A Major Project-II Report on

EFFECT OF BEDDING AND SHEARING PLANE ON SHEAR BEHAVIOUR OF SEDIMENTARY ROCK

Submitted in the fulfillment of the requirement for the award of the degree of

MASTER OF TECHNOLOGY

(GEOTECHNICAL ENGINEERING)

Submitted by:

JITENDER KUMAR

(2K17/GTE/11)

Under the supervision of

Prof. A. K. Shrivastava
Department of Civil Engineering

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(2019)

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, Jitender Kumar, Roll No. 2K17/GTE/11 student of M.Tech. (Geotechnical Engineering), hereby declare that the major project-II report titled "**Effect of bedding and shearing plane on shear behavior of sedimentary rock**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title of recognition.

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Date: 2K17/GTE/11

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Major project II report titled "**Effect of bedding and shearing plane on shear behavior of sedimentary rock**" which is submitted by Jitender Kumar, Roll No 2K17/GTE/11, Department of Civil Engineering, Delhi Technological University, Delhi in fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **Prof. A.K. Shrivastava**

Date: **SUPERVISOR**

Abstract

Shear strength is an important criterion while designing a structure over rock mass. This shear strength is significantly affected by the presence of joints or cracks. In sedimentary rocks there are discontinuities due to deposition of subsequent layers while formation. These discontinuities are called bedding planes and being the plane of weakness; these have a significant effect on the strength and deformation criterion. By keeping the above information in mind an organized laboratory investigation was planned to analyze the effect of these bedding planes on strength and deformation of rock mass. In this project, laboratory tests were performed for characterization of rock material, Kota sandstone, brought from Dabi mines, Kota, Rajasthan. Physical properties were evaluated by using the Indian Standards test procedures. Anisotropic effect due to presence of bedding plane was estimated by testing rock samples at different orientations, bedding planes being at angle to the loading direction. Oblique shear tests were performed for inducing fracture in rock sample and for estimating shear strength due to shear failure along a predetermined failure plane. Field shear tests were carried out on Kota sandstone to estimate shear strength due to sliding friction failure between fractured surfaces. This project mainly focuses on effect of a single parameter in particular affecting the strength: the angle between bedding plane and loading plane. Brazilian tensile strength tests were carried out to know the effect of tensile stresses on the mode of failure of rock material. Rock core samples were used for estimating physical properties and various strength tests were performed by following standard test procedures. Field shear tests were performed under constant normal load condition. Tests were conducted on air dried samples at room temperature for at least 15 days.

Acknowledgement

This project has been made possible by the technical contributions from The Delhi Technological University. I would firstly like to thank my guide Prof. A.K. Shrivastava for suggesting this interesting topic and providing valuable guidance and advice. Thanks to B.R.G. Robert (Assistant Prof., DTU) and a deep gratitude goes to all faculty at DTU for their time and technical expertise. I would also like to thank Rock Lab for lending help with the experimental setup. In addition i would like to thank Mohd. Anas for his help throughout the project.

Last but not least, a special thank you to all my friends and family for all the support and encouragement throughout this year at DTU.

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1 Introduction

1.1 General

Rock mass contain discontinuities such as bedding planes, fractures and fissures etc. which can be induced in a rock or can be available naturally, with different value of physical properties along these discontinuities. In sedimentary rock these discontinuities are present in the form of bedding planes. These bedding planes have remarkable effect on the behavior of rock mass; controlling the deformation and strength behavior of rock mass. Due to presence of these bedding planes sedimentary rocks are anisotropic in nature having different physical properties with different orientation of these bedding planes to the loading direction. So, these are one of the most important phenomena affecting strength of rock masses. That’s why engineering designs and stability analysis of the structure need to consider this anisotropic nature of these sedimentary rocks. Reliable estimation of strength of jointed rock masses can ensure economical and reasonable design for surface and subsurface structures in rocks.

Sedimentary rocks are formed by deposition of sediments in layers by flowing water, these layers after being deposited and cemented are called bedding planes. These planes are generally but not necessarily, if there are other faults in rock mass, the weakest plane of rock mass. These planes impart anisotropy to rock mass.

Anisotropy is the property of material being directionally dependent, which implies different properties in different directions, opposite to isotropy. It can be defined as a difference, when measured along different axes, in a material's physical or mechanical properties (tensile strength, Shear strength etc.). An e.g. of anisotropic material is wood, which is easier to split along its grain than across the grains. In same manner these bedding planes have anisotropic effect in rock mass affecting strength and failure mode of failure. Anisotropy can also be checked with non-destructive test by using ultrasonic pulse velocity test, in which it gives different values of traveling time of acoustic wave along and across the bedding planes.

Mechanical properties of bedded rocks are related to these bedding planes. Various studies have been done with focusing on mechanical behavior of these bedded rocks and many tests like conventional compression tests and oblique shear test are done with different angles of inclination of bedding planes to the loading direction

(Ghazvinian and Hadei 2012; Ghazvinian et al. 2013) to study the compressive strength, deformation, shear strength and effect of their orientation on strength and deformation.

For this study, Kota sandstone rock samples were brought from Dabi mines (Kota, Rajasthan). In regional language of Kota this stone is called DABRI stone. These stones are famous for being manually workable for dressing of the stone. Other than blasting large rock masses from its parent rock and using cranes for transportation of these rock blocks from the site to workplace for dressing, all other work is done manually with help of a chisel and a hammer.

This rock is grey in colour and has bedding planes with uniform spacing of 1mm. Rock blocks of suitable size and having similar bedding pattern and somewhat similar colour were chosen from the site and were transported to the Rock lab, DTU, for extraction of rock core samples. Rock core samples of diameter 54mm (NX) were extracted from rock blocks with the help of manually operated diamond rock core drill machine. This machine has a 161 cc SI engine, water tank and nozzle for free flow of water. Water works as a coolant and works as lubricant also for ease in operation. A 56 mm inner diameter diamond drill bit was used to obtain the core samples. Due to friction of inner wall of drill bit diameter of samples obtained have diameter 2mm less than size of drill bit. These rock core samples are further cut in appropriate sizes for different tests with help of rock cutting machine. Due to water used in cutting of the rock samples, natural water content of the rock samples gets disturbed. So the samples are kept at room temperature for at least 15 days, to bring the moisture content to normal.

1.2 Research objective

1. To perform various tests for determination of index properties of rock samples.
2. Brazilian tensile strength tests (ASTM 3967) are performed for accounting the effect of tensile stresses on failure mode and angle of inclination.
3. Standard test Method for performing laboratory field shear strength tests of rock specimens under constant normal Force (ASTM D5607) at different angle of inclination of the bedding planes with shearing plane for determining variation of shear strengths for this angle between bedding plane and shearing plane.
4. To use the data obtained from results for various failure criteria and mechanical model of bedded sandstone.

