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PREDICTION OF BEARING CAPACITY OF HIGHLY WEATHERED KHONDALYTIC ROCK FORMATIONS

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ABSTRACT

Various methods are available for exploration as well as to estimate the Bearing Capacities in weathered Rock formations. However, it is rather difficult to assess the methodology to be followed to arrive at the Correct Bearing Capacity of the Stratum at that depth. In this paper, an actual case is taken where the weathered rock formations are available at shallow depths to study various methods of estimation of Bearing Capacity. Bore Holes were dug, SPT in field and other laboratory tests were done. To supplement the Data Electrical Resistivity Survey is also made. Rock Core Sample is collected and Compressive Strength of rock specimen is also determined. When the stratifications are demarked as either weak/ weathered rock or dense sandy layers, each of the methods vindicates different SBCs. Hence reasonable judgment is required to recommend proper Bearing Capacity. In this paper discussion is presented for proper assessment of SBC.

Key words: Bearing capacity, Khondalytic rock, SPT.

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1. INTRODUCTION

It is very essential to study the characteristics of Sub Soil Strata and predict their behaviour, before taking up any construction. This will help in making economical / optimal design structures as well as helps in recommending measures for preventing from functional failure of structures. Especially, when the sub soil consists of Weathered Rock Stratum, it is rather difficult to assess the methodology to be followed to arrive at the Correct Bearing Capacity of the Stratum at that depth.

In this paper, a specific location where the weathered stratification is present is taken for the Study. Naval authorities are constructing "Officer's Mess quarters" at Malkapuram, Visakhapatnam, wherein the Sub –soils consists of highly weathered rock from very shallow depths. The present study is an attempt to estimate the Bearing Capacity of Highly Weathered Rock formations. It is intended to estimate the bearing capacity in such formations (Highly weathered formations) by various Methods. Adequate data is collected from the site and Laboratory Studies. The following Site Exploration and Laboratory Testing Program are conducted for determining the various Physical and Mechanical characteristics, and to know their load bearing behaviour. The formation at site is a highly weathered rock up to depth of 20Mtrs. But the rock is so weak & fractured that even core samples could not be collected.

2. FIELD INVESTIGATION

Soil Stratigraphy is determined by drilling two exploratory borings 150mm diameter up to nearly 20 Mtrs., using a rotary drilling rig equipment capable of collecting hard rock core samples using 54 mm diameter Nx diamond studded drill bit along with core lock arrangements.Collection of undisturbed samples during drilling were not possible except SPT-samples.

Attempts have been made to collect undisturbed samples below ground level at periodical intervals or a strata change whichever occurs first during investigations and it was not possible as the rock is highly weathered, very weak and friable belongs to Khondalytic origin, until close to termination depth of Bore Hole-1. The Bore Log Details are given in fig. 1 enclosed. Field SPT – Tests Conducted at regular intervals or a strata change in the bore holes.

Trail Pits are also made in this region and for conformation of boring results and to collect block UD-samples. Necessary tests on these samples are carried out.

Electrical Resistivity Survey has also been conducted to supplement the data near the plain area on the hill near Bore Hole-2. While Bore hole drilling is the direct method of sub-surface lithology exploration, Electrical Resistivity sounding is one of the indirect method to reveal the same for more depths with less time. A sounding at one location reveals sub-surface information vertically below it to the required depth. The sounding was conducted using Wenner's configuration and the depth of sounding extended to 20 meters. The survey results were analyzed by Geologist.

Non - destructive test is conducted using rebound hammer in an attempt to estimate rock strengths and mechanical properties[13].

3. LABORATORY TESTING

Laboratory testing Scheme is drawn up and index properties, Compressive Strengths of weak rock samples, megascopic tests on rock samples are conducted.

The following tests were conducted on undisturbed rock block samples:

- Index Properties of Weathered Khondalytic Rock.
- Compressive Strength tests on Dressed Rock Cylinders. One core Sample was collected close to termination depth at BH-1 using 54 mm dia NX – diamond studded drill bit along with core lock arrangements. All necessary Visual/ Physical/ Microscopic/ Megascopic/ Compressive Strength tests/NDT were carried out on these specimens to understand the pertinent characteristics with the help of a competent Geologist. Rock Core Samples are Classified as Metamorphic origin and named as "Khondalyte" and the properties and Geological Information of Rock Core Sample are given in table No:
- NDT using Rebound Hammer at 40% crushing load application on samples.

