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Geo-mechanical Consideration in Research Project of Constructing Sheikh Besharat Dam in Bijar County with Gamma-Gamma Methods

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Abstract

Undoubtedly, preliminary geological studies are among the most important and most fundamental principles of designing and constructing big constructions such as dams in different regions. As a comprehensive template, geo-mechanical studies related to geological studies have been able to provide invaluable information regarding surface properties and features of soil such as texture and structure, and permeability. Different methodologies have been exploited in estimating geo-mechanical studies, among most novel of them is gamma-gamma method. This study, in a practical way, conducts a geo-mechanical consideration in research project of constructing Sheikh Besharat Dam in Bijar County with gamma-gamma methods. Results of the study showed that in two tests, a total of 12 experiments has been performed in soil depths ranging from 0.075 m to 35 m which showed that except experiment 9 in test 1 and test 2 in experiment 2 where porosity level is more than other tests, porosity level in other considered tests and regions have been in levels close to one another. Density level of each of tests taken from 12 points in dam construction lands showed that this has been reported normal for 12 test cases, which is quite similar and close to normal conditions. Considering Young's modulus that has been performed based on gamma-gamma methods and data resulting thereof, we showed that the amount of reflection of geo-mechanical properties based on the obtained level of transparency between 550 and 1000 has been identified to be appropriate.

Keywords: dam, gamma-gamma, density, geo-mechanical properties, porosity level

Introduction

Universal study projects in terms of comprehensive consideration of physical and non-physical potentials in establishing big projects such as water dams are complex and meanwhile sensitive plans and surveys and any kind of fault or problem in their computation and evaluation areas could not only pose huge financial losses to project management and the country's economy, but it could also play a significant role in creating threats to individuals' lives as well as destroying the environment and other areas. Among projects that have, in recent decades, been widely noticed by public and private sectors, is construction of water dams. Threats caused by draught and water shortage crises around the world have further noticed the value and importance of the strategies for conservation and maintenance of water resources such as dam construction. In development of dam construction projects, enforcement of driving mechanisms and evaluation and explanation of problems and issues of operational development have always focused on. One of the most important encountered challenges in terms of quantitative and qualitative development of new dams or improving existing dams has been evaluation and measurement of the conditions of soil surfaces of potential areas, such as geo-mechanical properties, existence or nonexistence of sliding faults and other soil surface factors for establishment. To this purpose, enforcement of special circumstances of measuring geo-mechanical conditions and properties of each of study routes in the beginning of programs for development of fields have been noticed (Wray, 2012).

Today, given the staggering expense and high time and energy loss in regional studies in the form of experimental inferences, novel methods have been used with the purpose of considering geo-mechanical properties, among most popular of which gamma-gamma method can be named.

In studies of Chang and Kopaska in 2012 it was shown that artificial gamma irradiation as a method with appropriate level of certainty can be used for estimating the value of geo-mechanical parameters such as soil texture and structure as well as geo-physical properties such as porosity and permeability. Although by having more input parameters there is the possibility that more accurate responses can be achieved, due to the property gamma irradiation has in adapting itself with input data, good results could be obtained upon failing to access numerous parameters by choosing existing suitable parameters (Rahimi, 2006, 14).

In his studies regarding consideration of European oil fields and especially fields of the North Sea,Torres (2009) showed that around faults created in morphological units and especially breakages that stretch to soil surface, a smashed domain and a network of gaps with different dimensions are created. With the help of gamma ray dispatch and data reflection, dimensions of this domain is reported according to different construction conditions and deviates from the fault position at least 100 to 150 meters around. A cylindrical area with a diameter of at least 300 meters of sedimentary substratums, which lose their initial continuity and robustness, has been identified.

Works of Writhe and Drunken (2010) have shown that besides the effect that soil's quantitative and qualitative conditions such as its texture can reflect in many of its parameters, it is their main effect on permeability that has to be evaluated. The measurement criterion and measurement unit of permeability in a construction is Darcy's law, with its unit being md (millidarcy). For this purpose, the results of three meters of density, sonic, and neutron have been set as criteria and the reason for selection of these three parameters for work, is their higher link with porosity and this can be shown in the results of different geo-mechanical studies carried out.

Ounese (2011) used a gamma-gamma irradiation criterion to identify the effect main intermediate tension on construction resistance. By using experimental tests of breaking subsurface layer via gamma-gamma method in granite and sandstones and their comparison, Song and Hismen (2012) found the differences between various fracture criteria.