Because of the sedimentary characteristics of geological formation sandstone, having about parallel bedding planes, imparting anisotropy, is found in this region. Effect of bedding planes on mode of failure and strength of rocks is to be dealt in this study. Oblique shear strength test apparatus are used for inducing the fractured surface in rock core sample and to analyze the non-sliding failure of rock core sample due to tensile splitting and shear failure along various combinations of dip angle and bedding plane angle with respect to loading direction. Field shear apparatus is to be used for inducing Normal stress and Shear stress on specimens on a predetermined failure plane. Normal loads and shear loads are applied separately. In our study Field shear strength tests are to be performed on specimens having induced fractured surface. Loading is applied with respect to different angle of orientation of these bedding planes. Field shear strength tests are performed to analyze mainly the sliding failure criteria of fractured surface. Brazilian tensile strength tests are performed for accounting the effect of tensile stresses on mode of failure and strength. Along with these strength tests various tests are to be conducted for characterization of physical properties of rock material.

2 Literature review

2.1 Factors affecting strength of rock

2.1.1 Bedding plane

Rock masses as engineering material are generally not homogeneous and isotropic and may contain faults, joints and bedding planes. These discontinuities in rock mass affect its physical and mechanical behavior. Thus, attention should be given to strength and deformation behavior of such rock containing discontinuities for design of substructure and superstructure over rock mass.

Sedimentary rocks are formed by deposition of sediments in layers by, these layers after being deposited and being cemented are called bedding planes. These planes are generally but not necessarily, if there are other faults in rock mass, the weakest plane of rock mass. These planes impart anisotropy to rock mass.

Anisotropy is the property of material being directionally dependent, which implies different properties in different directions, opposite to isotropy. It can be defined as a difference, when measured along different axes, in a material's physical or mechanical properties (tensile strength, Shear strength etc.). An e.g. of anisotropic material is wood, which is easier to split along its grain than across the grains. In same manner these bedding planes have anisotropic effect in rock mass affecting strength and failure mode of failure. Anisotropy can also be checked with non-destructive test by using ultrasonic pulse velocity test, in which it gives different values of traveling time of acoustic wave along and across the bedding planes.

Anisotropic effect of such weak planes orientation is very significant that it must be noted in analysis and study of failure mechanism. Observations were done that different shearing failure modes were built up depending on the orientations of such weak plane with respect to the loading direction:

(1) Tensile fracture of sample across the weak planes (non-sliding failure mode),

(2) Tensile splitting of sample along the weak planes (non-sliding failure mode), and

(3) Sliding failure along the weak planes or combined effect of these mechanisms.

The mechanical properties of bedded rock masses are not only related to the intact rock but also the distribution and properties of these bedding planes. Existing studies have focused on the mechanical properties of bedded rock and carried out conventional compression tests with various loading angles (Ghazvinian and Hadei 2012) to study the deformation, compressive strength and other anisotropic properties of bedded rock masses by conducting tests at various loading angles (Ghazvinian et al. 2013).

These fractures can significantly affect the mechanical behavior of rock masses, especially in the area of the ground surface where the stress level is low. The deformation behavior of a rock mass is primarily controlled by the joints as their number increases. Hence, factors controlling the behavior of rock joints under different stress areas must be identified and incorporated in an appropriate model to describe mechanical behavior of these discontinuous rocks. Rock joints can be divided into two groups: In-filled joints and clean joints. The shear behavior of the in-filled rock joints mostly depends on the physical and mechanical characteristics of the material filled in these joints and its thickness.

2.1.2 Shearing plane

In both oblique shear test and field shear test, specimen is sheared across a predetermined failure plane or the assumed plane of weakness. This failure plane is called shearing plane. Joints, discontinuity or bedding planes affect the mode of failure across this shearing plane. Different shearing failure modes are observed depending on the orientations of weak planes with respect to shearing plane as, tensile fracture across the weak planes (non-sliding mode), tensile- split along the weak planes (non-sliding mode), and sliding failure along the weak planes combination of these mechanisms.

In field shear test, if test is used for intact rock specimen, moments may get generated and shearing plane could be in inclined plane with respect to predetermined horizontal plane. In field shear test strength of rock sample can also be affected by moisture content from the encapsulating material so the care should be taken when testing porous rock core samples at their natural moisture content. These types of samples should by coated non water absorbent layer to prevent absorption of moisture, before installing in encapsulating material.

In oblique shear test slope angle of predetermined failure can be changed between 30 to 45 degrees but angle of fractured surface depend upon various other features like bedding plane, joints, micro cracks etc. Keeping all other parameters constant, for e.g. size of sample, moisture condition, rate of loading and dip angle, and changing angle of bedding plane with this predetermined failure plane gives different values of shear strength and different mode of failure.

2.2 Shear strength

Shear strength is an important criteria for analyzing the failure of rock slopes, designing of earth dam structures, design of underground opening in jointed rocks and other engineering designs etc. Shear behavior of jointed rocks depend on orientation of joint, stiffness of surrounding rock, condition of joint i.e. unfilled joint/infilled joint, shearing area ratio etc.(Shrivastava and Rao, 2009). Shear strength of rock joint and discontinuities is measured from field shear strength test (ASTM D5607) or oblique shear test (Ghazvinian et al. 2013). In both oblique shear and field shear tests, shear strength is measured along predetermined failure plane. Though in oblique shear apparatus there is arrangement for changing angle of shearing plane.

Field shear strength test is usually conducted in the undrained state, because moisture content of rock sample gets changed due to moisture present in the encapsulating material, with an applied constant normal load. It includes procedures for both intact rock strength and sliding friction tests which can be performed on specimens that are homogeneous, or have planes of weakness, including natural or artificial discontinuities. As the strength of the rock sample increases, here referring to strength as UCS(uniaxial compressive strength), encapsulating material should also be changed so that it can hold the rock samples in proper position to avoid any displacements and so that it does not fail before the failure of samples, inducing error in final results. Examples of an artificial discontinuity include a rock-concrete interface or a lift line from a concrete pour. Discontinuities may be open, partially or completely healed or filled.

For non-planar joints or discontinuities, shear strength is derived from a combination base material friction and overriding of asperities (dilatancy), shearing or breaking of the asperities, and rotations at or wedging of the asperities. Sliding on and shearing of the asperities can occur simultaneously. Asperities are the collection of a surface's irregularities that account for the surface's roughness. In this test While maintaining a constant force normal to the nominal shear plane of the specimen, an increasing external shear force is applied along the designated shear plane to cause shear displacement. The applied normal and shear forces and the corresponding normal and shear displacements are measured and recorded. These data are the basis for calculating the required parameters. When this test method is used to determine the shear strength of intact specimen may generate overturning moments which could result in inclined shear break. Shear strength is influenced by the overburden or normal pressure; therefore, the larger the overburden pressure, the larger the shear strength. In some cases, it may be desirable to conduct tests in situ rather than in the laboratory to determine the representative shear strength of the rock mass, particularly when design is controlled by discontinuities filled with very weak material. Porous rock that is to be tested at its natural water content should be coated with a non-absorbing sealer to prevent absorption of water from the encapsulating compound.

In oblique shear apparatus, a cube, prism or a cylindrical specimen is placed between two beveled dies set up and sheared along a predetermined shearing plane with an inclination as given by the dies setup. Two components of normal and shearing force that directed normal and along to the shear plane, respectively, result from the splitting of the vertical force of the testing device. For specimen with an inclination of dip angle equal to 90°, shearing occurs with sliding mode along weak planes for angle of inclination of bedding plane up to maximum value of 60°.

Although shearing occurs through rock material for higher value of angle of inclination of bedding plane, however, the splitting of weak planes, along their strike directions would be more noticeable (Ghazvinian et al. 2013).

