Triaxial Behaviour of Rockfill Materials

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ABSTRACT

Two types of rockfill materials collected from two sites are modelled and tested under triaxial loading. The rockfill selected in this study had been used in the construction of the shell of the Ranjit Sagar in Northern India and Purulia dams in Eastern part of India. Stress-strain-volume change behaviour of the rockfill materials are presented and discussed. The behaviour of various rockfill materials has been compared.

KEYWORDS: rockfill, triaxial test, elastic parameters, stress strain behaviour.

INTRODUCTION

In the earth and rockfill dams, rockfill materials obtained either by blasting or from river bed are used in the shell of the dam. The blasted rockfill materials obtained by blasting the parent rock consist of angular to subangular particles. The material collected from river bed consists of rounded/ sub-rounded particles which are primarily weathered rocks. The rockfill material used in the dam construction is large in size and direct testing of the prototype material would require a test apparatus of a very large size. Various methods are used to scale down the size of the particles to facilitate testing of the rockfill materials. The behaviour of the rockfill materials is affected by such factors as mineralogical composition, particles grading, size and shape of particles and stresses. Triaxial tests have been conducted on modeled rockfill materials (Marsal 1967; Vesic and Clough 1968; Fumagalli 1969; Marachi 1972; Thiers and Donovan 1981; Venkatachalam, 1993; Gupta, 2000 and Abbas, 2003) to study the stress strain behavior of rockfill materials and fount that stress-strain characteristics of rockfill materials are non-linear, and inelastic. For the research programme, two hydro-electric projects have been chosen. The first project namely Ranjit Sagar hydro-power project in the Punjab State, Northern India has a rockfill dam of 160m height constructed over river Ravi. The transported river bed material consisting of rounded/ sub-rounded particles has been chosen. The second project viz. Purulia hydro-power project is located in West Bengal State in Eastern part of India. The fractured rockmass obtained by blasting the parent metamorphic rock, which consists of angular to subangular particles has also been chosen for this research program. This paper deals with the Stress-strain-volume change behaviour of the modeled rockfill materials. The behaviour of various rockfill materials have been compared.

Table 1: Rockfill Materials Used

Project name	Location	Name of the rock
Ranjit Sagar Dam	Located at river Ravi near village Thein in the Punjab State, India	Conglomerate, sandstone, quartzite, shale and claystone
Purulia Dam	Purulia, West Bengal State, India	Hornblande-quartz-schist

Rockfill materials

For the present study, one rockfill material of alluvial type and one more rockfill materials of quarried type were obtained. The details of the projects and the rocks comprising the rockfill materials are given in Table 1. The alluvial rockfill materials (Fig. 1) consist of rounded/sub-rounded particles, whereas quarried rockfill materials (Fig. 2) consist of angular particles. Physical characteristics are given in Table 2. The gradation curves of the particles of the two rockfill materials are shown in Figs. 3 and 4. Modeled rockfill materials with maximum size of particles, 25, 50, and 80 mm, were obtained using parallel gradation technique (Lowe 1964) for triaxial testing.

Figure 1: Ranjit Sagar Dam Materials

Table 2: Physical Characteristics of Rockfill Materials

S. No.	Details	Name of Project	
		Ranjit Sagar Dam	Purulia Dam
1.	Specific gravity	2.68	2.69
2.	Water Absorption (%)	1.00	1.90
3.	Aggregate Impact Value (%)	28.70	36.2
4.	Aggregate Crushing Value (%)	36.50	39.5
5.	Los Angeles Abrasion (%)	23.80	48.8

No.	Particle size (mm)
1.	80-50
2.	50-25
3.	25-12.5
4.	12.5-6.3
5.	6.3-4.75
6.	4.75-2.0
7.	2.0-0.425
8.	0.425-0.075

