

Effect of Particle Size and Confining Pressure on Breakage and Strength Parameters of Rockfill Materials

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ABSTRACT

Rockfill dams are mostly constructed using blasted rockfill materials obtained by blasting rock or alluvial rockfill materials collected from the riverbeds. In this paper effect of maximum particle size on breakage and strength parameter on two rockfill materials is investigated. Drained triaxial tests have been conducted on various sizes of rockfill materials used in the two dams. Test data has been analyzed and effect of size and confining pressure on breakage and strength parameters have been studied.

KEYWORDS: Triaxial tests, Rockfill materials, particle size, breakage and strength parameters.

INTRODUCTION

From time immemorial, man has used rockfill as a construction material for different structures like dams, embankments etc. Rockfill dams are increasingly used, because of their inherent flexibility, capacity to absorb large seismic energy, and adaptability to various foundation conditions. The use of modern earth and rock moving equipment and locally available materials make such dams economical as well. Rockfill materials consists primarily of angular to sub-angular particles obtained by blasting parent rock or rounded / sub-rounded particles collected from river beds. The behavior of rockfill material is affected by factors such as mineralogical composition, particle grading, size and shape of particles, and stress conditions etc. Besides these factors, in the case of large sized rockfill materials, the breakage of particles is significant. This paper deals with the effect of grain size and confining pressure on the particle breakage and strength parameter of alluvial (riverbed) and blasted (quarried) rockfill materials.

REVIEW

Virtually all the investigations involving soil testing with high pressure have resulted in considerable particle breakage (Becker, 1972; Hardin, 1985; Murphy, 1987; Colliat Dangus *et al.*, 1988; Fukumoto, 1990; Hagerty *et al.*, 1993; Lade *et al.*, 1996; Daouadji and Heicher 1997). Several authors have already attempted to quantify the particle breakage by defining factors based on the modification of the grain size distribution curves before and after the tests. These empirical factors have been written either as the variation of a particular grain diameter (Lee and Farhoomand, 1967; Lade and Yamamuro, 1996) or as the shift of the whole grain size distribution curve (Marsal, 1967; Hardin, 1985). There are several factors that affect the amount of particle breakage in a geological material (Lee and Farhoomand, 1967; Ramamurthy, 1969; Murphy, 1971; Billam, 1971; Lo and Roy, 1973; Ramamurthy *et al.* 1974; Gupta 1980; Hardin 1985; Kjearnsli *et al.*, 1992; Venkatachalam, 1993; and Lade *et al.*, 1996). The amount of particle breakage is affected by the stress level, stress magnitude and stress path. Large amount of particles breakage is generated when stress levels are higher and when large amounts of strains occur in regions of high stress magnitudes. The quantity of particle breakage is also a function of time (Yamamuro and Lade, 1993). The results of tests conducted by Marachi *et al.* (1972) show a decrease in the angle of internal friction with the increase in size of grains.

MATERIAL USED AND TESTING

Material of Ranjit Sagar Dam Site

The material collected from the river bed consists of rounded / sub rounded particles up to 320 mm in size. This contains pieces of conglomerate, sandstone, quartzite, shale, claystone, grits of chart and jasper, other material of older rocks and recent alluvium. The individual particles are very strong as it is very difficult to break the medium size particles with a hammer. Jointing in the rock pieces is random and the rock is isotropic. The rockfill material collected from the field is shown in Fig. 1.



Figure 1: Ranjit Sagar Dam Materials

The area is occupied by rocks of upper Shivalik Group and recent alluvium. The rocks are of sedimentary origin and consist of detrital material from various rocks types. In general, rocks are consisting of mature grains and sediments of quartz, clays, micas and heavy minerals. Previous study reported hornblende as an indicator and dominant heavy mineral in sediments of upper Shivalik. The rocks of upper Shivalik have been assigned a Quaternary i.e. Pleistocene age (Kumar 1985).

Material of Purulia Dam Site

The rockfill material collected from the site for testing is obtained by blasting the parent rock. The rockfill material consists of angular to subangular particles in shape and size upto 1200 mm. Rockfill material collected from dam site is shown in Fig. 2.



Figure 2: Purulia Dam Materials

The rock is fine grained, equigranular and often leucocratic. The biotite rich bands are prevalent throughout the rock mass. The rock is hard, compact and very strong, and often breaks with irregular fractures giving rise to angular to subangular rock fragments. The primary minerals which constitute the rock are quartz, biotite, muscovite and feldspar with other accessory minerals like tourmaline and hornblende.