The Field & Laboratory test results of the tests were as below:

4. FIELD TESTS RESULTS

4.1. Megascopic Properties of weathered khondalyte Rock

The Megascopic Properties of the rock are given in Table 1 below.

Table 1

Colour	**Brownish Red**
Grain & Shape	Coarse grained turned as fine grained
Minerals	Altered feldspars, quartz, Iron and garnets
Grade of Metamorphism	High grade Metamorphic rock changed as soft through weathering. Parent Rock being khondalite (Garnet Sillimanite Gneiss)
Name of the rock	Highly weathered Khondalite

4.2. Geological Information of Parent Rock

Geological Information of Parent Rock is given in Table – 2 here under.

Table 2

S.No.	**Description of Item**	**Bore Hole – 1**
1.	Name of Rock Sample	KHONDALITE (Garnet – Sillimanite gneiss)
2.	Classification (Geological)	Metamorphic Rock
3.	Color	Light Coloured (Leucocratic)
4.	Texture / Structure	Gneissose Structure
5.	Compressive Strength Hard Rock Kg/cm^2	650 *
6.	Permeability	Intact Rock is Impervious
7.	Hardness / Toughness	Indicated from crushing strength
8.	Microscopic Tests (A) On Core sample(Parent Rock) Mineral composition Essentials Accessories Nature or Rock Structure / Texture	 Garnet, Sillimanite, Quartz and altered feldspar. Garnet, Altered fieldspars, Manganese ores and micaceous material Jointing Nature
9.	Engineering uses	Foundations, Dressed blocks (Ancient Temples like Konark and Puri Jagannadh of Orissa).

*Compressive strength of core samples, as core sample is collected at near termination depth in BH-1. Under Unconfined Conditions, 54mm dia Cylinders with L/D ratio 2 was tested in compressive testing machine.

4.3. Laboratory Tests Results

The following tests were conducted.

- Index Properties of Weathered Rock.
- Compressive Strength tests on Dressed Rock Cylinders.
- NDT using Rebound Hammer at 40% crushing load application on samples.

Table 3 Index Properties of Khonadalite Rock

Property	Value
Dry density (kN/m3)	23.15
Saturated density (kN/m3)	23.85
Specific Gravity (G)	2.60
Void ratio (e)	0.123
Porosity (n) %	10.95
Compressive strength (MPa)	3.50

Table 4 Compressive Strength of Rock Specimens at 1m depth of B.H. – I

Samples No.	Diameter cm	Height cm	H/D	Load at failure kg	UCS kg/cm2
1.	5.0	10.0	2	725	36.90
2.	5.0	10.0	2	750	38.19
3.	5.0	10.0	2	700	35.65
4.	5.2	10.4	2	750	35.32
5.	5.2	10.4	2	775	36.50

Table 5 Compressive Strength of Rock Specimens at 1m depth of B.H. – II

Samples No.	Diameter cm	Height cm	H/D	Load at failure kg	UCS kg/cm2
1.	5.1	10.2	2	725	35.49
2.	5.4	10.8	2	825	36.02
3.	5.4	10.8	2	850	37.10
4.	5.4	10.8	2	875	38.21
5.	5.2	10.4	2	725	34.14

4.4. Rebound Hammer Results

NDT using rebound hammer has given a reading between 10 – 14 units, average value being 12. but a reading of 20 units is minimum. Hence it is not useful for weak rocks.

Top Soil Index Properties

Grain size analysis (Gravel = 12%, Sand = 65%, Silt & Clay = 23%)

Consistency limits (LL = 22%, PL – NP Soil, Ip = 0)

