olympic Garden” consists of four residential buildings as well as one separate building dedicated to the village committee, all of which
adopt the structure of reinforced concrete frame. The No.4 building has the deepest basement that is 10.55m below the ground. The overall state of this project is shown in Table 1 below.

Table 1. The overall state of Project “Chunxiao Garden of Fusheng Olympic Garden”.

| No. | Height of Building | Overall Construction Area | Upper Floor Height | Ground Level of Basement | Structural Design         |
|-----|-------------------|---------------------------|--------------------|--------------------------|---------------------------|
| 1#  | 40.9m             | 9042.46m²                 | 2.9m               | -9.400m                  | Reinforced concrete frame |
| 2#  | 40.9m             | 9708.48m²                 | 2.9m               | -4.750m                  | Reinforced concrete frame |
| 3#  | 36.5m             | 5026.82m²                 | 2.9m               | -8.950m                  | Reinforced concrete frame |
| 4#  | 32.2m             | 5442.82m²                 | 2.9m               | -10.550m                 | Reinforced concrete frame |
| 5#  | 12m               | 500.52m²                  | 4.4m               | No basement              | Reinforced concrete frame |

For this project, the major structure (± 0.00) is equivalent to the rolling height of +11.600~16.100m. The site elevation is +11.6~30.8m, the floor elevation of the basement is 9.25~12.9m, the designed elevation for the bottom of the foundation pit is —9.35~13m, and the depth of excavation for the foundation pit is 10m at maximum. The slope engineering works are first-classed for safety with the lack of conditions for slope. A comprehensive analysis leads to the decision for bolt support as the way of slope protection. The revetment is made up of shortcrete with a total area of support reaching 2380m².

3. The analysis of quality-related issues with the construction of bolt support

In this project, the constructions of frame latticed girders and bolts are performed in alteration, that is, the completion of construction for bolt support within a certain area is followed immediately by that of frame latticed girders for the same area. To ensure a smooth running of the project, we make fully preparation in terms of manual labor, raw materials and machinery, conduct a detailed technical briefing and draw up the specific measures to ensure quality.

As the construction works are ongoing within the No.2 area, the following problems arise from demoulding of the latticed girders. Firstly, as for the sectioned cementing of girders, the working procedures are discrete, which causes the cementing time to be extended. Secondly, the chutes are set up in a way that fails to conform to the specified standard, which leads to the loss of shotcrete and partial segregation of shotcrete. Thirdly, the installation of stencil lacks stability, which results in displacement or expansion. Fourthly, the appearance of concrete falls short of the requirements as it is riddled with rugged surface. Fifthly, the gaps created in the process of construction are left unprocessed, which is easily visible.

In order to address these problems, a QC working group is set up to monitor and analyze them. The influencing factors in the quality of in-site construction are listed in Table 2, which reveals that in terms of the frequency of occurrence, the techniques and environment of construction account for 45% and 20%, respectively, for which they are identified as the major factors. Therefore, the improvement to the techniques and environment shall be prioritized for quality control.

Table 2. The influencing factors in the quality and progress of construction works.

| No. | Item                        | Frequency | Frequency in percentage | Note |
|-----|-----------------------------|-----------|-------------------------|------|
| 1   | Approach to construction    | 30        | 15                      |      |
| 2   | Flaws to construction techniques | 2         | 1                       | 45%  |
| 3   | Inconsistent properties of concrete | 58       | 29                      |      |
| 3   | Improper operations         |           |                         |      |
4. Countermeasures for quality control of high-slope construction works

4.1 Quality control over the construction of latticed girders for slope

The slope needs to be trimmed as much as possible with any protrusion removed. Then, the ribbed outline for a single girder shall be shaped in excavation that is in line with the dimensions of both vertical and horizontal girders as well as the thickness of stencil. The bottom-leveled slop platform shall be complete with grid foundation. When the setting out is complete, the excavation could be allowed to start after being accepted by the supervisor. The construction of vertical girders shall precede that of horizontal girders. When vertical girders are constructed, the joint shall be reserved for its corresponding horizontal girder[2].

Before installing the reinforced concrete frame, the debris accumulating at the bottom of the frames shall be removed to ensure a tightly-sealed basis. Meanwhile, a layer mixed with cement and mortar at the ratio of 1:3 shall be laid at the bottom.

The surface of slope shall be fitted with short-length anchors and the mortar pads of the same thickness as the concrete protective layer shall be prepared. The reinforced steel bars are strapped and supported by the mortar pads with a medium clearance to the surface of slope. Meanwhile, the bars shall be securely connected to the short-length anchors.

The protective layer for the major steel bars in the frame shall be compliant with the design requirements with a minimum thickness of 50mm. The net protective layer shall be 35mm at minimum for the strapped steel bars and 40mm at minimum for the major girders.

Frame cementing shall be continuous and accompanied by vibration. In case of any signs of concrete displacement, instant hardening, early strength concrete or cover mould can be adopted. For the individual vertical girders, continuous cementing is required. In case of any disruptions, the gaps shall be processed as normal[3].

The construction of bolt lattice structure is a process that requires a close coordination between two separate engineering works, namely bolt and concrete lattice structure. The relative position between bolt and lattice structure is more important than their absolute position, for which it must be measured precisely to ensure precise positioning.

