Discussion on Papers

Behaviour of Coarse Grained Soils Under High Stress*

by

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Authors have shown in the paper that crushing of sand particles takes place under high consolidation stresses. Studies regarding crushing of particles, when the samples of sand, gravel and mixture of sand-gravel are tested under high normal pressures, were made on 200 Tonne Console Model Concrete Tester. The test material was filled in three layers (each layer lightly tamped) in mild steel cylindrical mold of 152.4 mm diameter by 304.80 mm height (internal sizes). A mild steel plate of 38 mm in thickness and 146 mm in diameter was placed on the test material to uniformly distribute the load applied by the hydraulic ram of the machine. A dial gage (least count 0:01 mm) attached with magnetic base (see Figure 23) employed to record compression in the material under the applied normal stress. These tests can be fairly compared with one dimensional consolidation tests in the sense that the test material was confined in steel mold during testing.

To make a comparative study about amount of crushing in Badarpur sand, standard Madras sand and Ramganga River bed sand, the specimens of these sands (between particle sizes 1.20 mm-0.60 mm) were compacted in modified Proctors compaction mold in standard manner. The specimens were also stressed under the load of 40 Tonnes (220Kg/cm^2) in the steel mold keeping the thickness of sample as 100 mm. It was seen that the crushing in Ramganga River Bed sand was the least (see-Table 1).

TABLE I

S. No.	Description	Ramganga River Bed Sand % Crushing	Standard Madras Sand % Crushing	Badarpur Sand % Crushing
1.	Under Compressive Stress of 220 Kg/cm^2	23.5	57.2	57.4
2.	After compaction in Proctor's mold.	13	26	25.2

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This shows that crushing in a river bed sand would be much less than in a deposit sand or in sand obtained from crushers. The results may also indicate that significant crushing may occur during compaction of sand in rolled fills under vibratory rollers which induce sufficiently high unit stresses.

