TESTING AND MODELLING THE BEHAVIOUR OF MODELLED AND PROTOTYPE ROCKFILL MATERIALS

by

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Dedicated

To

MY PARENTS,

My Brother

Prof. M. P. HONKANADAVAR

My Wife

NIRMALA

And My Children

MEGHA & PALLAVI

CERTIFICATE

This is to certify that the thesis entitled "**TESTING AND MODELLING THE BEHAVIOUR OF MODELLED AND PROTOTYPE ROCKFILL MATERIALS**" being submitted by **Mr. N.P. Honkanadavar** to the Indian Institute of Technology, Delhi is a record of bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the standard, fulfilling the requirements for **DOCTOR OF PHILOSOPHY** degree. The research report and the results presented in this thesis have not been submitted, in part or full, to any other university or Institute, for the award of any degree or Diploma.

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(N.P. Honkanadavar)

ABSTRACT

In the recent years, there has been enormous increase in the use of rockfill materials for the construction of rockfill dams to harness the natural water resources. Rockfill consists of gravels, cobbles and boulders obtained either from the natural riverbed or by blasting the rock quarry. The behaviour of rockfill material used in the construction of rockfill dams is affected by number of factors such as mineral composition, particle size, shape, gradation, relative density and surface texture of the particles. Therefore, the understanding and characterization of the behaviour of these materials are of considerable importance for the analysis and safe design of the rockfill dams.

In the present research work, two types of rockfill materials viz. riverbed rockfill material from two project sites viz. Noa Dehing dam site, Arunachal Pradesh and Lower Jehlum Project site, Jammu and Kashmir and quarried rockfill material from seven project sites viz. Kol Dam site, Himachal Pradesh, Middle Siang dam (two quarry sites), Arunachal Pradesh, Pancheshwar dam (two quarry sites), Nepal and Subansiri Middle dam (two quarry sites), Arunachal Pradesh have been considered. Noa Dehing dam riverbed and Kol dam quarried materials have been modelled to six maximum particle sizes (d_{max} = 4.75, 10, 19, 25, 50 and 80 mm) using parallel gradation technique and tested with 87% and 75% relative densities. Similarly, other site rockfill materials have been modelled to three maximum particle sizes (d_{max} = 25, 50 and 80 mm) using parallel gradation technique and tested with 87% relative density.

Consolidated drained triaxial tests have been conducted on these modelled rockfill materials for confining pressure varying from 0.2 to 1.6 MPa. The breakage factor has been determined at the end of the test for all the specimens tested. The rockfill materials have been tested for some of the index properties viz. specific gravity, water absorption ratio, aggregate crushing value, aggregate impact value, Los Angeles abrasion value, unconfined compressive strength, UCS (with strain measurements) and uncompacted void content, UVC.

The stress-strain-volume change behaviour has been plotted for all the rockfill materials tested. From the stress-strain behaviour, it is observed that the behaviour is non-linear, inelastic and stress dependent. From the volume change behaviour, it is observed that the volume change at failure increases with increase in maximum particle size and confining pressure. The effect of dilatancy is more in quarried rockfill materials as compared to that in riverbed rockfill materials. The volume change increases with decrease in relative density. Also, it is observed that the effect of confining pressure (σ_3) is similar on both riverbed and quarried rockfill materials. The ϕ-value increases with increase in d_{max} for riverbed rockfill materials while for quarried rockfill materials the ϕ-value decreases with increase in d_{max}. The angle of internal friction (ϕ) increases with increase in relative density.

The strength law has been proposed to determine the shear strength parameter, ϕ using the index properties of rockfill materials. A parameter B' has been proposed to represent three index properties viz. UCS, UVC and relative density, RD for each type of rockfill material. A relation has been successfully developed by using strength law to determine the failure stresses on the basis of B'-values and then the ϕ-values have been determined for all the riverbed and quarried modelled rockfill materials using proposed strength law. These values have been compared with the experimental ϕ-values. From the comparison, it is observed that the ϕ-values predicted by strength law match closely with the experimental values for all the riverbed and quarried modelled rockfill materials. This method provides satisfactory predictions.

In the absence of triaxial test data, ϕ-value can be determined by using strength law for any d_{max}. It means, using UCS and UVC test results and RD, ϕ-value can be determined for any maximum particle size (d_{max}). This method is less labour intensive and time consuming and economical and can be used where large size triaxial set up to test rockfill material is not available.

