Replacement Construction Technology of Collapsible Loess Subgrade in Typical Subtropical Humid Climate Area

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Abstract. Aiming at the problem of insufficient bearing capacity of collapsible loess in highway subgrade engineering, taking the second phase of KKH project in Pakistan as an example, Based on the analysis of the physical and mechanical properties of collapsible loess in this area and the actual situation of the project, the most effective construction technology is explored. The construction technology of replacing natural gravel is analyzed, and summarizes the actual operation of the construction methods, to provide some theoretical basis and construction reference for related projects. The results show that the design and construction requirements can only be met under the condition of strict implementation of the norms and standards, combined with the actual situation of the project, and the most effective construction technology explored can be applied to the construction of highway subgrade.

Keywords: Subtropical, Humid, Zone, Collapsible, Loess, Gravel, Replacement, Construction Technique

1. Introduction

Roadbed is the foundation of road engineering. It bears road load and transmits load to the depth of foundation. Therefore, the strength and stability of roadbed directly affect the quality and service life of roads.

In recent decades, with the massive construction of highway infrastructure in China, China has made in-depth research on roadbed in special areas, and accumulated rich construction experience. Wulibo, Niu Fujun, etc. [1] Through monitoring, the influence of the depth of waste filling and drainage measures on the freezing characteristics of subgrade is analyzed. Li Xian etc. [2] Through indoor collapsibility permeability test, reveal the law of influence of loess collapsibility on its permeability and its micro-mechanism. Xu Jian and Niu Fujun, etc.[3] took two groups of fillers as research objects, and analyzed the influence of powder and clay on frost heave property through indoor frost heave test. Yu Tianguang etc.[4] summarized the construction technology of improved expansive soil roadbed with gravel. Shidin Miao et al. [5] reveal the expansive properties of black cotton soil by a combination method of quantitative analysis of mineral content of black cotton soil.
Xueying Zhao et al. [6] combined with practical engineering, the mechanical response of saline soil under traffic load was analyzed by finite element software. Xueying Zhao et al. [6] combined with practical engineering, the mechanical response of saline soil under traffic load was analyzed by finite element software. Liu Chunlong et al. [8] selected soil samples from typical locations in Pakistan and determined the collapsibility coefficient of loess through laboratory tests, which provided reference for the construction of relevant projects in this area. [7] However, it mainly studies the engineering properties of saline soil, seasonal frozen soil, black cotton soil, collapsible loess and other special soils in China, and has no rich experience in the replacement of collapsible loess roadbed in subtropical wet areas.

In order to solve the problem of insufficient bearing capacity of collapsible loess in KKH project in Pakistan, gravel replacement method is adopted. This paper mainly expounds the application of this technology in practical engineering from the aspects of construction preparation, construction technology, construction quality control and matters needing attention of gravel replacement technology.

2. Engineering Overview

The total length of the project is 19.419 Km, the design speed is 100 km/h, the two-way four-lane standard and the roadbed width is 25.7 M. Its cross-section composition is: 1.0m (soil shoulder)+3.65 (hard shoulder)+2×3.65 (roadway)+0.6 (central partition belt)+0.6 (roadside belt)+2×3.65 (roadway shoulder)+3.65 (hard shoulder)+1.0m (soil shoulder). From the beginning to the end of the project, the route spans different geomorphic units, which are in turn piedmont alluvial plain area, loess ridge area, River Valley area, low-middle mountain wide valley area, low-middle mountain area, the overall terrain is low in the South and high in the north. K62+490~K63+370 is collapsible loess. It is inevitable that the direct construction of roadbed above is due to the long consolidation time of soil and the large settlement of roadbed after construction. According to the site investigation and design requirements, soft foundation replacement treatment is needed. The design document requires that the original surface soft soil of this section of subgrade be replaced by gravel.

3. Basic Physical Properties of Loess

The main physical and mechanical indexes of loess samples taken from different points in this area are shown in Table 1.

