GEOMECHANICAL CHARACTERIZATION AND CLASSIFICATION OF WEATHERED VOLCANIC ROCKS FOR ROCK ENGINEERING PRACTICE

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by

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Submitted

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to the

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DEDICATED

TO

* The memory of my mother and my father

* My sisters, brothers and Grand mother

CERTIFICATE

This is to certify that the thesis entitled, **“Geomechanical Characterization and Classification of Weathered Volcanic Rocks for Rock Engineering Practice**”, being submitted by **Mr.Endalu Tadele Chala** to the Indian Institute of Technology Delhi, for the award of **Doctor of Philosophy** is a record of the Bonafide research work carried out by him under my supervision, which to the best of my knowledge has reached the requisite standard.

The material contained in this thesis has not been submitted in part or fully to any other university or institute for the award of any degree or diploma.

Professor K.S.Rao

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Abstract

Rock weathering is one of the most significant geological processes, which degrades the engineering properties of rocks causing failure or large deformation in many projects including tunnels, dams, bridges and tall buildings. In tropical climates where there is a dynamic weathering environment (Thermal, Mechanical, Hydrological, and Chemical (TMHC) can have rapid weathering rates. This natural process of weathering is radically accelerated during clearing and excavations for civil or mining projects. It is important, therefore, to assess the impact of weathering on the engineering behaviour of weathered rockmass for open and underground works. The existing weathered material and mass classifications are semi quantitative and have also not given much attention to lithological characteristics. Especially, their applicability for volcanic rocks is not verified. Keeping these needs in mind, detailed field and laboratory investigation have been carried out near Bumbai-Pune-Satara-Koyna at six locations, by studying and investigating 23 weathered profiles and several borehole logs which belong to Deccan trap volcanic formation of India.

The microstructural features and mineralogical abundance of various weathered basaltic and pyroclastic volcanic rocks from Deccan trap formation were studied in laboratory using several analytical techniques such as petrographical and Scanning Electron Microscope (SEM), Energy Dispersive X-ray (EDX) and X-Ray Diffraction (XRD) techniques. On the basis of thin section studies two petrographic indices i.e. Micro-fracture Index, MI and Decomposition Index, DI was devised to identify the types of weathering. The physical and strength properties of various weathered basalt and pyroclastic rocks determined as per International Society of Rock Mechanics (ISRM) and Indian Standards (IS). The fresh Basalt has high density and specific gravity values with low porosity (maximum, 0.9%) whereas pyroclastic volcanic rocks have lower density values with high porosities (maximum 20.4%). For all the samples, with increasing weathering grade,

porosity increases in an exponential function. From the results of Vp, it can be concluded that for each type, the Vp decreases rapidly with the increasing weathering grades. High density, low porosity and the presence of mafic minerals are some of the reasons for high Vp values. The physico-mechanical properties measured experimentally in the present study and available data from literature has been superimposed on the plots. It has shown a very good correlation. These correlations have great importance to establish the geotechnical properties of volcanic rocks as a function of degree of weathering.

Triaxial test results and their analyses show that with increasing confining pressure from 1 to 30 MPa, strength increased as expected. Generally, it has been observed that, the rate of increase in strength is higher at lower confining pressure. This is because of micro-fractures and pore spaces between the grains getting closer at lower confining pressure. Predicting the rock strength in different stress or and strain conditions is necessary both for numerical simulations and theoretical analyses. The present uniaxial and triaxial test results along with data from literature were fitted into commonly used strength criteria and have been evaluated for their applicability for weathered volcanic rocks. Finally, various volcanic rock parameters such as α and B of Rao 1984), m of Hoek and Brown (1980), A and B of MMC and c and ϕ of p-q plots have been determined. These rock parameters are observed to be decreasing with increasing degree of weathering. The inconsistency of the pyroclastic volcanic rock parameters is higher than those of weathered basaltic rocks. These parameters can be used for predicting strength at any confining pressure using the minimum experimental data at material scale and along with rockmass classification scheme, the mass properties can be predicted.

