

# Preliminary analysis of engineering properties and engineering utilization of moraine deposits

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**Abstract.** In this paper, the morphology and distribution characteristics of moraine deposits, material composition and structure characteristics are analyzed, and the engineering properties of moraine are summarized. On the basis of studying the engineering properties of moraine deposits, the feasibility of utilization of moraine is preliminarily analyzed, and the feasibility of engineering construction on moraine deposits is discussed and analyzed. According to the material composition and distribution characteristics of the moraine, the moraine deposits can be considered as the building materials, which can be used as subgrade filling materials and filter materials of embankment dam.

## 1. Introduction

Generally, moraine deposits consist of materials carried by the glacier in the glacial process, which is directly deposited by the glacier, without other external forces, especially without melting ice water transformation, also known as glacial sediments. And the glacier melt water is also a major force. The formation of outwash deposition usually due to collective effect of ice and water. The moraine deposits referred to herein are not only purely moraine deposits, but also glacial sediments that are reshaped by water melting from glacier, which means, outwash deposits.

As a material formed under special conditions, moraines are mainly distributed in polar, mid-low latitude mountains and plateau areas, such as the Qinghai-Tibet Plateau, the Tianshan Mountains and the surrounding high-altitude areas. In the Karakoram Mountains, 37 percent of area is covered by glaciers <sup>[1]</sup>.

Because mountain glaciers are usually distributed in high-altitude mountain areas where human activities and constructions are relatively rare, the research on the engineering properties of glacial deposits has been relatively low in the domestic and international engineering community. So the construction of a variety of infrastructure projects and other buildings on moraine is very careful, and most of the projects under construction and proposed still take measures of avoidance. Based on the actual needs of engineering construction, scholars at home and abroad carried out a small amount of research on the moraine deposits. Compared with the domestic, western scholars started earlier, and their research results are more comprehensive, which mainly concentrated in the 1950s to the 1980s. Two of the international academic conferences have pushed the study of engineering properties of moraines to a climax. One time, the symposium on monographs engineering characteristics was held in Birmingham, UK in April 1975, and the other, the conference on the construction on the moraine foundation was held in March 1985 in Edinburgh, England.

In recent years, during the planning and construction of large-scale projects on the southeast edge of the Qinghai-Tibet Plateau, a large number of engineering geological problems related to glacial deposits have been encountered, such as the Yunnan-Tibet Railway Project, the Sichuan-Tibet Highway



Reconstruction Project, hydropower development in the Jinsha River, the Dadu River, and the Yalong River, and so on. Some foreign projects inevitably encountered in the moraine deposits, such as the China-Pakistan Karakorum Highway Reconstruction and Extension project in northern Pakistan, the hydropower development of upper reaches of the Indus<sup>[2-3]</sup>. And geological hazards and engineering geological problems caused by this special soil are also increasing.

With the successive commencement of infrastructure projects in these areas, the large scale of moraine, as a geological background of engineering construction, become an important condition for human's engineering construction. Therefore, it is rather necessary to make an intensive study of the engineering properties of the moraine and the prospective problems which might be encountered in the engineering practice.

Based on the study of hydropower development and planning in Tibet of China and the Indus River and its mainstreams of Pakistan, the engineering properties and the feasibility of effective utilization of moraine deposits is preliminarily analyzed in this paper according to the research results of predecessors.