Past studies shows that shear strength and deformability of fractured surface is considerably affected by the joint material between these bedding planes. Field shear tests show that the deformability of asperities considerably affects normal and shear behaviors of joints. For joints with equal wall compressive strength values, those having higher deformability show higher shear strength. This is due to the fact that higher deformability of asperities results in increasing the contact area during shearing (Khabat et al. 2013).

3 Methodology

Various laboratory tests are to be carried out to determine physical and mechanical properties of the rock material. This study did not accounted the thermal effects and all tests were conducted at room temperature. For uniform moisture condition, 15days air dried samples were used in testing for Brazilian tensile strength and Oblique shear strength. When testing for field shear strength of the rock material it was considered that, as moisture absorption of the rock material found out to be 1.74%, saturation of rock core sample due to moisture in encapsulating material was neglected. Experimental program for this study was as:

I. Extraction of rock cores from rock blocks with rock core cutting machine and sample preparation.
II. Characterization of rock material by testing for its physical and mechanical properties.
III. To conduct Brazilian tensile strength tests on rock core discs to analyze the effect of tensile stresses on splitting along bedding planes.
IV. To conduct oblique shear test for non-sliding shear failure and inducing fractured surface in rock core sample.
V. To conduct field shear test on fractured samples for sliding frictional failure.

3.1 Specimen preparation

For preparation of rock core samples rock blocks of suitable size and having similar colour and bedding pattern were chosen and were transported from Dabi mines, Kota, Rajasthan to Rock lab, Delhi Technological University, Delhi. Further, rock core samples of diameter 54mm (NX) were extracted with the help of manually operated diamond rock core drill machine having 161 cc SI engine with help of diamond drill bit having internal diameter equal to 56mm, shown in fig 3.3. Rock core samples obtained are around 2mm lesser in diameter the diameter of drill bit due to friction of internal wall of drill bit moving at very high speed. This machine is completely manually operated, has wheels and handle installed in it to move it from one place to another with ease, a water tank is provided on the top of rock core dill machine from which water comes out from a small nozzle through the drill bit. This water serves both as coolant and lubricant in drilling operation so the drill bit do not get hot and break, ease in operation of extraction of cores. In fig 3.1 manual dressing of the stone is shown with help of chisel and hammer. In fig 3.2 site is shown from where rock blocks are selected. In fig 3.3 a rock block is shown from a site in Dabi mines (Kota, Rajasthan), selected for extraction of rock core samples.

Fig 3.1-Dressing of stone with chisel and hammer (Dabi mines, Kota, Rajasthan)

Fig 3.2- Site from where rock samples are collected, Dabi mine, (Kota, Rajasthan)

Fig 3.3-Rock block selected for extraction of rock core samples
(Dabi mines, kota, Rajasthan)

Rock cores are extracted from these blocks with help of rock core cutting machine, as shown in fig 3.4. Extreme care should be taken while extraction of rock cores. First these blocks should be placed on a firm ground and should be held in place to avoid any unwanted movement. As these blocks have dry density of 2.6gm/cc, these stone remain in their place due to self-weight and have very little or no movement during extraction of cores. Other important thing to be taken care is that there is should be continuous supply of water from the nozzle while the whole operation of extraction of cores, otherwise drill bit will get too hot and will break, as drill bit is moving at very high speed, pieces of broken drill bit can hurt the operator significantly.

Fig 3.4-Extraction of rock cores from blocks with help of rock core cutting machine
(concrete lab, DTU)

Rock cores are extracted in such a manner that bedding planes are clearly visible when seen from cross section of rock core. A line diagram representing the cross section of the rock core showing bedding plane is shown in fig 3.5. In this figure a co-ordinate system is also shown for ease of describing loading direction with the bedding plane. This figure is inspired from Ghazvinian t. al. 2012. In fig 3.6 extracted rock core samples are cutting are shown and bedding planes can be clearly seen in this figure.

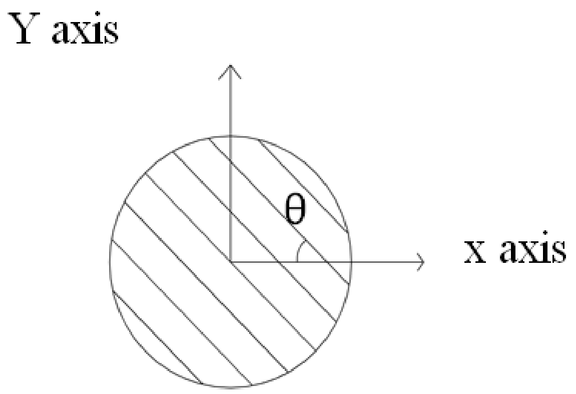


Fig 3.5-Angle of inclination of bedding plane with x axis (Ghazvinian et. al. 2012)

The angle of loading/inclination is defined here as angle between bedding plane and direction of loading either normal or shear, varying from 0°-90°. 3 nos. of samples are used for testing, for verification of the test results. Before performing various tests on these rock cores these cores are cut to suitable sizes for different tests as per the codal provisions for example for uniaxial compressive strength test height to diameter ratio should be 2:1, for Brazilian tensile strength test thickness to diameter ratio should be 0.5 etc. with help of rock cutting machine available at rock lab, DTU shown in fig 3.7. These samples are further kept to let dry at room temperature for at least 15 days so that the moisture content is uniform in all the samples and it does not have any significant effect on the strength and deformation criteria or any other property.

Flow chart for preparation of sample:

Selection of rock blocks of suitable size having similar colour and bedding pattren from Dabi mines, Kota, Rajasthan for extraction of rock cores for having similar characteristics.

Cutting of rock core samples to suitable sizes and air dried at room temperature for at least 15 days for providing uniform moisture condiiton for different tests.

These cores are then stored in wooden boxes away from too much light and dampness avoiding disturbance in moisture content.

These samples are further tested for different properties by following the standard test methods and codes. Tests performed on rock samples are for Dry Density, Porosity, Brazilian Tensile Strength, Point load index, Uniaxial compressive strength (UCS) value, Water absorption, Void ratio, Field shear strength, Oblique shear strength and Slake durability. Values of all these properties are shown in Table 5.1. These test results are further compared with standard results on similar rocks.

Fig 3.6-Rock core samples after cutting(concrete lab, DTU)

Fig 3.7-Sample preparation to suitable sizes for various tests, on rock cutting machine (Rock lab, DTU)

Brazilian tensile strength tests (ASTM 3967) are performed on many samples at different angle of inclination for accounting the effect of tensile stresses on mode of failure and effect of change in angle of inclination of bedding plane to the loading direction. Here for brazilian tensile strength test, rock core are disc samples with thickness to diameter ratio was kept constant, equal to 0.5 by keeping thickness of samples equal to 27mm and diameter of sample equal to 54mm for keeping all other parameter constant and changing only angle of inclination of bedding plane to the loading direction. As moisture content may affect the strength of rock cores, samples are used by air drying at room temperature for at least 15 days (ASTM 3967). Though loading on the specimen is applied though hand operated hydraulic jack, so there is no provision for controlling rate of loading so there can be some discrepancy in results but enough care should be taken so that loading is applied uniformly and gradually. For accounting the effect of different angle of inclination of bedding plane to the loading direction tests were performed at every 15° interval of angle of loading. Rock core discs cut to suitable sizes are shown in their saturated and unsaturated condition in fig 3.8. Apparatus for Brazilian tensile strength test is shown in fig 3.10. Slight modifications are done in the Brazilian tensile strength test apparatus for estimating failure load at different angle of inclination.

