Journal of Geology & Geophysics
ISSN: 2381-8719
El-Aal AK, J Geol Geophys 2015, 4:6
DOI: 10.4172/2329-6755.1000230
Research Article
Open Access

Geomechanical Aspects and Suitability of the Limestone (Sulaiy Limestone Formation) for Foundation Bedrock, Sulaiy Region, Saudi Arabia

Abd El-Aal AK[1,2*]

[1]Civil Engineering Department, Faculty of Engineering, Najran University, Najran, Saudi Arabia
[2]Geology Department, Faculty of Science, Al Azhar University, Assuit Branch, Cairo, Egypt

Abstract

The present study is a geomechanical study on the Sulaiy Limestone Formation Riyadh region, KSA which the limestone is the main rocks of the subsurface strata in this area. Due to high strength of rock formation, most of the buildings are designed on shallow foundations. Limestone strata may have cavities through its formation in some places which reduces the rock strength and increases its settlement. In our study, the geomechanical and physical analyses included point load strength (*Is*), uniaxial compressive strength (*UCS*), Schmidt hummer, dry density, porosity, permeability tests, (*TCR*), (*SCR*) and (*RQD*). The point load strength values are between 2.40 and 6.90 (*Mpa*). UCS of the different samples shows difference in values (55 to 143 *MPa*). Dry density shows slight differences in value (1.7 to 2.3 gm/cm^3) with an average of 2.32 gm/cm^3. Percentage of porosity is noticed by about (12%) and the lowest is (2%). The permeability is 22 milli Darcy (*mD*) (fair) and 202 milli Darcy (*mD*) (good). Schmidt hammer tests values are between 33 to 54. *TCR* is between 15-90%, *SCR* and *RQD* are between 20-90%. Then the allowable bearing stress is 18.90 kg/cm^2. We can consider only 3.00 kg/cm^2. The expected settlement is (Se=1.12 cm). Foundation level for building at 1.50 m below the lowest point on the ground surface. Finally, grouting should be added to fill the open cavities of limestone rock formation (if any) to the significant depth below footings before placing the foundations to gain more strength with reducing the limestone settlement.

Keywords: Limestone; RQD; Geomechanical and physical aspects; Settlement

Introduction

The purpose of this study is to investigate and provide reliable, specific and detailed information about the physical and mechanical properties, Such as point load strength (Is), uniaxial compressive strength (UCS), Schmidt hummer, dry density, porosity, permeability tests, (TCR), (SCR) and (RQD), site geology and any installations within the investigated area.

Foundation is an important part of every building, which interfaces the superstructures to the adjacent soil or rock below it. The superstructure loads will be transferred to the underlying soil or rock. Without a proper design and construction of foundation, problems such as cracking, settlement of building may occur and even to the extent, the whole building may collapse within its design life. Therefore, a proper foundation system is required to maintain the safeness of a building.

At the northwest part of Riyadh city, there are two units of limestone bedrock which have high potentiality of karst caves, sinkholes and open fractures. The first unit is exposed as NW-SE limestone belt at the eastern side of Riyadh city and is named as the Sulaiy Limestone Formation of Cretaceous. The Sulaiy Formation is typically composed of compacted limestone with few thin calcarenite beds. In outcrop, this formation shows slumping features in its lower beds exactly like those features which found in the Arab Formation. The higher beds, however, are unaffected by slumping and are moderately strong, forming erosion-resistant, well-defined steep scarp slopes. Cavities and sinkholes are likely formed in the lower beds of this formation at the contact with the Arab Formation rather than the in upper beds as they made up mainly of compacted limestone [1] (Figure 1).

