STUDIES ON STRENGTH, DEFORMATION AND ELECTRICAL RESISTIVITY BEHAVIOUR OF CERTAIN SEDIMENTARY ROCKS

BY

CHANDRAKANT S. GOKHALE

Civil Engineering Department

Submitted

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY, DELHI

AUGUST 1999

DEDICATED

TO

MY PARENTS

CERTIFICATE

This to certify that the thesis entitled " **Studies on Strength, Deformation and Electrical Resistivity Behaviour of Certain Sedimentary Rocks**" being submitted by **Mr. Chandrakant S. Gokhale** to the Indian Institute of Technology, Delhi, New Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY** is a bonafide research work carried out by him. Mr. Gokhale has worked under my supervision for the submission of this thesis, which to my knowledge has reached the requisite standard.

The thesis or any other part thereof has not been submitted to any other University or Institution for the award of any Degree or diploma.

J M Kate

Dr. J. M Kate

Associate Professor

Department of Civil Engineering

Indian Institute of Technology, Delhi

New Delhi - 110016

ACKNOWLEDGEMENTS

The author has great pleasure in recording his profound gratitude and indebtedness to his research supervisor Dr. J. M. Kate, Associate Professor in Civil Engineering Department for his inspiring guidance and constant encouragement which enabled the author to undertake the present research work. The author appreciates his understanding, untiring enthusiasm and great care he took in bringing up the thesis in the present form.

The author shall remain grateful to his caretaker research supervisor Dr. A. Varadrajan, Professor in Civil Engineering Department for his valuable suggestions, encouragement and help and for taking care of author's interest after submission of this thesis.

The author is thankful to the Govt. of Goa for deputing him under Quality Improvement Programme. The author is grateful to the Honourable High Court of Judicature of Bombay, Bench at Panaji, Goa for delivering favourable judgement in dispute case regarding his deputation, which enabled the author to carry out this research programme. The author is thankful to the Ministry of Human Resources, Govt. of India, for providing scholarship under Q. I. P. scheme.

The author shall remain grateful to Dr. A. M. Deshmukh, Professor and Head, Dept. of Civil Engg., College of Engineering, Farmagudi, Goa for his valuable suggestions and encouragement from time to time. The author is thankful to Dr. T. Ramamurthy, Professor Emeritus, I. I. T. Delhi, for his valuable suggestions.

The author expresses his deep appreciation and sincere thanks to the faculty members of Geotechnical engineering section, Civil Engg. Dept., I. I. T. Delhi. Special thanks are due to Dr. K. K. Gupta, Associate professor, Civil Engg. Dept. for providing computer for the preparation of the thesis and for his valuable suggestions and encouragement. The assistance rendered by the staff of the Rock Mechanics Laboratory especially by Mr. O. P. Sharma and Mr. H. S. Gupta, the Civil Engg. Workshop especially by Mr. K. K. Bali and Mr. R. S. Negi, the X-ray Laboratory, Scanning Electron Microscopy Laboratory, Building Science Laboratory and Glass Blowing Workshop of Indian Institute of Technology, Delhi is gratefully acknowledged. The author is thankful to Mr. Arora draftsman, Civil Engg. Dept., for preparation of figures for the thesis.

The author has great pleasure in expressing his sincere thanks to his friends and fellow research scholars especially Dr. A. S. Gupta, Dr. M. Singh, Mr. A. K. Gupta, Mr. S. Rao, Mr. R. M. M. Gowda, S. Kelapure and A. Agrawal for sharing the moments of joy and anguish and contributing towards this work through many useful discussions and suggestions.

The author is grateful to Mr. A. V. Vishvaroop, Assistant Director, Dept. of Industries, Govt. of M. P., Gwalior, Mr. S. S. Gokhale, M. P. Electricity Board, Bilaspur, Mr. P. R. Achawal, Revenue Inspector, Dept. of Revenue, Govt of M. P., Ratlam, Mrs. M. S. Gokhale, South East Coal India Limited, Bilaspur, M. P. and Mr. P. P. Dev, Senior Engineer, Advani and Co., Sonebhadra, U. P. for their help in the collection of rock samples tested in this study.