The proposed strength law has been adopted to predict the shear strength parameter of the prototype rockfill materials. These values of the shear strength parameter of prototype rockfill material have been compared with existing extrapolation technique by power law based on d_{max}. The power law requires laboratory test results for determining the strength parameter, ϕ for a maximum particle size. From the comparison, it is observed that ϕ-values from both methods match closely.

Using laboratory test results, the elastic and strength parameters required for HISS and HS models have been determined for both riverbed and quarried modelled rockfill materials. From the study of material parameters of HISS model, it is observed that the modulus of elasticity of rockfill material, E increases with increase in particle size and confining pressure for riverbed rockfill materials however, it decreases with increase in maximum particle size and increases with increase in confining pressure for quarried rockfill materials. The Poisson's ratio, ν remains almost constant with particle size for all the riverbed and quarried rockfill materials. The ultimate parameters, γ and β, hardening parameters, a_1 and η_1 and non-associative parameter, κ have, in general, a reverse trend for riverbed and quarried rockfill materials with respect to maximum particle size (d_{max}). The phase change parameter, n remains constant ($n = 3.0$) for all the d_{max} of both riverbed and quarried rockfill materials.

From the study of material parameters of HS model, it is observed that the reference stiffness modulus, E_{50}^{ref} increases with particle size for riverbed rockfill material while it has reverse trend for quarried rockfill material. The reference stiffness modulus, E_{oed}^{ref} and reference unloading and reloading modulus, E_{ur}^{ref} increases with particle size for both riverbed and quarried rockfill materials. The dilatancy angle, ψ decreases with increase in confining pressure and d_{max} while stress dependency factor, m' is assumed equal to 0.45 for all riverbed and quarried rockfill materials. The initial void ratio, e_{init} decreases with increase in maximum particle size.

A procedure has been proposed to determine the elastic parameters viz. E, ν and E_{50}^{ref} of both riverbed and quarried rockfill materials using index property, UVC, modulus of elasticity of intact rock, E_{ir}, confining pressure, σ_3 and Poisson's ratio of intact rock, ν_{ir}. Using the proposed procedure, the elastic parameters were determined for all the riverbed and quarried modelled rockfill materials and compared with the experimental values. From the comparison, it is observed that both determined and experimental values match closely. This procedure provides satisfactory predictions. Therefore, the proposed procedure can be used successfully for determining the elastic parameters of both riverbed and quarried rockfill materials for any maximum particle size (d_{max}) and confining pressure.

In the absence of oedometer test results, the oedometer reference modulus E_{oed}^{ref} is determined using reference stiffness modulus, E_{50}^{ref} and Poisson's ratio, ν. The unloading reloading reference modulus, E_{ur}^{ref} is taken equal to 3 E_{50}^{ref} for all practical cases.

The breakage factor for both types of rockfill materials were determined at the failure for all the specimens tested. It is observed that the breakage factor increases with increase in confining pressure and maximum particle size.

Stress-strain-volume change behaviour of modelled rockfill materials for both riverbed and quarried materials were back predicted using HISS and HS models and compared with the observed results. From the plots, it is observed that predicted and observed stress-strain-volume change behaviour of modelled rockfill materials for both riverbed and quarried materials match closely.

The prototype material parameters viz ultimate parameters, γ and β, phase change parameter, n hardening parameters a_1 and η_1 and non-associative parameter, κ required for HISS model have been determined by correlating with B' value as B' is a function of index properties of rockfill material. Material parameters for prototype rockfill material were determined by using a best fit linear extrapolation for both types of materials.

The prototype material parameters required for HS model viz. dilatancy angle, ψ has been determined by correlating with B' value as B' is a function of index properties of rockfill materials. The stress dependency parameter, m' is assumed equal to 0.45 for all the riverbed and quarried prototype rockfill materials. The parameter, initial void ratio,

e_{init} is correlated with UVC as UVC is basic characteristic of the rockfill material. Material parameters for prototype rockfill material were determined by using a best fit linear extrapolation for both riverbed and quarried rockfill materials.

Using the predicted elastic and strength parameters of all the riverbed and quarried prototype rockfill materials, stress-strain-volume change behaviour has been predicted using HISS and HS models.

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