The parent rock at this project site is metamorphic which falls into foliated type. Most of the time foliations are visible in hand-specimen scale. The rock i.e. biotite-gneiss belong to Daling-Darjeeling and Rangloit group of Archaean-Middle Proterozoic period. The rock is associated with granitic-gneiss, porphyritic-granite and other meta-sediments in and around the area.

GRADATION OF MATERIALS

Gradation of Prototype Materials

Representative rockfill materials are collected from different locations and are subjected to grain size analysis. The grain size distribution results are plotted and an average curve is drawn.

This curve has been designated as the average prototype curve of the representative rockfill materials. Prototype gradation curves for Ranjit Sagar and Purulia rockfill materials are shown in Figs. 3 and 4 respectively.

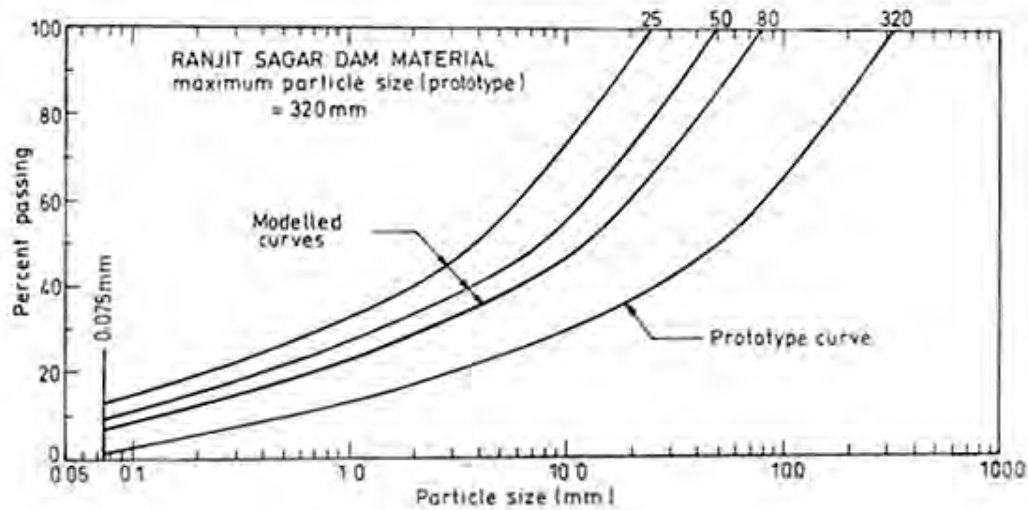


Figure 3: Grain Size Distribution for Prototype and Modelled Materials

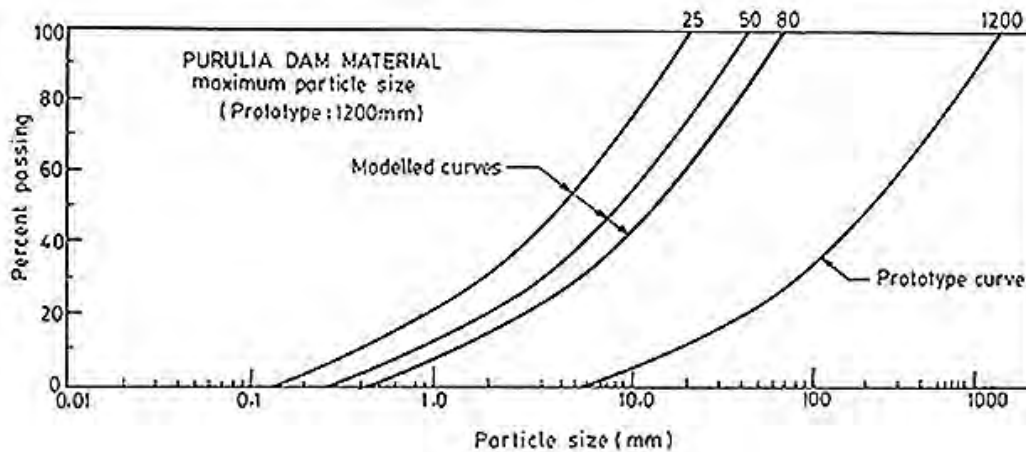


Figure 4: Grain Size Distribution for Prototype and Modelled Materials

Gradation of Modeled Materials

The particle sizes of the actual material are scaled down to some degree. The material so obtained, popularly known as modeled material is used for the testing.

Three modeled gradation curves are derived using John Lowe's Parallel Gradation modelling technique (Lowe 1964) having a maximum particle size of 80, 50 and 25 mm respectively.