Figure 2: Purulia Dam Materials

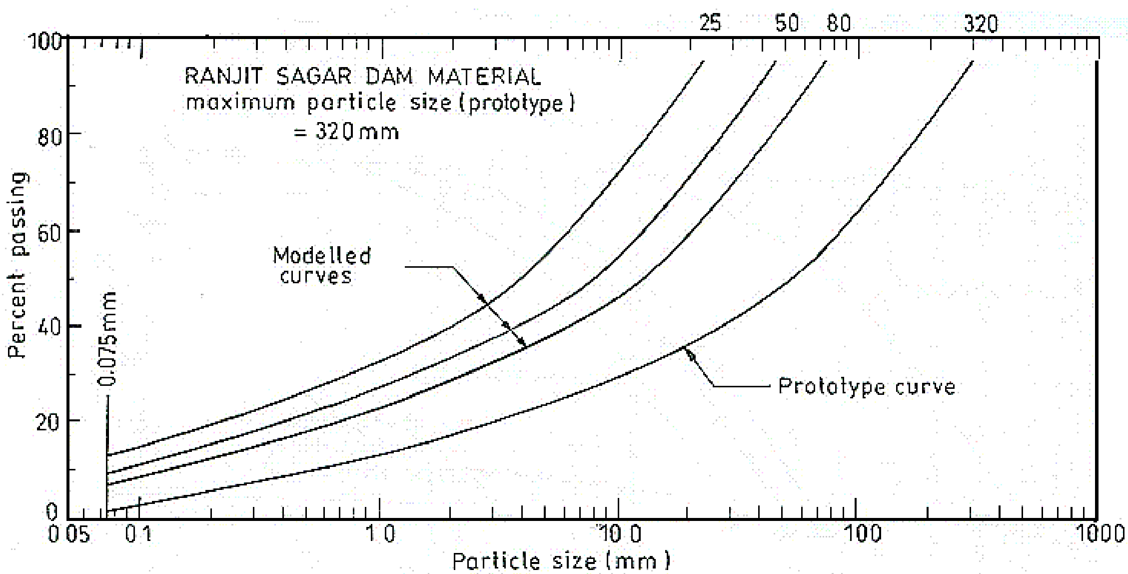

Figure 3: Grain Size Distribution for Prototype and Modeled Materials

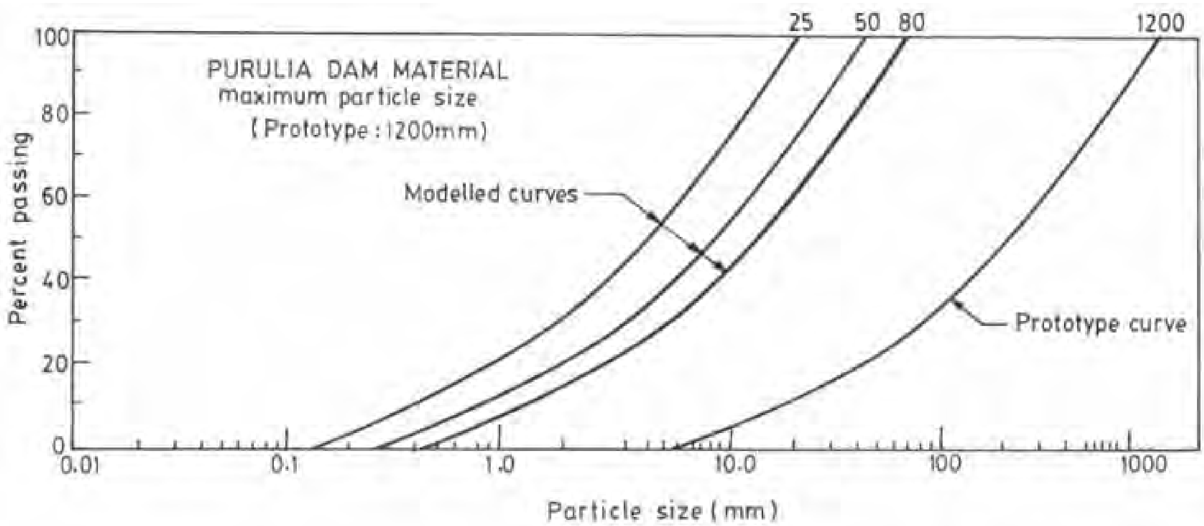

Figure 4: Grain Size Distribution for Prototype and Modeled Materials

Triaxial Tests

Consolidated drained triaxial tests have been conducted on the modeled rockfill materials at the Central Soil and Materials Research Station, New Delhi, India. A specimen size of 381 mm diameter by 813 mm long was used for testing. Details of the two triaxial cells used for the two sizes of specimens and the equipments used are given in Gupta, 2000. For testing, a dry density corresponding to 87% of relative density was adopted. Four confining pressures in the range between 0.2 and 1.4 MPa were used for each modeled rockfill material. The quantity of various sizes of rockfill materials required to achieve the gradation of the modeled rockfill material for preparing the specimen at the specified density was determined by weight. The sample was prepared using a split mold. The sample was compacted in six equal layers by vibratory compaction. The sample was saturated by allowing water to pass through the base of the triaxial cell and using a top drainage system for removing air voids. The sample was first subjected to the required consolidation pressure and then sheared to failure with a rate of loading of 1 mm/min. From the tests stress-strain-volume change behavior were plotted.

MODELLED ROCKFILL MATERIAL, RANJIT SAGAR

Stress-Strain-Volume Change Behaviour

Stress-strain-volume change relationships for the three modeled materials with maximum size of particle of 25 mm, 50 mm and 80 mm at four confining pressures viz. 0.35, 0.7, 1.1, 1.4 MPa are shown in Figs. 5 to 7 respectively. The behaviour is observed to be non-linear. The values of axial and volumetric strains at failure are given in Table 3. It is observed that for one maximum particle size material the axial strain at failure increases with increase in confining pressure. The axial strain at failure also increases with maximum particle size. Volume change response shows compression throughout the test. For one maximum particle size material the volumetric strain at failure increases with confining pressure. The volumetric strain at failure increases with size as well.

Table 3: Strains at failure in CTC test (Ranjit Sagar Modelled Material)

Maximum Particle Size (mm)	Confining Pressure (MPa)	Axial Strain at Failure (%)	Volumetric Strain at Failure (%)
25	0.35	7.5	1.43
	0.7	8.0	1.66
	1.1	8.5	2.10
	1.4	10.0	2.50
50	0.35	8.0	1.53
	0.7	9.0	1.87
	1.1	9.5	2.20
	1.4	10.0	2.72
80	0.35	9.0	1.69
	0.7	9.5	2.07
	1.1	10.5	2.37
	1.4	11.0	2.92

Elastic Parameters

The initial tangent modulus is expressed as a function of the confining pressure (Janbu, 1963), as

$$E_i = k p_a \left(\frac{\sigma_c}{p_a}\right)^{n'}$$

where, k and n′ are the modulus number and modulus exponent of the material respectively, σ_c is confining pressure and p_a is the atmospheric pressure.

The plots between, E_i/p_a and, σ_c/p_a are made for the various sizes and are given in Fig. 8. The values of k and n′ have been determined from these plots. The values of k and n′ for various sizes are presented in Table 4.

The value of lateral strain is calculated from the axial strain and volumetric strain measured, and Poisson's ratio is determined. The values of the Poisson's ratio, ν are also given in Table 4. Table 4 shows that the elastic parameters k and n′ increase and ν decreases with the particle size.

Table 4: Elastic Parameters of Ranjit Sagar Rockfill Material

Elastic Parameters	Maximum Particle Size (mm)		
	25	50	80
k	193.69	220.34	253.63
n′	0.6386	0.6683	0.7146
ν	0.31	0.30	0.29

Table 5: Strains at failure in CTC test (Purulia Modeled Material)

Maximum Particle Size (mm)	Confining Pressure (kPa)	Axial Strain at Failure (%)	Volumetric Strain at Failure (%)
25	300	5.0	0.09
	600	6.0	0.32
	900	7.0	0.55
	1200	8.0	0.89
50	300	6.0	-0.16
	600	7.0	0.13
	900	8.0	0.42
	1200	9.0	0.69
80	300	7.0	-0.52
	600	8.0	-0.11
	900	9.0	0.17
	1200	10.0	0.49

Table 6: Elastic Parameters of Purilia Rockfill Material

Elastic Parameters	Maximum Particle Size (mm)		
	25	50	80
k	167.07	286.02	451.13
n′	0.8162	0.6550	0.4068
ν	0.34	0.33	0.31

