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# Engineering Geological Assessment of the Proposed Kakasharaf Dam, Lorestan, Iran

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ABSTRACT

This paper describes the results of the engineering geological investigations and rock mechanics studies carried out at the proposed Kakasharaf Dam site. Analyses were carried out in terms of rock mass classifications for diversion tunnel, permeability of the dam foundation and determination of rock mass strength parameters. In this study, the Kakasharaf dam site, constructed on the Kakasharaf River to the south east of Khorramabad in Lorestan province, south western Iran, was investigated from the stand point of the aforementioned engineering geological aspects. The proposed Kakasharaf Dam site is located on sedimentary rock of the upper Cretaceous age and on Quaternary deposits. Sedimentary rocks consist of Buff-grey limestone, marl limestone and shale limestone. Studies were carried out both at the field and the laboratory. Field studies include engineering geological mapping, intensive discontinuity surveying, core drilling, pressurized water tests and sampling for laboratory testing. Uniaxial and tensile strength tests were performed and deformation parameters, unit weight and porosity were determined on the intact rock specimens in the laboratory. Rock mass strength and modulus of elasticity of rock mass are determined using Hoek-Brown empirical strength criterion. Engineering geological investigations, test result and computations indicated that there will be no foundation stability problems. Detailed geotechnical investigations are required for the final design of the dam.

## 1. Introduction

The proposed Kakasharaf Dam will be built on the Kakasharaf River, 20 km south east of Khorramabad in Lorestan province, south western Iran (Figure 1). It will be used for flow control and water storage for irrigation projects. The Kakasharaf Dam has a crest length of 340m, a maximum high above river bed level of 70 m, and a total storage capacity of 26 million $m^3$.

Geotechnical investigations have been carried out at the project site and in the laboratory. Various laboratory and in-situ tests were performed to assess the characteristics of rock masses. Detailed discontinuity surveying was also carried out.

## 2. The Geology of the Studied Area

Geological factors play a major role in designing and constructing a dam. Of the various natural factors that influence the design of dams, none are more important than the geological ones. There exist numerous examples of projects where the conditions of the foundation were not sufficiently known and the cost of construction and treatment greatly exceeded the original budget. Information on the regional geology of the area has given by Tamavan Consulting Engineers Company. The proposed Kakasharaf Dam site is located on sedimentary rock of the upper Cretaceous age and on Quaternary deposits. Sedimentary rocks consist of Buff-grey limestone, marl limestone and shale limestone.

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A generalized topographic map of dam site with location of boreholes and dam axis is shown in Figure 2. Conglomerates are heterogeneous, massive, grey-red, semi-consolidated, consist of boulder and pebbles within sandy-silty-clay matrix, and are slightly to highly weathered. Buff-grey limestones are well bedded, strong, and micritic with 5 cm of slip cleavage marl. Marl and shale limestone are Dark-grey with intercalation of black shale and sandy green shale contain fracture and slips cleavage and eroded. Quaternary deposits are composed of recent alluvial deposit, scree (soft deposits on slopes), and cone of deposition, young terraces, slope washed and debris cobbles gravel.

