Investigating of Geotechnical Parameters of Alluvial Foundation in Zaram-Rud Dam Site, North Iran

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Abstract

Geological parameters and engineering geology play a key role in the design and construction of dams. In this regard, the role of natural factors is never more important than the geological factors and engineering geology. However, this does not mean that only the characteristics of the formation should be obtained. Rather, the available materials and elements are more important than other materials. There are numerous examples of neglecting the geology of the site and the conditions to build the dam that have led to serious problems and financial losses during the construction. The Zaram-Rud Dam is located in Northern Iran in Mazandaran Province, about 20 km east of Sari over the Zaram-Rud River. In this site, based on the excavated boreholes, the geomechanical and geotechnical properties of the site are extracted, using the engineering geology and geotechnical conditions of the dam site, the depth texture, compaction texture, and permeability texture are investigated. The results indicated that the highest depth texture was of clay with low plasticity type in the site. Moreover, based on the compaction texture, it is in the “Hard” to “Very Dense” classes. Finally, based on the permeability texture of the alluvial foundation site in the riverside, the study area is in the “permeable” to the “semipermeable” classes.

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1. Introduction

Nowadays, considering the rapid growth of the population and the remarkable progress of the industries, the need for water resources is of great importance. Considering the hot and semi-arid climate of Iran, where rainfall is lower than the world average level and it is seasonal in most parts of the country, if the rainfall is not managed, it will be wasted in the form of flowing water and floods. Groundwater resources are also limited and will be destroyed in case of excessive use, therefore, there is an urgent need to control and manage the precipitation.

Dams are structures constructed to trap and enclose the water to be used for various purposes such as water storage for urban use, agriculture, electricity generation and flood control [1]. One of the important issues with regard to dams is the selection of the site since the appropriate and optimal conditions of the foundation are the basic requirements for dam construction. The dam sites should be considered in terms of stability against slipping, settlement, deformation, penetration, leakage, and uplift pressure (bottom pressure). Among these parameters, groundwater and leakage rate are the most important issues in the sustainability of dams. Excessive water escapes through the gaps and cavities in the rocks or in the embankment of the body of the dams or the bottom rocks and deposits reduce the capacity of the reservoir. The statistics show that the leakage flow under the dams has caused 25% of failures in all types of dams and 30% of failures in the earth-filled dam [2].

To better understand the geological conditions and the engineering geology and to determine the rate and type of water leakage from the dam site and the related solutions, water pressure tests, and experimental injection of grout into the primary drilled boreholes are carried out. For this purpose, determining the geometry of joints and discontinuities, the direction and opening position of the joints are of particular importance. Based on the data obtained from these experiments and considering the characteristics of the drilling core, it is possible to interpret the hydraulic behavior of the rocks and provide the details of the slurry injection operations to create a sheet pile [2].

Many studies have been conducted on various dam sites. For example, Kutzner [3], and Priest [4], studied the conditions of the ground for the formation of the dam in terms of the condition and sheet pile configuration based on the geology of the site. Lee et al. [5] investigated the concept of the hydraulic opening of joints, which was followed by Lee et al. [6], Priest [4] and Park et al. [7]. Moreover, numerous researchers assessed the geological properties of the engineering of the dams sites and the effect on the transmissivity; e.g., Turkmen [8], Ghobadi et al. [9], Kocbay et al. [10], Uromeihy et al. [11], Gurocak et al. [12], Nezhad et al. [13], Sadeghiyeh et al. [14], Rastegarnia et al. [15], and Rahimi et al. [16].

Considering the fact that each site has different engineering geological and joint features, evaluating geological engineering properties of each site will be of great importance for investigating the geological engineering characteristics and the permeability of the site. Therefore, in the present work, considering the geological
characteristics, engineering geology, geotechnical features, and alluvial foundation of the dam site, the conditions of the geotechnical parameters of the alluvial foundation in the site were investigated.

2. Experimental

The fieldwork included engineering geological mapping, discontinuity surveying, core drilling, Lufrance and Lugeon tests and the acquisition of 200 soil and 150 rock samples from the site of the proposed dam. The mapping was undertaken along north–south lines at different intervals in order to intersect the different geological units and was complemented by air photograph interpretation. The discontinuity survey included not only slope face and scanline mapping but also information from the rock cores. The orientation data were analyzed using a computer program based on equal area stereographic projection (Rockworks15, Rockware 2010) [17], in the form of contoured pole and rose diagrams. Quantitative description of discontinuities including orientation, spacing, persistence, roughness, aperture and filling were determined in accordance with ISRM [18].

After detailed geological and geomorphological fieldwork, a systematic geotechnical drilling campaign was planned and implemented with a wireline NQ type (75.7 mm diameter) diamond bit, along the dam axis and reservoir site. Twenty four boreholes were drilled to depths of between 30 and 120 m, also Logging and rock quality designation (RQD) measured at total core length of 619 m.

3. Results and Discussion

At the initial stage of the investigation the geology of the site was described in the field by conventional field techniques.

