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***Review Paper***

# Selection of geological parameters for design of footings on basaltic rock

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## Abstract

*Infrastructure development is part of social and national development. Various highway and railway projects consist of tunnels and bridges in the state of Maharashtra. As we are developing the infrastructure projects, various geological and design issues have been faced by project design and civil construction team. Geologically Deccan traps in the state of Maharashtra consist of Basaltic rock with high unconfined compressive strength (UCS) (70-250MPa). Based on Geological and Geotechnical investigation, project alignment and structural components are finalized. The physical and geo-mechanical properties on the recovered rock samples are determined and the design parameters are estimated. Based on the various bridge foundation project issues in Deccan trap, it is observed that chances of foundation damage cannot be ruled out due to high variation in UCS value of basalt rock. It is also observed that variation in rock class during the investigation stage and actual construction stage. In some projects in Deccan trap region, rock mass classification is done on the basis of RQD only. Total core recovery factors (TCR) is not considered and the rock mass data is analysed. But during construction stages design parameters determined are interpreted on a different scale. In this paper provisions in Engineering standard codes are reviewed and an attempt is made to propose practical solution for geological and foundation design issue in basaltic rock.*

**Keywords:** Foundation footing, rock mass classification, rock class, compressive strength, safe bearing capacity (SBC).

## Introduction

Basalt rock is an igneous rock which spreads to about 500000 square kilometer of India. In western part of area the basalt rock is known as Deccan trap. The Deccan Traps are formed about 66.25 million years ago due to series of volcanic eruptions for long time about 30000 years; at the Western Ghats and Arabian Sea. Basalt having specific gravity in the range of 2.7–3.3g/cm$^3$, average porosity of 1.28%, and compressive strength up to 3000kg/cm$^2$have strong resistance to weathering. As per geotechnical & geological parameters insitu rock strength varies from very hard to poor (grade 1 to IV) in nature[1].

Engineering properties of insitu rock are determined from laboratory tests on samples collected by a drilling core, block samples from outcrops or exposures along existing cuts. Engineering properties of intact rock depends on the property of mineral structure, fracture, foliation, bedding of strata and thus for the intact rock mass, considering the discontinuities is all the more important. For the better assessment of engineering properties of rock mass, the results of laboratory test and field observations of in situ rock mass are considered together. It is not necessary that engineering property of the rock mass is same, as that measured on rock core sample in the laboratory. But Project design is always based on rock properties observed during investigation and rock mass classification.

In most of cases, interpreted parameters proposed in design for footing differ from the actual parameters of in situ rock. It is also observed that various engineering standard codes lead to different interpretations for the same properties as the guidelines are generic in nature. The engineering design as per standards and codes based on geo-mechanical properties of observed samples and actual site geo-mechanical parameters might be different. In this paper, the limitations of interpretation of parameters as per standard codes for footings are discussed and suggested interpretation based on RQD for better understanding. It is emphasised that the interpretations for geological classification system for the tunnel and foundation design purpose need review.

## Rock Mass Classifications

Ritter[2] had observed the need of detailed rock mass properties for civil and geological purpose and tried to find the rock properties for tunnel design and support system to stabilize the civil structure. Later on depending on project case studies and engineering requirement Wickham et al.[3], Bieniawski[4,5] and Barton et al.[6] introduced the rock mass classification for various rocks. Researchers have proposed different rock mass classification systems based on various parameters that impact the rock behaviour under stress but with minor deviation.

As such, it was recommended to use more than one rock mass classification methods during the early stages of project sites. Presently Rock mass rating (RMR) and Barton's Q value are preferred for determining rock mass classification.

Bieniawski[4] proposed the for jointed rock mass, the Rock Mass Rating (*RMR*) system, also known as the Geo-mechanics Classification system. Bieniawski[5] had updated the rating system for different parameters of the RMR system based on worldwide project case studies. Here the RMR classification discussed is the modified version[5]. The RMR value of rock mass is based on the six geological parameters of rock mass mentioned below: i. Uniaxial compressive strength (UCS) of rock sample, ii. Rock Quality Designation (RQD), iii. Spacing of discontinuities, iv. Condition of discontinuities, v. Groundwater conditions and vi. Orientation of discontinuities.