Geological Setting

The geological sequence in the Kingdom of Saudi Arabia was classified into three main groups; 1) Precambrian igneous and metamorphic rocks of the Arabian Shield located on the western part of the country, 2) sedimentary rocks surrounding the shield to the east assigned to the Arabian Platform, and 3) narrow strip of the younger rocks mainly of Cenozoic age outcrops in the coastal area west of the Shield [2,3]. Limestone is the main constituent of the sedimentary rocks of the Arabian platform and appears either as outcrops or underlies surface soil or sand dune fields (Figure 2). The distribution of the Phanerozoic karastic zone in the Kingdom of Saudi Arabia is shown in Figure 1. Many sinkholes have beendiscovered throughout the Phanerozoic karst zone in Ar Riyadh area and the Eastern Province and were reported in different localities such as the Al Summan Plateau northeast of Ar Riyadh, in the terrain south of Ar Riyadh as far as As Sulaiy, and in the Eastern Province and Northern Provinces. Similar sinkhole occurrences were reported in similar geological conditions in Qatar, Kuwait, and Jordan.

Purpose of the Study

The purpose of this site investigation is to determine the existing engineering characteristics of the Sulaiy Limestone Formation and subsurface conditions at the site and to provide the designer with comments on the following:

1-Suitable footing types, founding depths and geotechnical design parameters which will be required for a safe and economic design and excavation of the engineering works, such as the soil bearing

***Corresponding author:** Abd El-Aal AK, Civil Engineering Department, Faculty of Engineering, Najran University, Najran, Saudi Arabia, Tel: +966592375765; E-mail: Ahmed_Aka80@yahoo.com

Received October 03, 2015; **Accepted** October 29, 2015; **Published** November 05, 2015

Citation: El-Aal AK Abd (2015) Geomechanical Aspects and Suitability of the Limestone (Sulaiy Limestone Formation) for Foundation Bedrock, Sulaiy Region, Saudi Arabia. J Geol Geophys 4: 230. doi:10.4172/jgg.1000230

Citation: El-Aal AK Abd (2015) Geomechanical Aspects and Suitability of the Limestone (Sulaiy Limestone Formation) for Foundation Bedrock, Sulaiy Region, Saudi Arabia. J Geol Geophys 4: 230. doi:10.4172/2329-6755.1000230

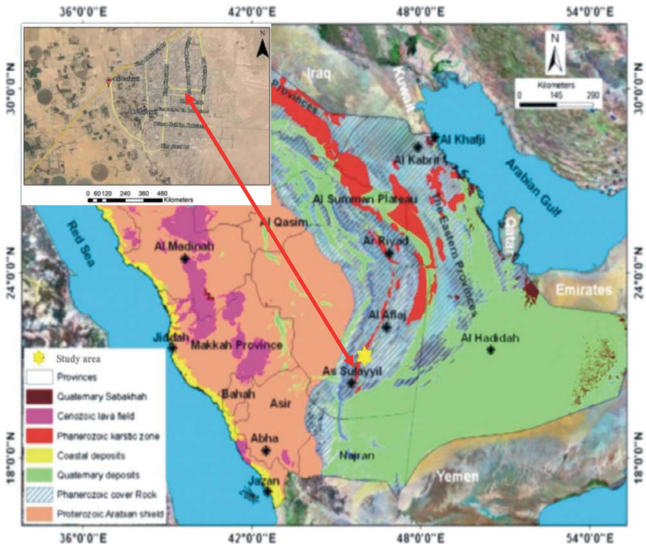

Figure 1: Geological map showing the locations of studied area, (*modified after* [2]*)*, the corner is a Google Earth Satellite Image showing the locations of studied area.

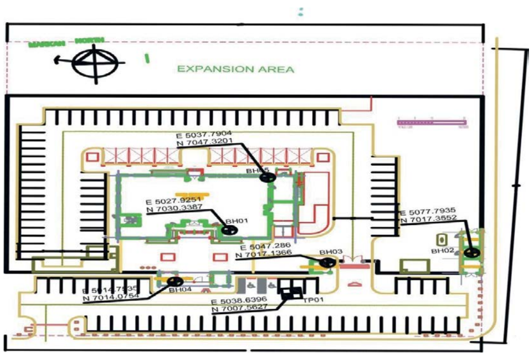

Figure 2: Schematic plan shoeing the location of some boreholes in study area.

capacity, expected foundation settlement at the site and other special recommendation which depends on the site nature.

