ENGINEERING BEHAVIOUR AND CLASSIFICATION OF WEATHERED ROCKS

By

ANAND SWAROOP GUPTA

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CERTIFICATE

This is to certify that the thesis entitled, "**Engineering Behaviour and Classification of Weathered Rocks**" being submitted by **Mr. Anand Swaroop Gupta** to the Indian Institute of Technology, Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY** is a record of the bonafide research work carried out by him. Mr. Gupta has worked under my guidance for the submission of this thesis which to my knowledge has reached the requisite standard.

The thesis or any part thereof has not been presented or submitted to any other University or Institute for any degree or diploma.

Dr. K. Seshagiri Rao
Assistant Professor
Department of Civil Engineering
Indian Institute of Technology, Delhi

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ABSTRACT

Rocks, at and near the earth surface, commonly occur in weathered state. The important geotechnical parameters, strength and deformational properties greatly deteriorate by weathering on mass as well as material scale. Therefore, to understand and predict the physico-mechanical behaviour of weathered rock and characterization of extent of weathering on material and rock mass is of great significance. Most of the available methods for characterization of weathered rocks involve subjective terminology and are not well established. Hence, they lack the ability to be used in any method of strength and deformation prediction. Keeping these facts in view, a detailed investigation has been carried out over three common Indian rocks, namely Delhi quartzite, Malanjkhand granite, and Nagpur basalt:

(i) To study the intrinsic properties and characterize the rock materials in fresh and differently weathered conditions, geologically and geotechnically.

(ii) To study the strength and deformational behaviour of weathered rocks in unconfined and confined compression state.

(iii) To develop a quantitative classification and assessment of strength behaviour of weathered rock mass.

The weathered rock masses have been studied at 13 vertical profiles, in the field. Rock materials have also been identified by simple field methods. Detailed material characterization was carried out by using advanced laboratory techniques, such as X-ray diffraction, optical microscopy, Scanning Electron Microscopy, and X-ray fluoroscopy. The physical and strength properties were determined by using ISRM and Indian Standards (IS) test procedures. Triaxial tests were conducted at confining pressures, σ_3 = 0.5, 1, 2, 5, 10, 25 and 50 MPa over the weathered and fresh rock specimens.

Detailed petrographic study reveals that Delhi quartzite, which is dominantly composed of quartz, weathers through increasing intensity of microfracture. Decomposition in quartzite is very obvious through high order of staining and dissolution of quartz grain. Weathering in Malanjkhand granite is conspicuous by density of microfracture and content of secondary minerals. Alteration features of felspars and shattering of quartz grains also mark the development of weathering in granite. The fine grained basic volcanic rock, Deccan basalt of Nagpur, has several distinction features at different weathering stages. Initial stage of weathering is identified by development of thin microfractures accompanied with altered micropores. At later stages, complete transformation of minerals into clays and well-developed macrofractures prevail. Geochemical study of the weathered and fresh rocks indicates that, in general, Na followed by Ca and K is the highest mobile element in the weathering of all three rocks.

Almost all physical and strength properties are significantly influenced by extent of weathering. Similar to strength properties, deformational modulus, E_t is also greatly affected by weathering. However, it is evident that initial modulus, E_i reduces more drastically than the E_t with progressive weathering stages. Close relationship between E_t and σ_c is observed throughout the weathering stages. This indicates that modulus ratio ($MR = E_t/\sigma_c$) does not change significantly even at highly weathered grade. This may be due to the fact that both σ_c and E_t decrease systematically with progress of weathering. Good correlations have been observed among the index properties varying with weathering grade of a particular rock. However, the comparison of these relationships for different rock weathering sequences reveals that a common relationship among the index properties can not be valid for all the rock types. In general, the index properties of rock material alone can not represent the extent of weathering, unless compared with their values for fresh rocks. Hence, for characterization of weathering extent, indices other than index properties should be preferred.

Study reveals that none of the existing chemical weathering indices is valid for engineering purposes. Loss on ignition may provide approximate estimation of altered minerals (clays and hydroxides) in crystalline rocks. It has also shown good correlation with petrographic indices and other index properties. Among the petrographic indices, crack density (ρ_{cr}) and Unsound Constituent indices provide good correlation with engineering index properties. To quantify the extent of weathering in terms of strength degradation due to weathering in rock, an index is proposed as Strength Ratio (R_s) which is the percentage of σ_c of weathered rock with respect to σ_c of fresh rock. Its usefulness is shown through the relationships with other indices for several rock types including sedimentary and metamorphic rocks. Furthermore, it can also be used in prediction of strength and deformation of weathered rocks in confined conditions, and classifications of weathered rock material.

Triaxial test results and their analysis show that the shear strength parameters, c and ϕ vary with σ_3 and effect of weathering. The cohesion intercept, c increases non-linearly and angle of internal friction, ϕ decreases linearly with increasing σ_3 for all the rocks.

The stress-strain response under uniaxial compression is also observed to be changing with increasing weathering stage. The crystalline rocks, in fresh state, deform linear-elastically (and quasi-elastically). At higher weathering grades, the rocks behave more plastically with characteristic S-shaped stress-strain curves; with increasing confining pressure, the shape of stress-strain curves also changes.

Observation on failure pattern under unconfined compression reveals that each weathering stage has a characteristic mode of failure. Generally, fresh rocks fail with tensile splitting and shear fractures. In many cases, formation of cones has been associated with failure. In moderately weathered rocks, fractures are more prominent than tensile fractures at failure. Highly and completely weathered materials deform due to multiple shear fractures propagated throughout the material.

The strength prediction made based on IITD criterion has been compared with those from Hoek and Brown criterion. It shows good agreement with experimental data of rocks at all weathering grades. The relationships have been proposed to evaluate the material constants for complete weathering range. The strength prediction involves the σ_3 values of fresh and weathered rocks, and material constant values for fresh rock.

The results of triaxial tests show that the variation of E_t is more systematic than E_i with increasing σ_3 and degree of weathering. In normalized form, E_t is related with σ_3 by power relationship. The determined constants show good correlation with index of weathering, R_s. This allows to make the prediction of deformation modulus of rock at any confining pressure and stage of weathering.

In common practice, the rock masses are studied and characterised by a classification system. Virtually, lack of well applicable and quantitative rock-weathering classification has guided to develop such a classification useful for common engineering purposes. This may also be applicable for the prediction of rock mass strength. The classification system has been developed by detailed field study of 13 weathered profiles. Important attributes of the classification system involve the recognition of weathered material, delineation of weathered zones at exposed profile, and study of rock mass parameters at profile. The profile and its zones are classified according to the final rating, R_w which is the sum of the ratings of rock mass parameters. Besides grading, it has also been attempted to link the R_w with failure criterion in order to predict the strength of weathered rock mass. For this, few relationships have been proposed employing the limited data available in literature.

Based on the outcome of the study, final statement can be made that with the help of given guidelines, and visual description one can classify the weathered rock in both mass and material scale. The suggested indices and relationships will be useful in predicting the engineering behaviour of rocks occurring in weathered conditions. The overall classification system may be effectively functional at preliminary investigation stage of any rock engineering project where detailed and expensive field tests are not feasible.

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