Mark et al (2009) found that the Mohr-Coulomb criterion, because of not considering the main intermediate tension and the total weight required for the resistance of surface substratumrim using gamma-gamma method, is very conservative.

Simons (2012) managed to present a model based on the criterion for recognizing soil structure in different stones. He used this model to determine surface substratum's wallfracture using gamma-gamma method.

Argris (2008) suggested a numerical method for simulating material fracture with fine particles.

With regards to the range of rainfall and ecological potentials in the western side of the country and also permanent and seasonal rivers especially in areas such as Kurdistan Province, the focus of practical and technical programs regarding quantitative and qualitative development of dams in these areas requires scientific investigations on geo-mechanical conditions of the ground in surface areas and comprehensive knowledge of ground structures and layers, and determination of physical properties of soil in the site or adjacent lands.

Given the amount of efficiency and value of energy production/consumption sector in the world, major studies have been conducted on ascertaining conditions in terms of exploitation and besides noticing geo-mechanical conditions of soil in regions, and application of widespread computer networks and information access tools, computation power and capability in geo-mechanical evaluation of fields have also been considered. In line with considerable progress and development of computer technology in different hardware and software fields, serious attempts have been made to specialize in computer programs by designing specific algorithms in industry (Aghamollayi, 2011:12).

The geology of the region under study

Sheikh Besharat Dam is located in Bijar County in Kurdistan Province and 8 km from the city of Hassan Abad or Sokand. The dam is being built on Koohzan River with the aim of providing water for 1480 hectares of lands down the dam and providing drinking and industry water for the city with the volume of over 3.9 million cubic meters. The height of this dam is 48 meters from the base and its total repository volume will be 29.4 million cubic meters.

Dam type	Earthy with clay core
Crest length	910 m
Height from soil surface	46 m
Dam body volume	20.2 million cubic meters
Normal repository volume	40.29 million cubic meters
Useful volume	90.19 million cubic meters

According to geologic maps 1:100,000 (GSI) and field surveys, quaternary deposits of low regions and pre-quaternary deposits of high regions comprise the area under study and the fault of Talesh is located between these two, placing second period deposits along beside quaternary deposits. This fault has a trust operation and its plane gradient is to the west-southern west, with high gradient at the surface and low gradient in depth (Berberian, 1983). According to geological maps, quaternary deposits in the area under study are wholly comprised of alluvium terraces and young deposits made of clay, silt, gravel, and sand sediments (in many places like alluvial fans with dimensions up to 30 cm) all of which are represented as a geological unit Qt. In field surveys, however, this unit that has significant spread (a length of 90 km), is separable to subdivisions like alluvial fan sand deposits, sand and gravel floodplain deposits and silt deposits of coastal plains. Figure 2 shows the geological map of the area under study.

Geological considerations of the region

To perform geo-technical considerations in this study, geo-technical studies related to different construction projects in the area under study (Department of Transportation, 2009) or geotechnical studies of regional water organization (Department of Energy, 2002) and many other projects were used. In these studies, there are over 20 exploratory bores. In most of bores drilled in surface-level sediments of river soil or floodplain sediments, sandy soils containing varying-dimensioned gravels are initially observed, with the thickness of these soils varying between 2 and 10 meters. These soils are placed in GP and GW grades and in some places, besides gravels, they contain gravel and silt. SPT numbers in these soils are often more than 30. After sandy soil, silty clay soils are observed. In bores drilled far from soil surface of rivers and floodplains, these clay layers are seen on surface. The soils are often placed in degree CL and occasionally in grade CH, with their thickness changing between 5 and 20 meters. SPT numbers in these soils varies between 4 and 13 with their fluidity changing between 40 and 60 percent and their plastic criterion changing between 20 and 40 percent. These clays are typically strengthened and placed in the degree of soft-to-intermediate clays.

After clay layers, sandy layers are observed in all bores. These sandy layers which are placed in the degrees of SP, SP-SM, and SM, are observed until the end of most 30-meter bores and in turn into clay substratums in some 30-meter bores, but in 50-meter bores, after passing from these clay substratums, sandy substratums are seen again and they extend to the end of 50-meter bores. A clay substratum intersects with sandy layers in depths over 30 meters. These clays are placed in the soil degree of CL, with their breadth changing between 2 and 8 meters.