Modelled gradation curves in respect of Ranjit Sagar and Purulia rockfill materials are shown in Figs. 3 and 4 respectively. Using these model grain size distribution curves, the required quantities of various fractions of rock fill materials have been calculated. The total quantities of materials thus required are sieved from the materials collected from two dam sites.

MATERIALS USED FOR TESTING

Three modeled rockfill materials obtained by geometrically reducing the particle size, with maximum particle size viz. 25, 50, 80 mm, have been used for the tests for both the materials. Figs. 3 and 4 show the grading characteristics of the two types of rockfill materials. Physical characteristics are given in Table 1. The dry density is calculated for the modeled rockfill materials. The values of the maximum dry density, minimum dry density and required dry density corresponding to 87% of relative density are given in Table 2. In accordance with the model gradation curves, the total dry weight required for achieving 87% of relative density is computed for each of the specimens to be tested. The quantity of individual fractions used for the test is given in Table 3.

Table 1: 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

Table 2: Relative Densities for the Rockfill Materials

S. No	Material	Particle Size (mm)			Dry Density (kN/m ³)	
		D _{max}	D ₅₀	γ_{max}	γ_{min}	Corresponding to 87% of Relative Density
1	Ranjit Sagar	25	3.8	22.0	19.2	21.6
		50	7.6	22.0	19.1	21.6
		80	12.0	22.9	19.5	22.4
2	Purulia	25	5.0	21.6	17.0	20.9
		50	9.6	21.6	17.2	20.9
		80	15.8	21.7	17.4	21.0

TRIAXIAL TESTS

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 1.40 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 prepared by compacting the material 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.

Table 3: Quantities of Various Fractions of Modeled Rockfill Materials for Triaxial Test

S. No	Material	Fractions (mm)	Quantities in Kg to achieve 87% of relative density		
			D_{max} (mm)		
			25	50	80
1	Ranjit Sagar	80-60	-	-	18.6
		60-50	-	-	12.4
		50-40	-	13.8	18.6
		40-25	-	33.8	26.9
		25-10	59.7	43.9	37.3
		10-4.75	35.8	25.9	20.7
		4.75-2.0	25.9	17.9	16.6
		2.0-.425	29.8	23.9	24.8
		0.425-.075	19.9	21.9	16.6
		<.075	27.9	17.9	14.5
	Total Quantity (kg)	199.0	199.0	207.0	
2	Purulia	80-50	-	-	33.2
		50-25	-	48.5	40.9
		25-12.5	46.5	36.9	33.2
		12.5-6.3	38.8	31.0	27.3
		6.3-4.75	13.5	11.6	9.8
		4.75-2.0	34.8	25.3	21.4
		<2.0	60.0	40.7	29.3
			Total Quantity (kg)	193.6	194.0

STRENGTH PARAMETERS

Failure envelopes in p-q space were plotted for the three sizes of the rockfill materials and the values of cohesion, c and angle of internal friction, ϕ are calculated. The values of cohesion, c and angle of internal friction, ϕ for the two materials are given in Tables 4 and 5. The relationships between the angle of internal friction and the maximum size of the particle for the two materials are plotted in Fig. 5 along with the other two materials. There is increase in the value of the angle of internal friction with the size of the particle for Ranjit Sagar rockfill material. Purulia rockfill material shows decrease in the angle of internal friction with the increase in size. Marachi (1969) has reported similar trend after conducting test on blasted angular materials as shown by Purulia rockfill material in this study. The values of the angle of internal friction for Tipaimukh and

Ranganadi dams river bed rockfill materials reported by Venkatachalam (1993) are also superimposed in Fig. 5. They show similar trend as that of Ranjit Sagar river bed material.

