Technical Use and Mechanical Properties of Landslide Gravel in Three Gorges Reservoir

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Abstract. The main treatment of the Wanzhou drawdown area in the Three Gorges Reservoir involving landslide and reservoir bank treatment is conducted. A comprehensive treatment of Wanzhou drawdown area in Three Gorges Reservoir involving landslide and reservoir bank treatment is conducted. The slope cutting improves the stability of landslides in conditions of periodic water level fluctuation, and when excavated gravel is used as the filler for reservoir bank treatment, it satisfies the ecological requirements of earthwork balance. Two kinds of landslide gravel collected for treatment were subjected to a series of tests, including particle analysis, heavy compaction, and a large-scale triaxial compress, and the engineering utilization control conditions and mechanical properties were obtained. The results show that the coarse particles content of landslide gravel is high, while the viscous is a little strong. Completed relations of water content ω and dry density ρd are obtained by heavy compaction tests, and for K = 0.93, internal friction angles (φ) obtained by consolidated drained (CD) and consolidated undrained (CU) triaxial test are 21.9°~22.4° and 18.2°~19.1° respectively.

1. Introductions

Slope cutting is an effective and widely used landslide treatment, but how to accommodate the excavation of soil in mountain locations is a problem. However, a realistic evaluation of the excavation soil could be conducted in comprehensive treatment programs. Excavated soil will be used as filling material if it can command engineering utilization conditions, which is expected to result in intense resource consumption. In reality, landslide gravel and completely/strong weathered rock show similar engineering properties after rolling, provided the filling conditions are controlled appropriately, and there are many precedents for using soft rock waste as subgrade filling. Through special scientific tests on the physical and mechanical properties of soft rock spoil, a marched construction scheme can be determined to satisfy the engineering quality requirements of high embankment[1]. By combining the laboratory test and field layered paving test of argillized or completely weathered spoil respectively, Wang et al[2] and Luo et al[3] put forward the evaluation method suitable for filling and utilization. Combined with the H/V spectrum ratio of microseismic and image entropy analysis, Rincon et al[4] has verified the feasibility of using soft rock spoil as an engineering filling material.
after reasonable evaluation. According to Zhang\cite{5}, the settlement control of high fill embankments with gravel soil is the most important in mountainous locations, and the most efficient approach to improving the compactness of filler is to regulate the technical indices of natural gravel. The mechanical properties of natural gravel can be measured by large-scale triaxial tests, and the strain characteristics of gravel that could satisfy the compactness requirement are studied by Xu et al\cite{6} and Zhou et al\cite{7}. He et al\cite{8} and Cui et al\cite{9} noted that natural gravel could satisfy the requirements of high embankment filling by realistic evaluation of construction conditions.

In summary, the most difficult aspect of using landslide excavated gravel as an engineering filler is to determine the appropriate utilization conditions. In this paper, the case study is a comprehensive treatment project in the Three Gorges Reservoir area. According to systematic test results on the compaction and mechanical properties of landslide gravel, appropriate utilization and control conditions for high embankment are proposed, which could satisfy the requirements of an engineering design and construction scheme.

2. Overview of comprehensive treatment project

The comprehensive treatment project is located in the water level fluctuating area of the Three Gorges Reservoir area, which is composed of landslide treatment and building a new expressway along the reservoir bank. Slope cutting will improve the stability of the landslide, and the excavated gravel will be used as filler on the expressway’s high embankment, in an attempt to achieve the objective of earthwork balance.

According to the design plan, the physical and mechanical properties of the filler should meet the indices as follows: the compaction coefficient \(K \geq 0.93\)\cite{10}, internal friction angle \(\varphi \geq 22^\circ\), and cohesion \(c \geq 25\text{kPa}\). Prior to that, two problems should be solved. One problem is that the natural water content \(\omega\) of gravel is high, and the allowable range of \(\omega\) should be obtained, otherwise the rolling construction can not satisfy the design compaction requirements. Another problem is that landslide gravel is a rock-soil mixture. Therefore, to acquire mechanical parameters for gravel, large-scale geotechnical tests should be considered.

Based on the above requirements, a field geological survey and sampling for typical gravel have been conducted (Figure 1). Then, a series of large-scale geotechnical tests for particle size distribution, compaction characteristics, and strength will be carried out, which makes it possible to put forward the utilization scheme for landslide gravel.

3. Basic characteristics of landslide gravel soil

Landslide gravel can be divided into two types. For gravel that is located in the middle part of landslide, the gradation is slightly finer. It is marked as Type 1#. For gravel that is located near gullies on both sides, the grading is a little coarser. It is marked as Type 2#. Both types of gravel were used for experimental study as follows.

