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Effect of Fragment Size, Uniformity Coefficient and Moisture Content on Compaction and Shear Strength Behavior of Coal Mine Overburden Dump Material

Pankaj Kumar Dewangan[1], Manoj Pradhan[1] and GD Ramtekkar[2]

[1] *Department of Mining Engineering, National Institute of Technology, Raipur, CG, India*
[2] *Department of Civil Engineering, National Institute of Technology, Raipur, CG, India*
pankajnitrr@yahoo.co.in

ABSTRACT

An understanding of the shear strength characteristics of geomaterials forming overburden dumps in coal mines is required for assessing the stability of overburden dumps. The effective shear strength of dump materials depends on a wide variety of interrelated parameters including: fragment size, intact particle strength, gradation, compaction density, water content, degree of saturation and others. In this study, an investigation was carried out to assess the effect of fragment size and moisture content on shear strength behavior of the coal mine overburden dump rock material by conducting a series of small and large scale direct shear test on samples differing in average fragment size, uniformity coefficient and moisture content. The overall mobilized shear strength was found higher in case of samples having larger average fragment size and lower moisture content. The angle of internal friction of all the tested samples was found to be increased with the increase in average fragment size while reduction in the same was noticed with the increase in moisture content.

Key words: Overburden dumps, fragment size, apparent cohesion, internal friction angle, direct shear test

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INTRODUCTION

Overburden dumps in coal mines mainly consist of natural soils, rock and intermediate earthy substances, basically a mixture of sandstones (well or poorly sorted; fine, medium or coarse; etc), siltstones, mudstones, shales, claystones and some coal, which is loosely placed and dumped. Particle sizes of rock materials forming these dumps vary from silt and clay size (< 75 microns to 0.075 mm) to coarse grained soils (> 0.075mm) including sands and gravels as well as large size cobbles (150mm to 300 mm) and boulders (> 300 mm). The overburden dumps in most of the opencast coal mines are usually formed by end tip dumping method which results in formation of dumps with relatively low density. Compaction of the dump matrix occurs by the weight of added material and by dumper movement on it without the use of any specific compaction equipment. Moreover these overburden materials are subjected to wide range of environmental, geomorphological and climatic changes including erosion, ageing, wet dry cycles, seasonal temperature fluctuations, cyclic loading due to earthquakes, blasting and machine movement etc. which results in continuous degradation of strength properties as well as change in fragment size with time. The effect of gradation and coarse size fractions on shear strength of soil, soil gravel mixtures, sand gravel mixtures, soil quarry dust mixtures and rock fill has been studied by various researchers [1-8]. Shear strength behaviour of overburden rock for dump slope design is generally carried out by small scale laboratory testing using standard size triaxial and direct shear test apparatus on mostly sand and silt size fines passing through 4.5 mm sieves due to limitations on the size of the testing equipment. The tests are generally carried out on samples compacted at its optimum moisture content or in dry condition. A shortcoming to this small scale laboratory testing is that oversized rock fragments are usually scalped to accommodate the testing equipment capacity. The influence of coarser fraction of rock fragments present on the overburden dumps on its shear strength is not taken in to consideration. Above shortcomings lead to uncertainties associated with the assignment of accurate shear strength parameters for slope stability modelling and design. Thus, there is a need to assess the effect of presence of coarser rock fragments and moisture content on shear strength of the overburden dump materials.

This research work primarily aims to investigate the effect of fragment size, uniformity coefficient and moisture content on compaction and shear strength behaviour of coal mine overburden dump material by conducting Procter compaction tests and a series of small and large scale direct shear tests.

CONCEPT OF SHEAR STRENGTH OF SOILS

Shear strength in soils develop due to three reasons - the structural resistance to displacement of the soil particles, the frictional resistance to translocation between the individual soil particles at their points of contact and the cohesion or adhesion between the surfaces of the soil particles, where the structural resistance to displacement is caused due to the interlocking of the soil particles. The frictional resistance to translocation is developed by granular fractions of soil, such as sand, gravel and crushed stone, whereas, cohesion is developed in fine grained soil fractions such as silt, clay, and organic and inorganic colloidal material. Cohesive forces are also developed by moisture-films surrounding the soil particles. Thus the shear strength of soil depends upon the soil composition and moisture content in addition to the density and the degree of consolidation [9]. In other words, the shear strength depends upon the cohesion, which in turn depends upon the soil water content, grain size and soil compaction and also the angle of internal friction. Both of which are independently affected by the moisture content and the confining pressure.

The concept of cohesive strength is more difficult to explain. There are two types of cohesion in soils: true cohesion and apparent cohesion [10]. True cohesion may result from chemical cementation (just like in rocks) and/or forces of attraction (e.g. electrostatic and electromagnetic attractions) between colloidal (10-3 mm to 10-6 mm) clay particles. It is stress-independent unlike frictional resistance that is a function of normal stress. Apparent cohesion may develop because of capillary stresses and mechanical interlocking. Apparent mechanical forces are often exhibited by the interlocking of rough (angular) soil particles. The interlock between the soil particles can offer some resistance to shear stresses even in the absence of a normal stress. This type of apparent cohesion is often the cause of cohesion measured in compacted soils. However, such apparent mechanical forces are susceptible to significant reduction by vibrations and other types of mechanical disturbance.