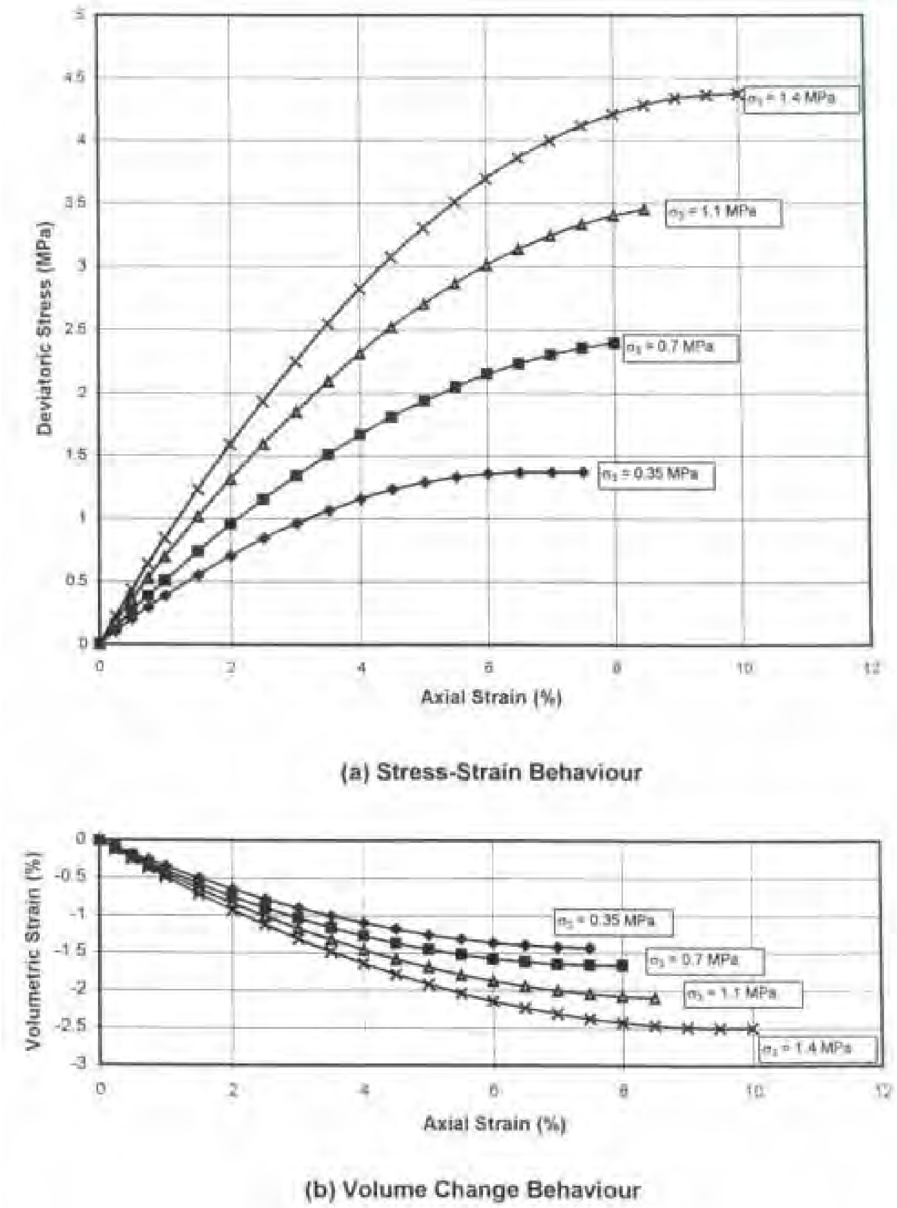

Figure 5: Stress-Strain-Volume Change Response (Ranjit Sagar, D_{max} = 25mm)

MODELLED ROCKFILL MATERIAL, PURULIA

Stress-Strain-Volume Change Behaviour

Stress-strain-volume change relationships for the three modeled materials with the maximum size of particle of 25 mm, 50 mm and 80 mm at four confining pressures viz. 0.3, 0.6, 0.9, 1.2 MPa are shown in Figs. 9 to 11 respectively. The behaviour is observed to be non-linear. The volume change response shows compression in the initial part of shearing and dilation is noted on further shearing of the sample. The values of the axial and volumetric strains at failure are given in Table 5. It is observed that for this rockfill material also the axial strain at failure increases with confining pressure and the maximum particle size. The compressive volumetric strain at failure increases with the increase in confining pressure but decreases with the increase in particle size.

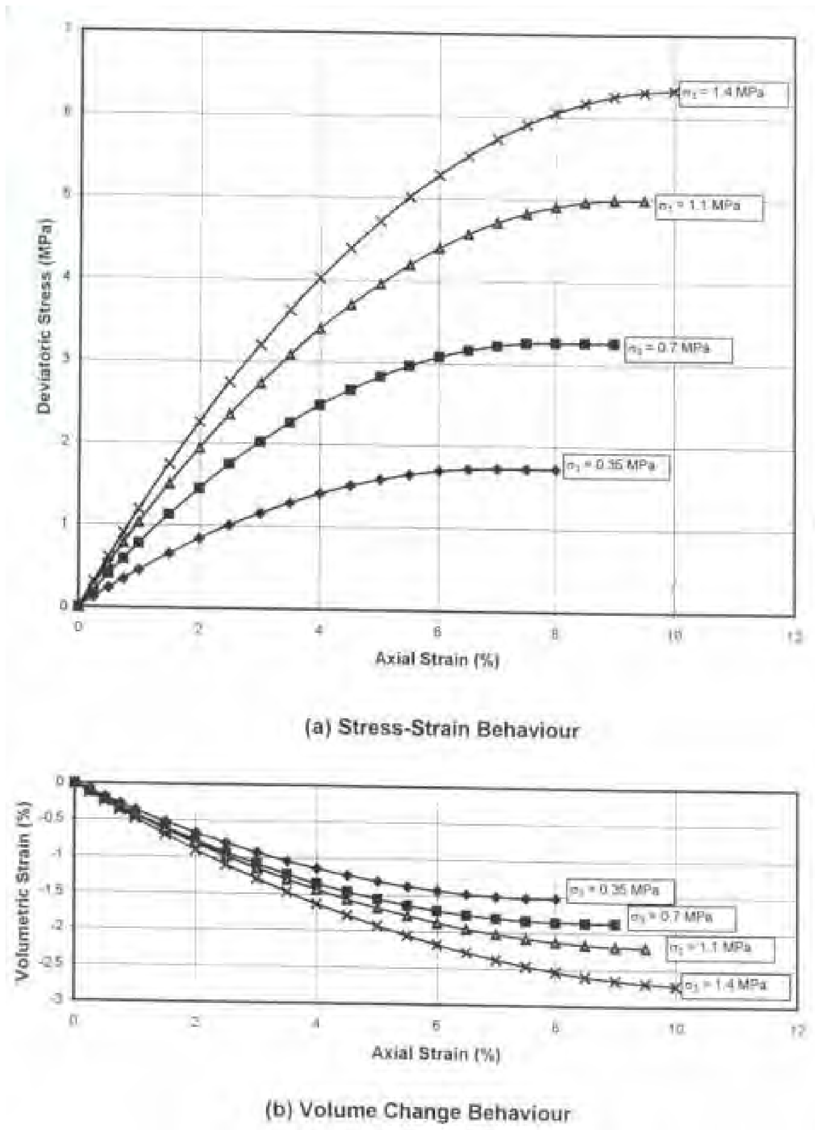

Figure 6: Stress-Strain-Volume Change Response (Ranjit Sagar, D_{max} = 50mm)