The author is thankful to the Director of Mines and Geology, Govt. of Rajasthan, Udaipur for carrying out chemical analysis of rocks tested in this study. Thanks are due to Mr. R. D. Mishra, Dept. of Earth Science, Univ. of Roorkee, U. P. for the assistance in the preparation of thin sections. The author is also thankful to Dr. R. Pateria, Lecturer, School of Studies in Earth Science, Jiwaji University, Gwalior, M. P. and Dr. P. S. Raikar, Reader, Department of Geology, Goa university for their help in thin section studies.

The author is grateful to Dr. S. N. Lal, Principal, Govt. Engg. College, Farmagudi, Goa, for allowing to use ultrasonic and other testing facilities available in the Rock Mechanics Laboratory during author's one and half month long visit to the Institute. The author is thankful to the laboratory staff and faculty of Civil Engg. of the Institute for their help during visit.

The author expresses deep sense of gratitude to Mr. P. A. Dev and Mrs. Preeti Dev for taking care of authors family during period of this research work and for their immense concern, affection and constant encouragement.

The author is grateful to Mr. N. R. Mudholkar and Capt. P. R. Mutgi, Dept. of Civil Engg. Govt. Engg. College, Farmagudi, Goa, for taking care of authors interests at Goa during his research period.

The author is thankful to his friend Mr. R. K. Jain (Superintending Engineer, N. W. D. A., New Delhi) and his family for their help, immense concern, affection and constant encouragement throughout the period of this research work.

The author is thankful to Mr. R. Shaikh and Mr. Avnish of Digital Point, New Delhi for helping in typing and printing of this thesis.

The author expresses deep sense of gratitude to all the relatives and friends for their immense concern and affection, which provided impetus to this work. The author sincerely thanks and appreciates to all those who helped directly or indirectly for the work reported herein.

No superlative will be able to do full justice in expressing the feelings for the contribution of the author's wife Shruti and daughters Rachana and Mansi towards the successful completion of this thesis.

AUGUST 1999

(CHANDRAKANT S. GOKHALE)

95RCE001

ABSTRACT

In fast developing countries like India, the need of large scale structures resting on or within rocks/rock mass like dams, reservoirs, tunnels, underground hydro-electric power plants, underground storage of oil and hazardous wastes etc. is ever increasing. This emphasizes the need to carry out rapid, economical and easy subsurface exploration and material characterisation for analysis and design of such structures. The geotechnical engineers have well realised the importance of certain geophysical techniques namely electrical resistivity and seismic refraction for subsurface exploration. Field electrical resistivity sounding data when interpreted furnish depth wise subsurface information viz. sequence and nature of various rock strata, their thickness etc. to a fair degree of accuracy. However geotechnical engineers are mainly interested in obtaining strength and deformation characteristics of rocks at different depths under varying stress and environmental conditions for analysis and design of structures.

The moisture present in the rock and confining pressure (lateral thrust at different depths associated with overburden stress) to which it is subjected are the two most important factors influencing engineering behaviour of rocks. The presence of moisture invariably reduces rock strength and thus leads to the progressive weakening of underground workings in rocks.

Under confined conditions (other factors remaining the same) the strength and modulus of elasticity are function of confining pressure. On this premise various empirical strength criteria for prediction of strength and empirical equations for prediction of modulus of elasticity under confined conditions have been developed and reported in the literature. The literature studies do indicate that confining pressure affects electrical resistivity of rocks in more or less systematic manner. This indicates towards the possibility of developing the empirical equations to predict rock strength and modulus of elasticity under confined conditions on the basis of electrical resistivity measurements.

The sedimentary rocks are commonly encountered during various civil, mining and tunnelling engineering construction activities. In terms of area of exposure the sedimentary rocks constitute about 75% of all rocks. Further the three common

sedimentary rocks viz. sandstone, limestone and shale account for above 80% of all sedimentary rocks. Hence study of these three rocks may cover large area of engineering interest.

Keeping all the above aspects in view, in the present study a detailed investigation is carried out on intact specimens of 12 sedimentary rocks (8 sandstones, 2 limestones and 2 shales) to study strength, deformation and electrical resistivity behaviour with following main objectives.

(i) To study the microscopic and megascopic physical properties, strength and strength index properties, geophysical and non-destructive test properties and pore size distribution (through water vapour adsorption method and mercury intrusion porosimetry) for physical characterisation.