3.1. The Studied Area

The study region with the area of 894 km$^2$ is located in the Tajan basin within 53° 5' to 54° 15' E and 36° 20' to 36° 35' N. Based on Iran’s divisions, the Zaram-Rud basin is located in the central and middle parts of Sari (Figure 1). According to the meteorological data of the study area, the highest rainfall level is in the fall and the lowest rainfall level is in summer, and the maximum freezing days are in January for 9 days. Based on the De Martonne classification, the study area is located in semi-humid climates.

![Figure 1. The geographical location of the study area along with the catchment area.](image)
3.2. Geomorphology and Geology of the Study Area

The catchment area of the Zaram-Rud River with an area of about 886 km² is a part of the catchment of the Tajan River, which is limited to the catchment area of Chahardandgeh from the south and to the catchment area of Neka River and Tajan plain from north and east. The physical characteristics of the catchment area directly affect the hydrological regime of the area and affect the climatic and ecological conditions indirectly (Figure 2 & 3). Based on these Figures, the highest altitude level is related to the eastern region at a height of 2800 m.a.s.l and the lowest elevation level is at the downstream of the dam in the west region in the level of about 300 m.a.s.l. In the eastern part of the region, the highest slope is on the river route, with the decreasing slope in the western parts.

Figure 2. The position of the dam in the calculation map of the studied area.

The axis of the dam is located in the Ahmadabad village, with a relatively perpendicular direction on the Varemi anticline. The river in this area has a relatively eastern-western orientation. The slope of the river at this site is about 1.3% and the current bed width is about 25 m with the flood bed width of about 150 m. The slope of the left hill side to the level is approximately 340 m near to 35° and it is approximately 30° from this level to the normal level, which is 385 m.a.s.l. The slope of the right hillside is relatively milder than the left side. This slope is up to 20° to the level of 340 m, and about 15° from this level to the normal level.

Based on the regional divisions, the project area is located in the Gorgan-Rasht Zone. From the perspective of lithostratigraphy, the study area is composed of the Mesozoic, Cenozoic, and Quaternary deposits. The deposits of the second and third period are mostly covered by quaternary deposits, however, their outcrops can be observed in some places. A large part of the area is located in these deposits. The deposits are mostly marl, limestone sand, lime, and sometimes conglomerate. According to the collected data, there are conglomerate and
sandstone deposits in some downstream parts and the gypsum deposits in the upper parts upstream parts (Figure 3-4).

The main faults include Khazar and North Alborz faults, within the distance of more than 20 km from the study area. In addition to the two mentioned main faults and other nearby faults along the east-northeast and west-northwest directions, there are some minor faults along the northern east-southern west direction crossing the pre-mentioned faults and creating a fault network almost in mosaics shape in this area.

![Figure 3. The general condition of the dam site.](image)

![Figure 4. The alluvial terraces in the dam site.](image)

### 3.3. Exploratory Boreholes

To achieve subsurface conditions and to compare them with the surface geological findings, drilling the borehole was required in the dam site. Thus, 24 exploratory boreholes were drilled in the site with the total length of about 1197 m. Of these, 8 boreholes in the right bank, 9 boreholes in the left support and 7 boreholes in the bed were drilled, where in addition to sampling, the field experiments such as Lefranc, Lugeon, and SPT were carried out, for which the location in the site are represented in Figure 5.
3.4. The Depth Texture of the Alluvial

On all disturbed and undisturbed samples taken from boreholes and exploratory wells, the classification tests were conducted including grading, hydrometry, and determining the Atterberg Limits. Based on grading the materials in the unified classification system, the dominant soil class in the foundation site was in the clay with low plasticity type (Figure 6).

Furthermore, the percentage of particles passing through the sieve #4 is between 21% and 100%, the percentage of particles passing through the sieve N.200 is between 7% and 99%, and ultimately the percentage
of particles smaller than 2 µm is between 0 and 55%. In addition, the liquid limit (LL) of the materials was from 17 to 58 with a mean of 39.63 and the standard deviation of 9.49 while the plasticity index was between 3 and 33 with a mean of 19.01 and a standard deviation of 6.41. Figure 7 depicts the drilling curves of the alluvial section of the borehole in the dam site.

![Drilling curves of the alluvial section of the borehole in the dam site.](image1)

**Figure 7.** The grading curve of various materials in the dam site.

Considering the above figures and the following tables, the thickness of alluvium varies from 5 m downstream of the dam and the AH-23 borehole on the left side up to 25.7 m on the right (BH-11 borehole). Moreover, according to the obtained results, the dominant depth texture in the overburden material is clay with low plasticity soil, which is the highest percentage of the texture in the dam site. The dominant texture is the sandy soil with a significant percentage of fine-grained clayey silty gravel and in some horizons; it is sandy soil with a clayey silty sand fine-grained percentage in the site, especially along the river, perpendicular to the dam axis (Figure 8).

![Depth texture in the dam axis.](image2)

**Figure 8.** The depth texture in the dam axis.
3.5. Compaction Texture
The standard penetration test was carried out at different depths to determine the compaction texture in different depths of the boreholes. The highest percentage of NSPT is higher than 50 impacts; thus, the dominant compaction texture of the soil falls in "hard" to "very dense" classes (Figure 9).