## 2. The basic characteristics of moraine deposits

### 2.1. Morphology and distribution

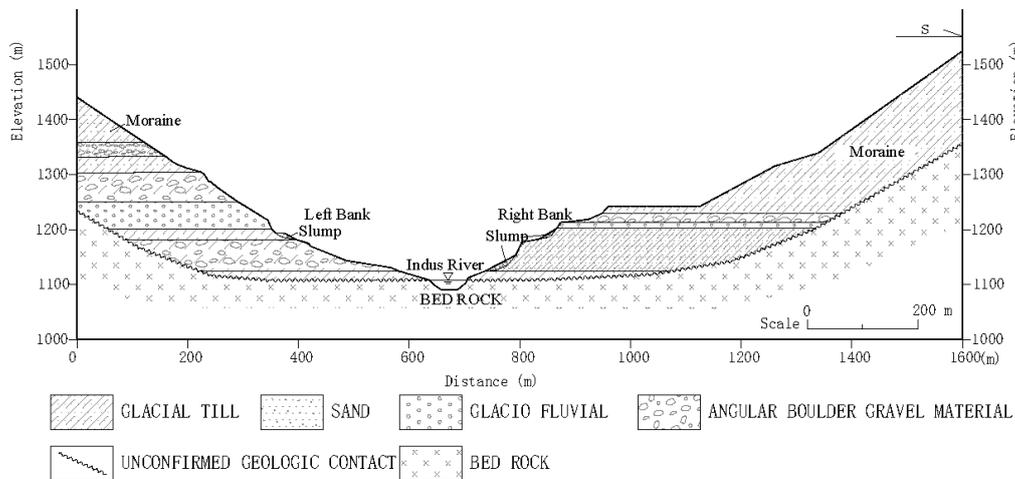
As a product of glacier transport and accumulation, the formation of moraines must have the following two conditions: First, to have certain altitude conditions; Second, the development of a higher mountain. So the moraines are generally present in the range of the lower glacier end of the higher mountains. The distribution height of the moraines is not defined by an accurate elevation. It is influenced by many factors, and the distribution height may differ greatly even in two places adjacent to each other. For the east-west mountain range, the moraine distribution on the north slope is lower than that on the south slope; for the north-south mountain range, the moraine distribution on the east slope is lower than that on the west slope.

The moraine in Figure 1 is located in middle Indus River in Pakistan, and its distribution has reached the lowest base level of erosion (Indus River) in the area. The altitude is about 1100m, far below the distribution altitude of local glacier. It shows the typical geological section of the moraine deposits in Figure 2.



**Figure 1.** Typical moraine deposits image in Middle Indus River

In Figure 2, the distribution elevation of the moraine deposits on both sides of the Indus river are not completely consistent, the distribution elevation on northern bank is lower than elevation on southern bank.



**Figure 2.** Typical Geological section of Moraine Deposits in Middle Indus River

The thickness of the moraine deposits is generally larger than that of other types of accumulations. The moraine deposits are mainly distributed in the amphitheater, glacial valley and ice storage tank, with the thickness of 50 - 150 m. The outwash deposits which are partially reshaped by water melting from glacier distributed at a lower areas than moraine deposits. The outwash deposits are mainly distributed on I~III terraces of the both banks of the valley. The thickness of outwash deposit is generally 30 -100 m.

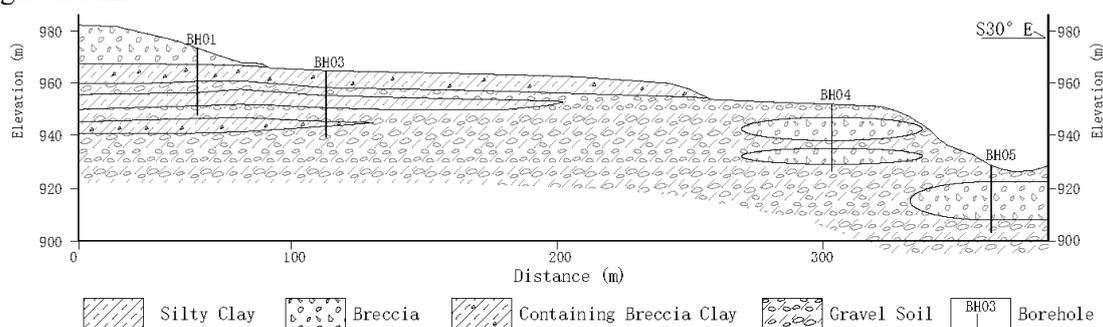
### 2.2. Material composition

Due to the difference of depositional environment and geographical location, the moraine has different material composition.

- In the area of hard and difficult to weather the rock, it is mainly the sand and gravel.
- In coarse-grained granites, gneisses and similar rock areas, it is mainly the sub-sand soil.
- In mudstone, shale, and similar, or slightly hard rock areas, the loam moraine and clay moraine is formed;
- Metamorphic rocks, particularly quartz and mica schist zones that are prone to fragmentation, form the coarse sand and clay moraine layers.