Fig 3.8- Rock core discs (saturated and unsaturated condition)

As it is clearly visible from fig 3.8 that when sample's surface is wet then bedding planes are clearly visible because when rock sample is wet it absorbs some portion of light and appears to be dark making the observer able to distinguish between different bedding planes, but when samples are dry it becomes little hard to properly distinguish between the bedding planes through images, though they are visible if seen directly live from the eyes. So we marked a line parallel to these bedding planes when they were wet and marked them with numbers for distinguishing between them and ease of collection of test data.

In general, Brazilian tensile strength test (ASTM D3967) do not have any means to provide different angle of inclination of bedding plane to the loading direction. So, here we have slightly modified the mould of Brazilian tensile strength test apparatus. As it can be seen from fig 3.10, graduations for different angles are provided on the mould of the apparatus.

Now samples can be put into mould with different angles of inclination of these bedding plane to the loading direction. Here θ can be taken as angle with horizontal axis as shown in Fig 3.5.

The value of brazilian tensile strength for different angle of inclination is shown in Table-5.1, and a graph is also plotted for the Brazilian tensile strength vs angle of inclination in Fig.4.3. All samples used for Brazilian test are air dried for 15 days for having identical moisture condition (ASTM D3967). Formula for calculation of tensile strength from load at which rock disc fails, given as:

$$\sigma = \frac{2P}{(\pi D t)} \qquad \text{Eq.3.1}$$

Where,

σ = Tensile strength from Brazilian tensile strength test, in MPa

P = Load recorded at failure of disc samples, in KN

D = Diameter of rock core disc (here, 54mm)

t = Thickness of rock core disc (here, 27 mm)

Fig 3.9- Brazilian tensile strength test apparatus (Rock lab, DTU)

For field shear strength test, ASTM D5607 is followed. A fractured surface is induced at different angle of inclination with the bedding plane, then upper and lower part of the specimen is kept in position with the help of encapsulating material and samples are sheared for accounting the effects of friction between upper and lower past's surfaces and shearing of asperities between them. In this test, If porous rock material is used or water absorption of the material is significantly high then sample should be tested at its natural moisture content and a non-absorbing sealer should be applied over it to prevent the water absorption from encapsulating material (ASTM D5607). But in our value of water absorption is 1.74% only so effect of moisture from encapsulating material is neglected.

Determination of water content and dry density is done on the basis of IS 1124 and IS 13030 respectively. Porosity and void ratios are also determined on the basis of IS 13030. For determination of water content rock samples are first immersed in cold water for 24 hours. After this samples are taken out of the water and surplus water on the surface is wiped out with the help of a cloth. Now this samples is weighted with the help of a weighing machine and the weight of the sample is taken as. For verification in test results more than three numbers of samples are used. These samples are now kept in oven for 24 hours at a temperature of 110°c. While testing rock samples for water content, sometimes an extra measure also be taken. After 6 hours a strip of paper is taken and kept over these samples. If this strip is blown away then it means that there is moisture content is present in the rock samples and these samples are further subjected to oven drying for 18 more hours. This strip is blown away due to vapour from moisture content present in the rock sample. If this does not get blown away then it means rock sample is free of moisture content can be used measuring dry weight. Water content of the sample is equal to ratio of difference of weight in saturated and dry condition to the dry weight.

For dry density of rock samples results from water content tests can be used. Dry density is equal to the ratio of weight of specimen to the volume of specimen. Dry weight of sample is obtained from water content test and due to using rock core samples, volume of specimen is easily calculated mathematically with help of diameter and height of specimen and thus dry density of specimen is calculated.

Void ratio of specimen is calculated by the formula described in Eq. 3.2:

$$eS = wG \qquad \text{Eq.3.2}$$

Where,

e = void ratio

S = saturation

w = water content

G = specific gravity

Porosity is further derived from void ratio by the formula described in Eq. 3.3:

$$e = \frac{n}{1-n} \qquad \text{Eq.3.3}$$

Point load index test is done on the basis of IS 8764-1998. Height to diameter ratio is kept equal to 2 and sample is tested diametrically by applying loading along the weak plane i.e. bedding plane as per IS code. Arrangement of point load index test apparatus and testing of sample is illustrated in fig 3.11. Rock core sample before and after failure is illustrated through fig 3.12

Fig 3.10-Arrangement of rock core sample for testing for point load index (Rock lab, DTU)

Fig 3.11-Rock samples before and after testing for point load index (Rock lab, DTU)

Point load index for cylindrical specimen is calculated with help of formula described in Eq. 3.4:

$$Is = \frac{1000P}{D2} \qquad \text{Eq.3.4}$$

Where,

Is = Point load index value

P = Load at failure (in KN)

D = diameter of specimen (in mm)

4. Laboratory experiment

Tests are to be performed for calculation of water absorption, point load index, Brazilian tensile strength , dry density, void ratio, porosity, slake durability, uniaxial compressive strength etc. Results of these tests are shown in Table 4.1.

Various tests are performed on the rock material to know values of different index properties:

- Porosity (IS 13030)
- Dry density (IS 13030)
- Point load index (IS 8764-1998)
- Water absorption (IS 1124)
- Void ratio (IS 13030)
- Slake durability index (IS 10050)
- Unconfined compressive strength (IS 9143)
- Brazilian tensile strength test (ASTM D3967)

Values of index properties are shown in Table-4.1 below:

Table-4.1 Index properties and their experimental values

Properties	Experimental values
Brazilian tensile strength	16.739 (θ=0°)
Water absorption	1.74% by weight
Dry density	2.6gm/cc
Point load strength index	5.86 MPa
Void ratio	0.045
Porosity	4.31%
Slake durability	99.5%
UCS	137.5 MPa

Brazilian tensile strength tests (ASTM 3967) are performed for accounting the effect of tensile stresses on failure mode and effect of angle of inclination of bedding plane with loading. Brazilian tensile strength test apparatus works on the principle that if we apply normal load compressive load in a direction then tensile stresses gets generated due to this load in direction perpendicular to the direction of normal load. These tests are conducted on the rock samples so that we know the effect of confining stresses on the mode of failure and what is the effect of tensile stresses on it. Because when we test the specimen in oblique shear strength test apparatus, in actual only one load is applied on the apparatus i.e. loading normal the dies. This normal load further gets distributed in normal and shear components over the specimen due to special arrangement of oblique shear mould. An example of testing and tensile failure of the rock material is shown in the fig 4.1. Angle of inclination of bedding plane with loading direct can be easily understood by fig 4.5. θ, angle of inclination is taken with respect to x- axis which is condition of bedding plane being perpendicular to the loading direction. Experiment on the sample illustrated in fig 4.1 is for angle of inclination with horizontal direct equal to 60°. Here from having a look at the figure, it can be clearly seen that there is tensile splitting of rock core discs along the weak plane i.e. bedding plane also along with the vertical cracks due to tensile splitting. This shows that there is a significant effect of these bedding planes on the strength and deformation criteria. These bedding planes splits at much lower value of stresses than loaded across the bedding plane.