2-Methods of construction of foundation and footings, site characters, groundwater conditions, quality control requirements and outdoor subgrade and soil retaining parameters.

3-Performing all necessary field and laboratory tests to obtain physical mechanical properties of the subsurface soil. This leads to the geological description of the obtained materials.

4-Developing conclusions and recommendations concerning design and construction of the most safe and economical foundations, site preparation, road and parking areas and retaining walls (if any).

Site Investigation

The investigation included 6 boreholes, 1 borehole with 15.0 m deep, 5 with 10.0 m and 1 test bit. The subsurface investigation revealed that the material at the site can be described as "a layer of fill material with variable depth (6.0-10.0) m, then a layer of very pale brown fractured weak lime stone up to the end of borings" as shown in the logs of boring in (Figure 2 and 3A-B) The ground water was not encountered within the drilled depth.

Geotechnical Field Work

The site was geotechnically investigated by (6) boreholes, and two (1) test pit, of depths 0.50 and 0.75 m (Figure 4A). The boreholes were drilled by ACKER mobile rig using rotary drilling system. The drilling was started at the existing natural ground surface at the location of each borehole.

During drilling, rock cores were extracted each 1.50 m of drilling depth. For each core, the coefficients of recovery (TCR), (SCR) and quality (RQD) were measured and the results were presented in the boreholes logs (Figure 4A-B).

Physical and Geomechanical Properties

The geomechanical and physical analyses included point load strength (Is), uniaxial compressive strength (UCS), Schmidt hummer, dry density, porosity, and permeability tests. A total of 10, one-inch diameter specimens were selected for determining UCS, PLT, TCR, RQD and SCR. Schmidt hammer rebound hardness tests were also conducted on outcrop sections of the Sulaiy Formation. The values of geomechanical and physical properties for the Sulaiy Limestone Formation are shown in Table 1.

Rock quality designation index (RQD)

The Rock Quality Designation index (*RQD*) was developed by Deere [4] to provide a quantitative estimate of rock mass quality from drill core logs. *RQD* is defined as the percentage of intact core pieces longer than 100 mm (4 inches) in the total length of core. The core should be at least (54.7 mm or 2.15 inches in diameter) and should be drilled with a double-tube core barrel.

RQD is intended to represent the rock mass quality in situ. When using diamond drill core, care must be taken to ensure that fractures, which have been caused by handling or the drilling process, are identified and ignored when determining the value of *RQD* [5]. In the present study the RQD is between 20% : 90%.

Total core recovery (*TCR*)

Total core recovery (TCR) is the borehole core recovery percentage.

Figure 3: A- view of the site under study, B-the Aker ACKER mobile rig with rotary drilling system to take to core samples.

Citation: El-Aal AK Abd (2015) Geomechanical Aspects and Suitability of the Limestone (Sulaiy Limestone Formation) for Foundation Bedrock, Sulaiy Region, Saudi Arabia. J Geol Geophys 4: 230. doi:10.4172/2329-6755.1000230

Figure 4: A-the JBC drilling the test bit, B- the depth of test bit.

