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RESEARCH ON: FOUNDATION ANALYSYS OF RESIDENTIAL BUILDING AT BHUGAON

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Abstract: The topic at hand explores the significance of strength and total structural load, along with a formula for evaluating the stability of rock foundations. Designing foundations for large structures is a challenging and time-intensive undertaking due to the multitude of load combinations and the simultaneous influences of diverse equipment and installations. The reliability of these engineering structures is vital for the prosperity of local economies. Irrespective of soil conditions, all buildings are classified within the third geotechnical category due to the substantial investments and high costs associated with their construction. Building foundations must meet or surpass safety standards to ensure effective coordination between equipment and nearby objects. Adhering to rigorous requirements regarding overall vertical displacement of the foundation and differential settlements between different foundation locations is crucial for optimal equipment performance. To assess the strength of foundations, experimental evaluations of rock qualities such as compressive strength, along with comprehensive structural load calculations, are conducted. These analyses play a crucial role in examining the robustness and dependability of rock foundations for large structures.

***Index Terms* - Foundation Analysis, Residential Building, Soil Investigation, Geotechnical Engineering.**

1 INTRODUCTION

The International Society for Rock Mechanics organized the inaugural Conference on Rock Mechanics in 1966 in Lisbon, while the definition of rock mechanics was established by the Committee on Rock Mechanics of the Geological Society of America in 1964, followed by the Committee on Rock Mechanics of the National Academy of Sciences in 1966.

Rock mechanics is a multidisciplinary field that combines theoretical and applied sciences to study the behavior of rock in response to its environmental conditions. It encompasses various types of excavations, including both surface and underground operations. The principles of rock mechanics are crucial in mine planning and design, aiding in the selection of mining methods, determination of optimal slope angles, design of support systems, and establishment of drilling and blasting parameters.

Another important aspect of rock mechanics focuses on the engineering properties of rock and their application in addressing rock-related problems. Geotechnical studies are essential for underground structures in rock, which are naturally occurring or excavated subsurface openings supported primarily by the surrounding rock without additional support systems within the openings. To ensure the proper design and stability evaluation of such structures, it is vital to assess the stresses and deformations induced by external or body loads and evaluate the structure's ability to withstand these forces and deformations.

1.1 Rock Material Classification

1.1 Rock Material Classification

The process of rock material classification involves several essential steps, starting with the identification of rock units present at the investigation site. These units are then described using appropriate classification elements, followed by a performance assessment to establish desired performance objectives for engineering applications.

Identification of rock units:

A. Describing rock units using classification elements:

i) Rock material properties
ii) Rock mass properties
iii) Geohydrologic properties

B. Selection of performance objectives:

i) Hydraulic erodibility in earth spillways
ii) Excavation characteristics
iii) Construction quality
iv) Fluid transmission
v) Rock mass stability

In order to ensure proper design and evaluate the stability of underground structures, it is crucial to have a comprehensive understanding of the mechanical properties of the rock. These properties provide valuable insights into how the material deforms or fails when subjected to external forces. Key mechanical properties include tensile strength, compressive strength, shear strength, creep or time-dependent properties, and strain or deformation properties. Various static testing methods can be employed to determine these properties, including uniaxial (unconfined) compressive, tensile, shear, and flexural strength tests, as well as triaxial compressive and shear strength tests. Additionally, elastic constants such as the modulus of elasticity and Poisson's ratio can be derived from the stress-strain relationship using uniaxial and triaxial testing methods.

1.2 Problem Statement

Traditionally, the study of rock mechanics has been a collaborative effort between civil engineers, military engineers, and mining engineers. These professionals have been actively involved in investigating the behavior of rocks for various construction and mining projects.

Civil and military engineers have relied on rock mechanics to design and construct deep foundations for structures like dams, buildings, and bridges. They have also utilized this knowledge to create rock cuts for highways, railways, and canals, as well as construct rock tunnels for power supply or vehicular use.

On the other hand, mining engineers have a particular interest in understanding the behavior of surrounding rock in mining operations. This understanding helps them extract materials from beneath the Earth's surface efficiently and safely.