From examining the test sample after failure shown in figure 4.1 it can be concluded that due to application of normal load strains get generated in the rock core disc but as there is no elongation of contraction these strains are stored as strain energy in the rock core disc. At the verge of failure this accumulated strain energy is released with a burst and fracture spreads in a wider area and sample fails with a burst. Thus samples are tested at different angles of inclination of bedding planes to the loading direction, value of these tests are illustrated in Table 4.2.

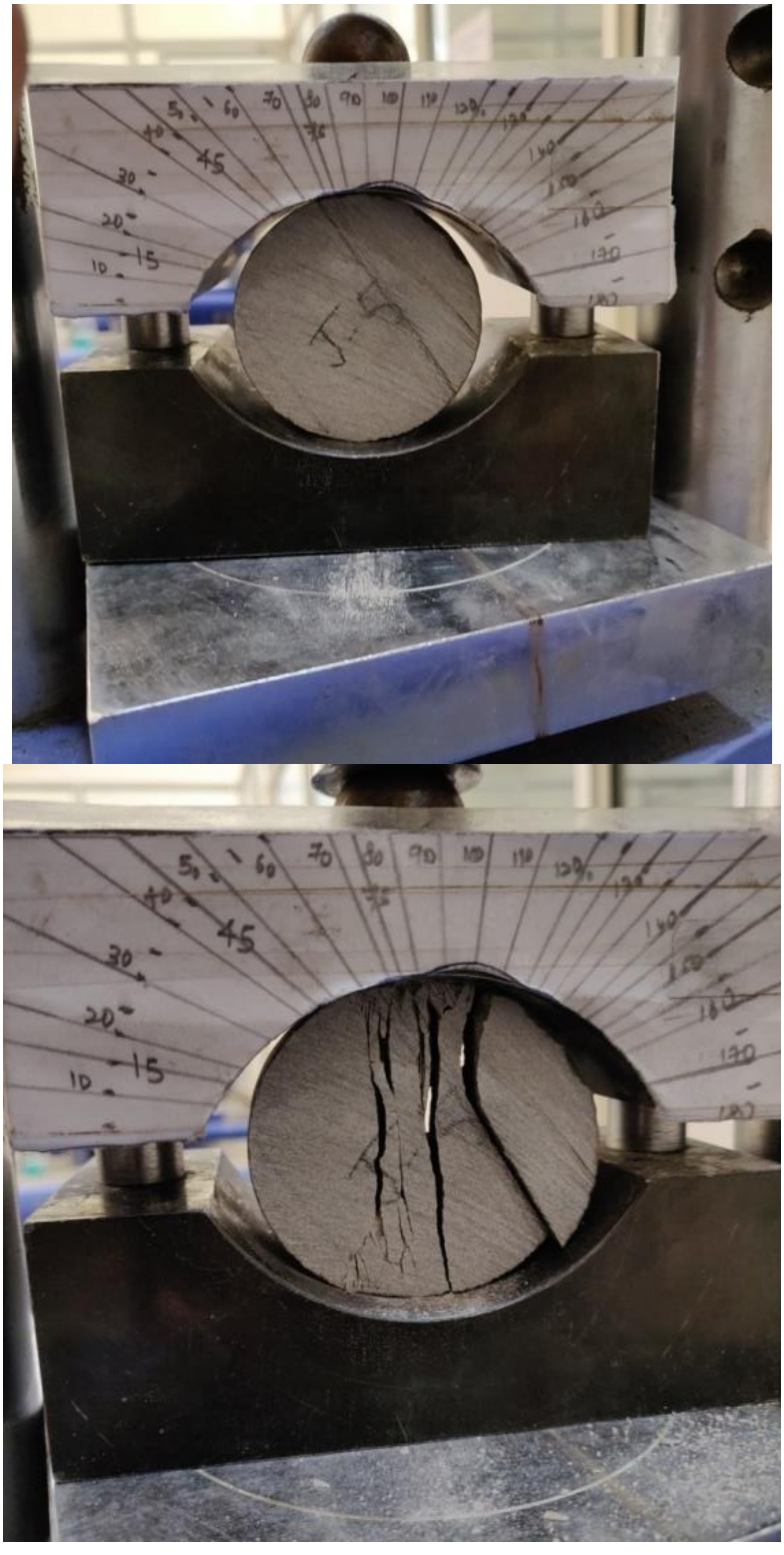


Fig 4.1- Samples before and after the failure (at θ=60°)

Fig 4.2- Different type of failure mode different angle of inclination(θ=0°-90°)

From Fig 4.2, it can be clearly seen that for different angle of inclination, type of failure mode is different. Values obtained for different angle of inclination of bedding plane to the loading direction are shown in Table-4.2 below:

Table-4.2 Tensile strength for different angle of inclination

S.No.	Angle of inclination(θ)	Diameter(mm)	Height(mm)	Load(KN)	Tensile strength(MPa)
J-1	0°	55	32.5	47	16.739
J-2	15°	55	24.5	34	16.063
J-3	30°	55	27.5	23.5	9.891
J-4	45°	55	30	36	13.889
J-5	60°	55	25	35	16.204
J-6	75°	55	27	23.5	10.204
J-7	90°	55	24.5	28	13.228

A graph for angle of inclination(θ), on x-plane vs tensile strength (in MPa) is shown below:

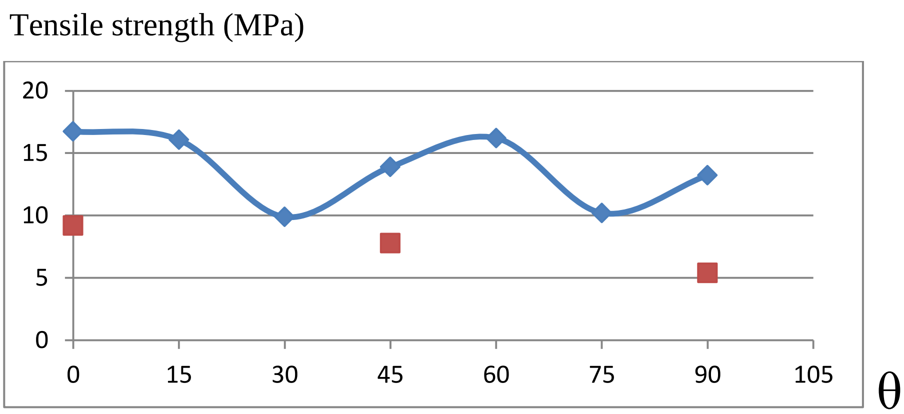
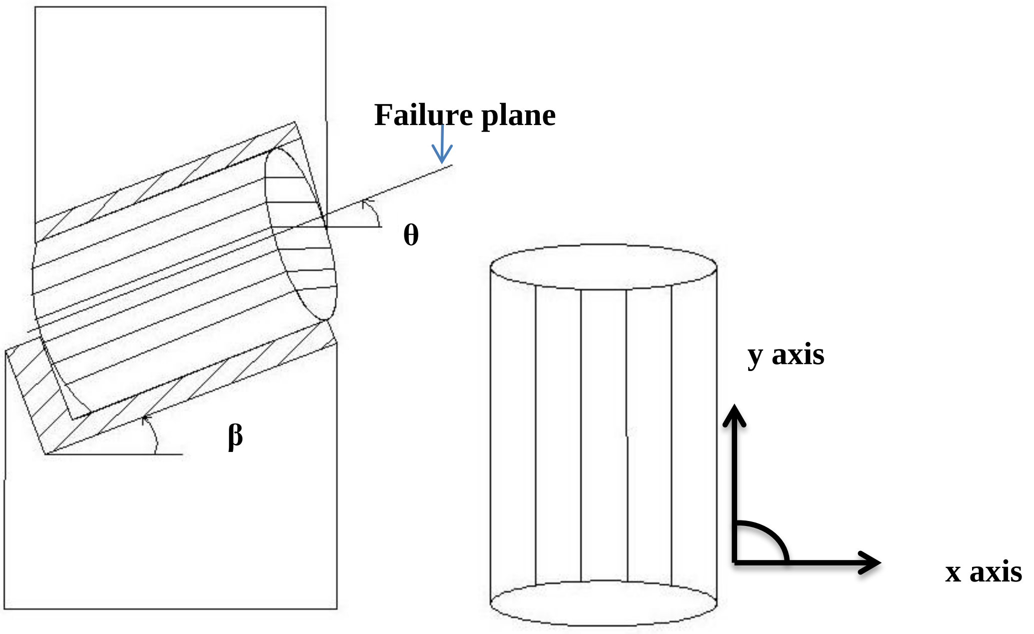