EFFECT OF PARTICLE SIZE AND MOISTURE CONTENT ON SHEAR STRENGTH

The influence of particle size on the shear strength was known to have insignificant differences in the case of sand [11] whereas, in the case of coarse-grained soils with large particle diameters, there have been many different opinions arising among the researchers. Numerous research were carried out on the influence of particle size of coarse grained materials on shear strength [1, 8, 12-18], but consistent conclusions, as to the differences or influence, were not made among the researchers.

One of the earliest and most comprehensive studies on the effects of coarse particles was carried out by Holtz & Gibbs [1]. They studied the effects of density, proportion of coarse fraction, gradation, maximum particle size, and particle shape on the shear resistance of gravel-sand mixtures. A total of 183 consolidated drained triaxial tests were carried out on up to 9 inch (230 mm) diameter remoulded specimens using sand as the matrix material and gravel size fragments (up to 76.8 mm) as the coarse fraction. The gravel contents tested were 20%, 35%, 50% and 65% (by weight). The specimens in each test series were compacted to the same relative density of either 50% or 70%. They found that increasing the maximum size of the gravel particles from 19.2 mm (3/4 in.) to 76.8 mm (3 in.) had no significant effect on the shear strength. Gupta [8] conducted drained triaxial tests on river bed material and blasted rock material having maximum particle size of 25, 50 and 80 mm. The angle of internal friction was found increased with the size of the particles for the river bed material and decreased with the size of the particles for the blasted material. Kirkpatrick [12] studies on Leighton Buzzard sand with uniform particle size using triaxial tests showed reduction of friction angle as the mean particle size was increased while the porosity was kept a fixed value. Becker et al [13] used a biaxial apparatus to measure the friction angle of earth dam material in a plane strain condition. They concluded that in general the friction angle decreases as the maximum particle size is increased but the difference in friction angle between the small size material and the large size material reduces as the confining pressure increases. Nieble et al [14] conducted direct shear tests on uniform crushed basalt and showed that as the maximum particle size increases, the friction angle decreases. Fakhimi et al [15] evaluated the effect of oversize particles on the friction angle and cohesion of the rock pile material by conducting several laboratory shear tests with a box 6 cm × 6 cm in size where the oversize particle was simulated using stainless steel spheres that were placed along the shear plane. The experimental findings suggested that the presence of the oversize particle causes an increase in friction angle while the cohesion can either decrease or increase depending on the size of the oversize particle with respect to the size of shear box and the location of the oversize particle along the shear plane.

Shear strength and dilatancy of well graded sand-gravel mixtures were investigated by Hamidi et al [16] by conducting large scale direct shear tests. The tests were conducted on three considered soils. Maximum grain size was 25.4 mm in base soil, and was limited to 12.5 mm for equivalent scalped and parallel gradations. They reported that the gradation of tested soils affected their shear strength by a change in maximum friction angle, which were related to both dilatancy at failure and the constant volume friction angle. They also concluded that the impact of gradation on the shear strength characteristics of the soil increased with surcharge pressure and decreased with relative density. The shear strength of the accumulation soil induced by the 2008 Sichuan Earthquake was investigated by Wang et al [17] using the laboratory direct shear test and triaxial test. The angle of shearing resistance was found generally increasing with the increment of the median particle diameter. In order to analyze the influence of the particle diameter of a sample on the shear strength of coarse-grained soils, large direct shear tests were performed by Kim et al [18] on the coarse-grained soils with maximum particle diameters of 4.5 mm, 7.9 mm and 15.9 mm. They found an increase in shear strength for the sample having larger particle diameter. The moisture content of a soil has a major impact on how well the soil will compact. When a soil is completely dry it will not compact to it greatest possible density because of friction between the soil particles. As the moisture content increases, the water lubricates the soil, allowing it to move more easily into a compact state and the density increases. Eventually the soil is compacted to its greatest possible dry density (the maximum dry density) and the moisture content at which this happens is referred to as the ‘Optimum Moisture Content’. If the soil is wetted further, the extra water replaces some of the solid soil particles and the dry density reduces. Soil compacted at moisture content greater than the optimum moisture content has exactly the opposite characteristics to the one compacted below it. For a particular compaction effort, the dry density of soil increases with the moisture content of the soil up to the optimum moisture content beyond which it decreases and when the compaction effort increases, the optimum moisture content decreases. The presence of water can modify the shear strength by changing the way that particles interact with each other. If the water content of soil sample is high enough to saturate the sample, pore pressure can develop during a shear testing that results in reduction of the shear strength. For situations where soil is not completely saturated, positive pore pressure may not develop, but still the presence of water between soil grains can act as a lubricating agent that affects the strength of the material. When a soil is sheared slowly in a drained condition giving enough time for dissipation of pore pressures induced by shearing, the mechanical behaviour of the material can be either like a normally-consolidated (i.e. no softening) or over consolidated (i.e. with softening) material. The behavior is mainly controlled by the amount of fines material, the compaction density of the sample, and the amount of normal stress in a shear test.