One of the initial sources of physical evidence for studying the subsurface rock is exploratory drilling. Rock cores obtained from these drilling activities provide valuable insights into the nature of the underlying rock formations. These cores consist of intact rock materials and offer indications of existing discontinuities, such as fractures or faults. Thus, accurately classifying these rock cores is a crucial step in comprehending the expected behavior of the rock during and after construction or mining operations.

Designing a structure within rock presents various challenges, which include the following:

- Limited information on in-situ rock mechanical properties: Prior to underground excavation, there is often a scarcity of data regarding the mechanical properties of the rock. This lack of information makes it challenging to accurately assess the rock's strength and behavior, which are crucial for designing a safe and stable structure.
- Complex stress and deformation calculations: Calculating the stress and deformation distribution within different sections of a rock structure can be difficult. Rocks are heterogeneous materials, and their behavior under load can be highly nonlinear and influenced by various factors such as discontinuities, joint patterns, and geological conditions. Obtaining precise predictions for stress and deformation requires sophisticated modeling techniques and a thorough understanding of rock mechanics.
- Determining load calculations for reinforced concrete structures: When designing structures within rock, it is essential to determine the appropriate methodology for calculating structural loads, particularly for reinforced concrete elements. The loads acting on the structure, such as dead loads, live loads, and environmental loads, need to be accurately estimated to ensure the structural integrity and safety of the rock-based construction. Accounting for dynamic loads, long-term effects, and possible rock movements further complicates this task.

1.3 Objectives

- Evaluating the integrity of subsurface rock formations.
- Recommending appropriate foundation options for the intended location.
- Assessing the structural resilience of the underlying bedrock.

1.4 Future Scope

The current study will provide valuable insights for various future activities related to foundation design, including but not limited to:

- Analysis of Underground Strata: Conducting a thorough analysis of the underground strata to evaluate its geological and geotechnical characteristics.

- Foundation Type Recommendation: Providing expert suggestions regarding the most suitable type of foundation based on the results of the underground strata analysis.
- Ensuring Residential Building Safety: Ensuring the safety and structural integrity of residential buildings by selecting appropriate foundation types that account for the specific underground conditions.
- Facilitating Slope Stability Analysis: Assisting in the assessment of slope stability by considering the information obtained from the underground strata analysis.
- Evaluation of Rock Engineering Properties: Gaining valuable insights into the quality and engineering properties of the rock formations, enabling a better understanding of their behavior and implications for construction projects.

1.5 Literature Review

1. **Jianping Li & Ernesto Villaescusa (2005)** New relationships have been established between critical strain and modulus and between critical strain and compressive strength for intact rock and rock masses.[1]

2. **G.Tsiambaos, George Tsiambaos and Harry Saroglou (2009)** original correlations of intact rock properties have been proposed in order to determine indirectly the uniaxial compressive strength and modulus of elasticity of intact rock.[2]

3. **Lianyang Zhang (2015),** involves the methods for determining RQD and evaluated the empirical methods based on RQD for estimating the deformation modulus and unconfined compressive strength of rock masses.[3]

4. **Bashar Tarawneh (2016)** The use of ANNs to predict N60-value using CPT data was assessed in this paper. A back-propagation neural network was used to examine the feasibility of ANNs to predict the N60-value.[4]

5. **Ravi Sundaram (2017)** studied the geotechnical issues in difficult or unusual ground conditions is the key to developing engineering solutions to overcome the problem.

6. **Aria Mardalizad, Andrea Manes (2017)** studied the mechanical response of a middle strength rock, namely Pietra sandstone, is assessed both numerically and experimentally under unconfined compressive loading condition.[6]

7. **Bo Wu & Wei Huang (2020),** carried out uniaxial compression occurs on the brittle tensile failure occurs in the composite stratum, and the strength is between the soft rock and hard rock.[7]

8. **Abiodun Ismail Lawal & Sangki Kwon (2020)** shown that the rock mechanics/geoengineering problems are highly characterized with limited data and knowledge, and site-specific.[8]

9. **Zhenjiang Liu, Chunsheng Zhang, Chuanqing Zhang, Huabin Wang, Hui Zhou & Bo Zhou (2021)** In Their study they conducted a laboratory study on amygdaloidal basalt, using a Synthetic Rock Mass (SRM) model that combined Discrete Fracture Network (DFN) and Finite-Discrete Element Method (FDEM) techniques. They examined how the heterogeneity of the amygdale structure and sample size influenced the mechanical properties of basalt, aiming to enhance understanding of its behavior.[9]