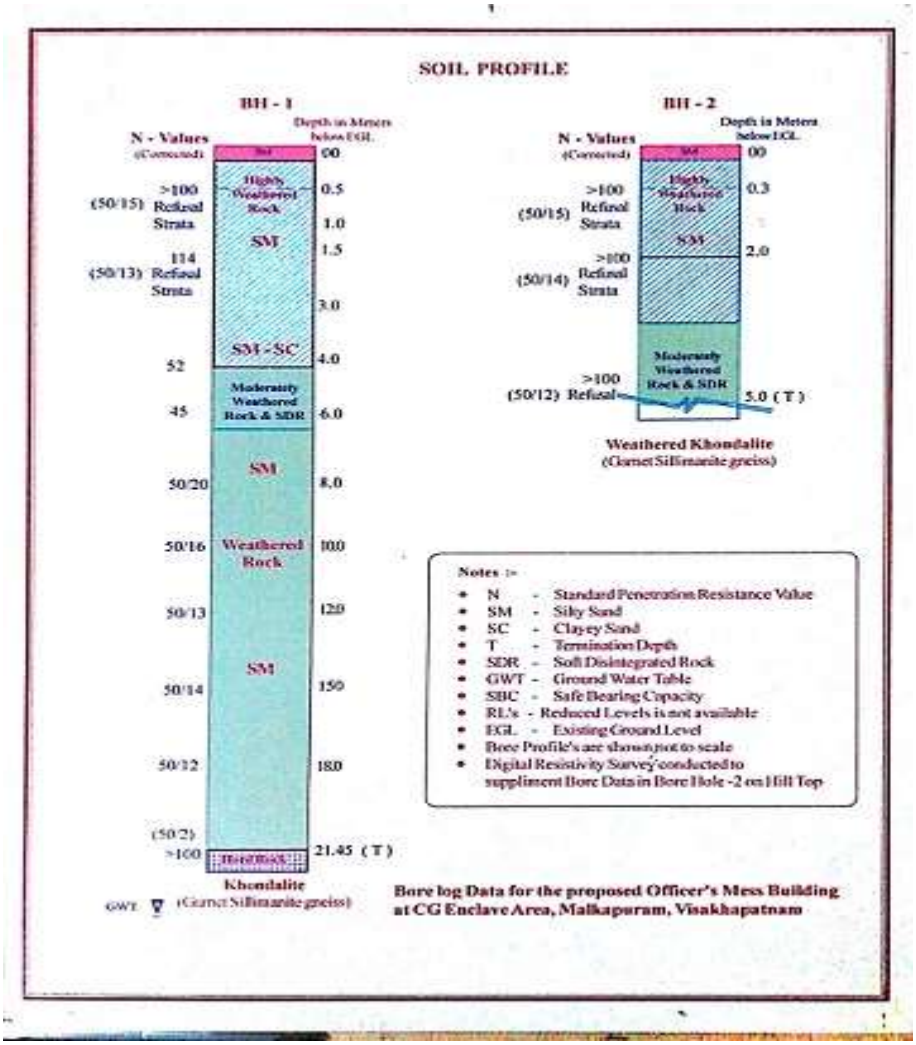

Figure 1 Borehole data presentation

4.5. Estimation of Bearing Capacity by Various Methods

- *SBC calculation based on IS Code IS 6403*: Safe bearing Capacity of an Isolated rectangular footing resting on a cohesion-less soils by taking refusal strata (N=50) into consideration the theoretical estimate[8], when ground water is far below base and width of footing as 1.2m and field density as 2.00g/cm3 is found to be more than 100t/m^2 and net bearing pressure based on permissible settlements for N-values nearly 50 for a settlement of 40mm is net allowable bearing pressure obtained close to 80t/m^2 from graph when GWT is located to be very deep from foundation Level .
- *SBC calculation based on Permissible Settlement (Ref:IS 8009)*: Considering the soil stratum to be a dense cohesion-less Soil, Settlement is calculated per unit pressure from standard Penetration resistance chart Vs Settlement given in IS 8009[4]. Taking conservative N-Value as 40 and width of foundation as 1.2m when GWT is at great depth the settlement may be read as 0.004m for 10t/m2 of applied bearing pressure. Hence for a bearing pressure of 90t/m^2 an expected probable settlement may be calculated as equal to 0.004 X 9 = 0.036m (36mm).
- *Net Allowable Pressure from RMR1 :* Rock Mass Rating for classification No:V description very poor rock, RMR falls is in the range of 0-20 and net allowable bearing pressure may be taken in between 40-55 t/m^2.
- *SBC of Rock from Compressive Strength:* compressive strength divided by a factor of safety ranging from 5-8 is expected to give the safe bearing pressure. For instance compressive

strength of dressed rock specimens are found to be 350t/m^2 and calculated SBC estimated to be 43.75t/m^2.

- *SBC based on semi-empirical methods from SCPT, DCPT and SPT:* Settlements of structures on cohesion less soils such as sand take place immediately as the foundation loading is imposed on them. Because of the difficulty in sampling these soils, there are no practicable laboratory procedures available for determining their compressibility characteristics. Consequently, settlement of cohesion less soil deposits may be estimated by semi-empirical method based on test results from SCPT, DCPT and SPT etc.
- *SBC based on Electrical Resistivity Survey:* Based on the results of ER Survey, the following is the analysis given by Geologist. Table – 6 gives the stratification based on ER Survey Results.