Eight alternative grades of weathered rock material classifications have been proposed using petrographical, physical and mechanical properties and characteristics of various grade weathered rocks. To quantify the extent of weathering in terms of physico mechanical properties, the concept of retention ratio (Rs) which is the percentage of weathered rock with respect to fresh as proposed by Gupta and Rao (2001), has been extended for Is (50), σ_t, R_N, E Vp, γ and QAI. These retention indices are the ratios of fresh to weathered varieties of the same rocks expressed in percentage from 0 to 100. To investigate the applicability of the classifications for other regions, available experimental results in the literature are also considered. Weathered volcanic Rock masses, due to their origin, exhibit certain characteristics that make their study not always appropriate through classical geomechanical classification systems including RMR, Q and GSI for predicting the various weathered rockmass properties. In the present study two alternative classifications for various weathered rockmass have been proposed. (i) Weathering indices chart based on Total core recovery (TCR) and rebound hammer value (R_N) and (ii) Classifications schemes based on rating system. The study and correlations developed between proposed and common rockmass classification indicates that these two classifications are very promising for strength characterization of various weathered rockmass.

To illustrate the effectiveness of proposed weathering indices chart in numerical modeling of weathered rockmass the core samples available from already drilled boreholes have been studied. From the borehole data the TCR and R_N values of respective core samples were determined and the geological strength index determined from lookup chart of Hoek and Marinos (2000). The rock slope stability analysis was done using numerical modeling techniques; Finite Element Method (FEM) based two dimensional analyses (RS2), Phase 2 9.0, software from Rocscience. The rock slope having four different quality of rockmass have been analyzed under static and pseudo-static conditions. Finally, the optimum support measures have been provided to the slope for stabilizing it and the corresponding analysis was also done.

सार

रॉक का मौसम सबसे महत्वपूर्ण भूवैज्ञानिक प्रक्रियाओं में से एक है, जो चट्टानों के इंजीनियरिंग गुणों को कम करता है जिससे सुरंगों, बांधों, पुलों और ऊंची इमारतों सहित कई परियोजनाओं में विफलता या बड़ा विरूपण होता है। उष्णकटिबंधीय जलवायु में जहां एक गतिशील मौसम पर्यावरण (थर्मल, मैकेनिकल, हाइड्रोलॉजिकल और केमिकल (टीएमएचसी) में तेजी से मौसम की दर हो सकती है सिविल या खनन परियोजनाओं के लिए समाशोधन और खुदाई के दौरान मौसम की प्राकृतिक प्रक्रिया को त्वरित रूप से त्वरित किया गया है।. इसलिए, खुले और भूमिगत कार्यों के लिए खासी चट्टान के इंजीनियरिंग व्यवहार पर मौसम के प्रभाव का आकलन करना महत्वपूर्ण है। मौजूदा खामी सामग्री और बड़े पैमाने पर वर्गीकरण अर्द्ध मात्रात्मक हैं और लिथोलॉजिकल विशेषताओं पर भी ज्यादा ध्यान नहीं दिया है। विशेष रूप से, ज्वालामुखी चट्टानों के लिए उनकी प्रयोज्यता सत्यापित नहीं है।. इन जरूरतों को ध्यान में रखते हुए, विस्तृत क्षेत्र और प्रयोगशाला की जांच, छह स्थानों पर, मुंबई-पुणे-सातारा-कोयना के पास, 23 भेजी प्रोफाइलों और कई बोरोले लॉग की जांच कर रही है जो भारत के डेक्कन जाल ज्वालामुखी गठन से संबंधित हैं।