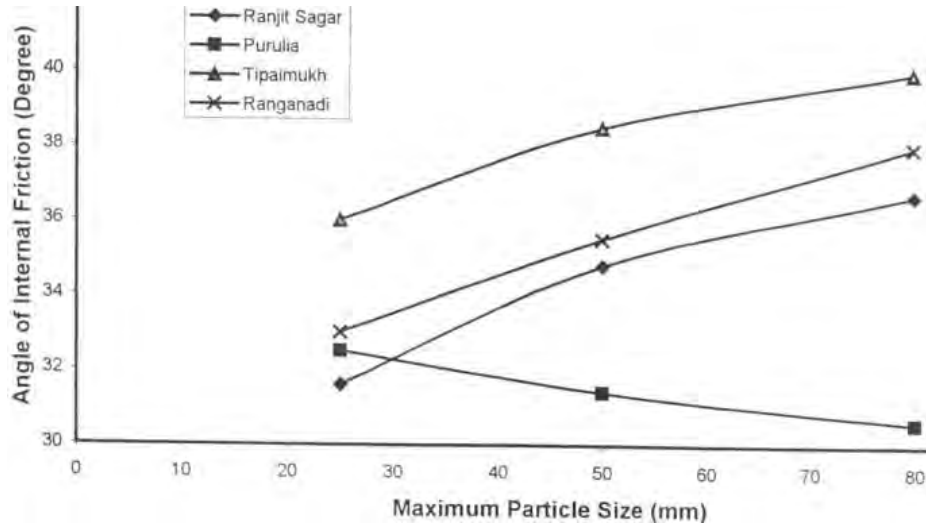


Figure 5: Variation of Angle of Internal Friction with Maximum Particle Size

Table 4: Values of c and ϕ for Ranjit Sagar Rockfill Material

D_{max} (mm)	c (kPa)	ϕ (degrees)
25	0.0	31.5
50	0.0	33.2
80	0.0	35.4

Table 5: Values of c and ϕ for Purulia Rockfill Material

D_{max} (mm)	c (kPa)	ϕ (degrees)
25	0.0	32.5
50	0.0	31.4
80	0.0	30.6

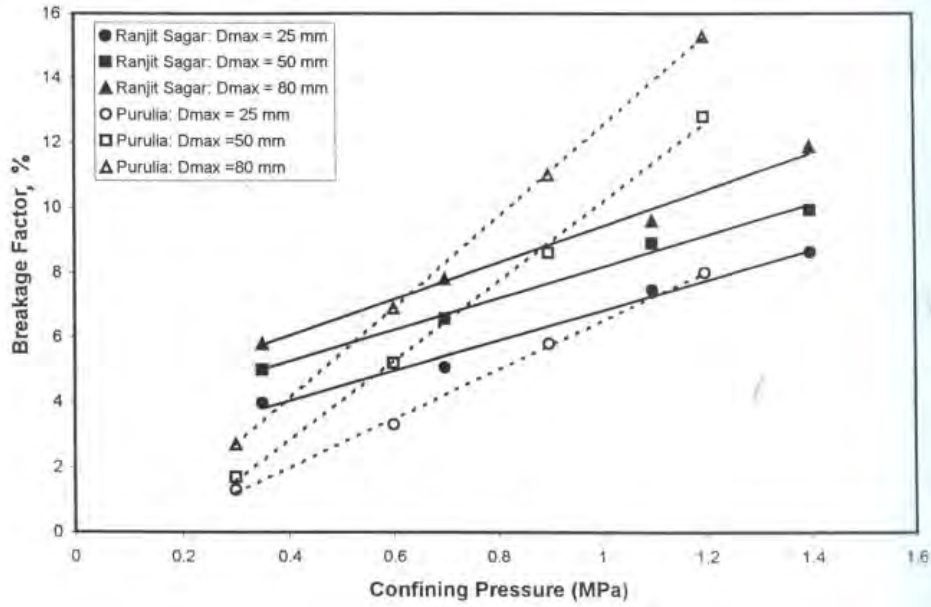


Figure 6: Variation of Breakage Factor with the Confining Pressure

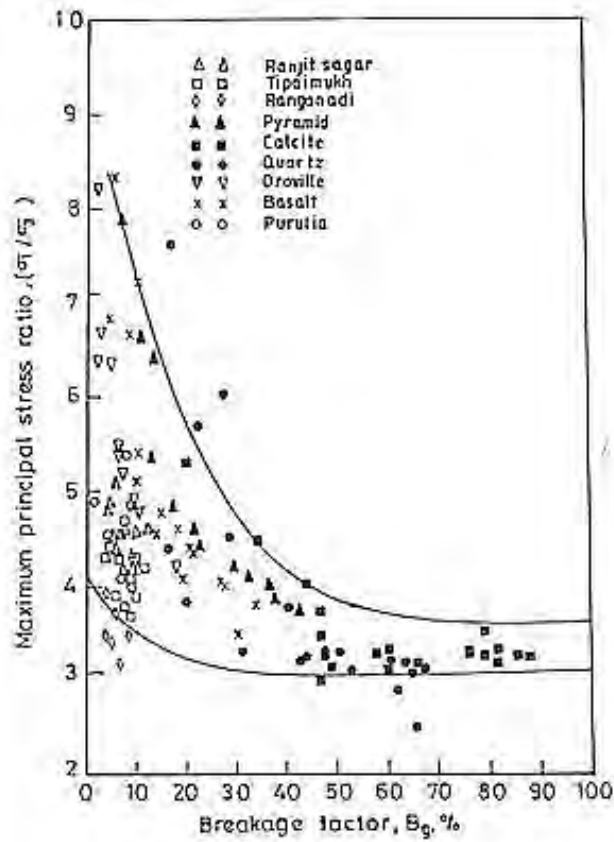


Figure 7: Relationship between Maximum Principal Stress Ratio and Breakage Factor

PARTICLE BREAKAGE FACTOR

The breakage is quantitatively expressed as breakage factor, B_g as proposed by Marsal (1965). The procedure for the calculation of B_g is given in Table 6. The values of B_g for the two materials are given in Tables 7 and 8.

