STUDY OF COMPRESSIVE STRENGTH OF JOINTED ROCKMASS

A PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

in

Civil Engineering

By

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Devi Prasad Mishra(10301035)

Department of Civil Engineering

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Under the Guidance of

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CERTIFICATE

This is to certify that the thesis entitled, "STUDY OF COMPRESSIVE STRENGTH OF JOINTED ROCKMASS" submitted by Sri Supriy and Sri Devi Prasad Mishra in partial fulfillment the requirements for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

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CONTENTS

ABSTRACT

Rock masses are hardly present in intact state in nature but are most commonly found in jointed form. In-situ test for determining the behaviour of jointed rock mass is costly and time consuming, hence attempts are being made by researchers to predict the strength and deformation behaviour of jointed rock masses under controlled laboratory conditions.

Considering its implications experimental study has been undertaken for determining strength characteristics of jointed rock mass. Models have been prepared using plaster of paris and different degree of anisotropy have been induced by inducing joints in them at orientation (β) varying from 0° to 90°.

The parameters studied are-

i) Variation of compressive strength ratio (σ_{cr}= σ_{cj} /σ_{ci}) of Plaster of Paris under unconfined conditions with joint factor.

ii) Variation of jointed cohesion (Cj), friction angle Φj and roughness parameters r=tanΦj.

where,

σ_{cj} =Uniaxial compressive strength for intact mass.

σ_{cj} =Uniaxial compressive strength for jointed mass.

n= Inclination parameter

r= Joint strength

The values for cohesion Cj for jointed specimen of Plaster of Paris was found to be 0.16 MPa and the value of friction angle Φj was found to be 39°. Hence the roughness parameter (r= tan Φj) comes out to be **.809** for the specimen of Plaster of Paris tested.

The optimum value of uniaxial compressive strength (σ_{ci}) evaluated from the above test was found to be 11.00 MPa.

Comparison also has to be made between the observed experimental values and the empirical relations given by various researchers previously.

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Chapter 1

GENERAL INTRODUCTION

INTRODUCTION

Natural geological conditions are very complex. Especially in India the geology of Himalayas is very complex. The rapid developmental effort has made suitable sites for construction of dams, reservoirs, tunnels, underground powerhouses, defense structures and many other structures. Higher dams and deeper underground excavation works are posing unique challenges to geotechnical engineers.

In general rock mass is an anisotropic and discontinuous medium having cracks, fissures, joints faults and bedding planes with varying strength along these discontinuities make the rock mass weaker, more deformable and highly anisotropic. Foundation on joined rock mass may settle beyond permissible limits. Dams underlain by discontinuous rock may undergo rotation and slip as a result of sliding of sliding of rock blocks along one or more planes of weakness. Water seepage under dams can cause energy loss and erosion of dam core. Water leakage into tunnel with lowering of the water table and consolidation settlement of clay layers as result can cause damage to the structure on surface.

The shear strength of a jointed rock mass depends on the type and origin of the discontinuity, roughness, depth of weathering and on the presence and type of filling material. The strength behaviour of rock mass depends on both intact rock properties and properties of discontinuities.

The strength and deformation response of a jointed rock depends on several factors as follows-

i) The angle made by the joints with the principal stress direction (β).
ii) The degree of joint separation.
iii) Opening of the joints.
iv) Number of joints in a given direction.
v) Strength along joint.
vi) Joint frequency.
vii) Joint roughness.

The present study aims to link the ratio of the intact and jointed strength with joint factor J_f and other factors.

Chapter 2

LITERATURE REVIEW

Rocks and their properties:

A better definition of rock may be given as granular, allotropic , heterogeneous technical substance which occur naturally and which are composed of grains, cemented together by mechanical bond, but ultimately by atomic, ionic and molecular bond within the grains Thus by "rock' as an engineer means a firm and coherent substance which normally can't be excavated by manual methods alone. Thus like any other material a rock is frequently assumed to lx homogeneous and isotropic but in most cases it is not so.

A homogeneous substance is one in which a small element has the same property as that of whole substances and a heterogeneous substance has different properties of the element within the body .An isotropic material is one that has the same property in every direction at any point. Based on the mode of origin rocks are classified into three groups such as igneous, sedimentary and metamorphic rocks .Igneous rocks are those rocks which are formed by the solidification of molten magma originating in the interior of the earth. When a rock or earth crust is weathered or decomposed and transported or deposited and subsequently consolidated and cemented partly or fully then the new products is known as sedimentary rock .Igneous rock which are formed at depth are known as igneous rocks and formed from lava and found mainly at the surface, are known as volcanic igneous rock. Information regarding the type of rock such as igneous, sedimentary or metamorphic is not sufficient when an engineering structure will be made on the rock mass. The rock may be igneous one, but it may consist of a lot of discontinuous in the mass which may make it unable to withstand high stress as due to structure.