डेक्कन जाल के निर्माण से बेसाल्टिक और पायरोक्लास्टिक ज्वालामुखीय चट्टानों के माइक्रोस्ट्रॉचरल फीचर और मिनरलोगिकल बहुतायत का प्रयोग पेट्रोफोग्राफिकल और स्कैनिंग इलेक्ट्रॉन माइक्रोस्कोप (एसईएम), एनर्जी डिसप्सीिव एक्स-रे (ईडीएक्स) और एक्स-रे विवर्तन जैसे कई विश्लेषणात्मक तकनीकों का प्रयोग करके प्रयोगशाला में किया गया। (एक्सआरडी) तकनीक पतली खंड के आधार पर दो पेट्रोग्राफिक इंडेक्स यानी माइक्रो फ्रैक्चर इंडेक्स, एमआई और अपघटन सूचकांक, डीआई को मौसम के प्रकारों की पहचान करने के लिए तैयार किया गया था। इंटरनेशनल सोसायटी ऑफ रॉक मैकेनिक्स (आईएसआरएम) और इंडियन स्टैंडर्ड (आईएस) के अनुसार निर्धारित विभिन्न बास्केट और पाइरोक्लास्टिक चट्टानों के भौतिक और ताकत गुणों का निर्धारण।. ताजा बेसाल्ट में कम घनत्व और अधिकतम गुरुत्वाकर्षण मूल्य (कम से कम 0.9%) होते हैं, जबकि पायरोक्लास्टिक ज्वालामुखीय चट्टानों में निम्न सरंकीकरण (अधिकतम 20.4%) के साथ घनत्व मूल्य कम होता है। सभी नमूनों के लिए, बढ़ते मौसम वाले ग्रेड के साथ, एक घातीय कार्य में छिद्रपूर्ण बढ़ता है वीपी के परिणामों से, यह निष्कर्ष निकाला जा सकता है कि प्रत्येक प्रकार के लिए, वीपी तेजी से बढ़ते मौसम ग्रेड के साथ घट जाती है। उच्च घनत्व, कम चिपचिपापन और मैफीक खनिजों की उपस्थिति उच्च वीपी मूल्यों के लिए कुछ कारण हैं। वर्तमान अध्ययन में भौतिक-यांत्रिक गुणों को प्रयोगात्मक रूप से मापा गया और साहित्य से उपलब्ध आंकड़ों को भूखंडों पर लगाया गया है। यह एक बहुत अच्छा सहसंबंध दिखाया है इनके सहसंबंधों को जिक्र करने के लिए ज्वलनशील चट्टानों के भू-तकनीकी गुणों को स्थापित करने के लिए बहुत महत्व है, क्योंकि मौसम की डिग्री के एक फ़ंक्शन के रूप में

त्रिअक्षीय परीक्षण के परिणाम और उनके विश्लेषण से पता चलता है कि 1 से 30 एमपीए तक बढ़ती दबाव के साथ, अपेक्षित रूप से वृद्धि हुई सामान्यतया, यह देखा गया है कि, कम दबाव वाले दबाव में ताकत में वृद्धि की दर अधिक है। यह सूक्ष्म-अस्थिभंग के कारण है और अनाज के निचले प्रतिरोध को कम करने के दबाव में करीब रिक्त स्थान है। विभिन्न तनाव में रॉक ताकत की भविष्यवाणी करना और नैनो सिमुलेशन और सैद्धांतिक विश्लेषण दोनों के लिए तनाव की स्थिति आवश्यक है। साहित्य के आंकड़ों के साथ वर्तमान एकमात्र और त्रिकोणीय परीक्षण के परिणाम आमतौर पर इस्तेमाल की जाने वाली ताकत मानदंडों में लगाए गए थे और ज्वालामुखीय चट्टानों के खाने के लिए उनके प्रयोज्यता के लिए मूल्यांकन किया गया है। अंत में, विभिन्न ज्वालामुखीय चट्टान मापदंड जैसे α और बी राव (1 9 84), होक एंड ब्राउन (1 9 80) की एम, एमएमसी के ए और बी और पी-क्यू प्लॉट्स के सी और φ निर्धारित किए गए हैं। इन चट्टान के मापदंडों को मौसम की बढ़ती हुई डिग्री के साथ घटते हुए देखा जा रहा है। पायरोक्लास्टिक ज्वालामुखीय चट्टान मापदंडों की विसंगतियां खामी बेसाल्टिक चट्टानों की तुलना में अधिक है इन मापदंडों का प्रयोग भौतिक स्तर पर न्यूनतम प्रयोगात्मक डेटा और चट्टान वर्गीकरण योजना के साथ किसी भी दबाव में दबाव की भविष्यवाणी के लिए किया जा सकता है, जन गुणों की भविष्यवाणी की जा सकती है।