Table 6 Electrical Resistivity Survey Interpretation results

Layer	Thickness (m)	Expected lithology
1.	0.0 – 1.0	Gravel & pebbles
2.	1.0 – 4.0	Highly weathered rock
3.	4.0 – 7.0	Rock boulders
4.	7.0 – 15.0	Fractured rock
5.	15.0 – 20.0	Hard rock with minor fractures

"There is no water table within 20 meters depth. The formations are harder with depth. In the foundation point of view, highly weathered rock is suitable to bear the structures that require 30 t/m^2. The boulder bed can take the load upto 50t/m^2. Fractured rock will have more bearing capacity than the boulders and hard rock still have more bearing capacity than fractured rock. ".

The SPT Values with respect to depth is represented in the Bore Log diagram fig - 1. All the SPT Values indicate the refusal strata. In general, in highly weathered or weak rocks, standard penetration reaches practically the refusal state with less than 450 mm penetration. Nevertheless, the test results provide a relative assessment of the quality of rock. The following are the interpretations which are recommended by (Douglas, 1983):[12-Page-135].

SPT Penetration Results Interpretations for Weathered Rocks[12]:

- Very weak rock when the penetration is 100 – 300 mm for 50 blows.
- Weak rock for 30 – 100 mm penetration for 50 blows.
- Virtual refusal represents medium or strong rock.

Strength classification of intact and jointed rocks based on compressive strength:

Table 7

Class	Description	Compressive Strength Mpa
A	Very High Strength	> 250
B	High Strength	100 – 250
C	Moderate	50 – 100
D	Medium Strength	25 – 50
E	Low Strength	5 – 25
F	Very Low Strength	< 5

5. CONCLUSIONS AND OBSERVATIONS

Drilling of Two Bore Holes of 150mm Diameter upto desired depth. using Rotary Rig at the proposed construction of officers mess building site in coast guard area and other test results and interpretations the following observations have been made.

- Ground water is not found in the investigation depth of 20m from bore hole observations and from electrical resistivity survey conducted in the site.
- Based on field "Standard Penetration Test" results Sub-Soils comprises of highly weathered and very weak rock formations having recorded penetration is between 100mm to 200mm for 50 blows.12, pageNo:135 and said to be intermediate between Dense Soil and very weak rock(strength<5Mpa). According to international standards rock compressive strength < 125psi (nearly 90t/m2 or 9 kg/cm2) are to be regarded as Soils.
- Crushing Strength test results obtained on weathered rock specimens are found to be 350t/m^2 by dividing with a factor of safety 8 is recommended to calculate Safe bearing capacity of rock11 is equal to 43.75 t/m^2.
- Allowable bearing pressures based on permissible settlements1 of 12mm on rocks found to be equal to 30t/m^2 (as given in the Settlement calculations)
- Evaluation of mechanical rock properties13 using NDT-Rebound Hammer (Schmidt Hammer) test are suitable for Rocks having a compressive strength of >10MPa (1000kg/cm2) for weak rocks is not applicable.
- Electrical Resistivity Survey data interpretation is found to be very helpful as a supplemental information for a wide area.This method is included in the code and used in soil investigation of the proposed site9 –Part-2
- Received an e-mail for my query on SBC of weathered rock from CBRI-Roorkee, Scientist stating that "Allowable bearing pressure of weathered rock. can be suggested about 50 t/m2 where RQD is not available and N > 100 as per the latest draft of NBC Section 6, which is under finalization.(enclosed)
- Foliations are observed in the rock samples which are characteristics of metamorphic rocks which have banded or laminated structures. Joints, bedding planes, or foliations are planes of weakness in the rock formation. As geological classification the rock is found to be Khondalite (Garnet Sillimanite Gneiss) in BH-1 is a metomorphic rock type.
- Weathering Conditions: The mineral constituents of rock may be altered by chemical weathering (decomposition) and/or physical weathering (disintegration). The weathered zone may be a few inches to several hundred feet deep it is very undulating on the Hill must be leveled before any construction activity may take place.
- For future investigations it is desirable to conduct load test for the, "Determination of safe bearing pressure" from plate load test is still most practical and proven test for recommending pressures in spite of many limitations. It is recommended that plate load tests be conducted on poor rocks1 where safe bearing pressure is suspected to be less than 100 t/m2

6. RECOMMENDATIONS

- It is recommended to provide Shallow foundations for the proposed Structure. An Isolated footings or Strip/Wall footings are adequate for this situation.
- It is recommended to take Allowable Bearing Capacity of 30 t/m2, for this highly weathered and very weak rock formation for the structural design of foundations. Settlement calculations considering this rock as very dense cohesion less soil indicate that this bearing pressure is expected to cause a probable settlement of 12mm.(from graph)IS-8009(Part-1). Low value of bearing capacities are due to the heterogeneous and foliated nature of this very weak rock

formation (permissible settlement is 50mm for Isolated foundation on sandy or hard clay soils)6.