Considering geo-mechanical model of subsurface layer with gamma-gamma method

To design surface soil's geo-mechanical model, elastic properties of surface soil must be calculated first. To calculate elastic moduli of surface soil, it is necessary to first read some physical properties of surface soil from physical curves. These properties include amount of gamma irradiation, surface soil density, neutron porosity, and duration of stress and shear waves' pass through surface soil. Elastic moduli of surface soil in dynamic form are calculated by equation (1):

$$\nu_d = \frac{0.5\times(\frac{\Delta t_s}{\Delta t_c})^2 - 1}{(\frac{\Delta t_s}{\Delta t_c})^2 - 1}$$

$$G_d = \frac{92915.71429\times\rho}{\Delta t_s{}^2} \tag{1}$$

$$E_d = 2\times G_d \times (1+\nu_d)$$

Where pass duration of stress wave and shear wave are represented in µs/f, density in grams per cubic centimeters and Young's modulus and shear modulus are considered in GPa. Given the fact that in designing geo-mechanical models, static values must be used, equation (2) is used to convert dynamic Young's modulus to static.

$$E_s = 0.4145E_d - 1.0593 \tag{2}$$

Where, Young's modulus, in static condition, is calculated in GPa.

Next, uniaxial compressive strength of carbonated surface soil is calculated using equation 3:

$$UCS = 135.9\times EXP(-4.8\times\phi) \tag{3}$$

Where φ is the porosity obtained from neutron curve.

To calculate operational stress of drilling fluid and in-situ tensions, parameters of drilling fluid weight and vent fluid's pressure are obtained from information of drilling and subsurface layer with gamma-gamma method. Operational stress of drilling fluid is calculated via equation 4.

$$P_W = (M_W \times 9.81\times Depth)/1000 \tag{4}$$

Where, MW is the weight of drilling fluid and $Depth$ is the depth of drilled formation.

In-situ tensions are calculated using equation 5.

$$\sigma_v = \int_0^z \rho(z)\times g\times dz = \bar{\rho}gz$$

$$\sigma_h = \frac{\nu_s}{1-\nu_s}\sigma_v - \frac{\nu_s}{1-\nu_s}\alpha P_p + \alpha P_p + \frac{E_s}{1-\nu_s{}^2}\varepsilon_y + \frac{E_s}{1-\nu_s{}^2}\varepsilon_x \tag{5}$$

$$\sigma_H = \frac{\nu_s}{1-\nu_s}\sigma_v - \frac{\nu_s}{1-\nu_s}\alpha P_p + \alpha P_p + \frac{E_s}{1-\nu_s{}^2}\varepsilon_x + \frac{E_s}{1-\nu_s{}^2}\varepsilon_y$$

$$\alpha = 1, \varepsilon_x = 1.5, \varepsilon_y = 0.5$$

In these equations, $\rho(z)$denotes the density of stone, which is a function of depth; g is gravitational constant and $\bar{p}$ is medium density; P_p is vent fluid's pressure; σ_v is in-situ orthogonal tension, σ_K is the minimum in-situ horizontal tension, σ_H is the maximum in-situ horizontal tension, which are calculated in GPa. α is Biot's coefficient; T_x and T_y are strain in the direction of the minimum and maximum horizontal tension. Inductive tensions in subsurface layer wall in their maximum and minimum values are calculated with vertical gamma-gamma method by equation (6).

$$
\begin{aligned}
&\sigma_{\theta\theta}\max = 3\sigma_H - \sigma_h - P_w - P_p \\
&\sigma_{\theta\theta}\min = 3\sigma_h - \sigma_H - P_w - P_p \\
&\sigma_{zz}\max = \sigma_v + 2\nu(\sigma_H - \sigma_h) - P_p \\
&\sigma_{zz}\min = \sigma_v - 2\nu(\sigma_H - \sigma_h) - P_p \\
&\sigma_{rr} = P_w - P_p
\end{aligned} \tag{6}
$$

Where, σ_{oo} is tangential inductive tension; $\sigma_{=}$ is axial inductive tension and $\sigma_{„}$ is radial inductive tension.

To design geo-mechanical model of surface soil in subsurface layer with the gamma-gamma method, based on inductive tensions created, the appropriate fracture criterion must be selected to determine permissible and appropriate range of mud pressure. In this study, Mohr-Coulomb criterion has been selected in this study as the fracture criterion. Parameters of this criterion are calculated corresponding to equations 7 to 9.

$$
\begin{aligned}
&A = 3\sigma_H - \sigma_h \\
&B = \sigma_v + 2\nu(\sigma_H - \sigma_h) \\
&D = 3\sigma_h - \sigma_H \\
&E = \sigma_v - 2\nu(\sigma_H - \sigma_h) \\
&(\sigma_1 - P_p) = C_0 + q(\sigma_3 - P_p)
\end{aligned} \tag{7}
$$

$$
\begin{aligned}
&\sigma_1 = C + q\sigma_3 \\
&C = C_0 - P_p(q-1) \\
&T = 0.1C_0
\end{aligned} \tag{8}
$$

Where C_o is the uniaxial compressive strength; T is uniaxial tensile strength and C is adhesive strength and the value of q is calculated using equation (9).

$$q = \tan^2(\pi/4 + \phi/2) \tag{9}$$

Where φ is inner fraction angle.