Table 6: Calculation of B_g (Ranjit Sagar Dam)

Max. Particle Size: 80 mm		Confining Pressure : 700 kPa			
Sieve Size (mm)	Max. Particle Size: 80 mm		Confining Pressure: 700 kPa		Breakage Factor (%)
	Wt. Retained before triaxial test (kg)	Wt. Retained after triaxial test (kg)	Initial Percentage Retained	Final Percentage Retained	
80-60	18.72	17.3	9.00	8.33	0.67
60-50	12.48	10.4	6.00	4.98	1.02
50-40	18.72	15.8	9.00	7.58	1.42
40-25	27.04	21.9	13.00	10.54	2.46
25-10	37.44	32.8	18.00	15.77	2.23
10-6.3	12.48	15.0	6.00	7.22	-1.22
6.3-4.75	8.32	10.9	4.00	5.22	-1.22
4.75-2.0	16.64	20.2	8.00	9.72	-1.72
2.0-.425	18.72	22.8	9.00	10.94	-1.94
.425-.075	35.36	38.1	17.00	18.33	-1.33
< .075	2.08	2.8	1.00	1.37	-0.37

Breakage Factor B_g (%) = $0.67 + 1.02 + 1.42 + 2.46 + 2.23 = 1.22 + 1.22 + 1.72 + 1.94 + 1.33 + 0.37 = 7.8$

Table 7: Breakage Factors for Ranjit Sagar Rockfill Materials

Maximum Particle Size (mm)	Ranjit Sagar Rockfill Material	
	Confining Pressure (MPa)	Breakage Factor B_g (%)
25 mm	0.35	3.96
	0.70	5.06
	1.10	7.46
	1.40	8.62
50 mm	0.35	5.00
	0.70	6.57
	1.10	8.90
	1.40	9.92
80 mm	0.35	5.80
	0.70	7.80
	1.10	9.60
	1.40	11.87

The values of Breakage factors are plotted against the confining pressure in Fig. 6. It is observed that the breakage factor increases with the increase in confining pressure for both the materials. The rate of increase in the breakage factor for the rockfill material from Purulia is higher than that for the material from Ranjit Sagar dam. Further, Breakage factor is more at higher value of confining pressure in the case of rockfill material from Purulia as compared to the material from Ranjit Sagar dam site. This trend is just reverse at lower value of confining pressure. Breakage factors also increases with the increase in the size of the particle for both the

materials. Similar trends have been reported by Venkatechalam (1993) for Tipaimukh and Rangandi river bed rockfill materials. This trend is found to be similar to the trend observed by Marsal (1965), Vesic and Clough (1968) and Marachi et al (1969). Ramamurthy et al. (1974) also concluded that magnitude of crushing increases with increase in particle size, which is in agreement with this work. The relationships between the particle breakage factor and principal stress ratio at failure is plotted in Fig. 7 in respect of Ranjit Sagar and Purulia modelled rockfill materials. The data for seven other materials as reported by Marachi *et al.* (1969) and Gupta (1980) have also been plotted in Fig. 7. The plotted points for Ranjit Sagar material as well as Purulia modeled rockfill lie within the boundaries shown. This figure indicates that the strength of materials decreases as the particle breakage increases. The plot further indicates that the stress ratio tends to become constant for higher values of breakage factor.

Table 8: Breakage Factors for Purulia Rockfill Materials

Maximum Particle Size (mm)	Purulia Rockfill Material	
	Confining Pressure (MPa)	Breakage Factor B_p (%)
25 mm	0.3	1.3
	0.6	3.3
	0.9	5.8
	1.2	8.0
50 mm	0.3	1.7
	0.6	5.2
	0.9	8.6
	1.2	12.8
80 mm	0.3	2.7
	0.6	6.9
	0.9	11.0
	1.2	15.3

CONCLUSIONS

Both the materials show increase breakage factor 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. The value of ϕ increase with the size of the particles for the river bed material, these values decrease with the size of the particle for the blasted material. Thus, the nature of particles (rounded/ angular) appears to influence certain behaviour of the rockfill material.

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