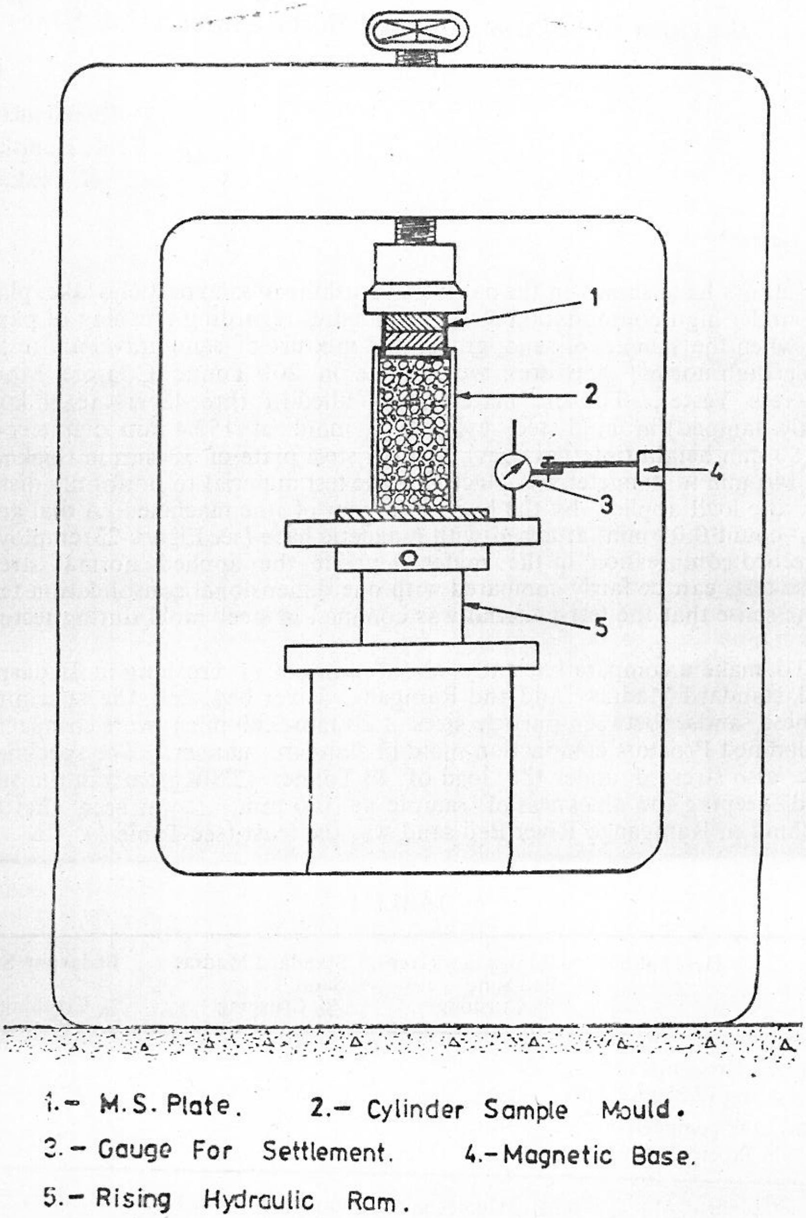

FIGURE 23. Typical detail of compressions test on 200 Tonne Consol Model concrete Tester

Ramganga River bed sand and gravels were tested in the following grades :—

Sl. No.	Type of test material	Designated in figure by letter
1.	Gravels—38 mm to 19 mm in size	A
2.	Gravels—19 mm to 10 mm in size	B
3.	Gravels—10 mm to 5 mm in size	C
4.	Gravels—10 mm to 5 mm—50% +5 mm to 2.4 mm—50%	D
5.	Gravels—38 mm to 19- mm—50% 19 mm to 5 mm—50%	E
6.	Mixture of sand and gravel Gravel—38 mm to 10 mm—40% 19 mm to 5 mm—20% Sand—1.20 mm to 0.60 mm—40%	F
7.	Sand—1.20 mm to 0.60 mm in size	G
8.	Sand—1.20 mm to 0.60 mm in size—50% 0.60 mm to 0.15 mm in size—50%	H

The percentage of crushing of particles was determined by performing gradation analysis after the test. The percentage of particles found in the original size range of the test material was considered as un-crushed material, while percentage of particles (by weight) finer than the original size range of the material was considered as crushed material. However in case of gravels the percentage crushing was determined by the help of visual examination. After the test, the gravels were picked from the mold in small layers and by visual examination uncrushed gravels (i.e. all those gravels whose even angularities etc even were not broken) were sorted out and kept on separate tray, while crushed gravels by weight (including damaged gravels) in the total material were termed as percentage crushing.

Initially test materials designated by B, C and D were tested under normal load equal to 10T, 20T, 30T and 40 Tonne load. The test material was filled in only 100 mm depth of the mold; remaining portion having been filled by loading plates. No measurement of compression of the sample was observed. Load was applied on average at the rate of 4 Tonne/minute. Percentage crushing versus applied stress are shown in Figure—24 (A). The results show the following. (1) Crushed gravels included fractured gravels or gravels splitting through whole grain (splitting of angularities or asperities were also noticeable). Completely crushed gravels (in shape of sand) were also found. About 50% to 70% of crushed gravels included sizes between 5 mm to 2.5 mm.

(2) Percentage crushing was greater in coarser gravels (19mm—10 mm in size) than in finer gravels (10 mm—5 mm in size).

(3) When the test material contained two gravel sizes i.e. gravels 19 mm to 10 mm in size and gravels 10 mm to 2.4 mm in size, the crushing of

finer gravels (10 mm—2.4 mm in size) was much greater than in coarser gravels. Line B′ of Figure-24 shows percentage of gravels (10 mm-2.4 mm) under different values to applied stress while the line B shows percentage crushing of total material.