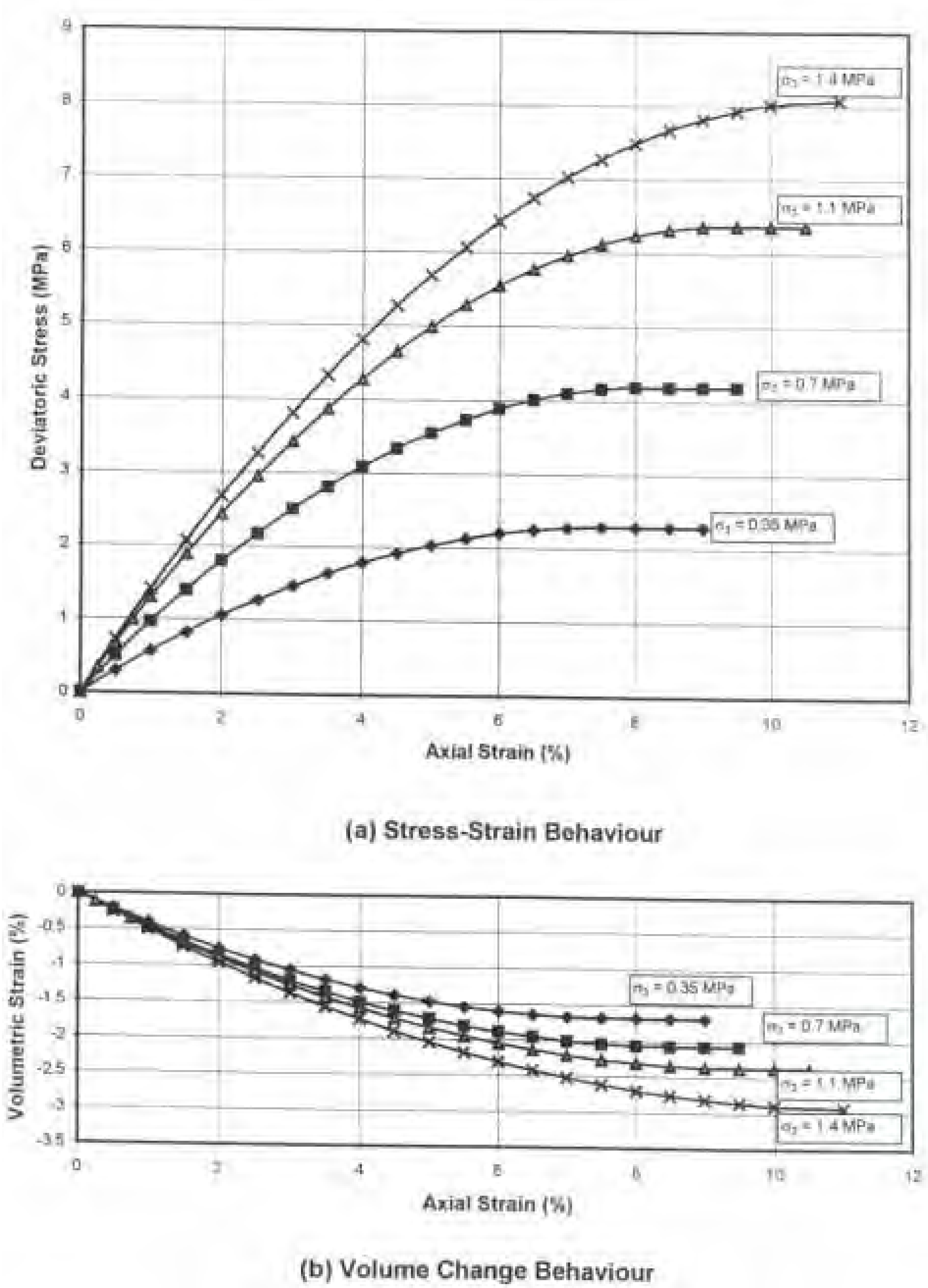

Figure 7: Stress-Strain-Volume Change Response (Ranjit Sagar, D_{max} = 80mm)

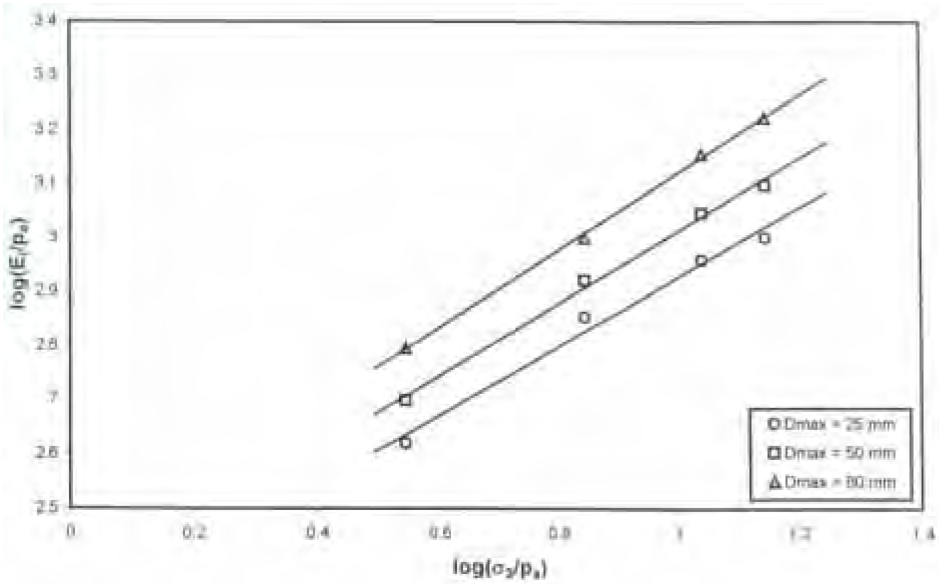

Figure 8: Variation of Initial Tangent Modulus with confining Pressure (Ranjit Sagar)

Elastic Parameters

The elastic parameters for this material are determined using the procedure presented earlier. The plots between, E_i/P_a and, σ_c/P_a were made for the various sizes. The values of k and n′ have been determined from these plots. The values of k, n′ and ν for various sizes are given in Table 6. It is observed that the elastic parameters k increases while n′ and ν decrease with the particle size.