Figure 1 and Figure 2 show the moraine in the middle reaches of the Indus River, and the underlying bedrock is gabbro, gneiss, etc. The moraine composition is complex, mainly loam, mixed with gravel, sand, etc.

The moraine (shown in Figure 3) is located on the left bank of a river in the southwest of China. The underlying bedrock is metamorphic rock, and the main components of the moraine are silty clay, gravel and gravel soil.



**Figure 3.** Geological section for Moraine Deposits of a river in the Southwest of China

On the whole, the moraine deposits are mostly composed of giant particles and coarse grains. The total amount of the two particles accounted for more than 85% of the total weight of moraine deposits. The content of fine particles in the moraine deposits is quite limited, generally not more than 15%. The particle size distribution of the moraine deposits is quite wide. From the giant stone of the more than 2000mm to the clay particles, all of them could be found in the moraine deposits. Therefore, most of the moraine has a large inhomogeneity coefficient.

### *2.3. Structural features*

The study on the typical moraine deposits finds that one of the major distinctions between the moraine deposits and the general loose deposits is that the moraine deposits are featured with complicated sedimentary features and structural features. The materials forming moraine deposits are not only gravelly soils with high strength, but also kinds of weak zones with low strength. In most time, the stability of the deposits are good if the weak zones and the free faces of deposits are not combined favorably, but if the free face is changed by someway and combined favorably with weak zones, the moraine deposits will slide along the weak zones possibly. The sedimentary features and structural features should be accurately grasped in the engineering when being confronted with this kind of deposits, which could not be incautiously regarded as the isotropic medium.

The typical geological section of Figure 2 and Figure 3 show that the material composition of the moraine deposits is very uneven. The upper part of the moraine deposits is mainly composed of block and detritus which is transported rapidly by glacier and water melting from glacier, it belongs to mega granular soil. The bottom of the moraine deposits is mainly breccia soil formed by slow transportation and deposition. Most of them are coarse grained soil.

## **3. Engineering mechanical properties of moraine**

The moraine deposits have special formation and evolution process, which is quite different from other deposits in material composition and structural characteristics, making their mechanical strength characteristics different from other deposits.

A large amount of physical and mechanical tests reveal that the moraine is characterized with a dense structure, high-density, and small pore volume, which belongs to typical soil with high bearing capacity and low compressive.

Because of its high degree of compactness and the composition of giant particles and coarse particles, the moraine soil generally has a large natural density. According to the statistics, the density of the moderate dense debris is usually  $2.0 \times 10^3 - 2.3 \times 10^3 \text{ kg/m}^3$ . The density of the dense gravelly soil is usually  $2.3 \times 10^3 - 2.6 \times 10^3 \text{ kg/m}^3$ . The density of moraine soil with more fine particles is generally  $1.9 \times 10^3 - 2.1 \times 10^3 \text{ kg/m}^3$ .

Moraine congeries are often with preferable shearing strength. Naturally, the cohesion can up to more than 150 kPa, and friction angle can be about  $35^\circ - 40^\circ$ ; when under the saturated condition, the cohesion can keep at 60 - 100kPa, and internal friction angle can be about  $30^\circ - 37^\circ$ . Moreover, the value of  $C$  is much more sensitive to water than that of  $\varphi$ . Generally, under the saturated condition, the cohesion may be reduced by half or so, but the change of the value of  $\varphi$  is almost within  $1^\circ - 3^\circ$ .

## **4. Discussion of Utilization**

### *4.1. Feasibility of the construction on the moraine*

The technical feasibility of carrying out construction activities on moraine deposits requires attention to two aspects: the stability and suitability of the site.

According to the investigation, the natural slope of the moraine deposits is generally above  $35^\circ$ , and it can even keep a vertical slope of up to 10m without instability. Most of the moraine is stable in natural condition, and the site is suitable for engineering construction after some necessary engineering treatment.

