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Significant Difference in Between Grain Size and Compaction State Influence on the Stress−Strain Response of Granular Sands

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ABSTRACT

Stress−Strain response of sands focusing sand's shearing stress, angle of shearing resistance, dilatancy and contraction during volumetric changes etc. is of highly research interest due to its application in soil modelling and prediction of soil hazards even in a case of soil liquefaction. In this research paper, grain size and state of compactness (loosest and densest) influence on the stress−strain response of 8 (eight) different and specific sized granular sand grain have been researched by analyzing the results of a digital direct shear test corresponding to a constant strain rate of 0.5 mm / minutes and increasing normal load (5 kg, 10 kg and 15 kg). In a bird's eye view of the results, shearing stress (irrespective of compaction state) increases only 4 % from smaller to larger grain whereas approximately 30 % increase is discernible in dense grain than that of loose grain (irrespective of grain size). Larger sized grain possesses approximately 1.5 times more angular shear resistance than smaller size but in densest state it is about 2 times more. Authors have opined that, Though both the grain size and state of compactness (loosest and densest) affects the stress−strain response, state of compactness reveals more significant influence. In a dilation−contraction region, a loose grain contracts (18 %) while a dense grain contracts initially (15 %) but finally dilates (21 %) for an increase of size during plastic volumetric deformation of the grain.

Introduction

Stress-Strain Characteristics (SSC) of sand grain in a shear and dilation-contraction region are a function of grain's size, shape, compactness, strain rate etc. and can be diagnosed by conducting Digital Direct Shear Test (DDST), a tool for measuring soil's shear strength parameter (cohesion and angle of internal friction). During plastic adjustment and readjustment of granular media, they dilate and contract and it seems to be more pronounced in a volumetric test of sand grain in DDST. In densest (Dr=100%) and loosest (Dr=0%) state, grains show their significant and valuable characteristics in compared to variable characteristics in other densities. In these states grain size always plays an important role in changing shear strength behavior but state influence is more discernible. Moreover, grain size could be function of the states, future goal to be researched. Author's present interest is to recapitulate most significant contribution in changing stress-strain behavior. Several researches have been conducted with SSC of soil (Bolton, 1986; Gan et. al., 1996; Sitharam et. al., 2000; Martinez, 2003; Yasin et. al., 2003; Wang, 2005; Fakhimi et. al., 2008; Bareither et. al., 2008; Hassanlourad et. al., 2008; Sadrekarimi et. al., 2010; Moayed et. al., 2011; Wang et. al., 2011; Jung et. al., 2012; Honkanadavar et. al., 2012; Ojha et. al., 2013).

For the present study, By increasing normal load, DDST was performed with eight specific grain size (0.075 mm, 0.150 mm, 0.212 mm, 0.300 mm, 0.600 mm, 1.18 mm, 1.70 mm and 2.36 mm) and constant strain rate of 0.5 mm /minute. Each sample was taken to their loosest state and densest state to observe the stress-strain response. As the unknown things obviously come to light through a research on the origin of complexity, grain's state of compactness is found to be the more valuable catalyst in changing stress-strain response than that of grain size.

Assumption and research approach

The DDST was carried out in geotechnical laboratory of Rajshahi University of Engineering & Technology (RUET), Bangladesh after collecting the sand samples from the local Padma river bank. Loosest and densest state of the sand samples was maintained through laboratory experiment and theoretical calculations. Specific sized sample was prepared using density concept.

$$D_r=(e_{max}-e/e_{max}-e_{min})\times 100 \quad (1)$$

D_r indicates relative density. e_{max} and e_{min} and e represent the void ratio at loosest, densest and initial states respectively. Loosest state (Dr= 0%) attained at a condition when e_{max}=e; densest state (Dr= 100 %) at e_{min}= e. The sample weight corresponding to shear box was considered according to state of compactness (loosest and densest). ASTM D 3080- Standard test method for digital direct shear test under consolidated drained condition was followed. The size of the shear box in DDST was 60 mm × 60 mm.

Soil behavior at critical state

A more advanced understanding of the behavior of soil undergoing shearing lead to the development of the critical state theory of soil mechanics (Rocoe et. al., 1958). In critical state soil mechanics, distinct shear strength is identified where the soil undergoing shear does so at a constant volume, also called the 'critical state'. The peak strength may occur before or at critical state, depending on the initial state of the soil particles being sheared.