Direct shear test on rock fill materials was performed by Yu et al. [19] to investigate the effect of moisture, particle size, gradation and shearing rate. The material was mainly gravels ranged from 2 mm to 9.4 mm in size. Tests were conducted at normal stress of 20 to 1000 kPa. The addition of 2% moisture to the gravels indicated slightly lower shear strength than that for the dry gravels. The authors concluded that water can lubricate the gravel grains and reduce the sliding friction coefficient between particles that results in reduction in the peak shear stress. Direct shear tests were conducted by Cokca et al. [20] on samples compacted at optimum moisture content (w=24%), at the dry side of optimum (i.e. w=18%, 20% and 22%) and at the wet side of optimum (i.e. w=26% and 28%). They reported that the behaviour of compacted clay like a granular soil on the dry side of optimum water content and a reduction in angle of friction and an increase in cohesion were observed as the compaction water contents approach the optimum value. The effect of moisture content on the shear strength parameters of stone dust were studied by Kandolkar et al. [21] by performing direct shear test. The study revealed that as the moisture content was increased towards the optimum value, the apparent cohesion of stone dust was increased and angle of internal friction was reduced. The cohesion was highest at optimum moisture content and thereafter it reduced as moisture content is increased beyond the OMC, whereas the angle of internal friction of stone dust reduced marginally as the moisture content was varied from dry to wet side of optimum.

MATERIALS AND METHODS

Site Description and Geology

Bulk quantities of overburden dump samples were collected from a large, partially consolidated rock dump from a large open-cast coal mine situated in Korba area of SECL. The Korba coalfield, constituting the south-central part of the vast stretch of Gondwana sediments of Son-Mahanadi Valley is located between the North Latitudes $22^0$15’ & $22^0$30’ and East Longitudes $82^0$15’ & $82^0$55’. It has a total aerial extent of about 520 sq. km. The southerly flowing Hasdeo River divides the coalfield into two parts, the western part of the being larger than the eastern part. The stratigraphic succession of the Korba coalfield based on surface and sub-surface data up to the depth of occurrence of the lower most quarriabble seam is given in Table -1.

Table -1 Generalised Stratigraphic Succession of Korba Coal Field

Age	Formation	Thickness	Lithology
Recent	Soil/weathered zone	4 to 20 m	Soil/sub-soil and laterite soil
Lower Permian	Upper barakar	0 to +34 m	Fine to coarse grained sand stone, sandy shale, grey shale, carbonaceous shale and coal seam E&F grade
	Middle barakar	<15 m to +300 m	Medium to coarse grained feldspathic sandstone, occasional shales, carbonaceous shale and thick coal seams, D, E & F grade

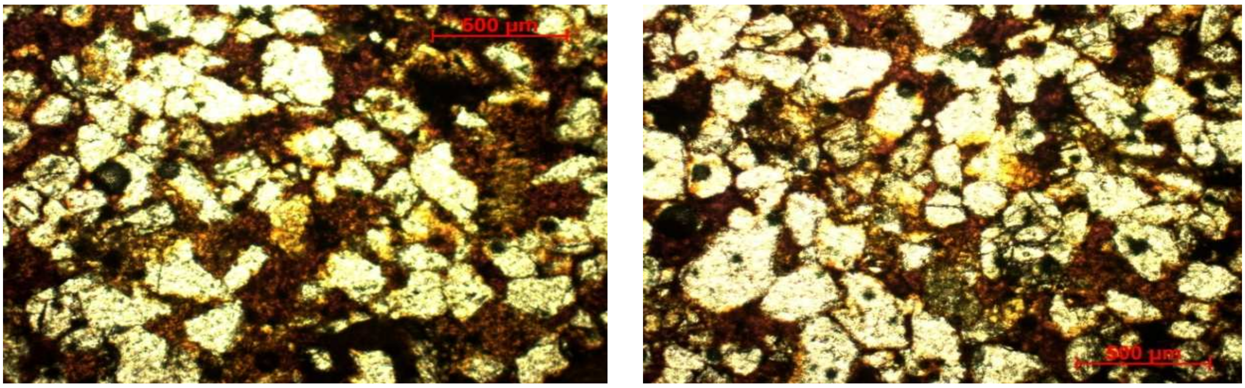
Dump Material Characterization

The various relevant geotechnical index properties were measured in the laboratory to classify the investigated materials. Laboratory tests were carried out on the experimental overburden dump material, which include specific gravity, moisture content, point load strength index, slake durability tests, Atterberg limits etc. The specific gravity of the experimental samples containing overburden rock fragments were determined using volumetric flask method as per IS: 2720 (Part 3-1980). Point load strength index and Slake durability of the material were determined as per IS: 8764 (1998) and IS: 10050 (1981) test procedure. The various important and relevant geotechnical parameters of overburden dump samples are listed in Table 2.

The overburden rock mainly consists of coarse ferruginous sand stone and pebbly sand stone with some shale. The dump material consists of 75-80 % sandstone, 10-12 % shale and remaining soil. The soil surface layer is 3–6 m. The photomicrograph images were obtained by using Petrological Research Microscope (model – Axioscope A1 POL, Carl Zeiss make, Germany). Fig. 1(a) and 1(b) are the photomicrographs of the thin section of the sandstone under plane polarized light and under cross nickol conditions respectively. The rock is medium to coarse grained, immature sandstone. Grains are angular to sub rounded indicating less transportation. The sandstone is poorly sorted. Majority of the grains are of quartz and feldspars whereas the matrix is of argillaceous material. The rocks were seems to be having high porosity and permeability as the pores are interconnected.