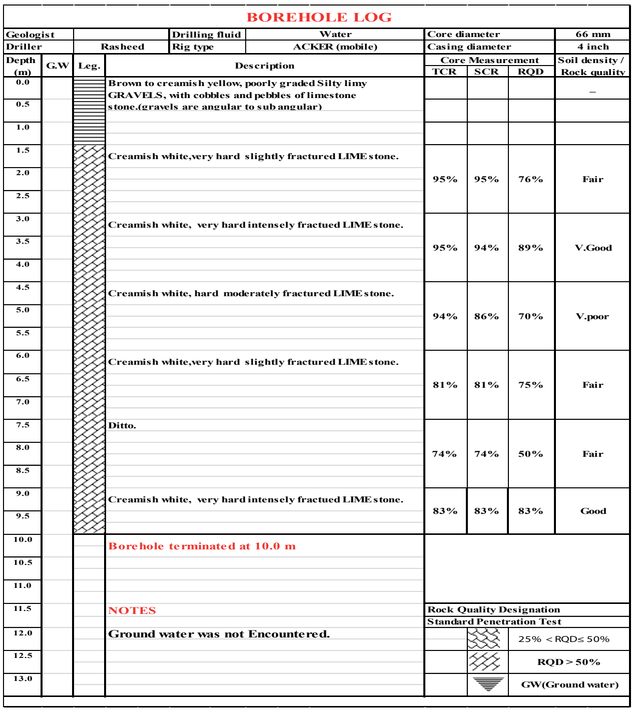

Figure 5: boreholes log represents the rock cores were extracted each 1.50 m of drilling depth which (TCR), (SCR) and (RQD) can be measured.

TCR is defined as the quotient:

$$TCR= (^{L}{}_{sum\ of\ pieces}/\ ^{L}{}_{tot\ core\ run})\ X\ 100\% \ ....(1)$$

$L_{sum\ of\ pieces}$=Sum of length of core pieces

$L_{tot\ core\ run}$=Total length of core run.

The TCR is commonly between 15% to 90%, (Figure 5).

Solid core recovery (*SCR*)

Sample No.	Permeability	Porosity	UCS	PLT	Density	SHT
1	202	12	143	6.9	2.2	45
2	24	10	65	2.4	2.0	23
3	135	2	77	3.9	1.7	54
4	198	6	61	4.5	1.9	51
5	22	2	76	3.2	2.1	36
6	68	5	59	4.6	1.6	33
7	92	6	64	6.1	1.8	43
8	186	5	55	5.8	2.3	49

Table 1: Geomechanical and Physical Properties of Sulaiy Formation.

Solid core recovery (*SCR*) is the borehole core recovery percentage of solid, cylindrical, pieces of rock core.

SCR is defined as the quotient:

$$SCR=(^{L}{}_{sum\ of\ solid\ core\ pieces}/\ ^{L}{}_{tot\ core\ run})\ X\ 100\% \ ……………..(2)$$

$L_{sum\ of\ solid\ core\ pieces=}$Sum of length of solid, cylindrical, core pieces

$L_{total\ core\ run}$=Total length of core run.

The (*SCR*) is ranging between (20%) to (90%) (Figure 5).

The point load test (PLT)

Point load testing is used to determine rock strength indexes in geotechnical practice. The point load test apparatus and procedure enables economical testing of core or lump rock samples in either a field or laboratory setting. The point load test (PLT) is an accepted rock mechanics testing procedure used for the calculation of a rock strength index. This index can be used to estimate other rock strength parameters. The PLT is an attractive alternative to the UCS because it can provide similar data at a lower cost. The PLT has been used in geotechnical analysis for over thirty years [6]. The PLT involves the compressing of a rock sample between conical steel plates until failure occurs. The apparatus for this test consists of a rigid frame, two point load platens, a hydraulically activated ram with pressure gauge and a device for measuring the distance between the loading points. The pressure gauge should be of the type in which the failure pressure can be recorded.

The point load strength values for the Sulaiy Limestone Formation are 2.40 and 6.90 megapascals (Mpa).

The uniaxial compressive strength test

The UCS is undoubtedly the geotechnical property that is most often quoted in rock engineering practice. It is widely understood as a rough index, which gives a first approximation of the range of issues that are likely to be encountered in a variety of engineering problems including roof support, pillar design, and excavation technique [6]. For most coal mine design problems, a reasonable approximation of the UCS is sufficient. This is due in part to the high variability of UCS measurements. Moreover, the tests are expensive, primarily because of the need to carefully prepare the specimens to ensure that their ends are parallel. UCS of the different types of limestone rocks of Sulaiy Formation in the study area shows difference in values (55 to 143 MPa).