![Figure 9](image)

**Figure 9.** The level of NSPT changes in the dam site.

The compaction texture of the soil in fine-grained material is predominantly hard in about 90% of the cases. In 9% of the cases, the soil compaction texture is very dense and is dense only in about 1%. Moreover, the compaction texture of the soil in coarse-grain material is always very dense (Figure 10).

![Figure 10](image)

**Figure 10.** The compaction texture in the dam axis.

3.6. Permeability Texture
To determine the permeability coefficient of the alluvial foundation and considering the importance of this issue in designing sheet pile element of the dam, the Lefranc Permeability Test was carried out with constant head
and falling head methods in parts with an approximate length of 1 m and at the distances of about 3 m along the boreholes. For each tested piece, a value was proposed as the permeability coefficient based on the permeability coefficients obtained from two constant head and falling head methods, as well as the process of evaluating the values obtained during the test in both methods and considering the soil rank in the depths of the experimental part or near it, the amount of S.P.T and the compaction texture of the soil. Furthermore, using the proposed permeability coefficients, the permeability texture zoning in the drawn sections are provided in Figure 11 & 12.

- $K(\text{cms})<10^{-5}$ Impervious
- $10^{-5}<K(\text{cms})<10^{-3}$ Semi-Pervious
- $K(\text{cms})>10^{-3}$ Pervious

**Figure 11.** The permeability texture perpendicular to the barrier axis.

**Figure 12.** The permeability texture in the dam axis.
As shown in the figures, in some areas, especially around the river, there are pervious or semi-pervious materials. So, the alluvial foundation should be modified through a method in terms of water tightness and the permeability control. In the dam site, since the thickness of the alluvial foundation is not noticeable, the water sheet pile element of the dam extends to rock surface and, hence, the watertight facing of the dam is not problematic. However, in the bulkhead of the dam, a watertight facing should be constructed by installing a suitable sheet pile so that to prevent any problem in dam construction.

4. Conclusion

Based on exploratory excavations, the rock bed of the dam site is composed of marl, sandstone, limestone silt, silty marl, sandy lime, mudstone, and sometimes micro-conglomerate and conglomerate, belonging to the Miocene epoch.

The deposits in the dam are often covered with overburden deposits and only have outcrops in some parts of the dam, including the left bank of the river and in the upstream of the dam on the right bank of the river. According to local investigations about these sedimentary deposits, some of the sandstone layers of the considered rock unit have a loose and weak cement such that some of these layers were washed during the drilling process and cannot be recovered. However, the effects of these layers were retrieved in the form of sand with recirculated water of the drilling at the opening of some boreholes. Some of these layers have outcrop at the surface and easily collapse in the form of sugar grains against hammer blows.

Within the deposits belonging to the Miocene (Mm.s.l) in the region, sometimes the gypsum interlayers are also observed; however, in the boreholes drilled in the Ahmadabad dam no considerable thick layer of these gypsum deposits were found. Nevertheless, existing the lenticular and gypsum interlayers in some parts of the dam is not impossible. Nevertheless, this is possible not only at the site of the Ahmadabad dam but also throughout the Zaram-Rud valley, which often composed of Miocene deposits (Mm.s.l). What is important is that most of these lenticular and gypsum interlayers are enclosed within impermeable marl layers.

The outcrops of the dam site are composed of residual soils, slope scours, alluvial terraces, riverbed alluvium, and materials left by landslides. Meanwhile, the deposits left by the landsides have considerable expansion and thickness. These deposits consist mainly of silty clay with sand and gravel, among which there are also sharp corner boulders. The maximum thickness of these deposits was observed in the AH-11 borehole at 25.7 m in the right side of the landslide.

The geotechnical characteristics and engineering properties of alluvial foundation materials show that the dominant depth texture in the outcrop is clay with low plasticity, however, in area where the height of the dam is maximum, the dominant texture is sandy soil with a significant percentage of fine-grained soil i.e. the clayey silty gravel, although in some horizons sandy soil with a significant percentage of fine-grained soil, i.e., clayey silty sand, is also found. Within the riverbed, there are pervious or semi-pervious materials that are completely taken from the bottom of the dam and will be watertight forehead under the bulkhead.

Most of the soil texture in cohesive clay materials is hard while in coarse-grained soils, it is very dense.

The rocks surrounding the reservoir are marl, sandstone, lime siltstone, silty marl, sandy lime, mudstone, microconglomerate, and conglomerate belonging to the Miocene period. The permeability of these rocks is very
low and they only penetrate some of the precipitations and enter the coarse-grained alluvial deposits of the riverbank due to the presence of large local fractures and the weakness of the texture of the rocks. The present deposits were caused by the erosion of the highlands and remained in the valleys and riverbed in the mountainous regions. These sediments have good permeability in coarse-grained areas, and in fact, they form aquifers with high porosity and a low expansion.

5. References

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