Table- 2 Geotechnical Properties of Overburden Dump Rock Material

Properties	Values
Specific Gravity	2.65
Point Load strength Index	0.4 to 1 MPa
Second cycle slake durability index	78 %
Liquid Limit	18.6%
Plastic Limit	Non plastic
Natural moisture content (NMC)	4%



(a) **(b)**

Fig. 1 Photomicrographs of sandstone rock fragment examined

Preparation of Experimental Samples and Test Program

During collection of samples from the dump, rock fragments more than 80 mm in size were discarded at the site itself. Particle size analysis of the dump materials were carried out in the laboratory as per IS Standard IS: 2720 (part 4) 1985 to know the size distribution of the rock fragments forming the dump and a modelled gradation curve (proto type sample) was prepared to represent the size of rock fragments present in the dump material. The natural moisture content of the dump samples was measured.

Testing the prototype dump material was almost impossible because of its coarseness and the limitations of the shear box dimensions. Therefore, the laboratory specimens were scaled by some degrees and all the compaction and shear tests were performed on this reduced gradation which is parallel to the proto type. During sieving of dump sample, the rock fragments passing through different sieve sizes ranging from 31.5 mm to less than 200 µm were collected in separate bags. Using parallel gradation technique developed by John Lowe [22], these rock fragments of different sizes collected in different bags were then mixed together to produce a well graded experimental sample having size distribution parallel to the proto type representing the particle size distribution of the actual dump material in the field. Numerous researchers have tested materials based on this model and validated the effectiveness of this model to estimate the shear strength of rock fills and rail ballast [6, 23-27]. After oven drying of rock fragments separated through sieving, two different types of modelled material were prepared using the above method having average fragment size of 9 and 1.6 mm respectively and were named as GTODS1 and STODS respectively. The gradation curve of both GTODS1 and STODS were kept parallel to Proto Type Sample (PTS) keeping their uniformity coefficient and coefficient of curvature same having the same gradational characteristics as that of PTS. One more sample named as GTODS2 was prepared differing in uniformity coefficient and average fragment size (Fig. 2). The purpose of varying fragment sizes of the samples was to assess the effect of presence of coarser rock fragments on shear strength behaviour of coal mine overburden dump samples. The gradational characteristics, including fragment size, gravels and fines content, uniformity coefficient, coefficient of curvature etc. are summarized in Table 3. Large shear box having size of 300 mm x 300mm x 190 mm was used for conduction of direct shear tests on GTODS1 and GTODS2. Small scale direct shear tests were performed on STODS using a shear box of size 60mmx60mmx31 mm. Heavy Procter compaction tests were conducted as per IS 2720 (Part 8) -1983 to establish the maximum dry density and optimum moisture content of the coarse grained rock dump sample i.e. GTODS1 and GTODS2. To measure the maximum dry density and optimum moisture content of STODS, light compaction test were conducted as per IS: 2720 (Part 7) – 1980.

Large scale direct (LSD) shear tests for this study were performed using multispeed direct shear equipment. All the LSD shear tests were conducted as per IS 2720 (Part 39, Sect. 1-1977) at five different values of normal stress levels and corresponding shear loads and horizontal (shear) displacements were monitored and recorded. Before shear test, the soil was compacted in five different layers in the shear box and then consolidated for some time under an applied normal stress. After consolidation, the specimen was sheared directly at a constant rate of deformation. To avoid the build of pore water pressure during the test, the strain rates chosen were very low and of the order of 0.2 mm/min. Small scale direct (SSD) shear tests were conducted on STODS in a similar manner at the same strain rate. In order to study the effect of moisture content, samples were compacted in the shear box at two different moisture content levels, first one corresponding to optimum moisture content (OMC) and second one at natural moisture content (NMC). In each layer compaction was conducted using a 2.5 kg rammer so as to obtain 90% compaction relative to the maximum dry density so that the results are comparable. All the LSD shear tests were conducted as per IS 2720 (Part 39, Sect. 1-1977) at five different values of normal stress levels and corresponding shear loads, vertical and horizontal (shear) displacements were monitored and recorded. All the LSD shear tests were carried out at five different normal stress levels ranging from 73.57 to 469.79 kPa while the SSD shear tests were carried out at normal stress ranging from 34.33 to 245.35 kPa. This corresponds to average normal stresses built up in embankment fills/slope heights of 10 m to 60 m.