(ii) To study the strength and deformation behaviour under uniaxial, hydrostatic and triaxial compression and influence of varying moisture on static elastic constants and shear strength parameters.

iii) To study the influence of varying moisture and confining pressure on electrical resistivity changes in rocks under uniaxial, hydrostatic and triaxial stress conditions and strain dependence of electrical resistivity under varying stress.

iv) To explore the possibility of prediction of strength and deformation behaviour under confined state based on the electrical resistivity measurements.

To achieve the above objectives an extensive laboratory investigation has been onducted. Physical characterisation has been carried out by conducting chemical ıalysis, x-ray diffraction, scanning electron microscopy, petrographic studies and by valuating physical properties. The pore size distribution analysis has been carried out y water vapour adsorption method as well as through mercury intrusion method. The eotechnical characteristics such as uniaxial compressive, Brazilian tensile and punch ıear strength have been determined. The strength index properties such as axial and ametral point load strength index, void index, slake durability index and newly troduced water evaporation index have been determined. The non-destructive test property such as Schmidt rebound index, permeability and geophysical properties namely compressional and shear wave velocity and electrical resistivity have also been estimated. The influence of varying moisture on uniaxial compressive and Brazilian tensile strength, compressional and shear wave velocity and electrical resistivity have been also investigated. The strength, deformation and electrical resistivity behaviour has been studied by conducting hydrostatic compression tests and triaxial compression tests (at four different confining pressures). During uniaxial, hydrostatic and triaxial compression tests both axial and diametral strains and electrical resistivity have been measured. On the basis of the analysis of experimental data of the study following major points have been brought out.

The pore-size distribution study indicate that while pore surface area distribution determined by both mercury intrusion method and water vapour adsorption method agree fairly, there is significant difference in pore volume distribution particularly for rocks having large size pores in significant amount. The proposed modified water vapour adsorption method can be used as an alternative to the mercury intrusion method. The modified water vapour adsorption method involves the data of conventional water vapour adsorption method and two simple and easily determinable parameters (water evaporation index and non-adsorption factor) newly introduced in the present study.

The study of correlations of strength and modulus with strength index properties as well as with non-destructive and geophysical properties indicate that while in some cases significant and useful correlations exist in other cases they are observed to be poor. Both strength and geophysical properties are observed to be influenced by moisture. The study indicates that rock permeability can be fairly predicted on the basis of resistivity formation factor and pore geometry.

Both confining pressure and moisture are observed to influence strength and deformation behaviour. The bulk modulus determined from hydrostatic compression tests is observed to be fairly close to that calculated on the basis of static elastic constants but significantly differs from that determined from dynamic elastic constants. The tangent modulus at desired confining pressure could be fairly predicted through Janbu's equation as well as by a relation proposed in the present work. The moisture affects shear strength parameters marginally to significantly. While the effect of saturation has been moderate to significant on reduction in cohesion, the effect has been observed to be marginal on angle of internal friction for majority of the rocks studied.

The electrical resistivity varies systematically with confining pressure. Through analysis of experimental data a power law relation between resistivity and confining pressure in non-dimensional form has been developed. In general electrical resistivity in uniaxial as well as in triaxial compression is observed to decrease with increase in axial stress until failure. As such resistivity changes in association of strains developed in the rock specimen. In a number of cases of uniaxial, hydrostatic and triaxial compression variation of change in resistivity with stress is observed to be qualitatively similar to that of stress-strain behaviour.

The four commonly referred empirical failure criteria (Bieniawski, 1974; Hoek and Brown, 1980; Johnston, 1985 and Ramamurthy, 1994) have been assessed for present experimental data. In general, the closest agreements between predicted strength and corresponding experimental value are provided by Ramamurthy criterion, Hoek and Brown criterion and Johnston criterion at pressure ranges corresponding to low, intermediate and high respectively. The moisture influences the parameters of these four criteria moderately to significantly and in general more or less systematically.

On the basis of resistivity-confining pressure data and triaxial test data a resistivity based strength criterion has been proposed. The studies clearly indicate that electrical resistivity can prove to be an important parameter to understand and predict strength and deformation behaviour of rocks in an unconfined as well as in a confined state. This may be effectively functional at preliminary investigation stage of any rock-engineering project where elaborate and expensive investigation through conventional methods is not feasible due to certain constraints.

It is fully recognised that the resistivity based strength criterion presented in this study is based on limited data. However, the results are encouraging and indicate plenty of scope for future work in this direction.

CONTENTS