4. Determine the Main Technical Standards

The replacement material is natural graded gravel without impurities. The mud content should be less than 5%, the maximum particle size should be less than 50 mm, and the strength of gravel should not be less than four grades (the wear rate of Los Angeles method is less than 60%). The thickness of loose pavement is 30 cm and compactness is 94%. The settlement difference between two times of vibration compaction of vibratory roller is less than 2 mm (one time of reciprocating compaction of roller is one time of rolling). [9] All of the above meet the requirements of relevant specifications [10-12]. Replacement width is about 28.9m at the breakdown platform on both sides of subgrade, whichever is the design drawing. Replacement depth will be excavated to the pebble layer according to the actual situation of the site and confirmed by the supervising engineer. Replacement of gravel and sand roof shall be the top surface of subgrade according to the design drawings.
Table 1. Basic Physical and Mechanical Properties of Loess at Different Depths

| Number | Depth/M | Initial Void Ratio $e_0$ | Dry Density $\rho_d$ (G.Cm$^{-3}$) | Initial Moisture Content $\omega_i$/% | Liquid Limit $\omega_L$/% | Plastic Limit $\omega_p$/% | Plasticity Index $I_p$ |
|--------|--------|--------------------------|-------------------------------|-----------------------------------|-------------------------|-------------------------|----------------------|
| 1      | 1      | 0.610                    | 1.58                          | 7.4                               |                         |                         |                      |
|        | 5      | 0.589                    | 1.60                          | 12.0                              | 22                      | 17                      | 5                    |
|        | 10     | 0.610                    | 1.59                          | 15.7                              | 28                      | 20                      | 8                    |
| 2      | 2      | 0.601                    | 1.60                          | 6.8                               | 25                      | 18                      | 7                    |
|        | 5      | 0.610                    | 1.65                          | 5.2                               | 23                      | 17                      | 5                    |
|        | 7      | 0.660                    | 1.55                          | 20.0                              | 26                      | 17                      | 9                    |
| 3      | 1      | 0.643                    | 1.54                          | 6.6                               |                         |                         |                      |
|        | 7      | 0.644                    | 1.55                          | 11.8                              | 25                      | 18                      | 7                    |
|        | 9      | 0.643                    | 1.55                          | 13.5                              | 26                      | 17                      | 9                    |
| 4      | 9      | 0.640                    | 1.56                          | 11.3                              | 29                      | 17                      | 12                   |
|        | 11     | 0.638                    | 1.56                          | 13.6                              | 31                      | 21                      | 10                   |
|        | 15     | 0.637                    | 1.56                          | 15.3                              | 33                      | 21                      | 12                   |

5. Construction Technology Strategy

5.1. Construction Preparation

To ensure that there are no other impurities in the replacement gravel, the mud content should be less than 5%, the maximum particle size should be less than 50 mm, and the gravel strength should not be less than four grades (Los Angeles method wear rate is less than 60%). Determine the source of sand and gravel needed for replacement, and screen the filling samples according to the specifications to ensure the quality of sand and gravel, and report to the test supervision engineer for approval.

Restoration of mid-side piles and installation of temporary isolation grille at 1 m of slope excavation line to prevent non-construction personnel from entering construction site and expressway.

Lofting and recording measurement data. Re-surveying the line and elevation, checking and adding the leveling points and control piles according to the design drawings and relevant regulations, and surveying and drawing the cross-section of the route are carried out by the relevant engineers and technicians. The results of measurement shall be recorded in writing and submitted to the supervising engineer for examination, signature and approval. According to the design requirements of the drawings, the replacement range is within 50 cm of the roadbed. Measuring and lofting out the replacement side pile and sprinkling white grey line as the boundary line of excavation and replacement. Double checking system of measurement is carried out during measurement, the results of measurement are checked and the requirements for checking measurement deviation are met.

5.2. Construction Process

The construction process of gravel replacement is shown in Figure 1.
Figure 1. Flow chart of gravel replacement construction technology

5.3. Excavation of Foundation Pit

Soft rotten soil is excavated according to the position of lofting pile and transported by dump truck to the specified abandonment site. Base leveling should be done by bulldozer 40 m after foundation pit excavation. According to site excavation, after excavation depth of 1.8 m, 22T vibratory roller should be used for pre-filling rolling. Compactness is not less than 94%. The edge and corner are compacted by artificial or frog rammer. After rolling, the base elevation of replacement should be measured and the original record should be made. After passing the inspection by supervision engineer, gravel replacement should be carried out.