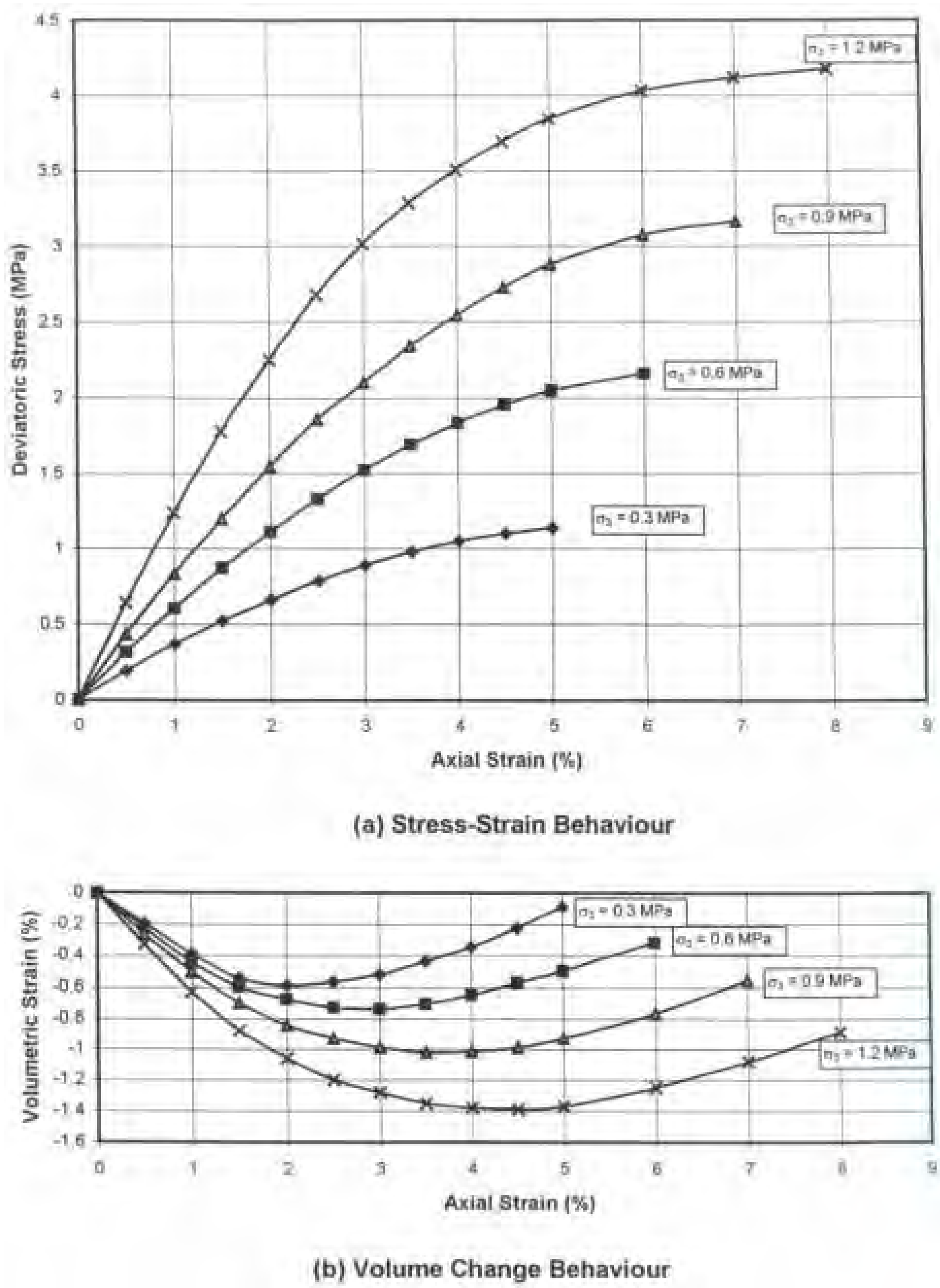

Figure 9: Stress-Strain-Volume Change Response (Purulia , D_{max} = 25mm)