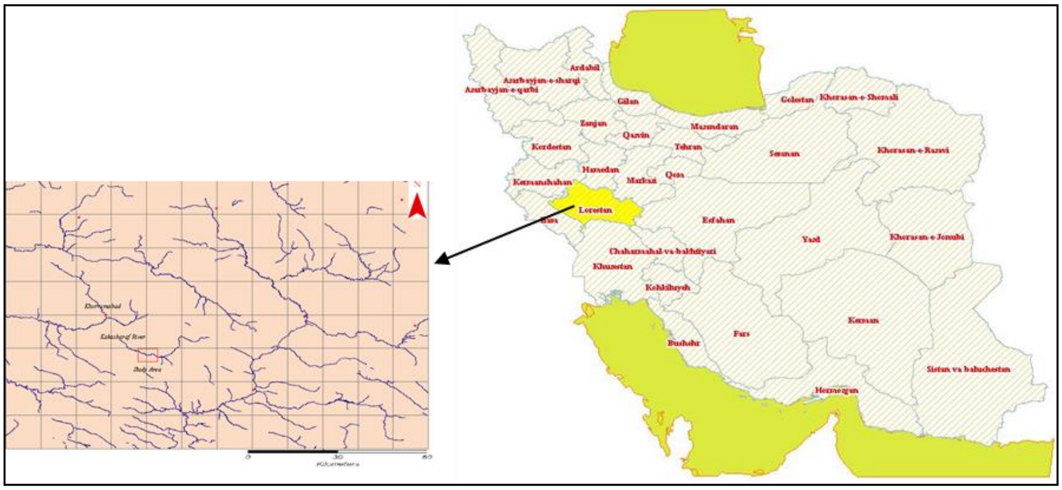


**Figure 1:** Location map of the study area

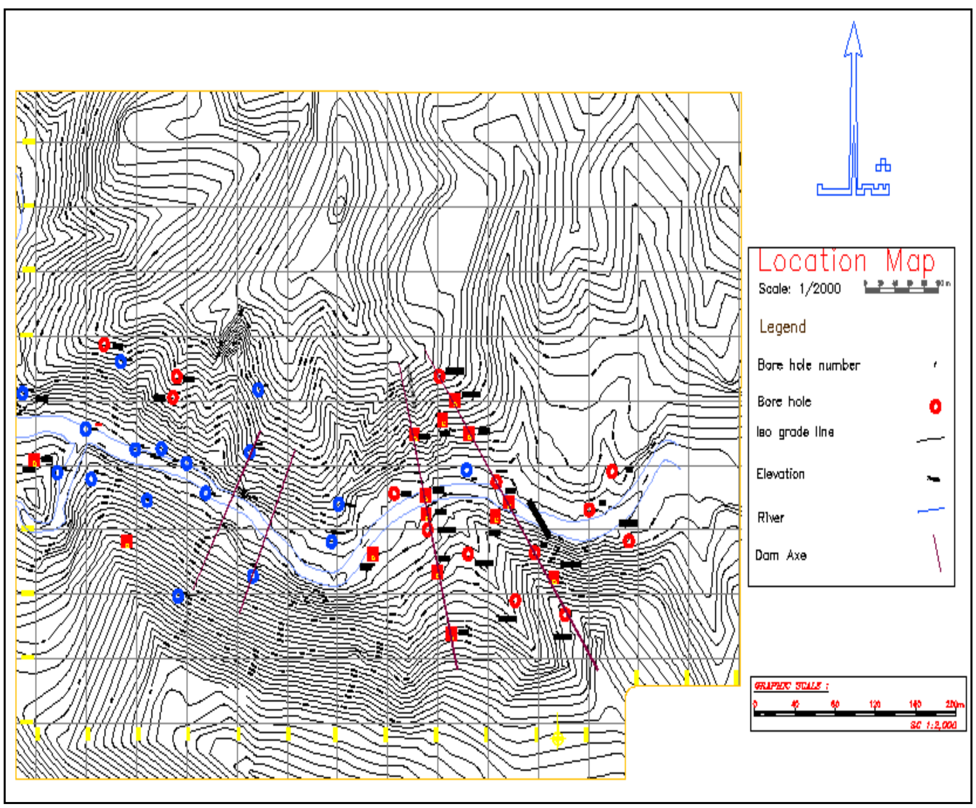



**Figure 2:** Locations of the boreholes and dam axis of the Kakasharaf Dam site

## 3. Characteristics of Discontinuities

In the study area many fissures and fractures with varying orientation developed in response to tectonic. Quantitative description of discontinuities including orientation, spacing, persistence, roughness, aperture and filling were determined at the site by exposure logging in accordance to ISRM (1978). The strikes and dips of 300 joints on the left shore of the dam, and 364 joints on the right shore were measured. Discontinuity orientations were evaluated utilizing a computer program based on equal-area stereo graphic projection namely Dips 5.1 (Diederichs and Hoek, 1989).

