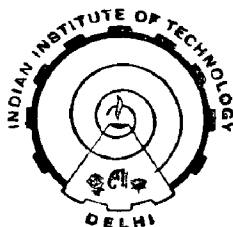


STRENGTH AND DEFORMATION BEHAVIOUR OF SANDSTONES

By
K. SESHAGIRI RAO

A thesis submitted
in fulfilment of the requirements for the degree of
DOCTOR OF PHILOSOPHY



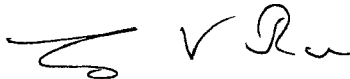
Department of Civil Engineering
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
DECEMBER 1984

TO MY PARENTS

CERTIFICATE

This is to certify that the thesis entitled, "STRENGTH AND DEFORMATION BEHAVIOUR OF SANDSTONES" being submitted by Mr. K. Seshagiri Rao 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. Seshagiri Rao has worked under our guidance for the submission of this thesis which to our knowledge has reached the requisite standard.

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



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ABSTRACT

The strength of rocks is an important parameter which depends on the stresses imposed by the engineering structures. Apart from the intrinsic properties, rock strength is significantly decreased with increase of moisture content. Though many theories exist, there is no unified theory to explain the behaviour completely. To predict the rock mass behaviour many strength criteria have been proposed. None of the several theories proposed was observed to be valid universally for all rock types. Keeping the above facts in view a systematic laboratory investigation was planned to study (i) the nature, (ii) the strength behaviour in partially and fully saturated states and (iii) the shear strength behaviour in triaxial conditions of four sandstones collected from different geological formations of India.

In this study nature of Kota, Jamrani, Singrauli and Jhingurda sandstones was brought out using thin section microscopic, X-ray diffraction and scanning electron microscopic studies. The physical and strength properties were estimated using ISRM and Indian Standards (IS) test procedures. Specimens equilibrated at different relative humidities, e.g. 0, 35, 60, 85, 95, 100 and saturated were tested in all test modes to evaluate the moisture effect on strength. Triaxial tests were conducted at $\sigma_3 = 25, 50, 75, 100$ and 125 kg/cm^2 . The anisotropic Kota sandstone was tested at different orientations,

β (inclination of bedding planes with major principal stress direction) = 0, 30, 65, and 90 degrees.

The Kota sandstone which has ^{the} highest quartz content with ferruginous cement has shown the maximum strength and modulus of elasticity, whereas Jhingurda sandstone with its low quartz content and high amount of argillaceous cement has exhibited ^{the} least strength and modulus of elasticity. The strength as well as modulus values range in between these extremes for Jamrani and Singrauli sandstones. The mineralogical composition and the intrinsic properties revealed the nature of strength behaviour.

The anisotropic Kota sandstone exhibits the least uniaxial compressive strength at $\beta = 30$ degrees and the highest at $\beta = 0$ degrees. The Brazilian and point load strengths increase gradually when β changes from 0 to 90 degrees. Unlike slates and shales the Kota sandstone has shown low degree of anisotropy.

The strength and modulus of elasticity decreased with increase of moisture content. To understand these changes from the physico-chemical view point, the principle of effective stress is brought into focus. Two mechanisms, i.e. (i) effective negative pore pressures and (ii) surface energy/inter particle changes were recognised as the causes for the strength changes due to moisture and explained them in the light of effective stress principle. A good correlation was observed among the effective negative pore pressures, $\bar{u}_w$ (computed through pore size distributions) surface energy, γ and strength changes due to moisture content.

The triaxial tests have been analysed for stress-strain response, shear strength parameters (c' and ϕ'), modulus of elasticity (E_t) and modulus parameters (K and n).

Based on the test results and analysis of published strength data on more than 80 rocks, a new empirical strength criterion has been proposed. According to this

$$\frac{\sigma_d}{\sigma_3} = B \left(\frac{\sigma_c}{\sigma_3} \right)^\alpha$$

This criterion uses uniaxial compressive strength, σ_c , and introduces two non-dimensional parameters α and B . It has been observed that α is a constant equals to 0.8 for all rocks, whereas B depends on rock type and quality. It has been noticed that the B value is a constant for each group of rock and the maximum variation falls in between 1.8 and 3.0. The criterion has been extended for strength prediction of jointed and anisotropic rocks by taking joint parameters σ_{cj} and B_j instead of σ_c and B in the equation. The predictions obtained from the proposed criterion have been compared with Bieniawski, Jaeger, Walsh and Brace, Hoek and Brown and Yubdhir et al criteria and found that the proposed criterion yields better agreement with the experimental observations.

To facilitate the predictions in the field, the joint parameters were correlated with CSIR and NGI rock mass classifications as

$$\sigma_{cj} = \sigma_c \exp \left[\frac{RMR - 100}{18.75} \right]$$

and

$$B_j = B \exp \left[\frac{RMR - 100}{75.5} \right]$$

Based on the extensive analysis, it has been concluded that the proposed criterion has the potential to predict the strength of isotropic, anisotropic and jointed rock in brittle and ductile regions as well.

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