Table- 3 Gradational Characteristics of Experimental Overburden Dump Sample

Sample Name	Maximum fragment size, D_{max}, mm	Average fragment size, D_{50}, mm	Coefficient of uniformity, C_u	Coefficient of curvature, C_c	% fines less than 4.75 mm by weight, f_{200}	% fines less than 0.6 mm by weight	Group symbol as per BIS
Proto type sample (PTS)	80	18.5	23	2.80	22	7	GW
Gravel type overburden dump sample 1 (GTODS1)	31.5	9	24	2.78	33	11	GW-GM
Gravel type overburden dump sample 2 (GTODS2)	31.5	18	8.8	2.78	34	8.5	GW-GM
Sand type overburden dump sample (STODS)	3.75	1.6	23	2.78	100	25	SM

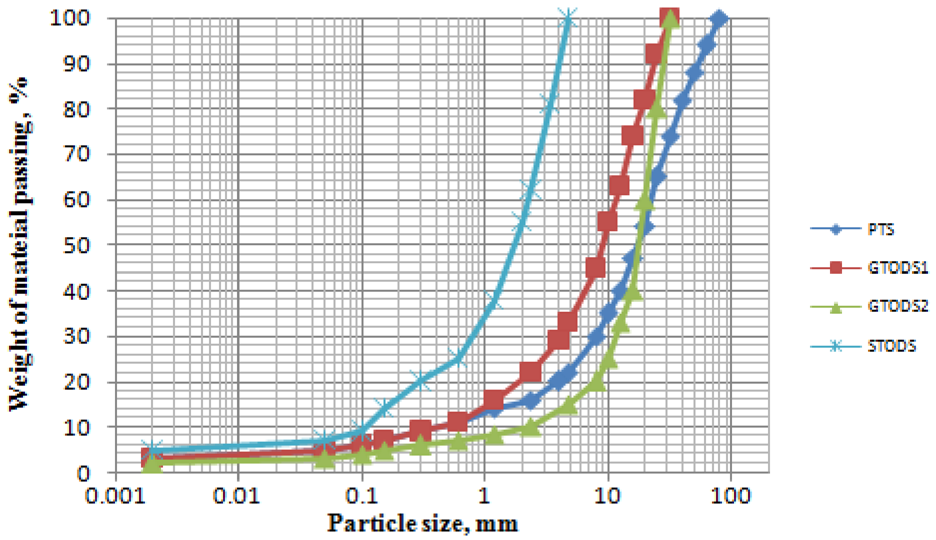


Fig. 2 Gradation curves of experimental overburden rock materials and Proto type

RESULTS AND DISCUSSION

Effect of Average Fragment Size on Maximum Dry Density and Moisture Content of Overburden Dump Material

The result of Procter compaction tests is presented in Table 4. Fig. 3 depicted the compaction curves of prepared experimental overburden dump material. The zero-air-void line is also shown in figure. Both GTODS1 and GTODS2 were having same gravel content of 66 to 67% and maximum fragment size of 31.5 mm but differ in average fragment size and uniformity coefficient. The average rock fragment size of GTODS2 was 18 mm as compared to 9 mm for GTODS1. The presence of larger fragment sizes in GTODS2 was considered to be main reason for increase in its maximum dry density as compared to GTODS1. The lesser water absorption capacity of larger rock fragments in GTODS2 as compared to the GTODS1 was the main reason for reduction in optimum moisture content of GTODS2 samples. A similar increase in optimum moisture content and decrease in maximum dry density of STODS were observed due to further decrease in average fragment sizes (1.8 mm). STODS was having higher fines content as compared to the above two mixtures, which was considered to be the main reason behind increase in optimum moisture content and reduction in maximum dry density of the mixtures. From the above tests, it was concluded that the optimum moisture content of the overburden dump samples is dependent on average fragment size and the fines content (Fig. 4).

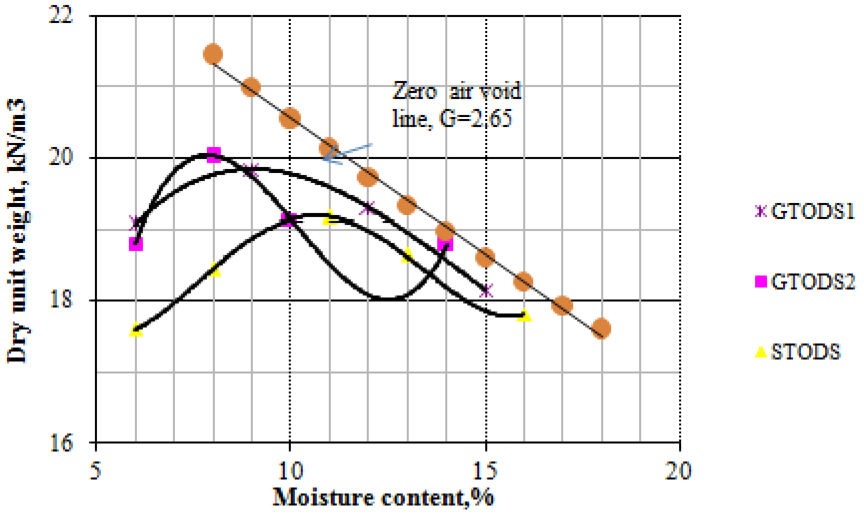


Fig. 3 Compaction curves of various experimental samples and zero air void line

Table- 4 Maximum Dry Density and Optimum Moisture Content of Various Experimental Samples

Sample	Maximum dry density, kN/m^3	Optimum moisture content, %
Gravel type overburden dump sample 1 (GTODS1)	19.83	9
Gravel type overburden dump sample 2 (GTODS2)	20.02	8
Sand type overburden dump sample (STODS)	19.18	11