Study and consideration of the status and type of shear fracture moduli according to inductive tensions caused in the wall of subsurface layer using gamma-gamma method after drilling operation are presented in table (1). Deep shear rupture which is mainly caused by tangential inductive tension. Shallow impact shear rupture is a model which is mainly caused by axial inductive tension. Step shear rupture with high angle which is mainly created by axial inductive tension. Narrow shear rupture, a model which is mainly created by radial inductive tension. Deep impact shear rupture, a model which is the mainly created by radial inductive tension. And step shear rupture with low angle, a model which is mainly created by tangential inductive tension, is also considered as a higher bound in shear rupture models of surface soil.

Table 1. The status and type of shear rupture models based on inductive tensions

Failure occurs if	$\sigma_1 \geq \sigma_2 \geq \sigma_3$	Shear fracture model
$P_w \leq A - C/1 + q$	$\sigma_{\theta\theta} \geq \sigma_{zz} \geq \sigma_{rr}$	Deep shear rupture (SWBO)
$P_w \leq B - C/q$	$\sigma_{zz} \geq \sigma_{\theta\theta} \geq \sigma_{rr}$	Shallow impact shear rupture (SSKO)
$P_w \geq C - E/q + D$	$\sigma_{zz} \geq \sigma_{rr} \geq \sigma_{\theta\theta}$	Step shear rupture with high angle (SHAE)
$P_w \geq C + qD/1 + q$	$\sigma_{rr} \geq \sigma_{zz} \geq \sigma_{\theta\theta}$	Narrow shear rupture (SNBO)
$P_w \geq C + qE$	$\sigma_{rr} \geq \sigma_{\theta\theta} \geq \sigma_{zz}$	Deep impact shear rupture (SDKO)
$P_w \leq A - C - qB$	$\sigma_{\theta\theta} \geq \sigma_{rr} \geq \sigma_{zz}$	Step shear rupture with low angle (SLAE)

Study and investigation of the status and type of tensile failure based on inductive tensions created on subsurface layer's wall using gamma-gamma method after drilling operation is shown in the table. Study of tensile failure fracture models in performing hydraulic failure operations, selection of size and type of drill bit and drilling speed rate are very important. These models show the amount of the least inductive tension required for formation's fracture. Vertical tensile rupture: the main inductive tension in creating this model of fracture is inductive tangential tension. Radial tensile rupture: the main inductive tension in creation of this model of fracture is radial inductive tension.

Table 2. The status and type of tensile fracture models based on inductive tensions

Fracture occurs if	σ_3	Tensile fractures model
$P_w \geq D - P_p - T$	$\sigma_{\theta\theta}$	Vertical tensile rupture (TVER)
$P_w \leq D - E$	σ_{zz}	Horizontal tensile rupture (THOR)
$P_w \leq P_p + T$	σ_{rr}	Radial tensile rupture (TCYL)

Table 3. Average in-situ and inductive tensions in surface soil under investigation

Radial tension	Minimum axial tension	Maximum axial tension	Maximum tangential tension	Minimum tangential tension	Maximum in-situ horizontal tension	Minimum in-situ horizontal tension	Vertical in-situ tension
28	62	69	110	142	81	73	54

The following table shows the average of physical properties for surface soil. Based on these properties, type of surface soil, porosity, and the amount of gamma ray irradiation on the structure can be understood. Based on pass duration of sound waves, surface soil's elastic moduli can be calculated. Gamma irradiation's unit API.

Table 4. Average physical properties of surface soil under investigation

Pass duration of shear sound wave	Pass duration of compressive sound wave	Neutron's porosity percent	Formation density	Gamma irradiation
133	69	14	2.5	14

The following table shows the values for parameters obtained from geo-mechanical model of surface soil under investigation.