The moraine deposits distributed in the valley zone are mostly in the reservoir area where there are hydraulic engineering which are already constructed, under-construction or in planning, and the moraine deposits will be flooded after the reservoir is impounded. Therefore, the seepage characteristics of the moraine deposits will be an important factor affecting the stability of the moraine deposits. The study shows that under the influence of sedimentary characteristics and strength characteristics, moraine deposits tend to form deep erosion notches under the reservoir flow and wave erosion. Then, the collapsed-type reservoir bank reformation of moraine slope will occur under the action of self gravity. During the change of the reservoir water level, relative to the reservoir water level, the change of the seepage field inside the deposits will show obvious lag effect. It will cause obvious reverse osmosis and reverse pore water pressure in the deposits during the rise of the reservoir water level. During the decline of the reservoir water level, the groundwater discharge is lagging behind, and the hydraulic gradient of the accumulation is increased. The change of groundwater seepage field during the above water level change will have a significant effect on the stability of the deposits, and do not exclude the possibility of local instability of the deposits after impounding.

For the engineering that use moraine as natural foundation or subgrade, its deformation characteristics are an important problem to be answered and solved.

#### *4.2. Utilization of moraine materials*

Moraine has the characteristics of large thickness and complex material composition. In general, the distribution of particles in the moraine deposits is wide, showing obvious inhomogeneity. The moraine deposits are mostly composed of giant and coarse particles, the total contents of the two sizes of particles are more than 85%. According to these properties, the moraine can be considered as building materials, such as subgrade filling materials and filter materials of embankment dam.

The requirement for roadbed stuffing is generally not strict. According to the engineering experience, from fine particle clay to coarse grained gravel and block stone, they can all be used as subgrade filling material. Many scholars and engineers have simulated the moraine soil layering method to study the road properties of moraine material. It is considered that moraine material is a kind of material suitable for highway subgrade filling<sup>[4]</sup>.

The construction material of embankment dam mainly includes core material, filling material and so on. The materials with different particle sizes in the moraine deposits can meet the filling requirements of different parts of embankment dam. On the core area of embankment dam, the main requirement of filling material is low permeability after compaction. The higher strength of the filling material for the shoulder of upstream and downstream is required to maintain the stability of the dam body and the core wall. Through appropriate engineering improvement measures, the moraine material can meet the requirements of embankment dam for seepage prevention and stability of dam body.

There are many successful cases with using moraines as materials for damming in China and abroad. Mud Mountain Dam in Washington of USA is an embankment dam of 130m high. It was the world's highest embankment dam with the core of moraine material at that time. The core wall of Mud Mountain Dam was filled with moraine and gravel mixture on the surface of the river valley<sup>[5-6]</sup>. The Portage Mountain Dam of British Columbia in Canada and the dam of the Pubugou Hydropower Station in China all used moraine materials as the core material<sup>[7-8]</sup>.

Usually, the impervious performance of moraine can be improved by adding clay or removing some coarse particles. If no clay is added, the composite geomembrane can be laid on the upstream surface of core wall to prevent seepage, and the geotextile can be laid on the downstream surface of the core wall to filter, the ability of anti-seepage failure of these continuous filter is better than the filter of particles. The natural moraine soil can be used as filling material of dam shoulder. The coarse particles screened from moraine material can meet the requirements of drainage and filtration in the downstream of embankment dam.

## **5. Conclusions**

Moraine deposits have the properties of large thickness, complex material composition and wide distribution of particles size, showing obvious inhomogeneity. The moraine deposits are mostly composed of giant particles and coarse particles. A lot of physical and mechanical tests reveal that the moraine deposits is characterized with a dense structure, high-density, and small pore volume, which belongs to typical soil with high bearing capacity and low compressive.

Most of the moraine deposits is stable in natural condition, and the site of moraine is suitable for engineering construction after some necessary engineering treatment. The change of water level in the reservoir area will obviously affect the stability of the moraine deposits at reservoir area, and do not exclude the possibility of local instability of the moraine deposits after impoundment.

The moraine deposits can be used as building materials, such as subgrade filling materials and filter materials of embankment dam. The impervious performance of moraine can be improved by adding clay or removing some coarse particles. The coarse particles screened from moraine material can meet the requirements of drainage and filtration in the downstream of embankment dam.

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