Review of soft rock weathered material for subgrade filling

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Abstract: With the continuous construction and development of Chinese infrastructure, more and higher requirements are imposed on the construction of expressway engineering. The construction of mountainous expressway has been gradually transformed from winding mountain to bridging and digging tunnels. Various forms of subgrade such as high filling and deep cutting, half filling and half cutting are unavoidable. The huge demand for roadbed filling and the inconvenience of transportation conditions have caused extreme costs for external materials. On the other hand, tunnel excavation brings a large amount of soft rock abandoned slag. If soft rock abandoned slag can be used for subgrade filling, it will not only help avoid resource waste, but also help reduce environmental damage. This paper introduces progress of researches at home and abroad on engineering properties, particle composition and distribution characteristics, CBR, compaction characteristics, etc. of soft rock, as well as the evaluation criteria and applicability of soft rock as subgrade filler in detail.

1. Introduction
With the continuous construction of expressway in mountainous areas, there is an increasing demand for subgrade filling. While the excavation of tunnel will bring massive waste, slag composed of weathered soft rock and using local materials to fill subgrade is the best choice. However, some soft rock waste slag cannot be directly used for subgrade filling. Typical soft rock waste slag, such as shale and siltstone weathered materials, have weak weathering resistance, poor strength and hydraulic properties. After encountering water and weathering, its compressive strength will decrease sharply, making it difficult to use in expressway construction. The resulting engineering waste slag not only brings additional transportation costs to the construction, but also causes environmental pollution and ecological damage. Thus, it requires further researches to achieve the full use of soft rock weathered materials.

Soft rock generally refers to the loose, soft and weak rock formations that have low strength, large porosity, poor degree of cementation, and is significantly affected by the cutting and weathering of the structural surfaces, or contain a large amount of expansive clay minerals \cite{1}. The rock with saturated uniaxial compressive strength that less than 30MPa is divided into softer rock (30MPa~15MPa), soft rock (15MPa~5MPa) and very soft rock (\leq 5MPa) by "Engineering Geology Handbook" \cite{2} and "Code for
Expressway Engineering Geological Investigation" (JTG C20-2011)[3]. Representative rocks include weathered tuff, phyllite, marl, sandy mudstone, shale, argillaceous sandstone, etc.

For a long time, soft rock has been less used as subgrade filler in the expressway construction, and the accumulated experience and achievements in the experimental research are also less. There are still many vague understandings of the mechanical properties of the soft rock filler. There is no uniform standard about the soft rock to guide the design and construction of expressway[4]. This article aims to summarize the advanced research results of engineering characteristics, construction technology, and improvement methods of soft rock and its weathered materials for subgrade filling at home and abroad, and provide a certain reference for the further road use research of soft rock and its weathered materials in the future.

2. Requirements for subgrade filler

The subgrade filler used in the expressway requires easy compaction, high strength and excellent water stability. Subgrade filling materials should have a certain strength and be tested in the field and should meet the design requirements before they can be used.

The strength requirement is determined according to the CBR value, and the minimum strength and maximum particle size of the subgrade filler should be determined through geotechnical tests. For soft rock, the "Specifications for Design of Expressway Subgrades" (JTG D30-2015) stipulates that soft rock can be used as embankment filler, but not road bed filler. When the weathered rocks used as embankment filler, the CBR of soft rock and its weathered material should meet the requirements shown in Table 1.

| Subgrade        | Depth below the bottom of the pavement (m) | Minimum CBR (%) |
|-----------------|--------------------------------------------|------------------|
|                 | Expressway, first-class expressway | Second-class expressway | Third-class, fourth-class expressway |
| Upper embankment| Light, medium, heavy traffic 0.8~1.5 | 4 | 3 | 3 |
|                 | Very heavy traffic 1.2~1.9 | 4 | 3 | - |
| Lower embankment| Light, medium, heavy traffic 1.5 or less | 3 | 2 | 2 |
|                 | Very heavy traffic 1.9 or less | 3 | 2 | 2 |

3. Engineering characteristics of soft rock weathered material

As early as 1965, Japan began to use sedimentary soft rock as subgrade filler, and carried out preliminary research on the engineering characteristics of soft rock filler. In recent years, with the development of transportation industry, soft rock and its weathered materials have gradually been used as subgrade filler in expressway construction, and some researchers have carried out related studies. The main engineering characteristics of soft rock and its weathered materials include grain composition, compaction, California Bearing Ratio (CBR), compression deformation, strength, etc.

3.1. Grain composition characteristics of weathered soft rock

The weathered soft rock filler usually has a wide range of particle size. The particle size of the gravel produced by blasting excavation ranges from the fine particle group to the giant particle group. Usually, the large particle size soft rock weathering material is required to crush before the filling of the subgrade. Due to the fact that large-size particles are difficult to crush during the compaction process and tend to centralize at the bottom, on the other hand, the composition of large particles cannot be completely matched with the existing subgrade and pavement testing methods.