10. **Xuefan Wang, Peng Peng, Zhigang Shan, & Zhongqi Yue (2021**) utilizated of digital factual data in real time series along two adjacent drillholes.[10]

1.6 Methodology

Site Visit for Data Collection in Residential Building:

1. A visit was conducted to the residential building site to gather relevant information for the study.
2. Review of Existing Methods: Core Logging and RQD Analysis:
   The core logging method was examined as a means of analyzing rock samples obtained through exploratory drilling. RQD (Rock Quality Designation) was determined by assessing the length of intact rock pieces exceeding a specified threshold size (e.g., 10 cm). The ratio of the total length of intact rock to the total length of the core was used to calculate RQD.
3. Utilization of Rock Mass Classification Systems:
   Various rock mass classification systems, such as the Rock Mass Rating (RMR) system or the Q-system, incorporate RQD as one of the parameters to evaluate the overall quality and behavior of the rock mass. These systems provide a comprehensive assessment of the rock mass based on multiple parameters, including RQD.
4. Testing for Rock Properties:
   Several tests were conducted to determine specific rock properties. These tests included measuring specific gravity, dry density, bulk density, water absorption, porosity, unconfined compression strength, point load index, modulus of elasticity, and

Poisson's ratio. These parameters play a crucial role in understanding the characteristics and behavior of the rock material.

1.7. Site Selection

In our initial research, we conducted literature reviews and explored online data, but unfortunately, we did not find any available data specifically addressing the foundation analysis of residential buildings in Bhugaon. Consequently, we selected this site, located in Bhugaon, Pune district, Maharashtra, India, as the focus of our present study.

1.8 Field Investigation

Following the pre-survey investigation of the site, our team maintained continuous correspondence with the company involved before commencing the field investigation. On October 8th, 2022, we conducted a surface survey at the site and extracted core samples using a Rotary Drilling Machine and the Core Cutting method. During this visit, we made various observations that were relevant to the foundation analysis. After discussions with the company, we requested the actual core samples for further analysis. These samples were taken from the same location to determine the depth of fresh rock along the alignment of the proposed building. On April 13th, 2023, we conducted the field investigation with the guidance of Dr. P. D. Sable. The investigation included the classification of cores based on their respective locations, organizing the core samples in boxes, sequencing the core logs in the boxes, selecting appropriate core boxes, washing the core samples for accurate interpretation, and measuring each core's lithological characters according to established laboratory norms.

1.7 Methods for Analysis

Different rock mass classification systems focus on different factors, making it advisable to use at least two approaches at any given site during the project. The following methods can be employed:

- Rock Quality Designation (RQD)
- Rock Mass Rating
- Rock Structure Rating
- Rock Tunneling Quality Index

1.8 Rock Quality Designation (RQD)

Rock Quality Designation (RQD) serves as a preliminary indicator of the extent of jointing or fractures within a rock mass. It is expressed as a percentage of the drill core length measuring 10 cm or more. High-quality rock typically exhibits an RQD value exceeding 75%, while low-quality rock falls below 50%. Various definitions exist for RQD, with the most widely adopted formulation by D. U. Deere in 1964.

According to Deere's definition, RQD is calculated by determining the percentage of solid core recovery exceeding 100 mm in length along the centerline of the borehole core. This calculation excludes portions of the core that are not hard or sound, even if they meet the 100 mm length criterion. Originally developed for use with core diameters of 54.7 mm, RQD finds important applications in estimating the support required for rock tunnels and bridges. However, it is important to consider certain limitations, such as concerns related to joint orientation, tightness, and the presence of infilling material. RQD alone provides a limited description of the overall rock mass and is primarily focused on assessing core quality.