Fig 4.3- Graph for angle of inclination(θ) vs tensile strength (in MPa) (compared with Shan-chao et al. 2017)

As it is clearly evident from the graph that for θ=15°-30° value of tensile strength decreases and then there is increase in the value of tensile strength then again for value of θ=60°-75° value of tensile strength decreases. This is due to the splitting along bedding plane also, which can be seen in Fig 4.2. At 0° angle i.e. loading across the direction of bedding plane, these is large accumulation of strain energy and at verge of failure this strain energy gets released with a burst and splitting along the weak plane also can be evident.

After performing various tests to know the effect of tensile stresses on mode of failure, specimens are prepared for field shear strength test. For field shear strength testing rock core samples are used, diameter and height of the samples are 54mm and 54 mm, keeping height to diameter ratio approximately unity. These samples are then air dried for 24 hours to obtain similar moisture condition. For inducing the fractured surface in rock core sample and knowing the value of non-sliding splitting strength, these samples are further placed in oblique shear testing apparatus at dip=90°, failure angle at 30° and angle of inclination(θ) at 15° interval. Special care should be taken while handling the oblique hear apparatus as it too heavy to be handled by a single person while using as whole assembly. Different parts of apparatus should be transported from one place to another with help of someone. Figure for arrangement of specimen in oblique shear apparatus is shown in figure 4.4 illustrated with the help of a line diagram.

This oblique shear apparatus is further put in the 2000KN capacity compression testing machine. Due to the special arrangement of the dies and mould for putting specimen in it, normal load gets distributed over the rock core specimen in two major components, normal stress and shear stress. Dip angle, which is illustrated through figure 4.4 is kept 90° for our experiment and slope angle of predetermined failure plane is fixed at 30°. Now only the angle of inclination of bedding plane is changed with respect to horizontal axis.



Dip angle=90°

Fig 4.4- Arrangement of oblique shear apparatus (here β=slope angle of predetermined failure plane, θ=angle of inclination of bedding plane with respect to predetermined failure plane)

Testing of rock core specimen in oblique shear apparatus is shown through the figure below:

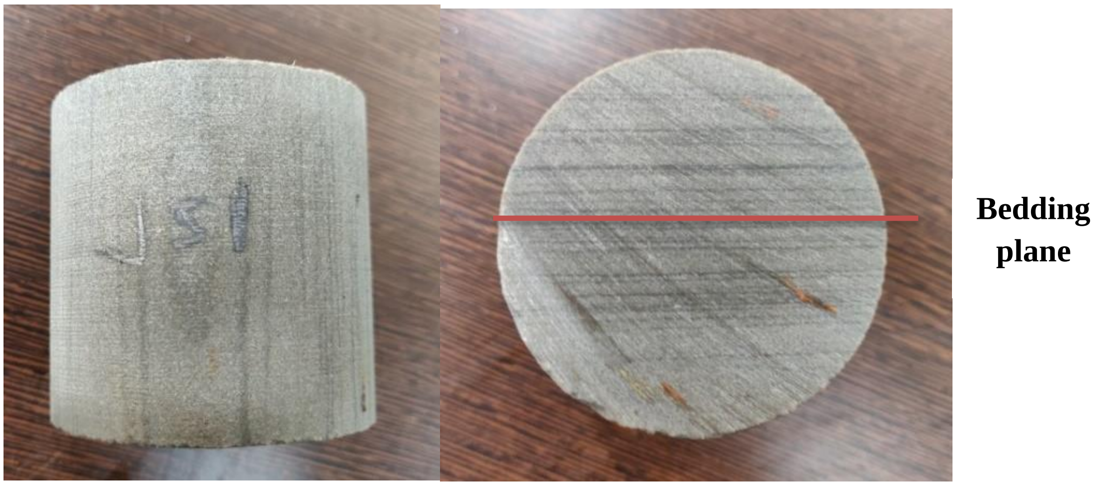


Fig 4.5- Rock core samples showing bedding plane before failure

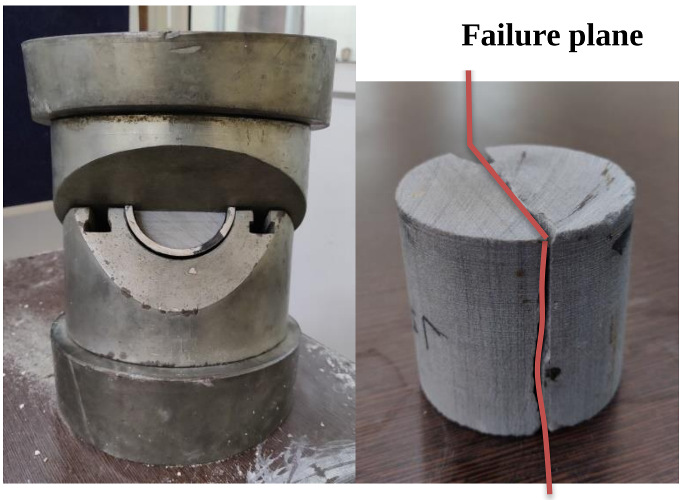


Fig 4.6- Rock core sample in oblique shear test apparatus and sample after failure

For testing for shear strength, samples is taken and put in the mould having bedding plane parallel to the direction of shear stress component of load, as shown in figure 4.6, then lower die of the oblique shear apparatus is set on the graduation of 30°. This angle is angle of predetermined failure plane. Then the whole assembly is loaded into the compression testing machine, as illustrated in figure 4.11. Compression testing machine (CTM) is connected with a data logger for collection of data. First, platens of the machine are moved closer to the oblique shear apparatus and when the platen is on the verge of touching upper die of the oblique shear apparatus CTM is stopped for a while and information of sample is loaded into the data logger, as data logger gives a loading graph and value of peak stress. Rate of loading is selected to 0.01KN/sec and clicked on tare to bring load value to initially zero. CTM is started and gives value of peak load and a loading curve as figure 4.12. Normal stress and Shear stress can be calculated manually also by formula described in Eq. 4.1 and Eq. 4.2 respectively (Ghazvinian et al. 2013).

$$N = F cos\beta \qquad \text{Eq. 4.1}$$

$$T = F sin\beta \qquad \text{Eq.4.2}$$

Where,

N= Normal component of normal load ($\frac{KN}{mm2}$)

F= Normal load at failure (in KN)

β= slope angle of predetermined failure plane

T= Shear component of normal load ($\frac{KN}{mm2}$)

Dimension of the specimen taken as diameter and height equal to 54mm. So area of fracture plane is taken equal to 2916 square millimeter. Stress is calculated as ratio of normal or shear component of normal load to the loading area.