RMR based approach gives weight age for all above parameters including UCS appreciating the impact of joint pattern and weakness introduced by weathering impacting project apart from seepage effects. UCS of Basalt alone leads to very high SBC and needs proper application of factor of safety.

## Determination of Design parameters

Based on geo-mechanical properties of rock, design parameters such as ultimate bearing capacity of rock and safe bearing capacity are finalized. Methods adopted in Selection of design parameters are also highlighted.

**Bearing Capacity of Rock:** Bearing capacity of foundation may be estimated using different methods adopting RMR, UCS or RQD as governing parameter. Some of the relevant methods available in literature for footings on rock are given below:

RMR method: The relationship between RMR and Net Safe bearing pressure is given below in Table-1[6]. It can be seen that higher the RMR higher is the SBC. The RMR value to be considered is the average RMR for specified depth based on the foundation dimensions. Lower value of RMR in the influence zone has to be considered for the foundation, if one fourth or more part of foundation dimension has lower value of RMR. With the SBC arrived at the settlement does not exceed 12mm. Due to limitations of settlement; the SBC should not be increased even if intact rock encountered locally in the zone.

**Table-1:** Net Safe Bearing Pressure Based on RMR[6].

| Rock mass Class | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| RMR | 100-81 | 80-61 | 60-41 | 40-21 | 20-0 |
| Net safe bearing Pressure qns (t/$m^2$) | 600-448 | 440-288 | 280-151 | 145-90-58 | 55-45-40 |

**Indian Standard Code Method based on UCS of rock:** Safe Bearing Capacity (SBC) of Rock is evaluated using the Equation-1 per IS code.

qns= qc $N_j$ (1)

qc = average uniaxial compressive strength of rock cores, $N_j$= empirical coefficient depending on the spacing of discontinuities.

**Table-2:** Value of $N_j$.

| Spacing of Discontinuities (cm) | $N_j$ |
|---|---|
| 300 | 0.4 |
| 100-300 | 0.25 |
| 30-100 | 0.1 |

Settlement evaluated using IS codal provisions ensures value less than 12mm as stated earlier.

However, it is necessary, to restrict the allowable bearing pressure. The Eurocode 7 presents charts for estimating allowable capacity of pad square foundations based on the classification of rock under four groups.

**IRC method based on UCS of rock:** IRC 78[7] proposes following Equation 2 for determining of SBC using UCS.

$$SBC = \frac{UCS}{20} \tag{2}$$

And recommends 3 MPa as limiting value for SBC.

**RQD Method:** Peck[8] has given correlation between RQD and SBC as shown in Figure-1.

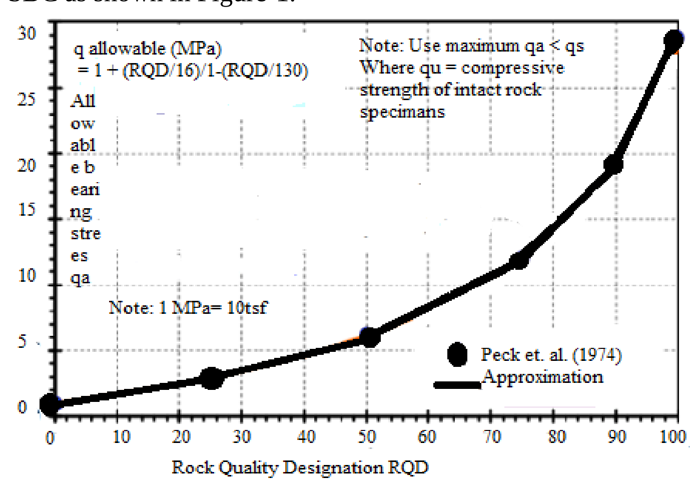


**Figure-1:** Correlation between RQD and SBC[8].

**Limitations of Foundations Bearing on Rock:** Different Engineering Standard Codes having different values for selection of SBC and given below: i. RMR method needs a thorough understanding of rock mechanics principles and implications of the parameters involved. RMR gives 0.6 MPa as maximum safe bearing capacity. ii. IS code method leads to very high bearing capacity which is generally restricted from local considerations. iii. EURO-7[9] code gives some guidelines for restricting SBC. No actual calculation scheme or requirement specified for settlement calculation. Settlement is less than 12mm is stated. iv. IRC 78[7] proposes 3 MPa as limit on SBC value.