The dominant discontinuities sets are distinguished on the left and right shore are shown in Figure 3 and Figure 4.
Right shore dominant discontinuity sets;

1m: 67/ 023
2m: 83/43
3m: 47/49
4m: 35/232

Left shore dominant discontinuity sets;

1m: 19/ 57
2m: 67/026
3m: 80/330
4m: 66/147

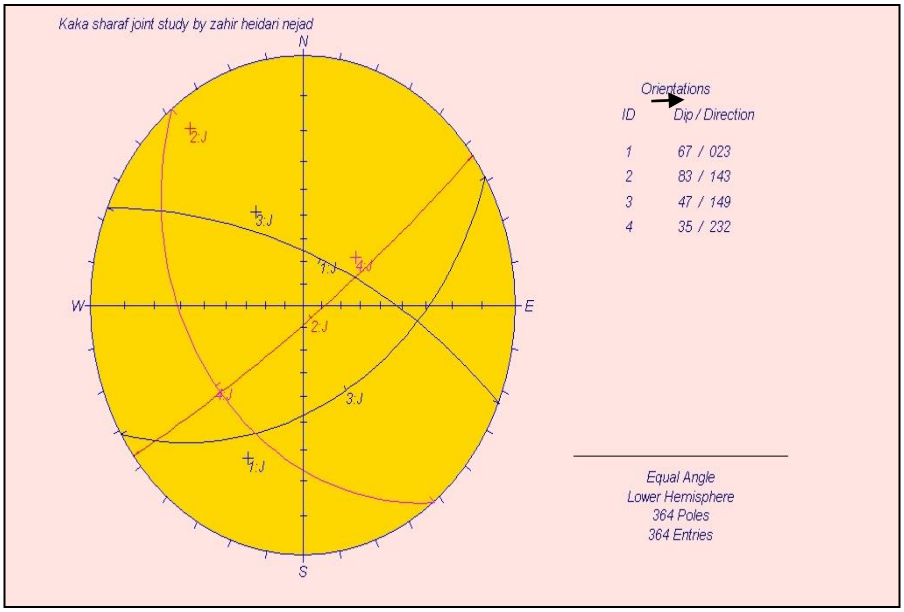



**Figure 3**: Dominant joint sets on right bank of the Kakasharaf Dam site.

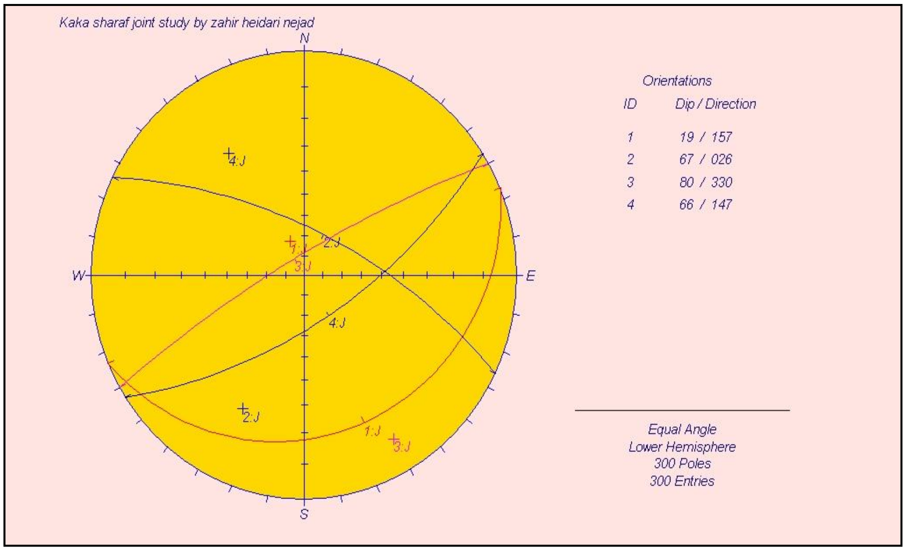
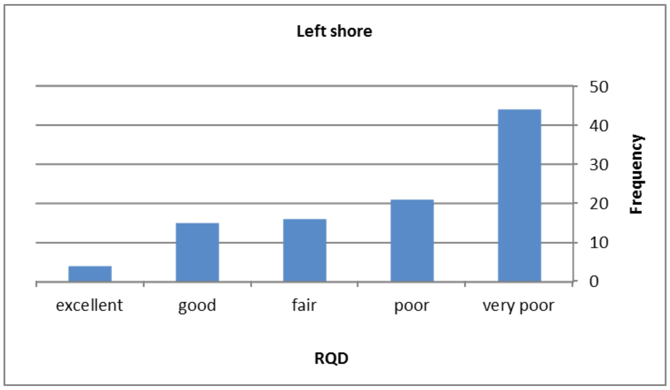



**Figure 4**: Dominant joint sets on left bank of the Kakasharaf Dam site.

The discontinuities are filled by clay, calcite, limonite, hematite and silica. It is noted that in some section of Kakasharaf Dam site, the clay fillings have been leached by surface waters.