Figure 2 shows the gradation curves for both types of gravel. It can be seen that the gradation of both types of gravel is good. The content of the gravel group (2mm-60mm) for Type 1# and 2# are 67.5% and 63.3% respectively, while the fine particle group (<0.1mm) for both types are 7.50% and 4.59% respectively. In addition, a test for natural water content \(O_0\) was conducted, and \(O_0\) for Type 1# and 2# is about 21% and 17%, respectively. This is because the water holding capacity of Type 2# is weaker than that of Type 1# owing to its higher gravel content.

In view of the limitation of the maximum particle size in the test, a particle size larger than 60mm is not allowed. An equivalent substitution method is used to scale the original gravel, and heavy compaction and large triaxial tests are carried out.
Figure 1 In-situ sampling of landslide gravel soil

Figure 2 Gradation curves for both types of landslide gravel soil

4. Compaction characteristics of landslide gravel

Due to the strong connection between water content $\omega$ and compaction dry density $\rho_d$, heavy compaction tests are carried out on both types of gravel to obtain the complete $\omega$-$\rho_d$ curves as well as the maximum dry density $\rho_{d_{\text{max}}}$.

The layered under compaction method is used, with a compaction cylinder of $\phi 300 \times H 285$mm, and a compacted sample consisting of three layers, each with a surface vibration of 6.5 minutes. Eight different $\omega$ are determined for each type of gravel, and they should cover the optimal water content $\omega_{\text{opt}}$.

Some of the compacted samples are shown in Figure 3; Figure 4 shows the relationship curves of $\omega$-$\rho_d$, and a statistics have been made for $\rho_{d_{\text{max}}}$ and $\omega_{\text{opt}}$. The water content range that could meet the compaction coefficient $K = 0.93$ and $K = 0.95$ are given here respectively in Table 1.

| Type of gravel | $\rho_{d_{\text{max}}}$ (g/cm$^3$) | $\omega_{\text{opt}}$ (%) | Range of $\omega$ for a certain $K$ |
|---------------|-----------------|-----------------|------------------|
| 1#            | 1.798           | about 17.0      | $\geq 0.93$ (%)   |
|               |                 |                 | $\geq 0.95$ (%)   |
| 2#            | 1.832           | about 11.5      | 12.5~19.5 (%)     |
|               |                 |                 | 13.5~18.5 (%)     |
5. Scheme of large-scale triaxial compression test

The YLSZ30-3 triaxial compression apparatus developed by Changjiang River Scientific Research Institute is used to conduct the tests, and it is a large-scale apparatus specifically for coarse-grained soil testing.

The shape of the sample is a cylinder with a size of $\Phi 300 \times H600$mm. The maximum confining stress can reach 3.0MPa. The designed maximum axial stress is 21MPa, and the maximum axial stroke is 300mm. A picture of the apparatus is shown in Figure 5.

For both types of landslide gravel, the samples are prepared under the compaction coefficient $K = 0.93$ and $K = 0.95$ respectively. Because the height of the sample is 60cm, in order to make the inner structure as homogeneous as possible, a layer by layer compacted method is used to prepare the sample. Considering the maximum height of the embankment is about 35 m, and also the traffic load is properly considered, the determined four levels of confining pressures $\sigma_3$ are 0.1 MPa, 0.2 MPa, 0.4 MPa, and 0.6 MPa respectively.

The viscosity of landslide gravel is obvious, especially for Type 1#. In view of studying the influence of drainage conditions on the strength of landslide gravel, a group of consolidated drained (CD) and consolidated undrained (CU) tests were conducted under $K = 0.93$. In addition, a group of CD tests under $K = 0.95$ is conducted to obtain the relationship between $K$ and strength. All test processes should be carried out in accordance with the “Standard for geotechnical testing method (GB/T 50123-2019)" [11] and the “Specification for coarse-grained soil test (T/CHES 29-2019)" [12].
6. Stress-strain and strength analysis of landslide gravel

For both types of gravel, the relationship curves of deviatoric stress ($\sigma_1-\sigma_3$) to axial strain $\varepsilon_1$ under each condition are shown in Figure 6 and Figure 7. Based on which, the corresponding Mohr's strength circles and fitting envelopes are achieved as in Figure 8 and Figure 9. Statistics for shear strength parameters are listed in Table 2. The following is an in-depth analysis from different perspectives.

Strength envelope: within the range of tested confining pressure, the strength envelope shows good linear relations, which indicates that friction effect is the dominant in large strain process under each condition. Direct contact and force transfer among coarse particles are not obvious due to the fine particle concentration. The particle breakage effect could be overlooked in this case. This is also the reason why the peak value of ($\sigma_1-\sigma_3$) is not obvious.

For the parameter of friction angle, $\varphi$: when compared with the same condition, Type 2# is always slightly larger than Type 1# and coarse particles should play a role in improving $\varphi$. For the parameter of cohesion $c$, for each condition, $c$ is no less than 30 kPa, so it is necessary to consider the contribution of cohesion to the strength of the landslide gravel filler.