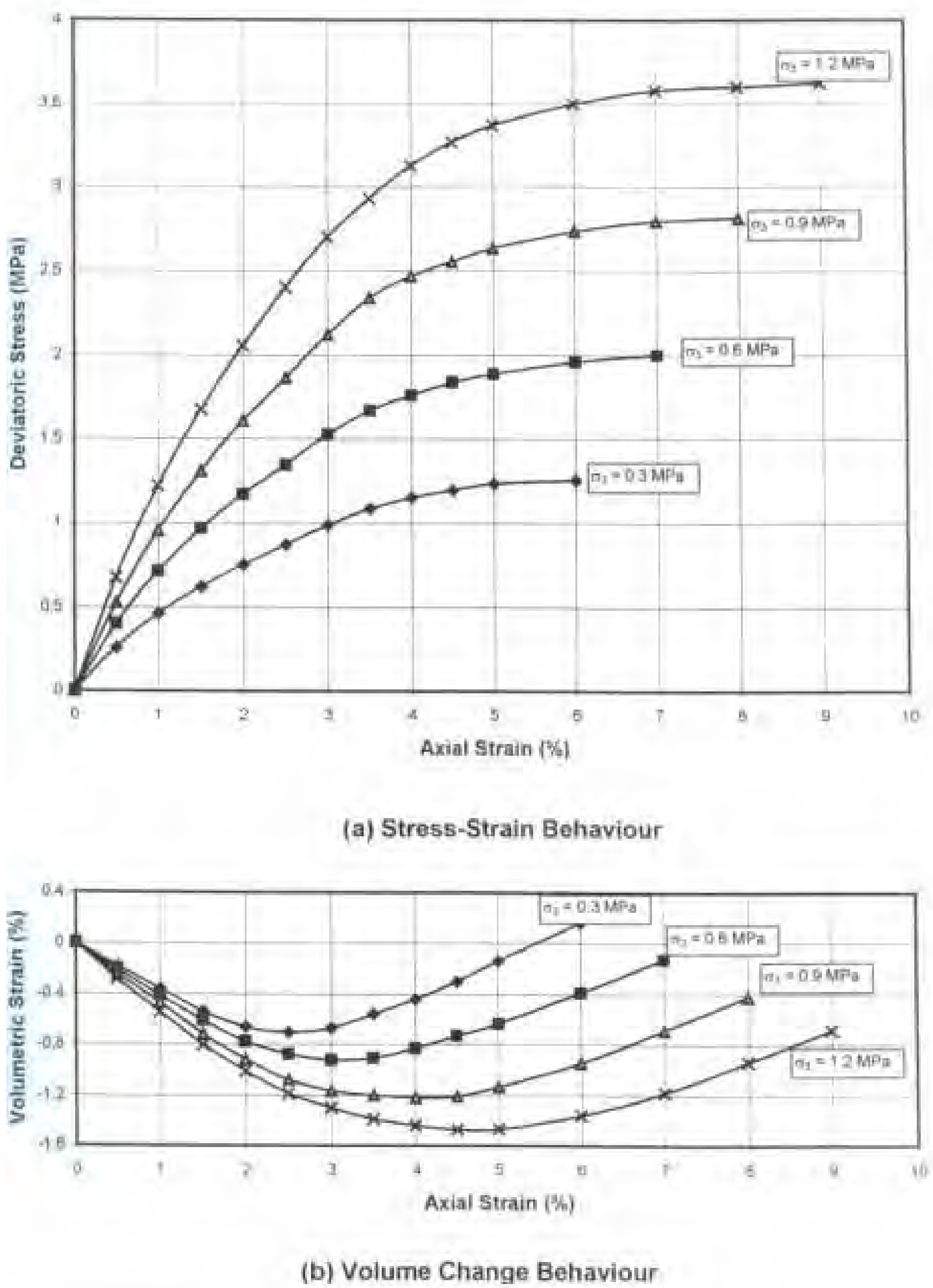

Figure 10: Stress-Strain-Volume Change Response (Purulia, D_{max} = 50mm)

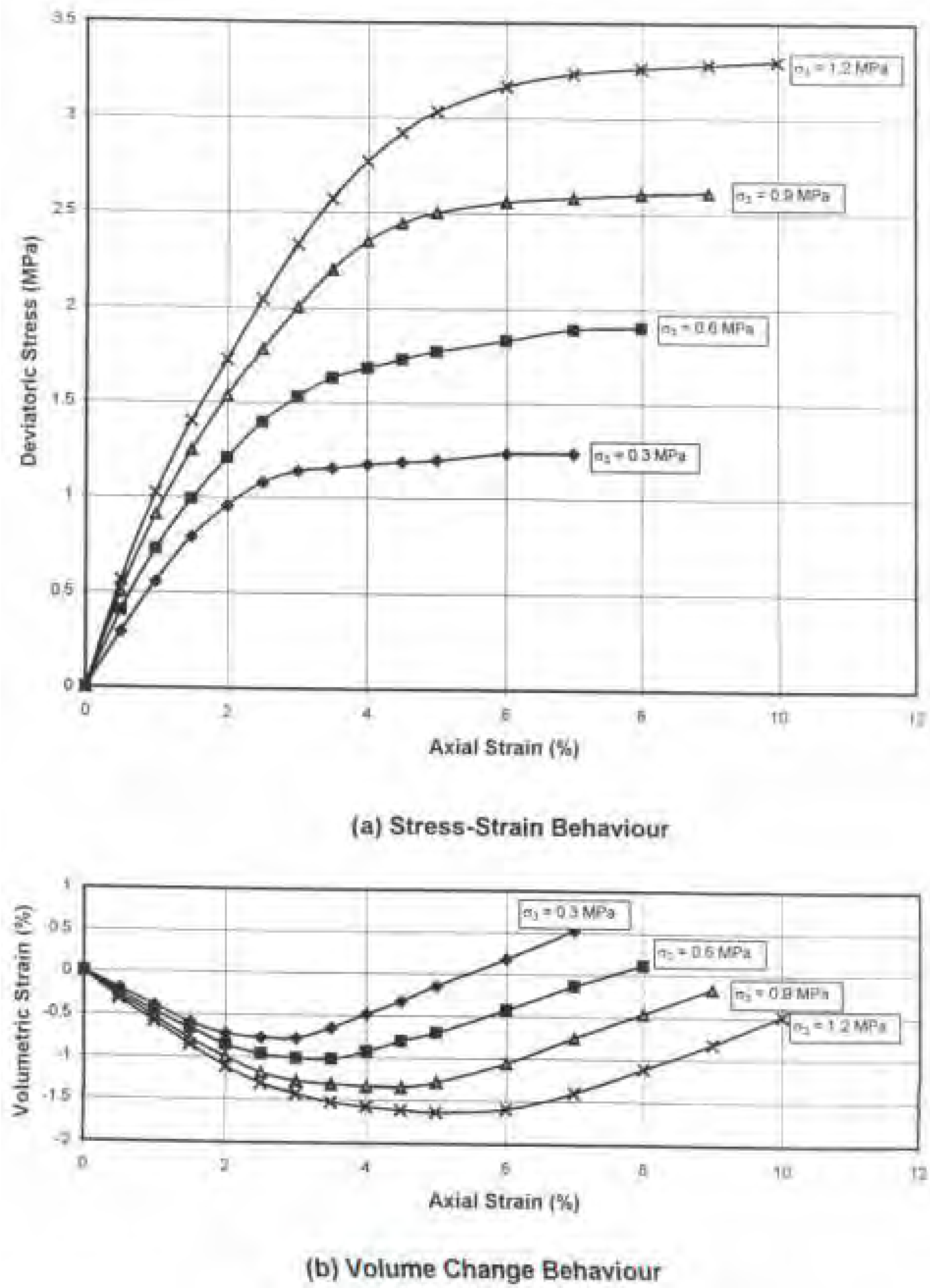

Figure 11: Stress-Strain-Volume Change Response (Purulia, D_{max} = 80mm)