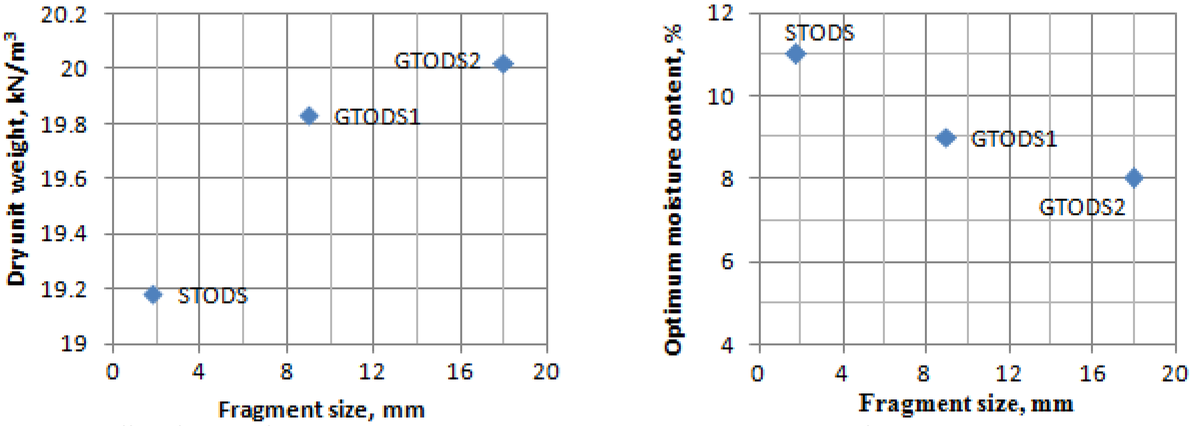


Fig. 4 Effect of average fragment size on dry unit weight and optimum moisture content of various experimental samples

Effect of Fragment Size and Uniformity Coefficient on Shear Strength of Overburden Dump Material

A series of small and large scale direct shear tests were conducted on experimental test samples (GTODS1, GTODS2 and STODS) having average fragment sizes ranging from 18 mm to 1.3 mm. All the samples were compacted at 90 % of their maximum dry density and OMC as determined from compaction tests. Consolidated drained direct shear tests were conducted at a constant rate of horizontal displacement of 0.5 mm/min at various normal stresses. The purpose of these tests was to assess the effect of presence of coarser rock fragments and uniformity coefficient on the shear strength parameters. In dry state, the overburden dump rock material was cohesionless and non-plastic, hence its shear strength was mainly by virtue of its angle of internal friction. But when it was compacted in moist, unsaturated condition, it develops apparent cohesion.

The peak and residual shear strength values for each test have been interpreted from the results shown in Fig. 5 and summarized in Table 5. The differences in the shear strength were quantified by determining the intercept with the shear stress axis giving apparent cohesion (peak and residual) and the slopes of the trend lines, estimating the friction angles (peak and residual). Both peak and residual cohesion was found higher in GTODS1 mixture because of its higher coefficient of uniformity which resulted in better interlocking and packing among the rock fragments. The peak angle of internal friction of GTODS2 mixture was found higher by 2^0 as compared to GTODS1 mixture as the average fragment size was more in case of GTODS2.The overall mobilized shear strength in the range of normal stress tested was found lower in case of GTODS2 mixture as compared to GTODS1 mixture. The Mohr-Coulomb failure envelope was approximated as linear within the stress range used in these tests.

A series of small scale direct shear tests were also conducted on STODS having same uniformity coefficient as that of GTODS1. The shear strength envelopes are presented in Fig. 6. Cohesion was found much higher in case of STODS while peak friction angles were found lower by almost 4 to 5^0 as compared to GTODS1. The reduction in friction angle was due to presence of higher fines content in STODS. Particle size affects the shearing strength by influencing the amount of shearing displacement required to overcome interlocking and to bring the grains to a free sliding position. Accordingly, a coarser material was supposed to exhibit greater shear strength than a finer material because larger particles need more effort to overcome interlocking than smaller particles. However increased apparent cohesion was recorded for STODS as compared to GTODS1 because of higher fines content.