During the field surveys, engineering geological map of the Kakasharaf Dam site and the geological cross section along the dam axis was constructed. In addition, an examination was made of 1759 m of the core, from 25 boreholes drilled by the General Directorate of state hydraulic works. The RQD values of the left shore and right shore were determined.

The histograms shown in Figure 5 were prepared using RQD divisions proposed by Deere (1962). From this figure, the rock quantities of the right shore have the following distribution: 4% excellent, 15% good, 16% fair, 21% poor, and 44% very poor. Similarly, the left shore have the following distribution of rock quality: 1% excellent, 6% good, 17% fair, 27% poor, and 49% very poor. Table 1 shows the main orientation, spacing, persistence, aperture and roughness of discontinuities. These were described using the scan-line survey Method following the ISRM (1978) description criteria.



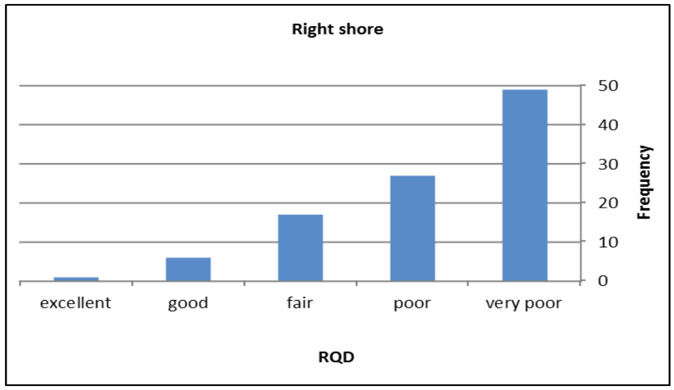




**Figure 5**: The RQD values of the left shore and right shore.

**Table 1**: Engineering properties of joints and bedding surfaces and their percentage distribution.

| Properties | Spacing | Description | Percentage | |
|---|---|---|---|---|
| | | | ml | Shl |
| Spacing (mm) | <20 | Extremely close spacing | 7 | 10 |
| | 20-60 | Very close spacing | 29 | 15 |
| | 60-200 | Close spacing | 35 | 43 |
| | 200-600 | Moderate spacing | 25 | 24 |
| | 600-2000 | Wide spacing | 4 | 8 |
| Persistence(m) | <1 | Very low persistence | 28 | |
| | 1-3 | Low persistence | 60 | |
| | 3-10 | Medium persistence | 12 | |
| | 10-20 | High persistence | - | |
| | >20 | Very high persistence | - | |
| Aperture (mm) | <0.1 | Very tight | 10 | 12 |
| | 0.1-25 | Tight | 8 | 3 |
| | 0.25-50 | Partly open | 13 | 16 |
| | 0.50-2.5 | Open | 18 | 15 |
| | 2.5-10 | Moderately wide | 48 | 45 |
| | >10 | Wide | 3 | 9 |
| Roughness | IV | Rough undulating | 10 | 7 |
| | V | Smooth undulating | 5 | 5 |
| | VI | Slickenside undulating | 9 | 3 |
| | VII | Rough planar | 62 | 76 |
| | VIII | Smooth planar | 6 | 5 |
| | IX | Slickenside planar | 8 | 4 |

## 4. Permeability Testing

During core drilling, pumping tests were carried out and the permeability of the sedimentary rocks is expressed in terms of Lugeon values. A total of 225 pumping tests were performed at the sedimentary rock units in 22 boreholes. Lugeon values and Test ratio of the sedimentary rocks at Kakasharaf Dam site is shown in Table 2.