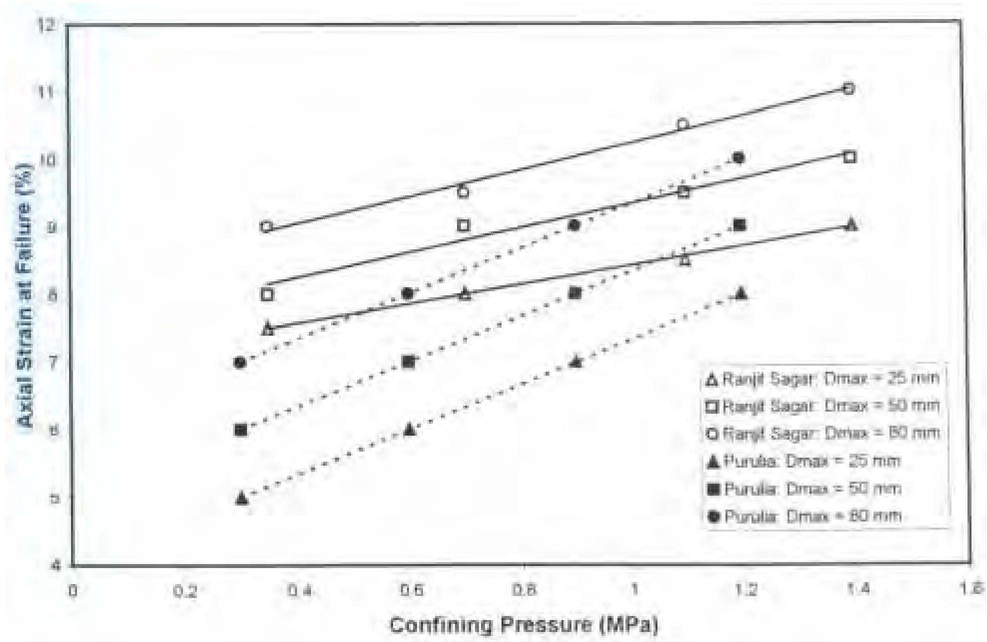

Figure 12: Variation of Axial Strain at Failure with the Confining Pressure

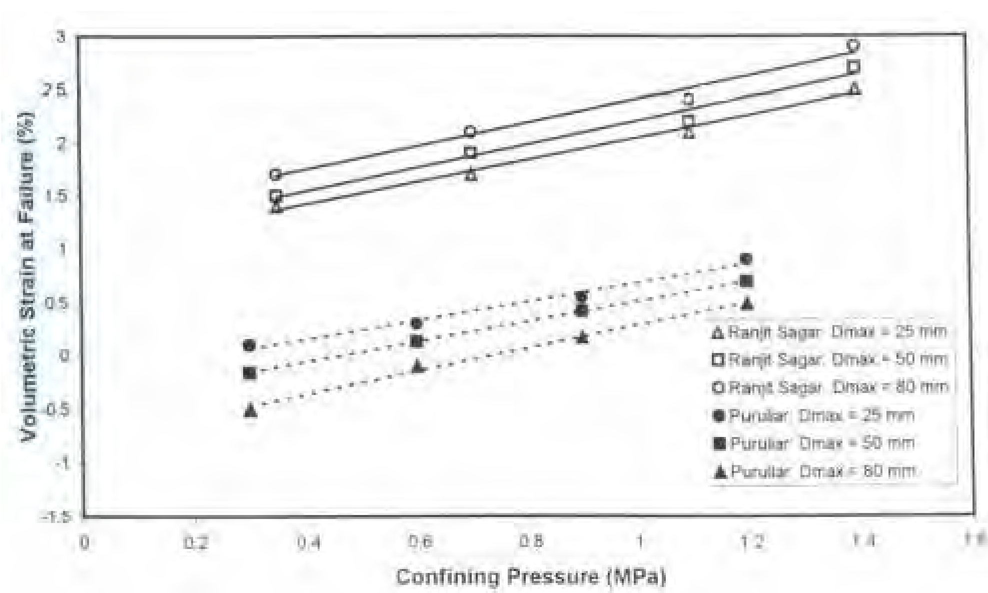

Figure 13: Variation of Volumetric Strain at Failure with the Confining Pressure

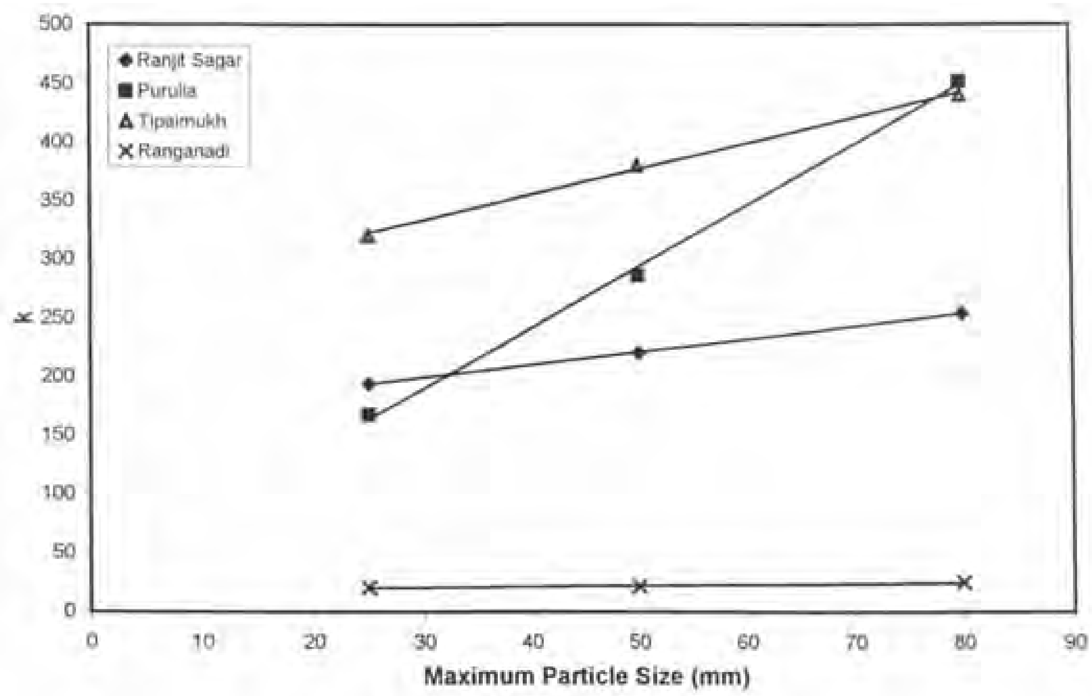

Figure 14: Variation of Constant, k with Maximum Particle Size

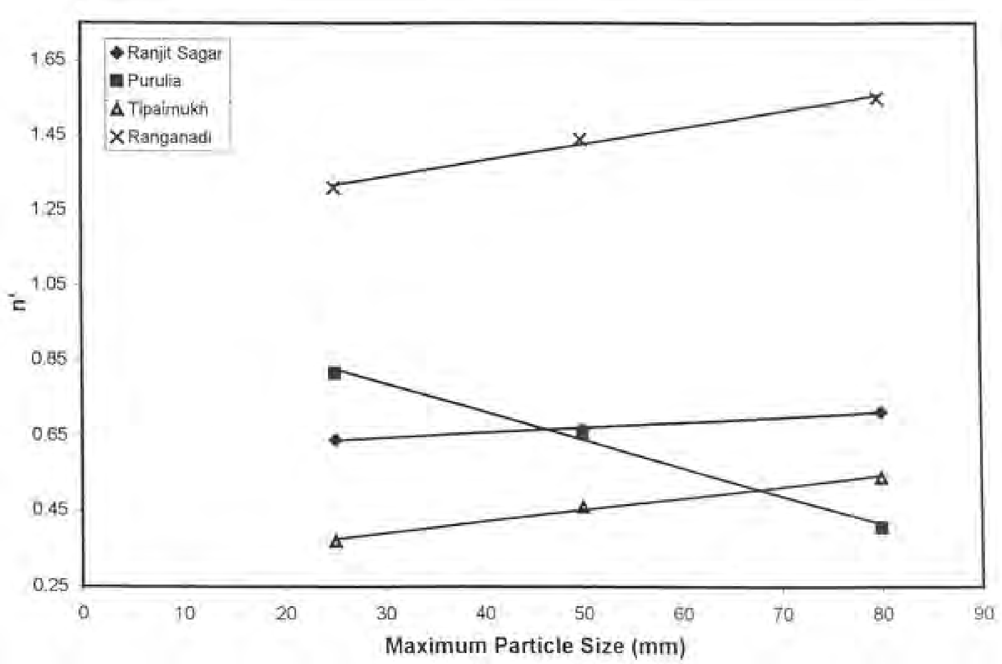

Figure 15: Variation of Constant, n′ with Maximum Particle Size

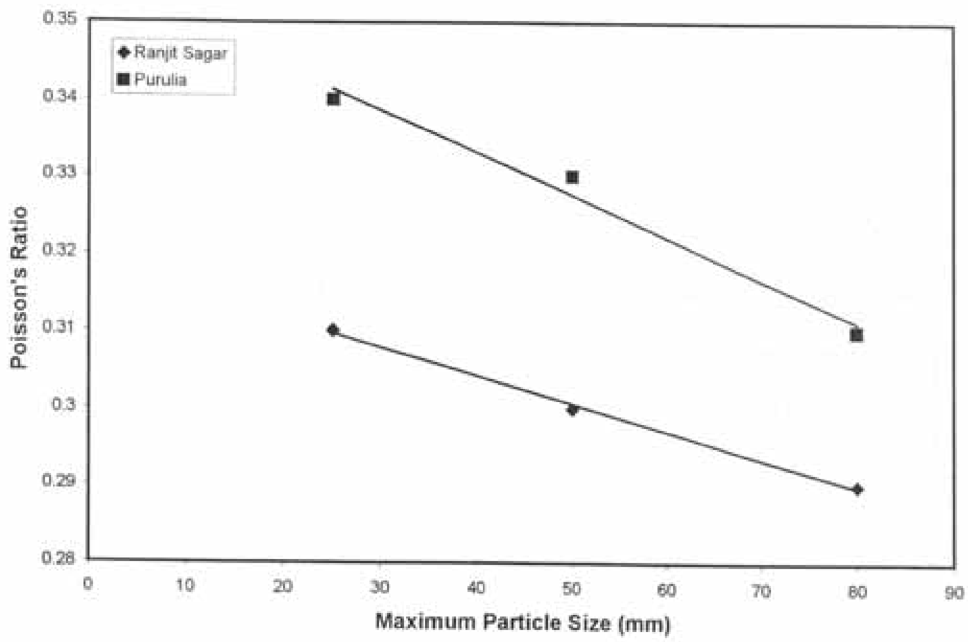

Figure 16: Variation of Poisson's ratio with Maximum Particle Size

COMPARISONS

The rockfill material from the site of Ranjit Sagar dam is primarily rounded to subrounded river bed material while that of Purulia dam site consists of broken (blasted) material with angular to subangular particle. The effects of the different type of particle on the behaviour are compared herein.

Axial and Volumetric Strain

The relationships between the confining pressure and the axial strain at failure are shown in Fig.12 for the two rockfill materials. For both the materials the axial strain at failure increases with the confining pressure as well as with the increase in the size of the particle. The rate of increase in the failure Strain with the confining pressure is nearly same for all the sizes for each rockfill material. However, the rate of increase in the failure strain for the rockfill material from Purulia is higher than that for the material from Ranjit Sagar dam. Furthermore, the axial strains at failure for the Ranjit Sagar rockfill material are higher than those for the rockfill material from Purulia. The test results reported by Gupta (1980), Sudhindra et.al. (1986, 1987, 1991) also indicate that the axial strain at failure increases with the increase in confining pressure. The study of Tipaimukh dam material reported by Venkatachalam (1993) also shows similar trend. The study by Marachi et al. (1969) also indicates that the axial strain at failure increases with the increase in the confining pressure.

The relationships between the confining pressures and the volumetric strain at failure for the two types of the rockfill materials are shown in Fig 13. The volumetric strain at failure is higher for Ranjit Sagar dam than that for rockfill material from Purulia The volumetric strain at failure increases with the increase in the confining pressure for both the materials. The failure strain increases with the increase in the particle size in the case of rockfill material from