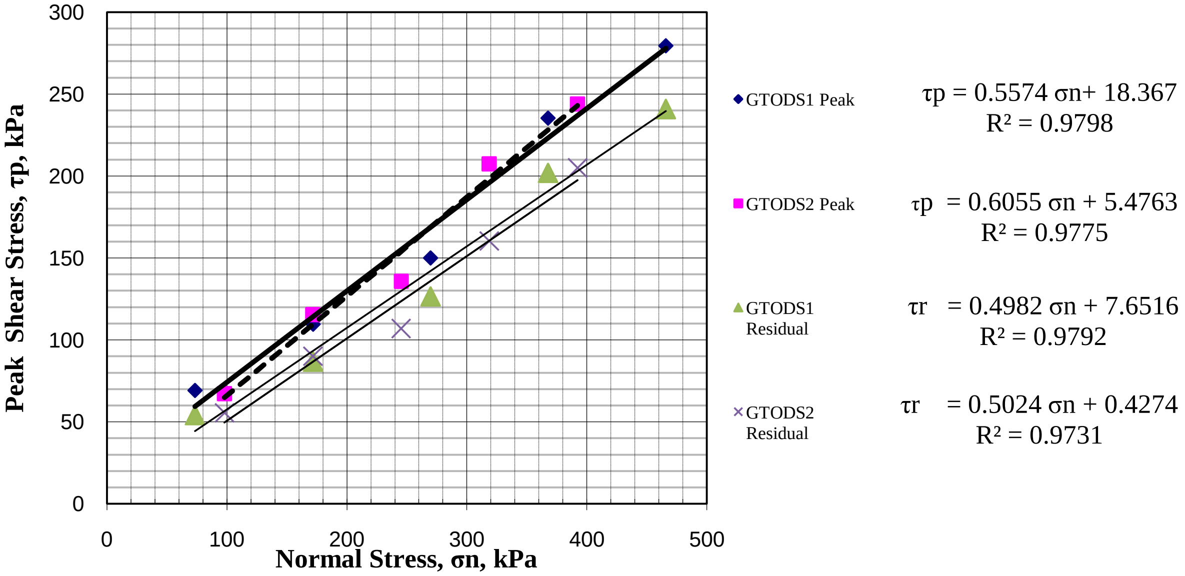


Fig. 5 Peak and Residual shear strength envelops for GTODS1 and GTODS2

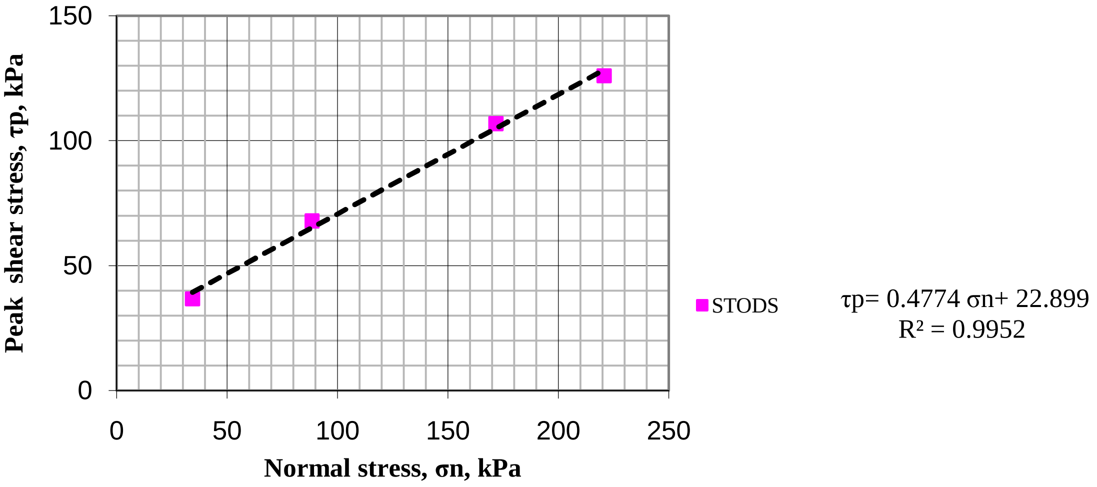


Fig. 6 Peak shear strength envelops for STODS

Table - 5 Peak Cohesion and Angle of Internal Friction of Experimental Samples

Sample	Peak apparent cohesion, kPA	Peak internal friction angle
Gravel type overburden dump sample 1 (GTODS1)	18.36	29.11^0
Gravel type overburden dump sample 2 (GTODS2)	5.476	31.17^0
Sand type overburden dump sample (STODS)	22.89	25.59^0

Effect of Moisture Content on Shear Strength of Overburden Dump Material

A series of large and small direct shear tests were also carried out on the above mixtures compacted at NMC to investigate the effect of moisture on the shear strength behaviour. The natural moisture content was found 4 %, hence the mixture was compacted at this moisture content. Large scale direct shear tests were performed on GTODS1 samples at the same strain rate and normal stress levels. The overall mobilized shear strength was slightly increased for mixture compacted at NMC due to significant increase in its friction angle component (Fig 7). However a slight reduction in both peak and residual apparent cohesion was noticed with the decrease in moisture content. The result clearly indicated that moisture has an important influence on the shear strength of overburden dump rock material.