To ensure accurate measurement of core length and calculation of RQD, it is essential to follow proper procedures as outlined in Figure 3.4. RQD is defined as the quotient specified in the provided figure.

$$RQD = \frac{\sum Length\ of\ Core\ Pieces\ > 100\ mm}{Total\ Lenght\ of\ Core\ Run} \times 100\ \%$$

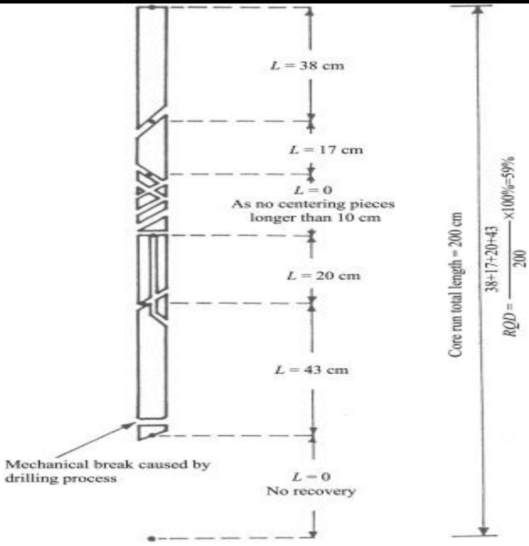

Fig. 3.4 General layout of RQD design.

RQD	Rock Mass Quality
<25 %	Very Poor
25-50 %	Poor
51-75 %	Fair
76-90 %	Good
91-100 %	Excellent

Table 3.1 Classification of RQD Index of Rock Mass Quality index

1.9 Core Logging for Rock Engineering

The Core Logging Committee, part of the South Africa Section of the Association of Engineering Geologists, initiated the development of a specialized guide for core logging .This guide was specifically designed to cater to the requirements of rock engineering in South Africa. The primary goal was to develop a comprehensive and widely accepted resource that fulfilled the following criteria:

a) Sufficient Detail: The guide should provide comprehensive information to ensure that the resulting core log contains all the necessary data for accurate interpretations of geological and rock engineering conditions related to typical engineering structures.

b) Practicality: The guide should strike a balance between providing necessary detail and avoiding excessive complexity, ensuring that it is practical and feasible to implement.

c) Standardization: The guide should consider and incorporate existing standardized procedures to the extent possible while minimizing variations, promoting consistency in core logging practices.

The guide provides a clear distinction between the borehole log and the core log. The borehole log encompasses relevant information related to the drilling process and the recovered core. It includes details about the drilling equipment, tools used, materi als employed, progress achieved, challenges faced, and tests conducted. Within the borehole log, the core log specifically focuses on describing the properties and characteristics of the retrieved core.

By adhering to this comprehensive guide, practitioners in rock engineering can effectively record and document essential information related to core logging, enabling accurate assessments and interpretations for geological and rock engineering purposes in South Africa.

1.10 Proposed Method of Core Logging

The objective of core logging is to provide a visual representation of the cores and allow for inferences to be made regarding the behavior of the actual rock mass. Only parameters that are significant to the rock mass behavior, enable correlations between boreholes, or contribute to a better understanding of the site's general geology are recorded.

Whenever possible, classifications with five class intervals are adopted, as they often reveal the extremes, middle, and two intermediate values within a group. Visual criteria or simple field tests using commonly carried equipment like a knife or geological pick are used to define the class interval limits.

Since many boreholes encounter or pass-through soil strata, descriptions of these soil horizons are an integral part of the borehole log. A highly regarded soil profiling system proposed by Jennings et al. has gained wide acceptance in Southern Africa. It would be advantageous to adopt a similar and compatible system for core descriptions to ensure consistency when comparing soil and rock profiles.

However, the existing soil profiling system was not originally designed for rock descriptions, and a direct extension of it does not provide an adequate description of the rock mass. Therefore, modifications and adaptations have been made to the soil profiling system to make it applicable to rock. The resulting system remains compatible with the soil profiling system but differs significantly in detail.

The core description includes not only the description of rock material but also the discontinuity surfaces and fracture filling materials. Although discontinuity surfaces and their filling play a crucial role in rock mass behavior, they are often given a secondary role in the core description. To address this, a three-part core description is proposed:

- The primary description focuses on the parameters that influence the basic properties of the rock mass.
- In addition to the primary description, a supplemental description of the discontinuity surfaces may be provided.
- Lastly, it may be pertinent to include a description of the fracture filling.

Depending on the specific engineering problem, it may be decided to include only the basic rock mass parameters, or to incorporate two or all three parts of the description. The core log should provide a factual description of the core, clearly distinguishing any interpretations or assessments made by the core logger from the factual information. It is acknowledged that assessments and interpretations are best made when examining the core in its fresh and least disturbed state. The core logger is often in a favorable position to make such assessments and interpretations, and excluding them from the core log would diminish its value.