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A loose soil will contract in volume on shearing, and may not develop any peak strength above critical state. In this case 'peak' strength will coincide with the critical state shear strength, once the soil has ceased contracting in volume. It may be stated that such soils do not exhibit a distinct 'peak strength'.

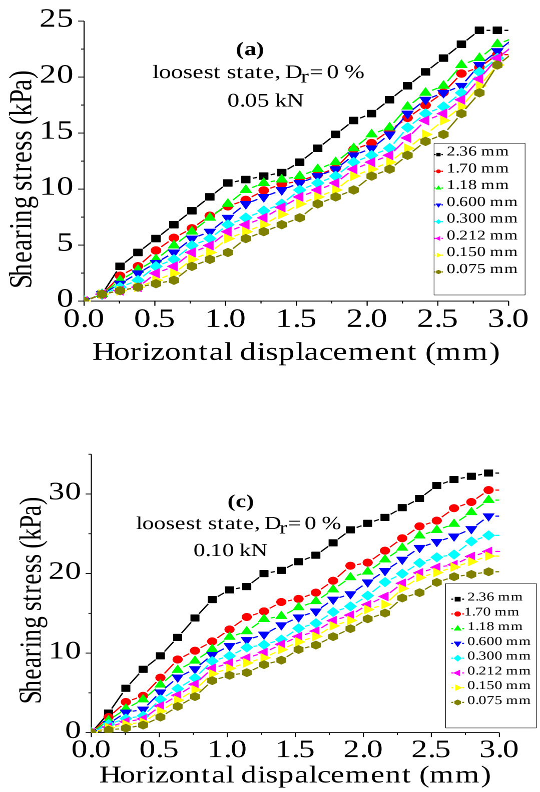
A dense soil may contract slightly before granular interlock prevents further contraction (granular interlock is dependent on the shape of the grains and their initial packing arrangement). In order to continue shearing once granular interlock has occurred, the soil must dilate (expand in volume). As additional shear force is required to dilate the soil, a peak' strength occurs. Once this peak strength caused by dilation has been overcome through continued shearing, the resistance provided by the soil to the applied shear stress reduces (termed "strain softening"). Strain softening will continue until no further changes in volume of the soil occur on continued shearing.

The constant volume (or critical state) shear strength is said to be intrinsic to the soil, and independent of the initial density or packing arrangement of the soil grains. In this state the grains being sheared are said to be 'tumbling' over one another, with no significant granular interlock or sliding plane development affecting the resistance to shearing. At this point, no inherited fabric or bonding of the soil grains affects the soil strength.

The Critical State occurs at the quasi-static strain rate. It does not allow for differences in shear strength based on different strain rates. Also at the critical state, there is no particle alignment or specific soil structure.

Influence on shearing stress

To visualize the difference between grain size and compaction state influence on shearing stress, Table 1 and corresponding graphs are prepared. Table 1 represents the peak shear stress values that a grain can sustain under different loading conditions and two compaction states (loosest and densest).