**Differences in Rockmass behaviour in Tunnel and in Footing:** Attempts are made with different approaches to arrive at bearing capacity of rock mass. These are similar to the analysis of tunnels adopting rock mechanics principles. RMR is widely used for this purpose. In the interpretation of RMR parameters, complexity arises on account of applying the principles well suited for tunnel being applied to foundation analysis.

In tunnel, the stress imposed by overburden is resisted by combined action of reduced rock mass strength with induced deformation, along with the mobilisation of strength of shotcrete, rock bolt etc. Here inherent strength of rock is utilised in sharing a substantial part of the imposed stress. The share of resistance of other components is as per their stiffness and is generally applied as per RMR of rock mass. The support system is devised based on RMR.

Stress imposed by super structure in case of foundation, is resisted by rock mass whose stiffness depends on jointing pattern, UCS, RQD, weathering and water table. The sum of ratings of these parameters is determined and indicated as RMR using the same guidelines for tunnel. The SBC is calculated as a function of this RMR.

Whereas in tunnel the stress is applied to lining subsequent to deformations in rockmass reaching equilibrium status, in foundations the stress is applied to rock mass through footing concrete and deformability of rock governs the subsequent deformations. As such different interpretations of parameters in determination of RMR for foundations are essential.

## Assessment of Parameters for RMR

Procedure for assessment of parameters involved in determination of RMR is given below.

**UCS of Rock piece:** The UCS is determined as per IS 9143[11] using rock cores with regular geometry having length/diameter ratio as 2. UCS can also be correlated with point load index determined as per IS 8764[12]. Zhang[13] has suggested the Equation 3 to get strength reduction factor SRF, using RQD.

$$SRF=10^{(0.013RQD-1.34)} \quad (3)$$

For foundations relevant and governing parameter for UCS is also considered as PCC strength or concrete strength of footing.

**RQD:** RQD is determined according to IS 11315 part 11 [14] from Equation-4.

$$RQD = \frac{sum\ of\ \ core\ piece\ lengths > 10\ cm}{Total\ drill\ run} \quad (4)$$

As per IRC 78[7] RQD is referenced as per Equation-5

$$RQD = \left(\frac{CR+RQD}{2}\right) \quad (5)$$

For determination of certain coefficient for pile.

RQD is also assessed based on joint volume as per Equation-6

$$RQD=115-3.3\ JV \quad (6)$$

**Ground water condition:** Ground water condition is assessed as ratio of joint water pressure/major principal stress, depending on water table.

**Spacing of discontinuity block size:** Joint count in a unit length shall include bedding planes, foliations, cleavages apart from well-defined sets of systematic joints. Spacing is determined as unit length/Joint count. Joint spacing S, is measured as perpendicular distance between adjacent discontinuities and is given by Equation-7.

$$S=L\ \sin\theta \quad (7)$$

Where, L= length measured along the core axis, ɵ = Acute angle subtended by joints with core axis, In case of weathered rock, judgment is required for determining joint spacing.

**Condition of discontinuity:** Schmidt hammer is used to determine strength of intact rock. It is generally assessed based on Core Recovery and Condition of rock mass weathering is described as per a convenient scale of C.R., RQD and for assigning to rating.

**Orientation:** Orientation of discontinuities is measured using protractor relative to core axis or using bore hole cameras.

The problem faced while assigning the ratings needed for above parameters is due to the absence of specific guidelines. Many times, different values are assigned for same parameter. Codes specify use of intact rock UCS, for assigning rating, when interpreted by different personnel ratings differ with use of UCS of intact rock, weathered rock or concrete strength.