Dry density

Dry density is defined as a mass per unit volume. The mass of a unit volume of rock in its natural state is different from the mass of the same volume of rock containing only its solid phase. The statistical calculation of volumetric weight are given in Table 1. Eight specimens with different dimensions (L × W × H) of the limestone rocks from the study area were prepared by disc saw machine; then dried in oven at 105°C for 24 hr. Volumetric weight of the different types of limestone rocks of Sulaiy Formation in the study area shows slight differences in value (1.7 to 2.3 gm/cm^3) with an average of 2.32 gm/cm^3.

Porosity

In general, porosity is the property of solid to have free spaces, or pores, between individual particles not filled by the structural materials. Quantitatively, porosity is defined by the volume of pores per unit volume of a material [7].

To determine the porosity of a rock, the specimens were dried at 105˚C for 24 hr and then weighed (W_1). Then, immersed completely in distilled water at 20i°C ± 2°C for 24 hr. The samples were removed from water, their surface dried by a damp cloth and weighed to the nearest 0.0001 gm. (W_2). The porosity (**N%**) by polished surface area were calculated as follows (**ASTM,** [8]).

$V_P=W_{2-}W_1$………………..(4)

$N=V_{P/}V_b*100\%$……………..(5)

$W_{1=}$Weight of the dry sample, gm.

W_2=weight of specimen after immersion, gm.

$V_{b=}$Volume of the bulk sample, cm^3.

$V_{P=}$Volume of the pore space in the sample, cm^3.

N= Total porosity of the rock%

The results of porosity of the studied samples are given in Table (1). The porosity of the studied limestone samples is widely varied, the highest percentage of porosity is noticed by about (12%) and the lowest is (2%).

Permeability

The average permeability in of the study limestone of Sulaiy Formation is 22 mille Darcy (mD) (fair) and 202 mille Darcy (mD) (good).

The schmidt rebound hammer

The Schmidt rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. There is little apparent theoretical correlation between the strength of concrete and the rebound number of the hammer. However, within limits, empirical correlations have been established between strength properties and the rebound number, (International atomic energy agency, [9]).

Schmidt hammer tests indicate that the values are between 33 to 54 Schmidt hammer rebound values (SHV).

Bearing Capacity and Settlement Calculations

Footing on (Sulaiy Formation) limestone rock

As per Canadian Geotechnical Society, Canadian Foundation Engineering Manual – 3rd edition, we can use the following equation for estimating the allowable bearing capacity of a footing on rock [10]:

$q_{all}=k_{sp}\ (UCS)$…………..(6)

where,

- (k_{sp}) is an influence factor depending on the nature of the rock, for intensely fractured rock (***k_{sp}=0.10***).
- (UCS) is the unconfined strength of the rock. In the current case the minimum value is (***UCS=189.2 kg/cm^2***).

Then the allowable bearing stress is **18.90** kg/cm^2. We can consider only ***3.00 kg/cm^2***.

Estimating the settlement

Willie [11] summarizes settlements of foundation on rocks are as following two different types. First, elastic settlements result from a combination of strain of the intact rock, slight closure and movement of fractures and compression of any minor clay seams (less than a few millimeters). Elastic theory can be used to calculate this type of settlement, AASHTO [11,12]. Second, settlements result from the movement of blocks of rock due to shearing of fracture surfaces. This occurs when foundations are sitting at the top of a steep slope and unstable blocks of rocks are formed in the face. The stability of foundations on rock is influenced by the geologic characterization of rock blocks. The information required on structural geology consists of the orientation, length and spacing of fractures, and their surface and infilling materials. Procedures have been developed for identifying and analyzing the stability of sliding blocks, stability of wedge blocks, stability of toppling blocks, or three-dimensional stability of rock blocks.