Because cohesion $c$ is a little high, and the permeability of compacted landslide gravel is poor, drainage conditions should be closely monitored. When $CD$ and $CU$ test results are compared under $K = 0.93$, there is a $2.9^\circ$ and $3.6^\circ$ decrease in $\varphi$ for Type 1# and 2# respectively, and when compared with $CD$ test results under $K = 0.93$ and $K = 0.95$, there is a $1.5^\circ$ and $1.9^\circ$ increase in $\varphi$ for Type 1# and 2# respectively, implying that improving $K$ should be an effective way to enhance the embankment.

| Type of gravel | $K$  | Testing condition | Shear strength parameters | $\varphi(\degree)$ | $c$(kPa) |
|----------------|------|-------------------|--------------------------|-------------------|----------|
| 1#             | 0.93 | $CD$              | 22.0                     | 48                |
|                | 0.93 | $CU$              | 19.1*                    | 45*               |
|                | 0.95 | $CD$              | 23.5                     | 57                |
| 2#             | 0.93 | $CD$              | 22.9                     | 32                |
|                | 0.93 | $CU$              | 19.3*                    | 32*               |
|                | 0.95 | $CD$              | 24.8                     | 31                |

"*" is the total stress strength parameters
7. Utilization scheme of landslide gravel

Based on test results and analysis above, and in view of satisfying the designed requirements for filler, several suggestions are proposed on the utilization of landslide gravel as a filler material.

From the viewpoint of water content control, the gravel with natural water content $\omega_0$ is not allowed to roll directly because the landslide is close to the Three Gorges Reservoir, and the main construction season overlaps with the rainy season (June to September). Therefore, to reduce rainfall infiltration, it is necessary to excavate intercepting and drainage ditches around the landslide gravel to be used. However, a special field should be prepared to turn over and dry gravel before rolling, which reduces $\omega$ to the range of Table 1 listed.

From the viewpoint of strength parameters, the strength obtained by the CD test under $K = 0.93$ can satisfy the designed requirements, especially when cohesion $c$ is significantly higher than the designed requirements. Meanwhile, it is clear the strength parameters obtained by the CU test under $K = 0.93$ can not meet the designed requirement. Therefore, the drainage control of filler should be fully considered. As such, drainage cushion or blind ditch must be arranged in mass filler.
In addition, for some sections where the stability reserve is not high, it is effective to improve the strength parameters of gravel by optimizing rolling water content. Improving the compactness coefficient of gravel will enhance the embankment directly, and it is clear that the strength parameters obtained by the CU test under $K = 0.95$ are obviously higher than the designed requirements. The water content range in Table 1 can be referred to in construction site inspection.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{Mohr_strength_up.png}
\caption{Mohr's strength circles and fitting envelopes for Type 1#}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{Mohr_strength_down.png}
\caption{Mohr's strength circles and fitting envelopes for Type 2#}
\end{figure}

8. Conclusion
In this research, a comprehensive treatment project in Wanzhou section of the Three Gorges Reservoir area is selected to be a case study. Through a series of tests, the feasibility and applicable conditions of landslide gravel used for high embankment filling are carried out. The following conclusions can be achieved.

As a natural geotechnical medium, landslide gravel is different in spatial distribution. The gravel in the middle part of the landslide is slightly finer and shows stronger viscosity, while in the gullies on both sides, the grading is a little coarser. It is related to the dynamic environment of landslide formation. Proper classification should be made when it is used as an artificial filler.

The water content $\omega_0$ of natural landslide gravel is higher than 20%, compaction coefficient $K$ cannot reach to 0.93 if gravel is rolled directly. A heavy compaction test was conducted to obtain the complete relation of $\omega-\rho_d$. For Type 1# and 2#, when water content is located in the range of
12.5%~19.5% and 7.5%~17.0%, the corresponding $K$ could exceed 0.93; and when water content is located in range of 13.5%~18.5% and 8.5%~15.0%, the corresponding $K$ could exceed 0.95. It can be used for quality control during layer rolling.

According to large-scale triaxial test results, the strength parameters obtained by $CD$ testing under $K = 0.95$ can satisfy the designed strength requirements of filler. However, there is a $2.9^{\circ}$ and $3.6^{\circ}$ decrease of $\phi$ for Type 1# and Type 2#, respectively, in the condition of CU. This is lower than designed requirements. In mass filler, a drainage cushion or blind ditch must be constructed. When $K$ is increased from 0.93 to 0.95, the strength parameters improve noticeably. For some sections where the stability reserve is low, improving the compactness coefficient of gravel should be an effective approach to improve the filler’s properties.

In addition, layered rolling sun-baked for gravel should be very helpful in improving construction quality. In the design of the construction organization, this factor also be considered, and the construction site should be reserved properly.

In summary, the engineering utilization of natural landslide gravel has been conducted. On the one hand, it avoids damaging the environment caused by borrowing massive earthwork, and on the other hand, it absorbs the excavated gravel produced by the project itself, and achieves a good earthwork balance. From the perspective of environmental protection, a feasible technical scheme is proposed.

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