भूस्खलन करने वाले रॉक सामग्री वर्गीकरण के आठ वैकल्पिक ग्रेड पेट्रोफिकल, भौतिक और यांत्रिक गुणों का उपयोग करते हुए प्रस्तावित किया गया है और विभिन्न ग्रेड के चट्टानों का सामना करना पड़ता है। भौतिक मैकेनिकल गुणों के संदर्भ में मौसम की मात्रा का आकलन करने के लिए, प्रतिभूति अनुपात (रुपये) की अवधारणा, जो कि गुप्ता और राव (2001) द्वारा प्रस्तावित ताजा के संबंध में खाए हुए चट्टानों का प्रतिशत है, को बढ़ाया गया है (50) , σt, आरएन, वीपी, क्यूएआई और ई। ये प्रतिधारण सूचकांक एक ही चट्टानों की खाने वाली किस्मों के लिए ताजा अनुपात है, जो प्रतिशत में 0 से 100 तक आते हैं। अन्य क्षेत्रों के लिए वर्गीकरण की प्रयोज्यता की जांच के लिए, साहित्य में उपलब्ध प्रायोगिक परिणामों को भी माना जाता है। ज्वालामुखीय रॉक जनजाति, उनके मूल के कारण, उन विशिष्ट विशेषताओं का प्रदर्शन करते हैं जो विभिन्न अध्ययनों के लिए आरएमआर, क्यू और जीएसआई सहित शास्त्रीय भौगोलिक वर्गीकरण प्रणालियों के माध्यम से अपने अध्ययन को हमेशा उपयुक्त नहीं बनाते हैं, जो कि विभिन्न चोंच वाले गुणों की भविष्यवाणी करते हैं। वर्तमान अध्ययन में विभिन्न व्यथित चट्टानों के लिए दो वैकल्पिक वर्गीकरण प्रस्तावित किए गए हैं। (i) कुल कोर वसूली (टीसीआर) और रिबाउंड हथौड़ा मूल्य (आर.एन.) और (ii) रेटिंग सिस्टम पर आधारित वर्गीकरण योजनाओं के आधार पर सूचकांक चार्ट का आकलन करना। प्रस्तावित और आम चट्टान वर्गीकरण के बीच विकसित अध्ययन और सहसंबंध यह इंगित करता है कि इन दोनों वर्गीकरण विभिन्न खामी चट्टानों की ताकत के लक्षण वर्णन के लिए बहुत आशाजनक हैं।

प्रस्तावित मौसम संबंधी सूचकांक चार्ट की प्रभावशीलता को स्पष्ट करने के लिए पहले से ड्रिल किए गए बोरहोलों से उपलब्ध मूल नमूनों का अध्ययन किया गया है। बोरहोल डेटा से संबंधित कोर नमूनों के टीसीआर और आर एन मूल्य निर्धारित किए गए थे और भूगर्भीय ताकत सूचकांक होक और मरिनस (2000) के लुकअप चार्ट से निर्धारित किया गया था। रॉक ढलान स्थिरता विश्लेषण संख्यात्मक मॉडलिंग तकनीकों का उपयोग किया गया था; परिमित तत्व विधि (फेम) आधारित दो आयामी विश्लेषण (आरएस 2), चरण 2 9.0, रोक्साइंस से सॉफ्टवेयर। रॉकमास के चार अलग-अलग गुणवत्ता वाले रॉक ढलान को स्थिर और छद्म-स्थिर स्थितियों के तहत विश्लेषण किया गया है। अंत में, यह स्थिर करने के लिए ढलान को इष्टतम समर्थन उपायों प्रदान किया गया है और इसी विश्लेषण भी किया गया था।