**Table 2:** Lugeon values and Test ratio of the sedimentary rocks at Kakasharaf Dam site.

| Id | Lugeon values | No. of tests | Test ratio | Description |
|---|---|---|---|---|
| 1 | >25 | 83 | 37 | Highly permeable |
| 2 | 25-5 | 84 | 38 | Permeable |
| 3 | 5-1 | 36 | 16 | Slightly permeable |
| 4 | <1 | 20 | 9 | Impermeable |

## 5. Physical and Geomechanical Characteristic of the Marl Limestones

Geomechanical characteristics of a total of 12840 mm core samples of marl limestone were determined in the Engineering Geology Laboratory. The dry unit weights, saturated unit weights, porosity, weighted water absorptions, uniaxial compressive strengths, Poisson ratios, velocities of P and S waves and dynamic and static elasticity modules for the marl limestones were determined on the basis of ASTM (1980, 1996).

**Table 3:** Statistical evaluation of index and geomechanical properties of marl limestones in the study area.

| Properties | Min | Max | Average | Variance | Standard Deviation |
|---|---|---|---|---|---|
| Saturated unit weight, $r/s$ ( $t/m^3$) | 2.480 | 2.600 | 2.560 | 0.004 | 0.690 |
| Dry unit weight, $r/d$ ( $t/m^3$) | 2.410 | 2.560 | 2.510 | 0.006 | 0.077 |
| Water absorption by weight, $A_a$ (%) | 0.640 | 4.570 | 2.310 | 0.777 | 0.881 |
| Porosity, n (%) | 1.640 | 10.850 | 5.250 | 0.002 | 0.0467 |
| Dry Poisson ratio, $v_n$ | 0.120 | 0.300 | 0.210 | 0.002 | 224.970 |
| P ware velocity, $v_p$ (m/s) | 0.120 | 0.310 | 0.240 | 50612.600 | 224.970 |
| S ware velocity, $v_s$ (m/s) | 5173 | 6084 | 5545.460 | 9030.140 | 95.020 |
| Point load strength index, is 50 (MPa) | 2870 | 3188 | 30340330 | 0.302 | 0.549 |
| Uniaxial compressive strength, ---- (MPa) | 3.030 | 4.360 | 68.410 | 19.770 | 24. 896 |
| Static elasticity modules, $E_s$ (GPa) | 35.780 | 47.010 | 47.520 | 24.011 | 0.881 |
| Dynamic elasticity modules, $E_d$ (GPa) | 59.740 | 70.470 | 65.920 | 18.188 | 4.264 |

## 6. Physical and Geomechanical Characteristics of the Shale Lime Stones

Geomechanical characteristics of a total of 15810 mm core samples of shale limestone were determined in Engineering Geology Laboratory.

The dry unit weights, saturated unit weights, porosity, weighted water absorptions, uniaxial compressive strengths, Poisson ratios, velocities of P and S waves and dynamic and static elasticity modules for the shale limestones were determined on the basis of ASTM (1980, 1996) And ISRM (1978). Minimum, maximum, average and standard deviation for these parameters are given in Table 4.

## 7. Engineering Classification of the Rock Mass

The marl limestones and shale limestones were classified according to the RMR (Bieniawski, 1989) system in order to determine what kinds of support systems should be used in the diversion and power tunnels. RMR values, the parameters used in rock- mass classification and corresponding point totals for best- and worst- case-scenarios, are given in Table 5 and Table 6 and Table 7.

**Table 4:** Statistical evaluation of index and geomechanical properties of the shale limestone in the study area

| Properties | Min | Max | Average | Variance | Standard Deviation |
|---|---|---|---|---|---|
| Saturated unit weight, $r/s$ ( $t/m^3$) | 2.500 | 2.680 | 2.620 | 0.001 | 0.040 |
| Dry unit weight, $r/d$ ( $t/m^3$) | 2.440 | 2.690 | 2.590 | 0.003 | 0.050 |
| Water absorption by weight, $A_a$ (%) | 0.640 | 2.750 | 2.250 | 0.360 | 0.600 |
| Porosity, n (%) | 1.640 | 6.960 | 3.190 | 2.160 | 1.470 |
| Dry Poisson ratio, $v_n$ | 0.450 | 0.220 | 0.180 | 0.0003 | 0.020 |
| P ware velocity, $v_p$ (m/s) | 0.160 | 0.270 | 0.200 | 0.0017 | 0.040 |
| S ware velocity, $v_s$ (m/s) | 0.130 | 5568 | 5201 | 52007 | 228 |
| Point load strength index, is 50 (MPa) | 4932 | 2919 | 2686 | 31982 | 179 |
| Uniaxial compressive strength, ---- (MPa) | 2301 | 4.800 | 3.470 | 0.794 | 0.891 |
| Static elasticity modules, $E_s$ (GPa) | 36.080 | 69.560 | 55.930 | 146.130 | 12.090 |
| Dynamic elasticity modules, $E_d$ (GPa) | 30.950 | 48.170 | 39.900 | 39.580 | 6.290 |