Table 5. Average of parameters obtained from geo-mechanical model of the surface soil under investigation

Minimum permissible pressure of mud weight	Minimum in-situ horizontal tension	Operational weight of drilling mud	Minimum permissible pressure of mud weight	Pore fluid pressure
160	73	54	45	26

Previous research on this area

To consider permeability of subsurface layers and determine geo-mechanical parameters of bulk soil of the region under study, simultaneous with conducting field drillings, experiments were conducted in 5-meter sections, the results thereof implied higher permeability as permeability to depth decreased.

Table 6. Results of soil mechanics performed in geo-mechanical studies of the area of Sheikh Besharat Dam

Bore number	Sample type		Sample number	Depth (meter)	Density (gr/cm3)	Humidity percent	Porosity percent	Compressive strength (kg/cm2)	Poisson ratio	Young's modulus
1	Test 1	Marn	CB-1-1	3.0-3.25	2.20	9.70	15.1	-	-	-
	Test 2	Marn	CB-2-1	5.0-5.3	2.22	10.20	13.2	57.5	0.29	691.1
	Test 3	Marn	CB-3-1	7.0-7.25	2.20	13.40	19.7	48.3	0.28	552.24
	Test 4	Marn	CB-4-1	10.-10.25	2.25	11.20	12.6	62.7	0.29	770.83
	Test 5	Marn	CB-5-1	11.7-12	2.31	9.70	11.2	110	0.26	952.86
	Test 6	Gypsum	CB-6-1	14.75-15	2.22	25.3	28.8	71.2	0.28	739.51
	Test 7	Marn	CB-7-1	25.75-26	2.31	14.30	16.7	-	-	-
	Test 8	Marn	CB-8-1	30.75-31	2.32	10.20	12.1	-	-	-
	Test 9	Marn	CB-9-1	34.0-34.25	2.36	14.03	17.3	-	-	-
2	Test 1	Marn	CB-1-2	0.75-1.0	2.23	-	-	-	-	-
	Test 2	Marn	CB-2-2	8.0-8.3	2.23	11.5	14.6	58.9	0.29	529.77
	Test 3	Marn	CB-3-2	12.75-13.0	2.25	14.6	12.1	65.4	0.28	710.53

Table 7. General results of chemical experiments carried out on the samples taken from Sheikh Besharat Dam

Bore number	Sulfate percent	Chalk percent	Chlorine
1	0.11	0.56	0.020
2	0.12	0.56	0.021

Conclusion

According to the investigations on the results obtained from the study we showed that using gamma-gamma methods with the purpose of geo-mechanical consideration in the research project of constructing Sheikh Besharat Dam in Bijar County, it has been determined that we can achieve a proper and comprehensive evaluation of the geo-mechanical properties and conditions of the region under study.

We showed in this paper that according to the experiment of gamma-gamma method, pass duration of compressive and shear sound waves of surface soil, formation density, and neutron porosity, elastic moduli, and uniaxial compressive strength of surface soil can be calculated and based on these parameters, the amount of in-situ tensions of a formation can be achieved. Inductive tensions are created under the influence of surface soil drilling that leads to instability of subsurface layer wall via gamma-gamma method. To predict these tensions it is necessary to have the geo-mechanical model of surface soil at one's disposal. Geo-mechanical explanation of surface soil is given according to tension regime and selecting appropriate criteria for surface soil fracture. Thus, drilling of the formation under question is located in the stable window area of drilling mud and shear fracture model of the surface soil under study is based on deep shear fracture model, and the tensile rupture model will be in a vertical state.

In this study which was done under regional conditions of Kurdistan Province and within the area of Bijar County in Kurdistan Province and with investigation of geo-mechanical properties of the lands around Sheikh Besharat Dam, and that has been conducted with two tests and a total of 12 experiments and in soil depths ranging from 0.075 to 35 meters, it has been shown that except experiment 9 in test 1 and test 2 in experiment 2, where porosity level has been more than other tests, the level of porosity in the rest of investigated tests and regions have been close to that of one another.

Density level of each of the tests in 12 spots of the dam construction site's lands has shown that this level for the 12 conducted test cases has been quite identical and close to normal conditions.

Considering Young's modulus that has been performed based on gamma-gamma methods and data resulting thereof, we showed that the amount of reflection of geo-mechanical properties based on the obtained level of transparency between 550 and 1000has been identified to be appropriate.

Designing geo-mechanical model of surface soil in operations of production, increased harvest, analysis of the subsurface layer wall with gamma-gamma method, hydraulic fracture, choosing the type of drill bit, and drilling speed rate would play determinative roles and would be very useful in study of geo-mechanical status of the earth, faults and the reservoir subsidence phenomenon.

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