5.4. Grit Rolling

Replacement gravel should be filled in layers and the thickness of layers should be less than twice the maximum size of aggregate. In this project, 30 cm loose pavement thickness is used to measure the volume of gravel per vehicle. According to the volume and loose pavement thickness, the area of gravel per vehicle should be calculated. The grid line is marked with lime at the base of the vehicle to ensure a grid for each vehicle. After the filler is transported to the construction site, the special person is responsible for directing the unloading and strictly controlling the unloading and paving thickness. After the filler is transported to the construction site, the special person is responsible for directing the unloading and strictly controlling the unloading and paving thickness. After the gravel feeding is completed, the bulldozer paves the gravel and levels it manually. The maximum particle size of gravel is not more than 40 mm. The virtual height is measured and recorded. During the rolling process, the smooth wheel should overlap 1/2 of the wheel width and must exceed the joint of the two sections. The first two times should be 1.5-1.7 km/h, and the second time should be 2.0-2.5 km/h. Specific rolling methods are as follows: first static pressing once, after leveling the area with obvious convex and concave phenomena, the relative compactness is 88.167%, then strong vibration once, the relative compactness is 90.567%, the second time of strong vibration, the relative compactness is 92.2%, the third time of strong vibration, the relative compactness is 93.267%, the fourth time of strong vibration, the detection of relative compactness is 92.2%. Relative compactness 94.217%, qualified, static
pressure once over. Longitudinal overlap of rolling is not less than 2 meters, transverse overlap is not less than 50 centimeters, rolling until no obvious wheel tracks, and the surface is flat. According to the requirements of "Construction Scheme of Soft Foundation Replacement Test Section", the elevation after compaction is measured. The compactness test is shown in Table 2.

### Table 2. Compactness Testing

| Pile Number (Position) | 1 Times Static Pressure | Vibration 1 Times | Vibration 2 Times | Vibration 3 Times | Vibration 4 Times |
|------------------------|------------------------|------------------|------------------|------------------|------------------|
|                        | Compaction Degree (%)  | Compaction Degree (%) | Compaction Degree (%) | Compaction Degree (%) | Compaction Degree (%) |
| K62+540                | 88.4                   | 90.2             | 92.2             | 93.0             | 94.2             |
| K62+580                | 88.1                   | 90.4             | 92.3             | 93.3             | 94.1             |
| K62+600                | 88.4                   | 90.6             | 92.5             | 93.4             | 94.2             |
| K62+680                | 88.5                   | 90.0             | 92.0             | 93.6             | 94.3             |
| K62+700                | 88.1                   | 90.9             | 92.1             | 92.9             | 94.0             |
| K62+740                | 87.5                   | 91.3             | 92.1             | 93.4             | 94.5             |
| **Average Value**      | **88.167**             | **90.567**       | **92.2**         | **93.267**       | **94.217**       |

5.5. **Looseness Coefficient Detection**

According to the measured compactness of each section with a spacing of 500 square meters, the compactness of each observation point before and after each rolling is collected. When the compactness of the roller reaches 94% by vibration rolling, that is, the compactness is qualified and meets the requirements of specifications and design. Before paving, 8 sections, such as mileage K62+540, K62+560, K62+580, K62+600, K62+680, K62+700, K62+720, K62+740, are laid with loose paving coefficient detection points, which are controlled by marking piles. Each section of marking piles is arranged around the outside of the construction area. The elevation of the test points set by the leveler after rolling is qualified, combined with the elevation of the test points observed before and after filling and spreading. The coefficient of loosening is shown in Table 3, from which the coefficient of loosening is calculated to be 1.17.
### Table 3. Compaction Coefficient of Natural Gravel

| Pile number | Base elevation (m) | Before rolling | After rolling | Loosening coefficient |
|-------------|-------------------|----------------|---------------|-----------------------|
|             |                   | elevation (m)  |               |                       |
| K62+540     | 892.516           | 892.816        | 411.757       | 0.24                  | 1.200                  |
| K62+560     | 892.670           | 892.99         | 411.778       | 0.269                 | 1.188                  |
| K62+580     | 892.825           | 893.125        | 411.499       | 0.25                  | 1.200                  |
| K62+600     | 892.980           | 893.3          | 411.318       | 0.273                 | 1.172                  |
| K62+680     | 893.598           | 893.928        | 411.312       | 0.276                 | 1.194                  |
| K62+700     | 893.753           | 894.053        | 411.446       | 0.25                  | 1.200                  |
| K62+720     | 893.907           | 894.207        | 411.447       | 0.274                 | 1.094                  |
| K62+740     | 894.062           | 894.372        | 410.347       | 0.267                 | 1.161                  |
| **Average Value** |   | 0.310          | 0.262         | 1.176                 |

### 6. Construction Summary and Suggestions

The whole filling process is excavated and loaded by excavators, transported by dump trucks, roughly leveled by hand with bulldozers, and strictly leveled by graders. Flow-line construction mode of 22T vibratory roller for rolling and sand-filling method for measuring compactness. The first two rolling speeds of roller are 1.5-1.7 km/h, and then 2.0-2.5 km/h.