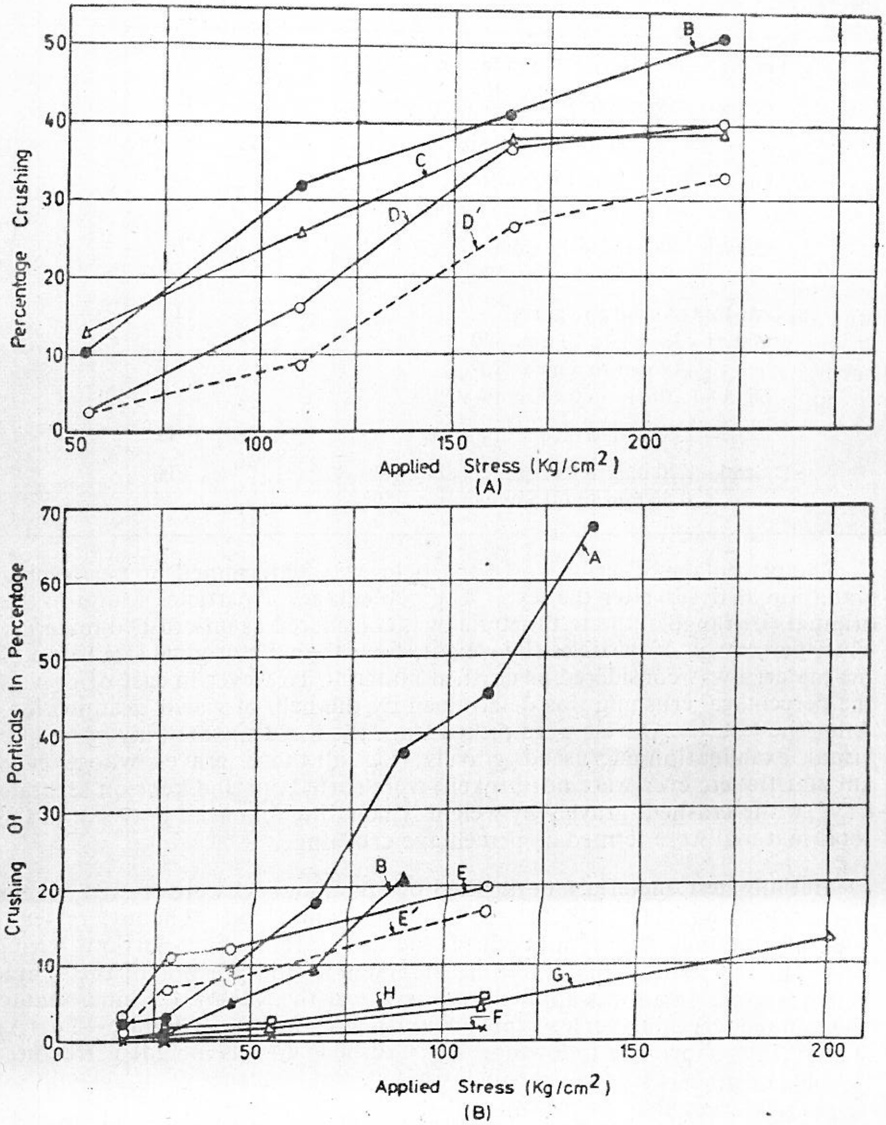

FIGURE 24. Percentage crushing (by weight) of particles versus applied normal stress for Ramganga river bed gravel, sand and mixture of gravel and sand. (A) when specimen thickness is only 100 mm and average rate of applications of normal load is abcut 4 Tonnes/min. (B) When specimen thickness is 300 mm and average rate of application of normal load is about 0.3 Tonnes min.

Test materials designated by A, B, E, F, G and H were then tested by keeping the thickness of specimen equal to 300 mm and the rate of application of load kept very slow (i.e. on average about 0.3 Tonne per minute). Measurement of compression of the test material was also made by provision of a dial gage. Load control valve attached with the Console concrete tester was used to control the rate of ram movement in upward or downward direction. When running the valve under no load, this valve controls the strain rate or rate of movement in inches per minute. On the other hand, when loading the specimen, this valve is essentially giving the stress rate in terms of Kg/cm² per minute. However in case of test materials under study, rate of increase of stress was slower initially increasing thereby with time at higher stresses (See Figure 25). Each grade of material was tested under loads equal to 3T, 5T, 8T and loads upto 20 Tonnes. The results are shown in Figure 24 (B). It was seen that during loading, the load (as indicated by dial gage) occasionally dropped by ½T to 1 Tonne accompanied by audible sound of cracking of gravels (see Figure-26). This indicated that when crushing of gravels was taking place, there was instantaneous increase in the compression of the test material faster than the rate at which loading ram (due to oil pressure) was rising. This drop of stress hardly lasted even a fraction of second before the stress again started rising.