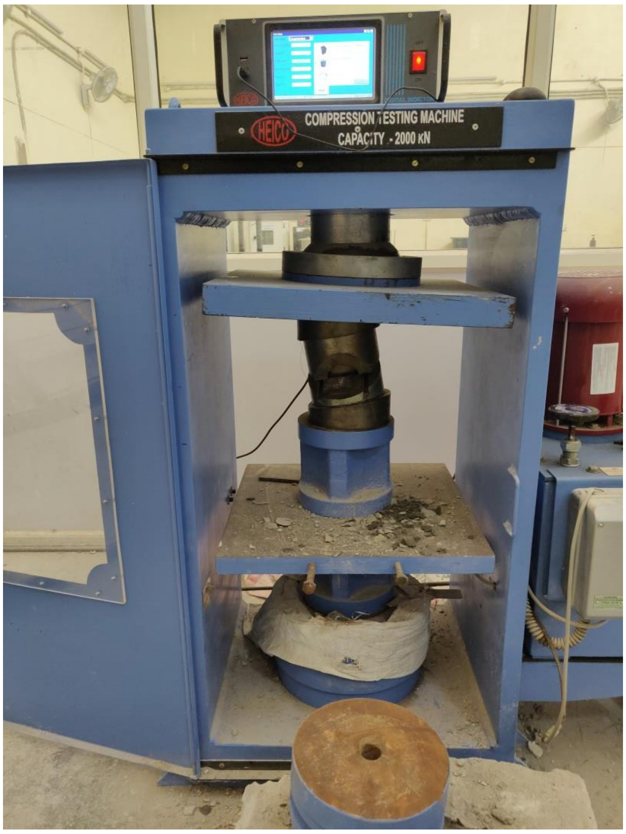


Fig 4.7- Application of normal load by CTM (Rock lab, DTU)

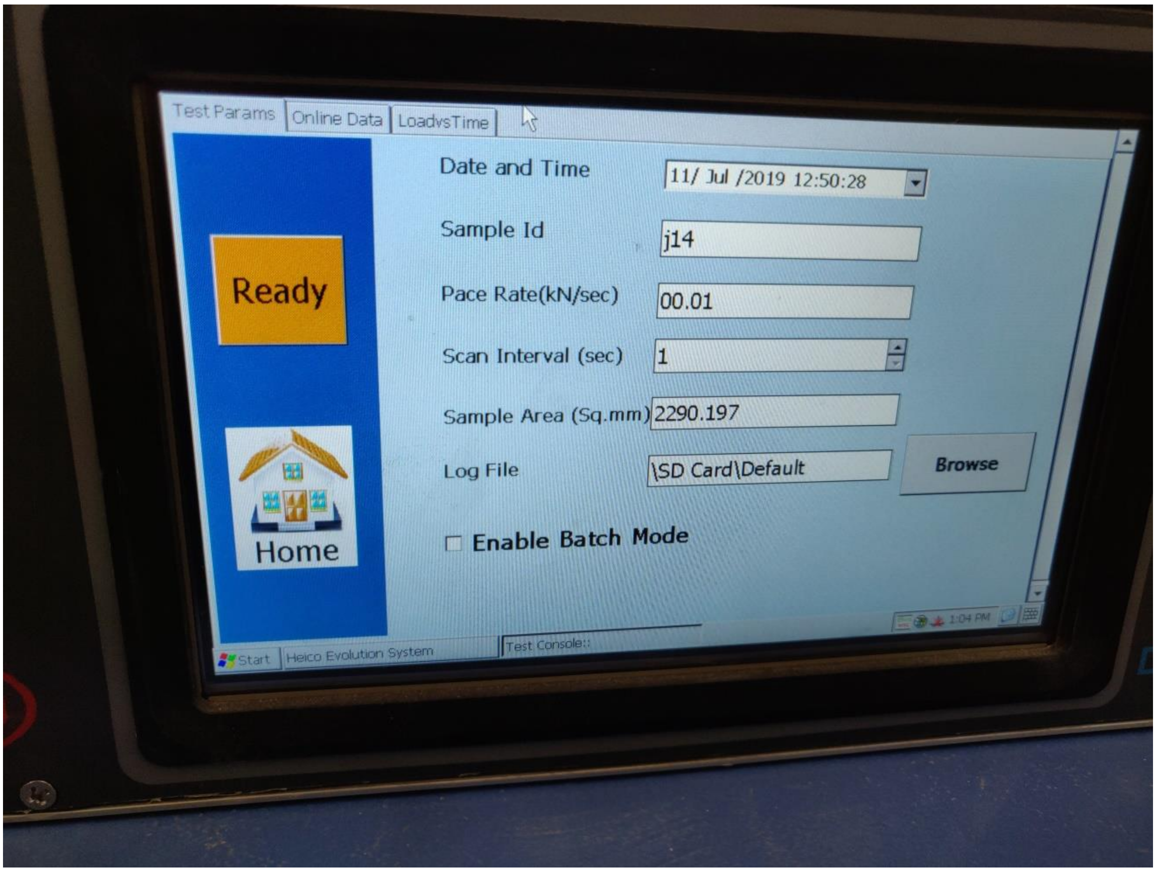


Fig 4.8-Arrangement for test, Data logger (Rock lab, DTU)

Fig 4.9- Value of peak load and samples after failure (Rock lab, DTU)

Peak load is recorded as 72.8 KN and value of normal and shear components of load is calculated by the formulae described in Eq. 4.1 and Eq. 4.2 respectively. Taking β=30° and F= 72.8 KN, value of normal and shear components of load is:

N= 63.04 KN

T= 36.4 KN

Here bedding plane are kept parallel to the shear component loading direction and when bedding plane are kept perpendicular to the shear component of loading direction, peak load value is equal to 186.6 KN. Failure of sample in this condition is shown in fig 4.10.

Fig 4.10-Sample after failure when loaded at bedding planes being perpendicular to the direction of shear component of load (Rock lab, DTU)

As it is event from the figure 4.10, tensile splitting along the bedding planes also occur with shearing failure of rock core sample along the predetermined failure plane. But this type of failure does not occur when loaded at bedding plane being parallel to the direction of shear component of loading and there is a large difference in strength when loaded across and along the bedding plane. Due to this type of splitting along the bedding plane when loaded perpendicular to shear direction, this sample cannot be further used for field shear test.