**Table 5:** Classification of the marl limestone at the dam site based on RMR system

| Parameters | Parameters rating or description | | | |
|---|---|---|---|---|
| Uniaxial compressive strength, (MPa) | Min | Rating | Max | Rating |
| Rock Quality Designation (%) | 4 | 1 | 120 | 12 |
| Spacing of discontinuities (m) | 10 | 3 | 95 | 20 |
| Condition of discontinuities continuity (m) | < 0/006 | 5 | > 2 | 20 |
| Spacing (mm) | > 20 | 0 | < 1 | 6 |
| Roughness | > 5 | 0 | None | 6 |
| Filling | Polished | 0 | Smooth | 1 |
| Weathering degree | None | 6 | Hard | 2 |
| Ground water conditions | Highly | 0 | Slightly | 5 |
| Orientation of discontinuities RMR | Wet | 7 | Dripping | 4 |
| | Unfavorable | -10 | Unfavorable | -10 |
| RMR | | 12 | | 66 |

**Table 6:** Classification of the shale limestone at the dam site based on RMR system

| Parameters | Parameters rating or description | | | |
|---|---|---|---|---|
| Uniaxial compressive strength, (MPa) | Min | Rating | Max | Rating |
| Rock Quality Designation (%) | 2 | 1 | 95 | 7 |
| Spacing of discontinuities (m) | 7 | 3 | 80 | 15 |
| Condition of discontinuities continuity (m) | < 0/006 | 5 | > 2 | 20 |
| Spacing (mm) | > 20 | 0 | < 1 | 6 |
| Roughness | > 5 | 0 | None | 6 |
| Filling | Polished | 0 | Smooth | 1 |
| Weathering degree | None | 6 | Hard | 2 |
| Ground water conditions | Highly | 0 | Slightly | 5 |
| Orientation of discontinuities RMR | Wet | 7 | Dripping | 4 |
| | Unfavorable | -10 | Unfavorable | -10 |
| RMR | | 13 | | 56 |

**Table 7:** Classification of marl and shale limestone based on RMR values

| | Marl limestone | | Shale limestone | |
|---|---|---|---|---|
| | **Worst condition** | **Best condition** | **Worst condition** | **Best condition** |
| RMR value | 12 | 66 | 13 | 56 |
| Group | V | II | V | III |
| Description | Very weak rock | Good Rock | Very weak Rock | Medium Rock |

## 8. Discussion

Kakasharaf Dam will be built on sedimentary rocks which consist of marl limestone and shale limestone. Quantitative description of discontinuities was performed at the site by exposure logging in accordance with ISRM (1978).

Sedimentary rocks at the site are "slightly permeable ”according to pumping test results and grouting is offered to prevent leakage under the dam foundation from permeable zones. On the other hand alluvium was determined as “highly permeable" and was decided to remove it by using the cut-off method. Laboratory tests on core samples were carried out to find the physical parameters. As a result of uniaxial compression tests, marl and shale limestone are in the high strength rock group. Evaluation of marl and shale limestone for rock mass classifications due to RMR values, indicated that marl limestone is in very poor to good quality and shale limestone is in very poor to fair quality.

Strength of rock masses at Kakasharaf Dam site was expressed by using Hock-Brown empirical failure criteria (Hoek et al, 1995). Uniaxial compression strength of the rock for marl and shale limestone is 68 to 41 and 55.93 MPa, respectively. All these results have led to conclusion that foundation rocks are suitable.

## 9. Conclusion

Kakasharaf Dam, will be located on the sedimentary rocks. Engineering geological investigations, test results and computations indicate that Kakasharaf Dam can be safely constructed on the proposed site.

## Acknowledgements

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