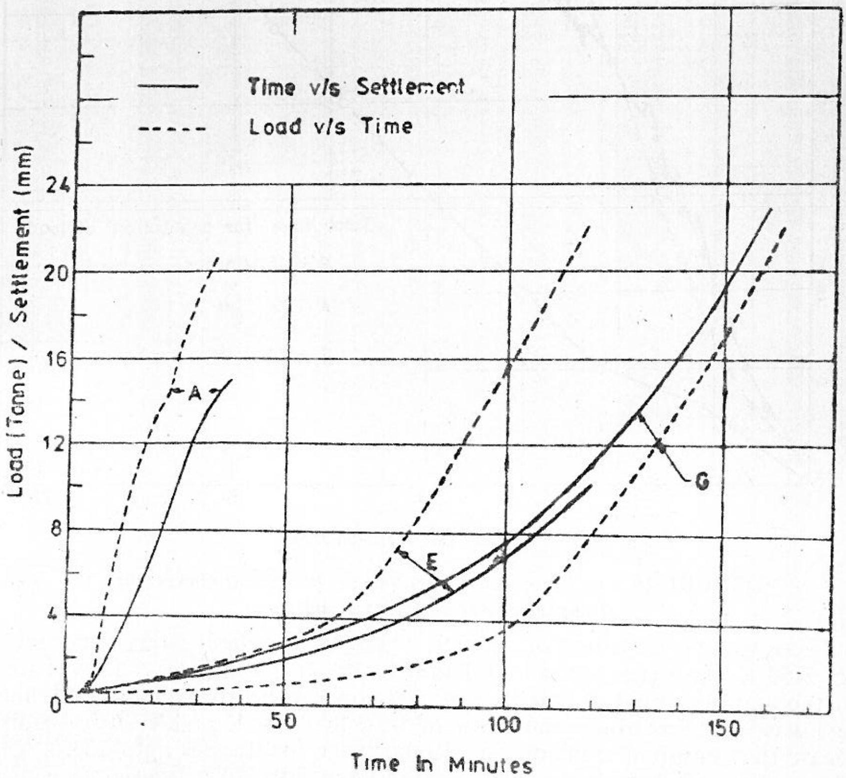

FIGURE 25. Load (in Tonnes) versus time and settlement (in mm) versus time curves for Ramganga river bed gravel and sand.

It was seen that all the gravels in contact with mild steel loading plate got crushed when the load exceeded 8 Tonnes. It was considered that this may have happened due to transfer of load to gravels by a very hard surface of mild steel. With this view, tests were conducted after the jute pad or sand placed on thick cloth placed on gravels was kept in between the loading plate and the test material. It was found that this considerably reduced (at lower loads even eliminated), the crushing of gravels in contact with loading pad.