- Recommended depth of foundation may be taken as 1.5 m below the existing ground level in the flat ground beside play ground, on hilly area located above, in view of undulations, 1.5m depth after site leveling operation of the Ground. Minimum depth of foundation6 in soils specified as 50cm below GL (RL's of the site are seems to be essential requirement for decision making).
- Necessary Steps may be taken to provide good drainage for the proposed site, so that it drains-off any rain-water that may accumulate. It is advisable to provide a one meter plinth protection around the building. GWT is not available hence softening of rock due to ground water may not arise..
- Pre-wetting of the building site is found to be helpful prior to excavations for foundation pits or site leveling of the undulating hilly terrain. The exposed hill vertical surface is very highly weathered must be removed by at least 1 m and benching of slope may be taken up. Softening of weathered rock11 has been observed when exposed to moisture during excavations for investigations.
- Structures to be constructed near BH-1 area, the upper floor roof slabs of the buildings beside play ground may be extended towards the hill side for an economic cutting and leveling of the existing hill.
- Non Destructive Tests like Rebound Hammer for interpretation of mechanical properties of rocks13; Mapping of the ground by Geophysical methods like Electrical Resistivity Survey are -helpful as supplemental information in decision making.9 (II), Hence may be included in future investigations because of the fact that not even one-millionth of soil is tested 12.
- Codal Provision: Safe bearing pressure should be recommended always less than the safe uniaxial compressive strength of lean concrete leveling course of the individual foundations, otherwise richer plain concrete layer should be laid to prepare smooth surface for laying R.C.C. foundations1.
- Codal Provision: In case of R.C.C. strip foundation on heterogeneous soil and rock deposit, longitudinal reinforcement (along wall) should also be provided to take care possible bending moments.1
- Code indicates that Rock is usually recognized as the best foundation material. However, design engineers should be aware of the dangers associated with heterogeneity and unfavorable rock conditions since over stressing a rock foundation may result in large differential settlements or perhaps sudden failure. a separate code1 has been formulated
- (Kind Attention: Structural Design Engineer, about 8, 9, 10)

7. DISCUSSION OUTLINE

The soils exhibited a stratum of intermediate between dense Soils & weathered rock.

Comparison made in calculation of bearing pressures, it is considered as a rocky stratum and also if it is considered as dense sandy soil layer.

No rock core samples could be collected as it was not possible as the rock is highly weathered, very weak and friable. As such electrical resistivity survey is conducted to establish any faults in these rocky layers.

Though the weathered or weak rocks, in general, practice, reaches SPT Values refusal with less than 450 mm penetration. However, the test results provide a relative assessment of quality of rock. Thus in the present case the penetration for 50 blows is around 100 mm – 200 mm indicating very weak rock.

The stratum encountered is intermediate between hard soil and soft rock. If tests are done by allowing samples to absorb water by dripping water on top surface (not dipped in water), its is

Various methods are available for exploration as well as to estimate the Bearing Capacities in weathered Rock formations. In this paper, an actual case is taken where the weathered rock formations are available at shallow depths to study various methods of estimation of Bearing Capacity. Bore Holes were dug, SPT in field and other laboratory tests were done. To supplement the Data Electrical Resistivity Survey is also made. Rock Core Sample is collected and Compressive Strength of rock specimen is also determined. When the stratifications are demarked as either weak/ weathered rock or dense sandy layers, each of the methods vindicates different SBCs. Hence reasonable judgment is required to recommend proper Bearing Capacity. In this paper discussion is presented for proper assessment of SBC showing far lower strengths. If we allow water to soak into sample by dripping from top until the wetness is observed at outer surface and test for its compressive strength the values are quite less.

When the stratifications are assessed as either weak rock or dense sandy layers, each of the type vindicates different SBCs. One shall be careful in recommending SBC's as lesser value of SBC increases the cost of foundations and higher values may result in brittle failure of foundations. In this paper discussion is presented for proper assessment of SBC.

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