Before the formal construction, the experimental section can be paved to familiarize the constructors with the construction technology of roadbed filling, determine the types of construction machinery and the matching combinations of various machines, and complete the determination of various parameters (loose coefficient, loose thickness, rolling times, optimum moisture content) in the construction of replacing gravel with soft foundation. The thickness of loose pavement is 30 cm, the coefficient of loose pavement is 1.17, and the number of times of rolling is not less than 6 times (static pressing once, vibration rolling four times, static pressing once), and the rolling speed is controlled in the range of 1.5-2.5 km/h.

In the process of construction, the thickness of loose pavement should be strictly controlled, and the filling with super-particle size should be strictly controlled. Particles with particle size exceeding 2/3 of the thickness of the layer must be removed.

Because the water content of fillers is generally low, it is necessary to control the water content before, after and during the rolling process to ensure that the water content is within the deviation range of the optimum water content (+2%, -2%) to ensure the rolling quality.

When rolling, the roller rolls from the edge of the subgrade to the center of the subgrade in turn, and the rolling speed is controlled at 1.5-3 km/h. Wheel tracks overlap not less than 30 cm along the line. The inner side (joint with the edge of existing roadbed) and the outer shoulder should be rolled 2-3 times more.

### 7. Conclusion

Loess has the characteristics of large void ratio, strong water sensitivity and not easy to compact. After the loess is soaked in water, the soluble salts between particles dissolve, the cementation strength...
between particles weakens, and the strength and stability drop sharply under certain load, which has caused serious harm to Subgrade engineering. Based on the KKH project in Pakistan, this paper adopts gravel replacement measures to solve the deficiency of the bearing capacity of collapsible loess subgrade, so as to improve the overall quality of highway and extend its service life. At the same time, it also provides construction suggestions for the future construction of soft soil subgrade in this area.

References
[1] Wu Libo, Niu Fujun, Lin Zhengju, Qi Wei, Feng Wenjie. Effect of replacing-filling and dewatering-draining measures on frozen characteristics of weak subgrade in cold valley region[J].Journal of Traffic and Transportation Engineering, 2018, 18(04):22-33.
[2] Li Xian, Hongbo, Li Lincui, Wang Li. Experimental Research on Permeability Coefficient Under Influence of Loess Collapsibility[J]. China Journal of Highway and Transport, 2017, 30(06): 198-208+222.
[3] Xu Jian, Niu Fujun, Niu Yonghong, Liu Hua. Analysis on the Effect of Replacing-Soil Method on Inhibiting Frost Heave of Railway Roadbed in Seasonal Frozen Soil Region[J]. China Railway Science, 2011, 32(05):1-7.
[4] Yu Tianguang, Zhang Kai, Zhou Shengzhan, Gao Kun. Construction Technology of Improved Expansive Soil Subgrade with Gravel[J]. Construction Technology, 2014, 43(05):97-99.
[5] Shiding Miao, Jianzhou Shi, Yanbin Sun, Peng Zhang, Zhaoqi Shen, Honggen Nian, Jinqiu Huang, Xueqiu Wang, Peiping Zhang. Mineral abundances quantification to reveal the swelling property of the black cotton soil in Kenya[J]. Applied Clay Science, 2018, 161.
[6] Xueying Zhao, Aiqin Shen, Yinchuang Guo, Peng Li, Zhenhua Lv. Pavement mechanic response of sulfate saline soil subgrade section based on fluid–structure interaction model[J]. International Journal of Pavement Research and Technology, 2017.
[7] Zhao Ping, Xu Zhengxuan, Tang Lin, Zeng Deli. Research on the Black Cotton Soil Swell-shrink Characteristics and the Depth of Black Cotton Soil Influenced by the Atmosphere in Ethiopia[J]. Journal of Railway Engineering Society, 2014(04):46-50.
[8] Liu Chunlong, Zhang Zhiqiang, Liu Fengyi, Liu Naifei, Sun Hongchao, Lu Wenjun. Research on collapsibility of a loess site in Pakistan[J]. Coal Geology & Exploration, 2019, 47(02):177-182.
[9] Zhang Caili, Chengziman, Xu Xiudong, Liu Shuxiang and Sun Junjun. Research on Settlement Properties of Backfilled Sea Sand Subgrade[J]. Highway, 2017, 62(02):30-35.
[10] JTG D30-2015 Code for Design of Highway Subgrade[S]. Beijing: China Communications Press, 2015.
[11] JTG D50-2006 Design Code for Highway Asphalt Pavement [S]. Beijing: China Communications Press, 2006.
[12] JTG F40-2004 Specification for Construction Technology of Highway Asphalt Pavement [S]. Beijing: China Communications Press, 2004.