For foundation, however, state of weathering based value is apparently relevant and cognizance of weathering is imperative. Likewise, spacing between discontinuities of weathered rock, where, guide lines, based on Core recovery or RQD codes could be evolved needs clarity. An attempt is made here to focus on these aspects in the suggestions. Many times, it is not possible to physically check the core-boxes and the analysis is to be based on the high quality photos. The spacing between discontinuities shall be related to RQD for ease of understanding. The water table fluctuates as per season and may need to be considered conservatively at Ground Level.

On the basis of above, it is proposed to restrict the crushing strength of rock as per IS code 14593[15]. Rating suggested for spacing between Discontinuities based on RMR value as well as Condition of discontinuities for washed sample, which would be helpful in finalizing the rock class based on drilling data for other hard rock strata also. Suggestions are indicated in Table-3 for contributing to RMR.

**Table-3:** Suggestions for interpretation of RMR parameters.

| Parameter | Criteria | Codal provisions | Suggestions |
|---|---|---|---|
| UCS | Value Measured | As per IS 13365 Part 1 Annex B[16] Guidelines UCS of Sample considered as per IS 9143:1979[17]. The minimum value in the influence zone is suggested as representative value restricted upto crushing strength of concrete. Similar approach is given in IS (14593 pile code)[15]. | If UCS value is available for any run, minimum of UCS and concrete strength shall be considered for RMR. In the absence of UCS values, instead of minimum value within zone of influence the minimum value shall be considered, but within same layer. The weathering state of layers shall be differentiated based on RQD as below.<br>RQD 10 – 25 – Completely weathered rock.<br>RQD 25 – 50 – Highly weathered rock.<br>RQD 75 – 100 – Slightly weathered / Fresh rock<br>For rock having RQD <10, SBC shall be worked out considering it as IGM having SPT N as refusal (N >= 50). |
| RQD | Value Measured | As per IS 13365 Part 1[18] Guidelines, RQD calculated as per standard practice based on site observations. | Rating shall be considered based on RQD calculated as per standard practice, from core box study, with due weight age for mechanical break. |
| Spacing between Discontinuities | Run length (m)/Number of joints | As per IS 13365 Part 1[19] Guidelines, visual observation for marking the spacing upto the CR>50 with rating as 10. For CR<50% where such measurement are not possible conservatively RMR considering spacing as very closed with rating as 5. | Rating for Spacing between Discontinuities I related to RQD as:<br>RQD 90-100; rating for discontinuity spacing 20<br>RQD 75-90; rating for discontinuity spacing 15<br>RQD 50-75; rating for discontinuity spacing 10<br>RQD 25-50; rating for discontinuity spacing 8<br>RQD < 25; rating for discontinuity spacing 5 |
| Condition of discontinuities | Interpreted value | As per IS 13365 Part 1[14] Guidelines, visual interpretation of cores majority of the joints shows clay gauge and some cases it washed. As such for this rock mass sicken sided wall rock surface has been considered and rating of 10% small pieces. | For low RQD zones, Rating shall be considered as 10 if clay gauge is seen. |
| Ground water condition | Joint water pressure and Major principal stress | As per IS 13365 Part 1[14] Guidelines, joint water pressure/major practical stress, with WT at G.L. is considered for arriving at rating for ground water condition conservatively water condition as G.L. There is no ambiguity in the clause for 13365-Part-1. | Water pressures corresponding to water table at GL, shall be used to determine the ratio of joint water pressure and major principal stress and rating interpreted. |
| Adjustment of joint orientation | Core box | As per IS 13365 Part 1[14], if CR is100%, orientation of joints is as per actual measurements. | If core are not available for inspection and interpretation, the strike and dip orientation of joint is considered as unfavourable with rating of (-15%). If the core recovery is 100% orientation of joints is as per measurement of values on core pieces |

## Conclusion

Suggestions for interpretation and modification of engineering parameters are indicated based on various case studies of project in different site conditions, best quality and economical practices. On the basis of above suggested recommendation, rock class can be finalised more realistically using the geotechnical investigation data and arrive at appropriate project design, and save project cost. The suggestions will be relevant for other projects in India.

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