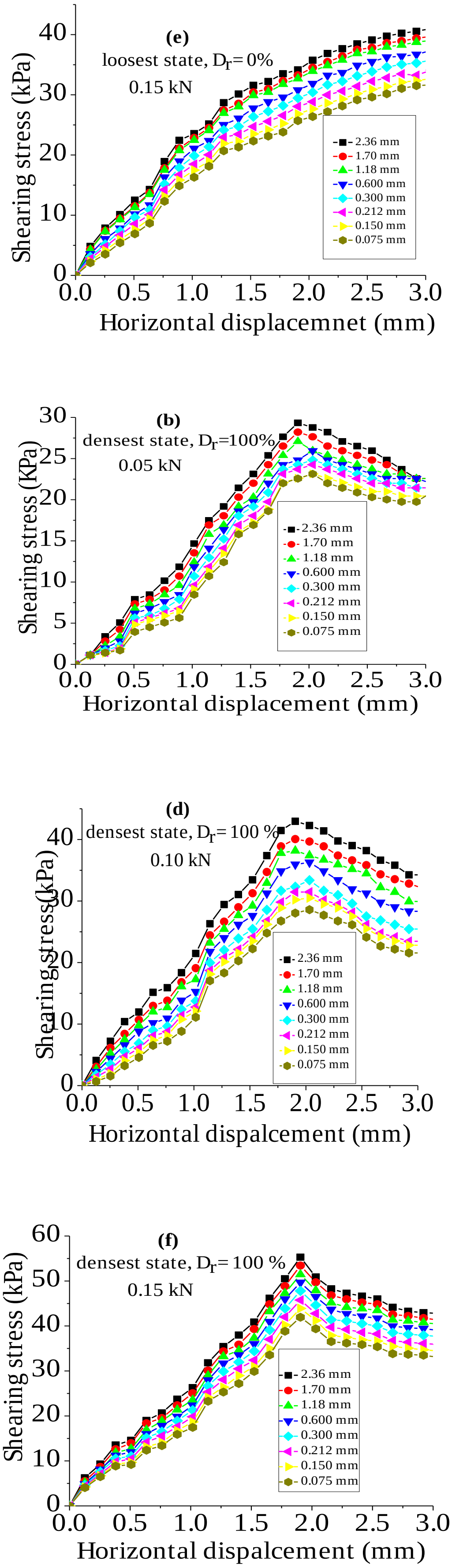


Figure 1. Shearing stress versus horizontal displacement in loosest and densest states

The graphic representation of table 1 is shown by Fig. 1. Fig. 1 is a clear representation of grain's capability to sustain shear stress in a loosest and densest state. Particle size plays an important role on the shear strength behavior of granular materials (Islam et. al., 2011). Obviously, grain size has an effect but, the grain behavior in terms of shear taking capability from loosest to densest state is more significant. Despite of discrete nature of grains interlock and discontinuous behavior, an increase of 30 % (on an average) for shearing stress in a densest state from loosest state is visible whereas for consecutive grains, 4 % increase (on an average) is found. Three normal loads are being used to satisfy the research needs but they are only considered to factor the shear loads. In Figure 1, different graphs such as a, b, c, d, e and f is shown. In every case, strain rate was fixed (0.5 mm/minute). In densest and loosest states, the normal loads were fixed. Shearing stresses versus horizontal displacement are calculated in KPa (kN/m^2) and mm respectively. In loosest state, grain's shearing stress increases continuously whereas in a densest state it increases up to a specific peak beyond which no further increase is seen. This specific peak occurs in a granular interlock when it tries to resist the stress with full resistance for the last time. Consequently, this peak point gives a different dimension to densest state and obviously to granular behavior. For an example, a peak shear stress of 55.29 kPa is found in a densest state for 2.36 mm grain whereas in loosest state the peak is 41.03 KPa. For same sized grain (2.36 mm), shearing stress increase from its previous one (1.70mm) is around 1.5 times. Compaction state influence is significantly influencing a granular behavior by this way.

Influence on angular shearing resistance

Both internal friction angle and interface friction angle of sand increases with increasing relative density (Gireesha et. al., 2011). Angle of internal friction increases with increase of particle size for Ranjit Sagar materials but for Purulia rock fill materials opposite value is observed (Gupta et. al., 2009). However in current research, angle of internal friction is found to be higher in a higher sized grain than that of a lower size. In a densest state, angle of internal friction is always higher than that of loosest state. This phenomenon seems to be more pronounced than that of grain size influence. In consecutive grain, angle of sharing resistance increase is 1.5 times. On the other hand, in densest state, angle of shearing resistance is 2 times more than of loosest state of a particular grain. Angular shearing resistance of sands is important in geotechnical engineering because of the design modification. In Fig. 2, angle of shearing resistance for loosest and densest grain are plotted to understand this phenomena. This angle of internal friction versus grain size clearly showing the research results that, in a densest sample, the angle of sharing resistance is always high.

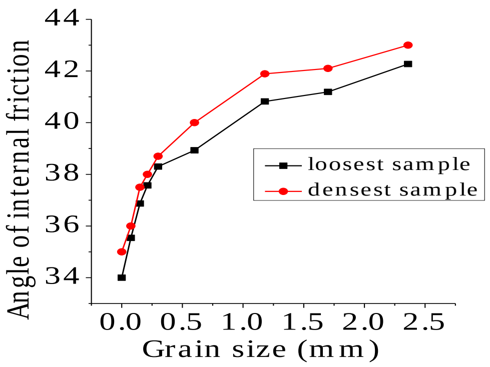


Fig. 1. Angle of internal friction in loosest and densest states

Angle of internal friction in loosest state for the eight different sized grains (from 0.075 mm to 2.36 mm) are 35.54°, 36.87°, 37.57°, 38.30°, 38.93°, 40.82°, 41.19°, 42.27° respectively and for densest state 36°, 37.5°, 38°, 38.7°, 40°, 41.89°, 42.10°, 43° respectively.