For the evaluation of the grain composition of subgrade filler, the non-uniformity coefficient $C_u$ and the curvature coefficient $C_c$ are generally used. The former reflects the steepness of the particle size distribution curve. The larger the unevenness coefficient, the more uneven the filler, that is, the difference between coarse and fine particles is large. In the compaction process of uneven filler, fine particles can be filled in the framework of large particles, and the material is easy to compact. The curvature coefficient reflects the overall shape and fine particle content of the gradation curve. Fillers with $C_u >5$ and $C_c$ between 1.0 and 3.0 have a good grain composition.

For soft rock filler under natural conditions, its $C_u$ and $C_c$ may conform to a certain distribution law.
For example, Yang \cite{5} studied the particle size distribution of weathered metamorphic soft rock in the Qinling Mountains and showed that its $C_u$ and $C_c$ obey the normal distribution law. But there may also be the phenomenon of missing particle groups. For example, Liu \cite{6} found that coal gangue samples in five coal mines in northern Xuzhou and related literatures have the phenomenon of discontinuity to some extent. The discontinuity in the range of 0.5~2mm is more obvious.

In addition, due to the low strength of soft rock fillers, the filling and compaction process is often accompanied by a large amount of disintegration and fragmentation, that is, the particle gradation is not static, but is accompanied by dynamic changes in the compaction process. Li \cite{7} analyzed the particle size gradation of the weathered muddy slate after compaction and pointed out that the particles larger than 2mm in the weathered slate after compaction were significantly reduced.

In summary, the natural soft rock weathered material often has the phenomenon of lack of particle groups. At the same time, the proportion of large particle diameters can be reduced due to compaction.

3.2. Compaction characteristics of soft rock weathered material

Compaction characteristics are one of the key indexes of subgrade compaction control. The relationship between the maximum dry density and the moisture content of the filler must be obtained through indoor compaction tests before filling, so as to determine its optimal moisture content and maximum dry density.

The compaction process of the soft rock weathered material can be roughly divided into three stages, namely the initial compaction stage, the rapid compaction stage and the stable stage \cite{8}. In the initial compaction stage, the increase in the dry density of the filler is relatively small, but the rate of increase is greater. In the rapid compaction stage, the increase rate of the dry density increases significantly, and the growth rate will slow down. While in the stable stage, the dry density increases slowly until it stops increasing.

As for the main factors affecting the compaction characteristics of soft rock weathered material, scholars have also conducted extensive research \cite{9, 10}. In summary, the content of fine particles, coarse particle content, and water content in the soft rock weathered material all have an impact, specifically as follows:

(1) As the content of fine-grained soil increases, the maximum dry density decreases, while the optimal water content increases.

(2) The maximum dry density of coarse-grained soil is closely related to the content of coarse particle $P_5$. When $P_5$ is less than the optimal value, the maximum density gradually increases. That is, when the content of coarse particles is at its best, the maximum dry density has a maximum value.

(3) When the water content is zero, the dry density value is large. When the water content is slightly increased, the dry density decreases. When it decreases to a certain value, the dry density value increases with the increase of the water content.

3.3. CBR characteristics of soft rock weathered material

CBR refers to the penetration test of a standard specimen after immersion in water and when the penetration amount reaches 2.5mm, the ratio of the unit pressure to the standard load pressure. It is an important index basis for judging the applicability of filling engineering.

The material composition and structure of the filler are the main factors that affect CBR, including particle size, strength, roughness, density, shape, and water immersion test characteristics \cite{11}. For the soft rock filler, the main factors affecting its CBR reflected in the following aspects:

3.3.1. Influence of the composition

The CBR value is inversely proportional to the viscosity of the soil. The greater the viscosity, the smaller the CBR value \cite{12}.

3.3.2. Influence of water immersion

The increase of water content will lead to the decrease of CBR, and the increase of the proportion of the mudstone in the filler will also lead to the decrease of CBR \cite{13}.
3.3.3. Influence of compaction
The studies of Wang [14] show that with the increase of compaction, CBR increases significantly.

3.4. Compression deformation characteristics of soft rock weathered material
Compression deformation characteristics reflect the ability of subgrade filler to resist deformation under the action of gravity stress and vehicle load. Some experts and scholars have done detailed research.

The influence of water immersion on the compression characteristics of soft rock weathered materials is also significant. The compressive modulus of soft rock filler is significantly lower than that of hard rock materials, and with the influence of water immersion softening, the compressive modulus greatly decreases. Dry-wet cycle is one of the important factors affecting the compression characteristics of soft rock weathering material. The results of large-scale compression deformation tests on slate filler by Zhang [15] showed that the increase in the number of dry-wet cycles will reduce the peak compressive modulus of soft rock filler. On the other hand, the compressive modulus remained basically unchanged after 6-10 times of dry-wet cycles [16].

It can be seen that water is the main factor that affects the compression deformation characteristics of soft rock fillers. Both water immersion softening and dry-wet cycles will cause a substantial decrease in the compressive modulus of soft rock fillers.