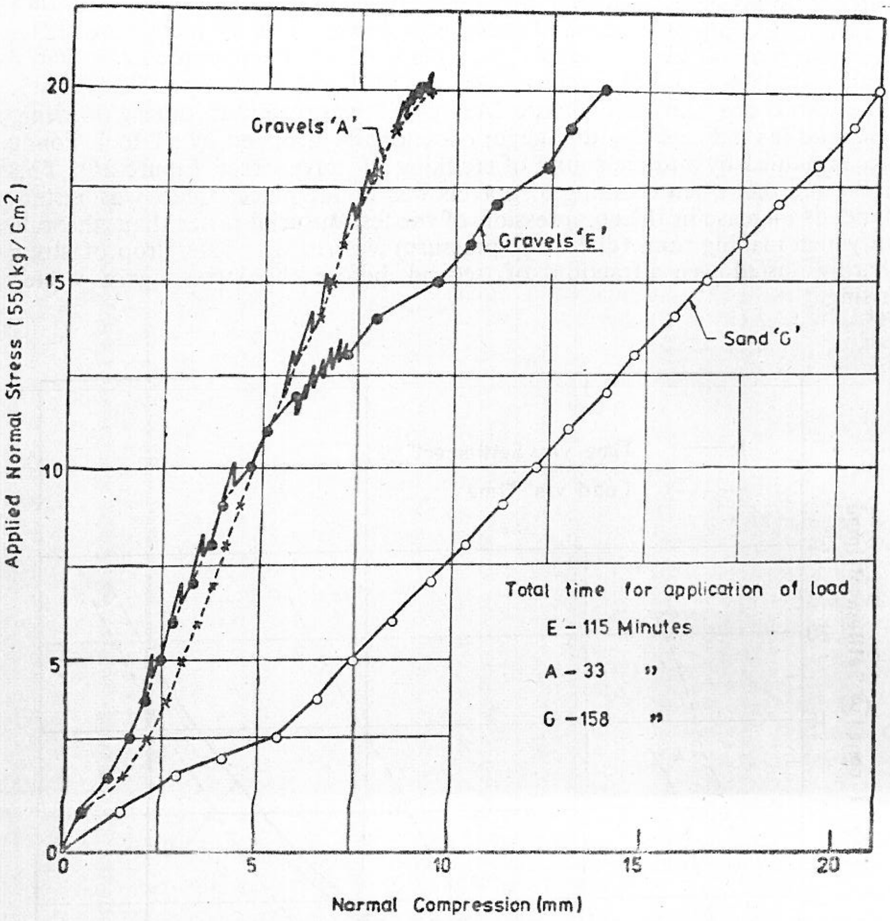

FIGURE 26. Applied normal stress versus settlement curves for Ramganga river bed gravel and sand.

There was no crushing of gravels when the applied stress was lower than 5.50 Kg/cm^2 (i.e. equal to 1 Tonne load on the sample). It was seen that the audible sound of cracking of particles was heard when the applied stress was increased above the value of 5.50 to 11.00 Kg/cm^2. The results indicate that nominal crushing shall take place for stresses upto 27.50 Kg/cm^2 (number of gravels crushed ranged from 5 to 10). It was seen that the number of crushed gravels was maximum in top layers, its number was much less in lower layers than in higher layers of the sample i.e. the maximum crushing of gravels (about 66%) took place in top 75 mm layer; the number of crushed gravels kept on reducing with increase in depth of layer. During compression, gravels tend to roll to denser arrangements; this activity of lower layers induces additional rolling activity in higher layers with greater intensity. Since during rolling of a particle over one another, the tensile stresses are developed behind the contact, resulting in crushing of particles (Smith and Liu—1953 and Ramamurthy, 1968) such situations of developments of tensile stress occurred more in gravels situated at top layers (than at lower layers). This phenomenon may have been responsible in actuating greater crushing in higher layers of the sample.

When the test material contained mixture of sand and gravel; it was noticed during tests that nominal crushing took place even at high compressive stress of 56.50 Kg/cm². *When the applied stress was increased upto* 113.00 Kg/cm², the crushing occurred in only sand and not in gravels (only angularities of 4 gravels were broken). When the test material contained fine and medium sand crushing took place in fine sand only.

The results as shown in Figure 24 (B) indicate the following :—

(1) Percentage crushing is greater in coarser gravels than in finer gravels. It may be noted here that compressive strengths of coarser and finer gravels were the same, unlike the Badarpur sand (of which coarser particles were fissured and weathered and possessed lower strength than finer particles) studied and reported by authors.

Crushing of Ramganga sand was much less than that of gravels. It may be noted that gravels were made of quartzite. Crushing of Ramganga sand was much less than reported by authors in case of Badarpur sand. This may indicate that a deposited sand may show greater crushing than a river bed sand (which has naturally undergone great amount of rolling activity).

(2) Percentage crushing in finer gravels was greater than in coarser gravels when the test material contained two gravel sizes (Line E' in Figure 24 (B) shows percentage crushing in finer gravels i.e. 19 mm to 5 mm in size).

(3) In a test material consisting a mixture of medium sand and gravel, no crushing in gravels took place even at very high normal stresses and that crushing took place only in sand.