Influence on volumetric dilation and contraction

In loosest state, grain compression decreases approximately about 18% from one grain size to another grain size with the increase of grain size. In densest state initial compression decreases and it is approximately about 15% from one grain size to another grain size and final dilation increases approximately about 21 % from one grain size to another grain size with the increase of grain size.

Different graphs in Fig. 3 describe how dilation−contraction phenomena occur in densely and loosely held granular sands in a laboratory environment. Loosely held sand generally contracts and do not exhibit any distinct shear strength rather showing discrete nature.

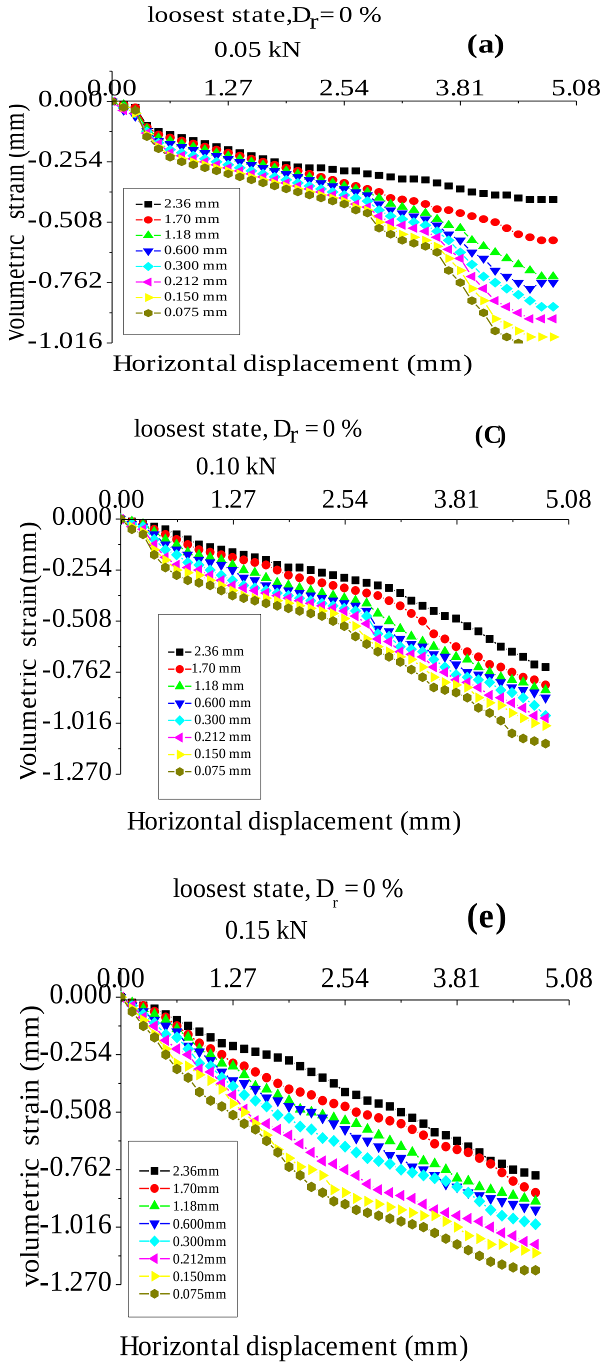


Table 1. Peak shear stress at two different states (loosest and densest)

Grain size(mm)	Peak shear stress (0.05 kN normal load) (kPa)		Peak shear stress (0.10 kN normal load) (kPa)		Peak shear stress (0.15 kN normal load) (kPa)	
	loosest	densest	loosest	densest	loosest	densest
0.075	22.31	23.13	20.22	28.60	31.37	41.94
0.150	22.32	23.14	22.18	30.50	32.70	43.90
0.212	22.94	24.26	22.78	31.47	34.11	45.76.
0.300	22.97	24.82	24.81	33.38	35.80	47.80
0.600	23.56	25.95	27.21	36.27	37.39	49.67
1.18	23.57	27.08	29.23	38.18	39.06	51.45
1.70	22	28.21	30.49	40.07	39.71	53.42
2.36	24.17	29.34	32.63	42.97	41.03	55.29