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B	material constants in IITD Criterion for intact fresh rock (Dimensionless)
B_w	material constant in IITD criterion for weathered rock mass (Dimensionless)
c	cohesive strength (MPa)
D	disturbance factor in Hoek and Brown criterion for intact rocks (Dimensionless)
E_i	initial tangent modulus (GPa)
E_t	deformational modulus at 50% failure strength (GPa)
EDX	energy dispersive x-ray microanalysis
FEM	finite element method
G	shear modulus (GPa)
GSI	geological strength index (dimensionless)
Ip	the ratio of sound and unsound mineral constituents (%)
Jwt	state of joint weathering
Jn	no. of joints per meter (m)
Jwd	joint width (m)
Jr	roughness of the most unfavourable discontinuity
Ja	degree of alteration (%)
J_f	joint factor
k	coefficient of weathering
m	material constant in Hoek and Brown criterion for intact rocks (Dimensionless)
m_j	material constant in Hoek brown criterion for jointed rockmass (Dimensionless)
MRs	mass retention ratio (Dimensionless)

MR	modulus ratio of intact rocks
n	joint inclination parameter in IITD criterion (Dimensionless)
N_X	54 mm diameter drill core
QAI	quick absorption index (%)
r	joint strength parameter in IITD criteria (Dimensionless)
r^2	coefficient of determination
Rs	strength ratio (Dimensionless)
RMR	rock mass rating (Dimensionless)
Rw	weathered rockmass rating (Dimensionless)
RS_2	rock soil 2 dimensional
R_N	rebound number (Dimensionless)
s	material constant in Hoek and Brown criterion for intact rock (Dimensionless)
s_j	material constants in Hoek and Brown criterion for jointed Rockmass (Dimensionless)
SEM	scanning electron microscope
Sd	slake durability index (%)
SC	sound mineral constituent (%)
THMC:	dynamic environment (Thermal, Hydrological, Mechanical and Chemical)
UC	unsound constituents (%)
Vp	sonic wave velocity (m/s)
V_o	velocity of ultrasonic wave in fresh rocks (m/s)
V_w	velocity of ultrasonic wave in weathered rock (m/s)
WPI	weathering potential index (%)
Wm	Miura index (%)
Wa	water inflow pressure (m)
SRF	stress reduction factor (dimensionless)

WICh weathering indices chart

XRD x-ray diffraction

α slope of the plot between $\log\left[\left(\frac{\sigma_1-\sigma_3}{\sigma_3}\right)\right]$ and $\log\left(\frac{\sigma_c}{\sigma_3}\right)$ for fresh intact Rock (Dimensionless)

α_w slope of the plot between $\log\left[\left(\frac{\sigma_1-\sigma_3}{\sigma_3}\right)\right]$ and $\log\left(\frac{\sigma_{cw}}{\sigma_3}\right)$ for weathered rocks (Dimensionless)

α_j slope of the plot between $\log\left[\left(\frac{\sigma_1-\sigma_3}{\sigma_3}\right)\right]$ and $\log\left(\frac{\sigma_{cj}}{\sigma_3}\right)$ for jointed rocks (Dimensionless)

β angle between fracture plane and the direction of major principal stress (^{0})

ε_a axial strain (micro strain)

ε_d diametrical strain (micro strain)

η porosity (%)

σ_n normal stress (MPa)

σ_c uniaxial compressive strength (MPa)

σ_{cw} uniaxial compressive strength of weathered rock (MPa)

σ_{cm} uniaxial compressive strength of rock mass (MPa)

σ_{tb} Brazilian tensile strength (MPa)

$I_{s(50)}$ point load strength MPa)

σ_1 major Principal stress (MPa)

σ_3 minor principal stress (MPa)

$\sigma_1-\sigma_3$ deviator stress (MPa)

τ shear strength (MPa)

ϕ	angle of internal friction (^{0})
υ	Poisson ratio (Dimensionless)
γ	Density(kN/m^3)