This indicates that when a test material is a well graded, material consisting of fine as well as coarse particles, the magnitude of crushing even at high normal stresses shall be much lower than in a uniform graded material and that the crushing if any, under high normal stresses shall take place only in finest sizes of a well graded material. It is quite probable that a well graded material (like a mixture of sand and gravel) may not also show any significant crushing of particles during shear and therefore alteration of the shear parameters of the material at high normal stresses due to so known 'crushing phenomenon' may not take place.

Uniform graded material (particularly of coarses particles) forms an open matrix and therefore permits greater rolling activity of one particle over one another. This phenomenon can therefore be attributed to effect greater crushing in uniform graded material of coarse particles. It may also be noted that higher unit normal stresses at contact points of particles shall develop in coarse particles than in fine particles, chiefly because number of contact points shall be lesser in coarse particles than in fine particles. Greater crushing of coarser particles in uniform graded materials may not therefore be chiefly dependent upon the tensile strength of particles as reported by authors.

Authors have shown significant amount of crushing during high consolidation pressures in case of fissured and weathered sand of Badarpur. The crushing of the sand particles has been so enormous under consolidation pressures only that it changed uniformly graded material into a well graded material before the process of shear i.e. from an open matrix to a closed matrix. It has been long known that the angle of internal friction of a material shows a decrease with increase in amounts of fines (of the same nature) in materials containing coarse sizes. Therefore, lowering of the value of angle of internal friction of uniformly graded Badarpur sand at high lateral pressures may have been chiefly due to introduction of fines in the material at high lateral pressures and further crushing of weathered and fissured sand during process of shear may not have contributed significanly towards lowering of value of angle of internal friction. It is suggested that authors may use their triaxial data to obtain stress paths (i.e. effective normal stress versus effective shear stress at the failure plane at the various stages during the process of shear) for more accurate determination of shear strength parameters under different values of lateral pressures and for giving idea about changes on the shearing plane that may have taken place during process of shear. This would also assist design engineers to assess the change in value of angle of internal friction due to introduction of fines in a uniformly graded sand.

Authors have shown a noteworthy result about tensile strength of sand particles, it being as high as 700 kg/cm^2 which is equal to about half the permissible tensile strength of mild steel. More accurate testing method may be necessary to confirm this value.

Well graded filters are more commonly employed in earth dams than uniformly graded ones. It is clear from the above that no significant crushing in well graded filters may take place that may alter shear parameters under high normal stresses. Crushing in uniformly graded filters may alter the shear parameters under high normal stresses but it would not be significant in stability analysis of earth dams as filters generally form a very small portion of an earth dam; the crushing of particles may however reduce the drainagibility of filters—it would also not be significant as the fines introduced will also be of pervious nature.

Generally pervious fill materials for an earth dam (including filters) are obtained from the river bed; it is therefore necessary that tests are conducted on river bed sand, mixture of river bed sand and gravels under high lateral pressures on high pressure triaxial apparatus (like that of authors) so that alteration of shear parameters if any under high normal stresses may be taken into account in design of future earth dams. It may be necessary to apply high lateral pressures at a very slow rate instead of applying it instantenously, during high pressure testing.

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Assistant Engineer, Sri P.C. Sharma, Scientific Assistant and Sri M.K Gupta Model Assistant of concrete Laboratory, Kalagarh in performation of the tests reported in the discussion is thankfully acknowledged.

Authors' Reply

The discusser has presented information on the investigations which he has carried out on coarse grained materials varying from sands to gravels. All the experiments were conducted in a metallic cylinder under uniaxial compression on the coarse grained materials. These results are influenced considerably by the friction developed at the inner surface of the mould. This produces stress variation along the depth of the sample and therefore crushing has varied considerably with depth. Some of the points raised by discusser have in fact been explained in the main paper. The authors have indicated on page 58 that there is a minimum amount of fines which is likely to decrease significatly the effective angle of shearing resistance. Additional crushing would not be of greater consequence in altering shear strength parameters. The authors do not find any special advantage of plotting stress paths as suggested by the discusser to give an idea to the designer the variation in the shearing plan.

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