4.2 Bolt tensioning

According to the designed mileage, the measuring tap is used to perform measurement. Setting out is conducted with leveling survey combined. Meanwhile, iron drill and paint marking are used to locate the anchor hole precisely. The drilling rig is put in place in strict accordance with the designed hole position, tilt angle and direction. Various measuring tools are used to control the angle. The error of tilt angle for the guide rail of the drilling rig shall be within the range of ±1°, with that of the direction in no excess of ±2°.
The drilling process shall be carefully recorded, including the pressure and speed of drilling as well as the state of stratum and underground water. The diameter and depth of the drilled holes shall be no less than the designed value with 50m over-drilled. When it is drilled to the designed depth, the operation shall not be halted immediately and a continued drilling for 3 to 5 minutes is required to prevent pinch-out at the bottom of the hole. Meanwhile, cleaning shall be started promptly for the anchor hole. The drilling shall be stopped immediately in case of collapse. Under this circumstance, the supervisor shall be notified before grouting takes place to solidify the wall of the hole. In 24 hours, the drilling could resume or the technique of drilling with casing can be applied as an alternative. As soon as the drilling process is complete, high-pressure air can be used to remove the unwanted debris from the hole. The installation of anchored steel bars could start upon inspection by the supervisor as acceptable[4].

As for anchor cable grouting, the neat cement slurry with a 0.5~0.55 ratio of water to cement is adopted. The normal pressure of 0.4~0.6Mpa is used for one-off grouting. In case the secondary grouting technique is applied, the neat cement slurry with a 0.6~0.8 ratio of water to cement is adopted. Besides, the second-time grouting can not be started until the hardened cement from the first-time grouting reaches 5Mpa in strength and the pressure is required to range 1.5~2.5Mpa. The hose used for a second-time grouting shall be fixed securely onto the rod and its outlet shall be capable of reverse stop when hole grouting is ongoing. The relevant regulations and design requirements shall be complied with and the entire process shall take place under supervision to ensure the quality of the anchoring works[5].

The tensioning and locking works can not begin until the strength of the slurry as well as the crown and waist concrete reaches 80% of the designed value. In case the drilled hole is designated for acceptance experiment, the works shall be performed only after it reaches the designed level in strength and is experimentally inspected as acceptable. The drilled hole for acceptance experiment shall be finalized on spot by the supervisor and representative designer. Dedicated equipment shall be used to perform tensioning. Before the work commences, the equipment shall be calibrated and the anchoring tools as well as clippers shall be inspected as compliant before use. Before the anchor cables are tensioned, 10-20% of the designed tensile load shall be applied for 1 to 2 times, which is conducive to a close contact between different parts while making the cable completely straight. After the differential load is made up for, the prestress shall be imposed on the anchor cable incrementally according to a specified 5-tier system, that is, 25%, 50%, 75%, 100% and 110% of the designed load. When the fifth-tier load is applied, it shall be sustained for 10-15 minutes before being removed. Within 48 hours of the locking, a compensated tensioning shall be conducted promptly should any visible loss of prestress is spotted.

4.3 The techniques used for quality control over concrete spraying for slope
The materials used for concrete spraying shall be technically compliant with its blending ratio to be finalized through experiment. For concrete with additives, the blending shall be done uniformly as the additives are added. Meanwhile, a compulsory blender shall be used to complete the blending within a short space of time to prevent the ingress of moisture[6].

Clean up the area to be sprayed and keep it hydrated. Use an ejector for concrete spraying with the in-work wind pressure greater than 0.5Mpa. The water pressure shall be higher than wind pressure by 0.1Mpa. The blow head shall be kept perpendicular to the surface of spraying with a desired clearance of 1.5~2.0m. When the surface of spraying is covered with the steel bar network, the blow head shall tilt a little bit but no less than 70°. The spraying shall be performed bottom up in sections and layers. Meanwhile, the blow head shall be in helical motion slowly and repeatedly.

The ejector shall be capable of excellent performance and supplying continuous and uniform concrete. It shall be technically compliant with the in-work requirements. Before spraying, the areas to be sprayed shall be clean up and checked for the dimensions of fractured surface to ensure compliance with the design requirements. For nighttime operations, adequate lighting shall be ensured for the
working areas. Meanwhile, the operatives shall wear appropriate PPEs to ensure personal safety and the quality of work.

The technical measures to ensure the compactness of sprayed concrete as follows:

- Enforce strict control of the blending ratio, which needs to be determined through experiment. For the concrete, every single indicator shall conform to the relevant specifications. Automated weighing shall be adopted for feeding to ensure compliance with the requirement on precision.
- Enforce stringent control of the quality of raw materials with their indicators compliant with requirements.
- The wind pressure shall be determined reasonably for concrete spraying to ensure continuity and uniformity of spraying. Meanwhile, equipment maintenance shall be strengthened to ensure their excellent performance in work.
- The spraying work shall be performed by experienced and skilled operatives to ensure a close connection in between different concrete layers.
- The spraying shall be performed in close proximity to the excavated surface on the slope. The next-time explosion, if any, shall be 4h apart from the completion time of concrete spraying as a minimum.

5. Conclusions

By performing inspection on the four major indicators to bolt support in the engineering project, it is found that they are all within the specified range of deviation, for which the design requirements and applicable regulations are complied with. Upon self-check, the quality of construction is completely classed as excellent. As for the partial engineering works on lattice girders, a total of six sub-divisional works are complete with the overall rating of 94.5. There are two sets of inclinometers deployed across the buildings to monitor deformation to the foundation pit. When such a deformation is in excess of the level that rings the alarm, the supporting axial force is increased duly depending on the actual state or the number of supports is increased to contain the deformation to the enclosing structure. Some observation points are set around the foundation pit to monitor surface subsidence. Besides, in the areas surrounding the buildings are set the observation points as well for the same purpose, which provides useful data as reference. With an effective control enforced throughout the construction process, all the monitoring data is found to be within the range that is deemed safe. The desirable outcomes have been achieved through the control of three priority procedures including the construction of latticed girder, bolt and slope concrete spraying.

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