In the other hand, the settlement due to mat foundation placed on limestone formation with closed cavities reduced the settlement up to three times compared to that with open cavities. Therefore, grouting should be recommended to fill the open cavities of limestone rock formation to the significant depth below footings before placing the foundations to gain more strength with reducing the limestone settlement. Recommendation of the study are given for geotechnical investigation engineers to expect the maximum depth for cavity probing search through any project depending on the loads and widths of the shallow foundation. The following equation can be used for estimating the elastic settlement (*Se*) under rigid foundation [13]:

$S_e = \frac{qB}{E}(1-\mu^2)\,\alpha_r$……………(7)

In the current case:

- q=3.00 kg/cm^2
- B=500 cm
- E=1000 kg/cm^2
- μ^2=0.30
- α_r=0.82 (for L/B=1), i.e. a square rigid footing

Then, the expected settlement is (***Se***=1.12 cm).

Conclusion and Recommendations

This paper is prepared to study and investigate the physical and mechanical properties, Such as point load strength (Is), uniaxial compressive strength (UCS), Schmidt hummer, dry density, porosity, permeability tests, (TCR), (SCR) and (RQD), site geology and any installations within the investigated area.

Based on the above mentioned rock properties and the expected structures, suitable footing types, founding depths and geotechnical design parameters which will be required for a safe and economic design and excavation of the engineering works, such as the bearing capacity, expected foundation settlement at the site and other special recommendation which depends on the site nature are also calculated as flows:

1. The suitable foundation type, for buildings and fences, is reinforced concrete isolated Footings.

2- Foundation level for buildings at **1.50 m** below the lowest point on the ground surface at each building, and for fences at **1.50 m** below the lowest point on ground surface along the fence.

3- The allowable net bearing stress is **3.00 kg/cm²**. Under this stress, the expected settlements will not exceed 25 mm, and the angular distortion between any adjacent columns should not exceed (1 vertical: 500 horizontal).

4- A plain concrete layer of minimum thickness 10 cm should be placed under each footing.

5- Finally, it is recommended to inject cement-based grout into subsurface cavities in order to improve strength and reduce permeability.

6- Recommendation of the study are given for geotechnical investigation engineers to expect the maximum depth for cavity probing search through any project depending on the loads and widths of the shallow foundation.

References

1. Abdeltawab (2013) Karst limestone foundation geotechnical problems, detection and treatment: Case studies from Egypt and Saudi Arabia. International Journal of Scientific & Engineering Research 4: 376-387.
2. Youssef A, El-Kaliouby H, Zabramawi Y (2012) Integration of remote sensing and electrical resistivity methods in sinkhole investigation in Saudi Arabia. Journal of Applied Geophysics 87: 28-39.
3. Shehata W, Roobol JM, Stewart I, Khiyami H, Al Khammash A, et al. (2007) Evaluation of a subsidence hazard in the Al Khafji area. Confidential report Saudi Geological Survey.
4. Deere DU, Hendron AJ, Patton FD, Cording EJ (1967) Design of surface and near surface construction in rock, 8th US Symposium on Rock Mechanics, Minnesota.
5. Deere DU (1989) “Rock quality designation (RQD) after twenty years”, US Army Corps of Engineers Contract Report GL-89-1, Waterways Experiment Station, Vicksburg.
6. (ISRM) International Society for Rock Mechanics (1985) Suggested method for determining point load strength: ISRM Common testing methods. Int J Rock Mech Min Sci Geomech Abstr 22: 112.
7. Hoek E (1977) Rock Mechanics Laboratory Testing in the Context of a Consulting Engineering Organization. Int J Rock Mech Min Sci and Geomech Abstract 14: 93-101.
8. ASTM (1958) Standers of Building stones. Part 5: 9-35.
9. International atomic energy agency (2002) Guidebook on non-destructive testing of concrete structures, Vienna, Austria.
10. Canadian Geotechnical Society (1992) “Canadian Foundation Engineering Manual (3rd edn)”, BiTech Publishers, Canada.
11. Hoek E, Diederichs MS “Empirical estimation of rock mass modulus,” International Journal of Rock mechanics and Mining Sciences 43: 203-215.
12. AASHTO (1997) LRFD Bridge System Design Specification (Interim Revisions), American Association of State Highway and Transportation Officials, Washington, DC.
13. Das B (1995) Principles of soil dynamics, PWS Kent, MA.