3.5. Strength characteristics of weathered soft rock
Regarding the stress-strain characteristics of soft rock, the stress-strain of soft rock specimens can be divided into four stages: initial compaction, linear elastic deformation, plastic deformation and softening after failure. At the same time, the phenomenon of soft rock softening with water is very obvious.

The main factors affecting the strength characteristics of soft rock weathered materials can be divided into the following categories:

3.5.1. Composition of the filler
Yan [17] showed that the stress-strain curve of red-bed soft rock is strain-hardened, and the greater the compressive strength of the coarse-grained material, the greater the friction angle of the filler.

3.5.2. Impact of water immersion
The results of Xiao [18] on the strength characteristics of carbonaceous soft rock showed that the strength of the carbonaceous soft rock decreased in the early stage of saturation, while the strength decreased in the later stage.

3.5.3. The influence of confining pressure
The large-scale triaxial test results of Cao [19] on metamorphic soft rock fillers show that the particle breakage rate will gradually increase and the internal friction angle will show a decreasing trend with the increase of confining pressure.

Existing research results show that particle size gradation, confining pressure, and water content are important factors affecting the strength characteristics of soft rock weathered materials. Similarly, the influence of water cannot be ignored. Water immersion will lead to a substantial decrease in the strength index of soft rock weathered materials.

4. Construction technology of soft rock filled subgrade
In expressway construction, the compaction effect of soft rock-filled embankment is an important factor affecting the quality of the project, and to a large extent determines the service life of the expressway and the maintenance cost after the construction is completed. Many roads that have been built have suffered from various diseases such as embankment instability, embankment cracks, and embankment settlement in a short period of time because the compaction effect of the embankment cannot meet the requirements. In order to obtain a good compaction effect, it is necessary to determine a reasonable slackly lay thickness, tonnage of the roller, times of rolling and other parameters.
Wang [20] determined the paving thickness to be 50cm through physical test and research on site, using a 12t vibratory roller, layered rolling 8-10 times to achieve the required degree of compaction construction technology.

Scholars and engineers at home and abroad have done a lot of work on the quality monitoring and guarantee of soft rock embankment construction. The current main methods include compaction method, test section method, elastic modulus method, settlement method, etc. [21]. In addition, since the soft rock tends to disintegrate after being immersed in water and its strength is greatly reduced, special attention should be paid to the waterproof and drainage control of the subgrade during the construction process.

5. Improvement of soft rock subgrade filler

As mentioned in section 3.1, the weathered soft rock material in the natural state often has the phenomenon of lack of particles, or the particles are broken during the filling and compaction process, resulting in poor gradation. In addition, the soft rock has low strength and softens when exposed to water. As a result, it is difficult to guarantee the quality of the filler when it is directly applied to the filling of the subgrade, and it is easy to meet quality problems such as uneven settlement and cracking of the pavement in the later operation process. Therefore, the improvement of soft rock filler has become one of the commonly used quality assurance measures in expressway engineering at home and abroad. The improvement methods of soft rock fillers are roughly divided into physical improvement and chemical improvement.

5.1. Physical improvement

The physical improvement is mainly to improve the particle size gradation of the filler and improve the compaction quality by adding missing particles to the original filler or pre-rolling and crushing.

5.2. Chemical improvement

Chemical improvement is to form a layer of gel structure network inside the filler by adding cement, quicklime and other additives to improve the strength and water stability of the filler.

The above-mentioned soft rock filler improvement methods have certain limitations. For example, the effect of physical improvement on the water stability of the filler is not obvious, the early strength of quicklime improvement is low, which affects the construction period, and the shrinkage of the soil after the cement improvement. In summary, the improvement of soft rock road performance requires specific analysis in combination with specific conditions, and further research on new improvement technologies is carried out.

6. Conclusion

Soft rock weathered materials are widely distributed in our country. The reasonable use of soft rock weathered materials as subgrade filler helps to balance the filling and excavation, reduce waste slag, and reduce costs and influence to the environment. Much research on the soft rock weathered materials as subgrade fillers focus on the following aspects:

1) The engineering characteristics of soft weathering material are closely related to the physical and chemical composition of its parent rock. The soft rock has low strength and is easy to disintegrate when exposed to water. Under different conditions, the characteristics of soft rock will undergo non-negligible changes.

2) Soft rock as subgrade filler is different from soil filler and hard rock filler. Its particle gradation will vary with the rolling process, the length of exposure time, and the degree of water immersion, so it cannot be controlled like hard rock fillers to achieve the optimal density.

3) The improvement of soft rock filler is mainly to add materials which are commonly used in engineering such as sand, cement or quicklime to make up for the deficiencies of particle gradation, strength, water stability, compactness, etc. of the soft rock filler. But both the project quality and the economic benefits should be taken into considering. If the cost of the improved measures is greater than the external transportation of filling material, it will lose its practical significance.
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