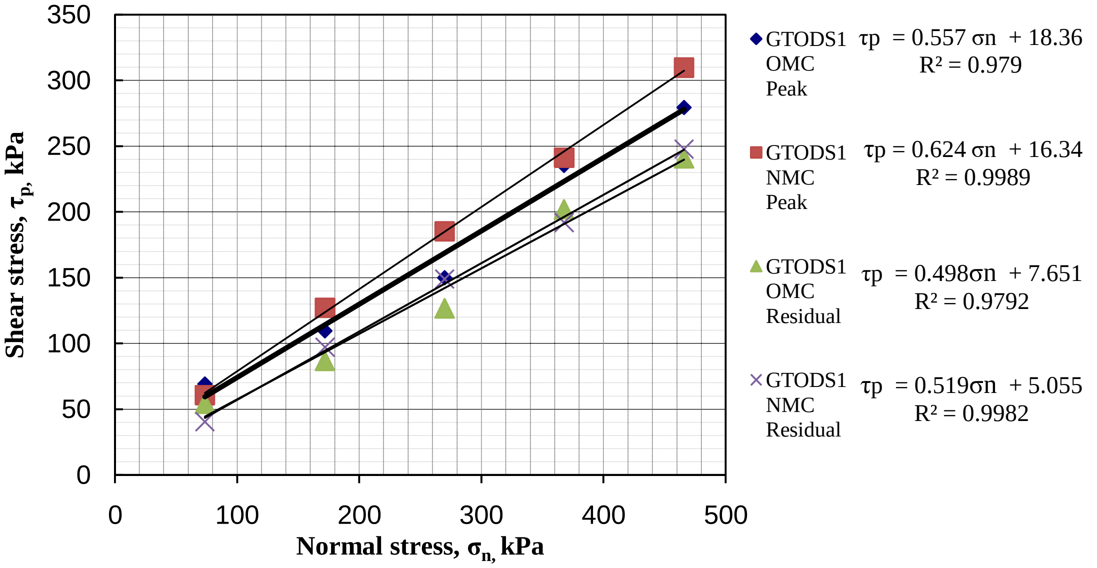


Fig. 7 Peak and Residual shear strength envelops for GTODS1 at OMC and natural moisture content

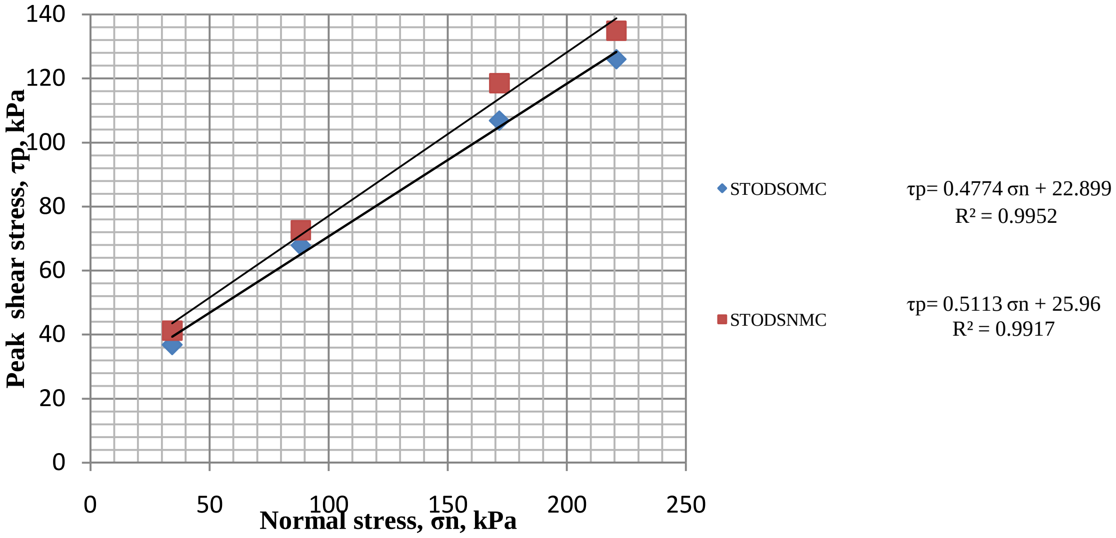


Fig 8 Peak shear strength envelops for STODS at OMC and natural moisture content

Small scale direct shear tests were also conducted on STODS compacted at NMC, at the same strain rate and same normal stress. A similar effect was observed in the shear strength behavior of the mixture (Fig. 8). The peak shear stress was found little higher in case of samples compacted at NMC. The peak friction angle was noticed 2^0 more and peak apparent cohesion was slightly lower for the STODSNMC as compared to STODSOMC. One of the main reasons for this increase in apparent cohesion was due to increase in matric suction for sample compacted at lesser moisture content. Capillary stresses develop between particles in a partially saturated soil due to surface tension in the water. The surface tension (negative pressure) in the water produces an equal and opposite effective stress between the soil particles, which results in an apparent cohesion. The magnitude of this type of apparent cohesion can be extremely large, especially in fine grained soils. Such capillary stresses can be overcome by an increase in the degree of saturation.

CONCLUSION

In order to assess the effect of fragment size on shear strength of overburden dump material, a series of consolidated drained direct shear tests (both large and small) were conducted on two different test mixtures compacted at their optimum moisture content and having same gradational characteristics as that of proto type. One more mixture was prepared from the same dump material having difference in coefficient of uniformity and subjected to LSD shear tests. Direct shear tests were also carried out on the first two mixtures at NMC to investigate the influence of moisture on the shear strength behaviour. Following conclusions can be drawn on the basis of above study:

- The average fragment size of the dump matrix were probably the most important factors influencing the dry unit weight and optimum moisture content of the mixture containing coal mine overburden rock material. The optimum moisture content of overburden rock material investigated increased with the reduction in average fragment size. Reduction in dry unit weight of overburden dump rock material was noticed because of decrease in average fragment size of the mixture.
- The angle of internal friction of all the tested samples was found generally increasing with the increase in average fragment size of the mixture while cohesion was found increased in mixture having higher fines content.
- An increase in both peak and residual cohesion was found for mixture having higher coefficient of uniformity because of better interlocking and packing among the rock fragments.
- The overall mobilized shear strength was found slightly more for mixture compacted at NMC due to significant increase in its friction angle component. A slight reduction in peak and residual apparent cohesion was noticed with the decrease in moisture content for samples having coarse size rock fragments. However a slight increase in apparent cohesion was observed in case of samples having higher fines content.

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