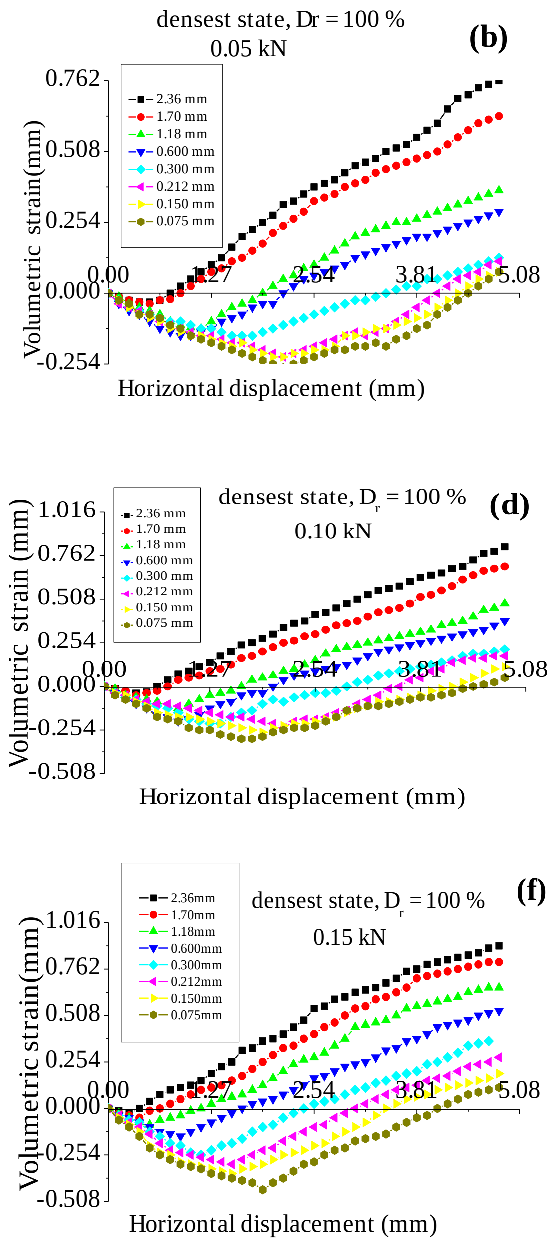


Figure 2. Volumetric displacement versus horizontal displacement in loosest and densest state

On the other hand, dense sand finally dilates to achieve a peak shear strength. Strain softening also occurs. So, these phenomena are satisfying with critical state theory. The graphs are certainly showing the true nature of sand in dilation-contraction region.

Conclusions

Different catalysts are influencing the grains stress-strain response. Grain compaction state and size has been considered in current research. For having a clear idea, 8 (eight) different grain size were considered in their loosest and densest state. Because, 8 (eight) different sized sand will certainly reveal different characteristics and finally it was helpful to comment on their nature. Tough loosest and densest state prevails theoretically; it was research endeavour to maintain the density very close to 0 and 100 %. The whole research has been judged with theory and practice of soil mechanics and different research papers as well. When a sand grain body is altered from its loosest state to a very dense or densest state, its inter-granular gap reduced to the lowest vale. Having zero air voids, the sand grain tries to be compacted and resist any disturbance made by external load mechanism. That is why a densest sand grain shows a good result comparing a loosest sand grain. The numerical value and corresponding graph practically nominates grain density / compaction state as a more significant catalyst in influencing stress-strain response of sand than that of grain size.

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Currently, He is working as a Lecturer in the Department of Civil Engineering at Stamford University Bangladesh. He has engaged himself in research activities from the very beginning of his teaching career. He published his first technical paper in Australian Geomecahnics Journal and his research work followed and resulted in some other journal papers on challenging fields of Civil engineering. Current researches are focusing on Constitutive modeling of geomaterials, Generation of Liquefaction potential map of Dhaka ,Bangladesh, Feasibility study of the Floating Foundation, Assessment of the use of carbon nanofiber in building foundation, Effect of polymer mesh on the shear strength behavior of clayey soil, Cyclic Stress-Strain behavior of chemically treated soil etc. Moreover, He conducted extensive research on effect of particle size on the shear strength behavior of soil.

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