Ranjit Sagar dam where as reverse in trend is observed in the case of Purulia dam. The rate of increase in the volumetric strain at failure with confining pressure is nearly same for the two types of rockfill materials and for all the sizes. The responses observed by Venkatachalam (1993) in respect of Tipaimukh and Ranganadi dams river bed materials are comparable to those of the rockfill material from Ranjit Sagar.

Elastic Parameters

The relationships between the elastic parameters and the size of the particle for the two materials are shown in Fig 14 to 16 along with the other materials. The material constants k and n′ both increase with the increase in the size of the particle for Ranjit Sagar rockfill material. The constant k increases while n′ decreases with the increase in the maximum size for the material from Purulia. The values of k and n′ for Tipaimukh and Ranganadi dams river bed rockfill materials reported by Venkatachalam (1993) are also plotted (Figs.14 and 15). Their behaviour is similar to that of Ranjit Sagar river bed material. Also, river bed materials show flatter curve as compared to Purulia which shows steeper slope. The Poisson’s ratio decreases with increase in maximum size for both the materials.

CONCLUSIONS

In this study, consolidated drained triaxial tests have been conducted on rockfill materials taken from two dam sites of India. The results obtained are summarized as follows:

(1) The stress-strain-volume change behaviour in general is non-linear for both the rockfill materials. The volume change behaviors of the two rockfill materials are different from each other. The Ranjit Sagar rockfill material undergoes volume compression throughout the test. Purulia rockfill material shows compression in the initial part of shearing and dilation is noted on further shearing of the sample.

(2) Both the rockfill materials show increase in axial strain and volumetric strain with the increase in confining pressure for all the sizes of the particles. Thus the effect of confining pressure is same for both the materials.

(3) Both the rockfill materials show increase in axial strain at failure and k value, and decrease in the value of ν with increase in particle size. But, whereas, volumetric strain at failure and the value of exponent n' increase with the size of the particles for the river bed material, these values decrease with the size of the particle for the blasted rockfill material.

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