1.11 Rock Mass Rating (RMR)

Rock Mass Rating (RMR) is a widely used classification system for assessing the quality and stability of rock masses. It provides a numerical value that represents the overall rock mass quality based on several key parameters. RMR was developed by Bieniawski in 1973 and has since been widely adopted in rock engineering and geotechnical practices.

The RMR calculation takes into account five main parameters:

1. The Uniaxial Compressive Strength (UCS) of the rock material.
2. Rock Quality Designation (RQD), which indicates the extent of jointing or fractures in the rock mass.
3. Spacing of Discontinuities (S), which measures the density and distribution of fractures or joints.
4. Condition of Discontinuities (RMR), which assesses the state of the fracture surfaces and the presence of infilling materials.
5. Groundwater Conditions (G), which considers the presence and level of groundwater in the rock mass.

The RMR formula is as follows:

RMR = (0.5 * UCS) + (0.1 * RQD) + (0.05 * S) + (0.1 * RMR) + (0.15 * G)

The UCS is measured in MPa, and RQD, S, RMR, and G are given on a scale from 0 to 100.

The RMR value obtained from the formula corresponds to different rock mass classifications, ranging from very poor to excellent. The higher the RMR value, the better the rock mass quality and stability.

RMR provides a valuable tool for preliminary rock mass assessment, design of support systems, and predicting potential geotechnical hazards in rock engineering projects.

1.12 SAMPLE CALCULATIONS AND RESULT

Calculations for Safe Bearing Capacity placed on rock (IS 13365 and IS 12070)		
Foundation Depth (m)		**6.0 m**
Borehole ID	**BH-4**	
Parameter	**Value**	**Rating**
Strength of intact rock (MPa)	175	12
Rock quality Designation	15	3
Spacing of discontinuities	Moderate	10
Conditions of discontinuities	1mm-5mm	6
Ground water condition	Wet	7
Adjustment for joint orientation	Fair	-7
Total		**31**
According to IS 12070 (table 3) classification of rock	**IV**	
Net safe bearing capacity qns T/m2	**135-48**	
Recommended Safe Bearing Capacity 80 T/m^2		

SAMPLE CALCULATION OF ALLOWABLE BEARING CAPACITYSAFE BEARING PRESSURE FROM RMR CRITERIA (BH-1)

1.13 Conclusion

In this project, we have successfully completed various stages, including the finalization of the site area and the intriguing process of core extraction. We have gained a comprehensive understanding of the rock quality designation process and conducted detailed laboratory analyses on the rocks, as well as soil grain size analysis. The tests performed on the rocks included specific gravity, dry density, bulk density, water absorption, porosity, unconfined compression test, point load index, modulus of elasticity, and Poisson's ratio. Similarly, the grain size analysis of soil-sediment provided information their different sizes and based on that the nature of material viz., gravel, sand, silt, clay, suspension etc. category and the free swell index based on the IS classification.

Based on the analysis of borehole sample of batches 1, 2, 3, and 4, all the boreholes have exhibited excellent conditions for foundation purposes. The subsurface profile revealed the presence of two main layers. Layer-I consists of filled material with boulders, predominantly comprising Deeply weathered basalt (known as *murum* in local language) and basalt rock boulders. This layer extends from the ground surface to a depth ranging from 3.0m to 6.0m below ground. It is important to note that the thickness of the filled up/boulder layer may vary during actual excavation.

While, the Layer-II is underlain by Layer-I, which constitutes the basalt bedrock. In the boreholes, this layer was found to be completely weathered to slightly weathered compact or amygdaloidal basalt. The core recovery ranged between 4% and 98%, with Rock Quality Designations (RQD) ranging from nil to 91%, respectively.

Therefore, considering the above-mentioned findings, it is recommended to install spread/raft foundations directly on the natural strata encountered at the site. The allowable bearing capacities of these strata are sufficient to support such foundations.

Overall, this project has provided valuable insights into the site's rock and soil characteristics, allowing for informed decisions regarding foundation design and construction. The comprehensive understanding gained from the investigations and laboratory tests will contribute to the successful implementation of the foundation project.

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