After obtaining fractured surface at desired angle shear strength value is noted down and these fractured samples are further used for testing in field shear strength test apparatus for of shear strength due to sliding friction of fractured surfaces and shearing of asperities, which in turn gets affected by change in the value of constant normal load. Arrangement for the field shear strength is shown in figure below:

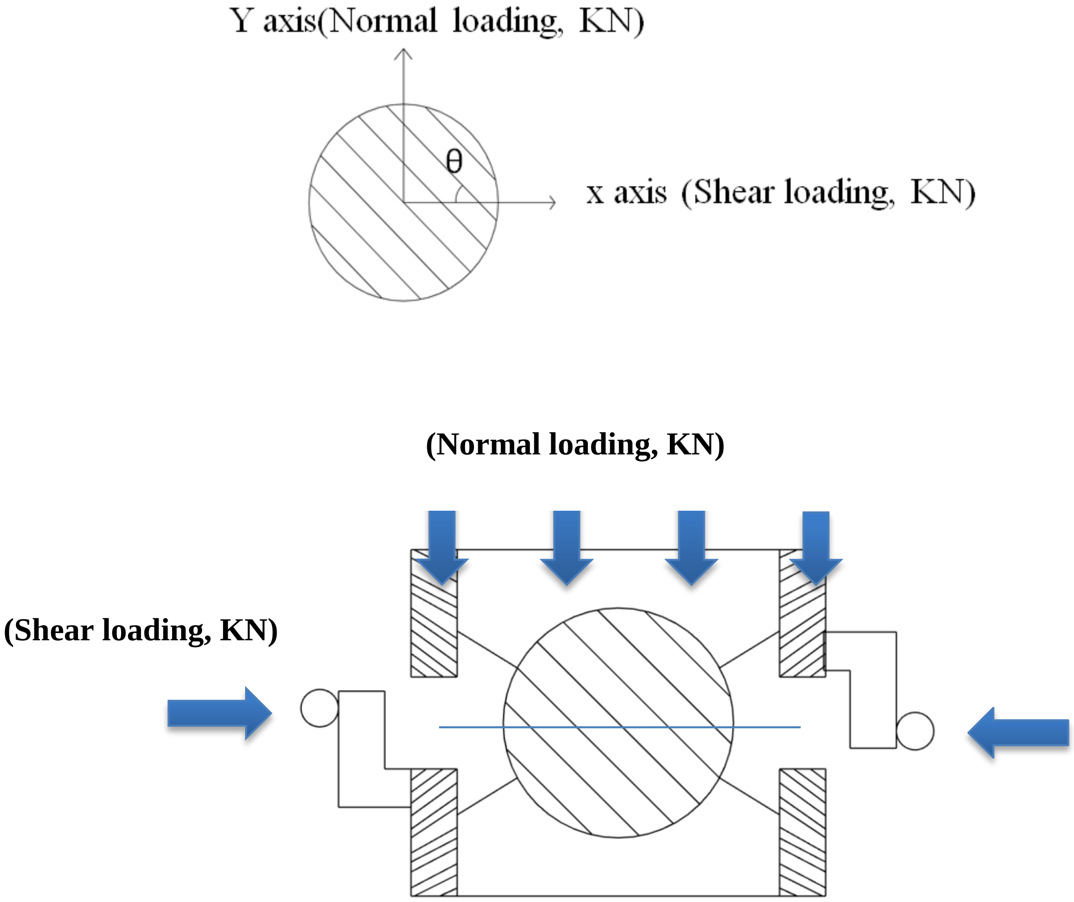


Fig 4.11- Arrangement of rock core sample in field shear apparatus (ASTM D5607)

Arrangement of the rock core sample is done as shown in Fig 4.11. Rock sample for field shear test requires Encapsulating material to hold it in its place so that it can transfer the load to rock core specimens. Here encapsulating material is taken, plaster of Paris (POP), with water content ratio 0.5 to the weight of the POP (ASTM D5607). Encapsulating material is filled in this sampler, shown in figure 4.12 and core sample is placed, so that encapsulating material dry up and hold the rock core sample in its place for field shear strength test. Before putting the encapsulating material in the sampler, it should be cleaned thoroughly and should be free of any dirt and impurities. Oil should be applied over the inner surface of the sampler for easy removal of the mould.

After casting first upper portion of the fractured sample as shown in figure 4.13, remove the sample after it dries up and gain some strength for its further test, put this into another sampler filled with fresh encapsulating material, care should be taken that there is at least 5mm space between upper and lower portion (ASTM D5607) so that encapsulating do not take the normal or shear load as it is there only for distribution of load, not to take the load. If 5mm gap is not given there can be discrepancy in the test results. After completely drying, remove the samples by rotating the screw given in figure 4.13. It should be noted that encapsulating material completely dries up and gains some strength so that there is no sign of bulging or change in shape of the hardened encapsulating material, otherwise it will not fit into the field shear strength test apparatus.

Fig 4.12-Sampler used for preparation of samples for field shear test (Rock lab, DTU)

Fig 4.13-preparation of samples for field shear test for intact rock core specimen shearing along the bedding planes (Rock lab, DTU)

Fig 4.14- Testing the sample in field shear apparatus(Rock lab, DTU)

A field shear strength test apparatus is shown in figure 4.14, it can be seen that there are two hydraulic jacks. One hydraulic jack is for application of normal load and other hydraulic jack is application shear load. When sample is prepared as illustrated in fig 4.13 and encapsulating material gains sufficient strength so that it does not fails before the failure of specimen itself. It is loaded into the field shear strength test apparatus as illustrated in figure 4.14. First normal load is applied over the specimen by tightening the screw of hydraulic jack so that sample remain in position and after this shear loading is applied over the specimen to obtain the value of friction failure due to sliding of fractured surface and shearing of asperities.

Sample loaded at bedding plane bedding plane being parallel to the shear component of loading direction have a single fractured surface and thus sample is further used for testing in field shear strength test apparatus for friction failure due to sliding of fractured surfaces. Sample is mounted as per the arrangement shown in figure 4.11 and first normal load is applied over the sample equal to 1KN. Now loading is applied in predetermined failure plane, in our case is the fractured surface and the load at failure is recorded, which is equal to 45.8KN. Shear stress is calculated as ratio of shear load at failure to the fractured surface area. This comes out to be equal to 15.71MPa.

Though it should be considered that there are some errors in the value of shear stress as fractured surface is irregular and have slightly different area on which shear load acts. Error due to parallax should also be avoided.

5. Conclusion

1) By looking at the physical properties of the rock material, it can be concluded that it is highly durable stone and have lower values of water absorption and porosity. Thus it works very well as a building material.
2) By analyzing the results from brazilian tensile strength tests, it can be concluded that bedding planes significantly affect the strength of rock material, there is tensile splitting along the bedding planes when component of tensile stress over the bedding planes increases more than its tensile strength.
3) There is accumulation of strain energy in the rock material, thus when sample is at verge of failure, there is a sudden burst in the sample and fractured area is much wider than the theoretically proposed fractured surface.
4) In oblique shear test there is tensile splitting along the bedding planes when sample is loaded at bedding plane being perpendicular to the shear component of the load. This type of failure occurs because tensile stress due to normal component of loading exceeding the tensile strength of rock material.
5) Shear strength in field shear strength test is because of friction failure due to sliding of fractured surfaces.

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