Rock and rock mass:

An intact rock is considered to be an aggregate of mineral, without any structural defects and also such rocks arc treated as isotropic, homogeneous and continuous. Their failures can be classified as brittle which implies a sudden reduction in strength when a limiting stress is exceeded.

Intact Rock mass:

Strength of intact rock mass

Strength of intact rock mass is influenced by the following factors

(1) Geological

(2) Lithological

(3) Physical

(4) Mechanical

(5) Environmental factors

When rock is on the earth surface there is no conforming pressure. If the rock mass is present below the earth surface, conforming pressure on the strength of the rock has investigated extensively. Various investigations have been conducted to study the influence of conforming pressures show a non-linear variation of the strength with conforming pressures. In important aspect of rock behaviour under uniaxial condition is the change in behaviour from brittle to ductile nature at the conforming pressures.

Uniaxial Compressive Strength:

The uniaxial compressive strength of rock mass is represented in a non-dimensional form as the ratio of compressive strength of jointed rock to that of intact rock . The uniaxial compressive strength ratio is expressed as

$$\sigma_{cr} = \sigma_{cj}/\sigma_{ci}$$

where σ_{cj}= uniaxial compressive strength of jointed rock and σ_{ci}= uniaxial strength of intact rock. The uniaxial compressive strength ratio of the experiment data should be plotted against the joint factor. The joint factor for the experimental specimens should be estimated based on the joint orientation, joint strength and joint spacing. Based on the statistical analysis of the data, empirical relationship for the uniaxial compressive strength ratio as a function of a joint factor (J_f) is derived.

Elastic Modulus

Elastic modulus is expressed as the tangent modulus at 50% of the failure stress considered in this analysis. The elastic modulus ratio expressed as

$$Er = Ej/Ei$$

Where Ej is the tangent modulus of joined rock

Ei is the tangent modulus of intact rock.

Strength criterion of Anisotropic Rocks

Unlike isotropic rocks, the strength criteria of anisotropic rocks are more complicated because of variation in i the orientation angle β. A number of empirical strength criteria have been proposed in the recent past based on the classical Navier-Columb and Griffith's criteria.

An idealized cylindrical specimen of anisotropic rock with an oblique plane weakness making an angle β with the axis of major principal stress σ_1 .The angle β is designated as the orientation angle.

Hock and Brown (1980) showed clearly that strength of all rock is maximum for $\beta=0$ to 90^o and is minimum for $\beta=20$ to 30^o.

Influence of single plane of weakness:

In a laboratory test the orientation of plane weakness with respect to principal stress direction remains unaltered. Variation of the orientation of this plane can only be achieved by obtaining cores of direction. In a field situation either in foundations of darn around underground or open excavation the orientation of joint system remains stationary but the direction of the principal stress rotates resulting in a change in the strength of the rock mass.

Chapter 3

LABORATORY INVESTIGATION

Laboratory Testing:

In this chapter the experimental investigation has been carried out to determine the shear the shear strength of the rock joints are presented through sections, model testing parameter studies, experimental setup and experimental study.

Material Tested:

Researches have been conducted on model materials so as to get uniform, identical or homogeneous specimen in order 10 understand the failure mechanism, strength behavior. It is observed that the use of plaster of Paris has been used as model material to simulate weak rock mass in the field. Many researchers have used plaster of Paris as a model because of its ease in casting, flexibility, instant hardening, low cost and easy availability. Any type of joint can he modeled by plaster of Paris. The reduced strength in relation to actual rocks has made plaster of Paris one of the ideal materials for modeling in Geotechnical Engineering.

Preparation of Specimen:

Commercially available plaster of Parts from local market has been procured. This plaster of Paris powder produced by pulverizing partially burnt Gypsum is dull white in colour with smooth feel of cement. T he water content, at which maximum density is to be arrived, is found out by conducting number of trial tests at different percentage of water.

Fur the preparation of specimen 135 gm of plaster of Paris is mixed thoroughly with optimum moisture content of water to form a uniform paste. The plaster of Paris specimen prepared by pouring the plaster mix in the mould is vibrated in the vibrating machine for 2 minute for proper compaction and to avoid presence of air saps. After this
it is allowed to set for five minutes. After hardening the specimen is kept at room temperature of 48 hours.

Curing:

After keeping in the sunlight and oven the specimens were placed inside desiccators containing concentrated Sulphuric Acid. This is done to maintain the relative humidity in the range of 40 to 60%. This humidity is maintained constant in desiccators by keeping a solution of concentrated Sulphuric Acid of 47.7 cc with distilled water of 52.3cc. Specimen were allowed to cure inside the desiccators till constant weight to be attained (about 15 days)

Introduction of Anisotropy:

In the rock mass joints planes may be oriented in different directions with respect to the stress field and this may vary from place to place. To, investigate these aspects in this study single plane of weakness and its inclination with respect to major principal stress direction has been considered.

31 .5Making Joints in Specimens:

The following instruments are used for making joints in the plaster of Paris

1) ‘V’ Block

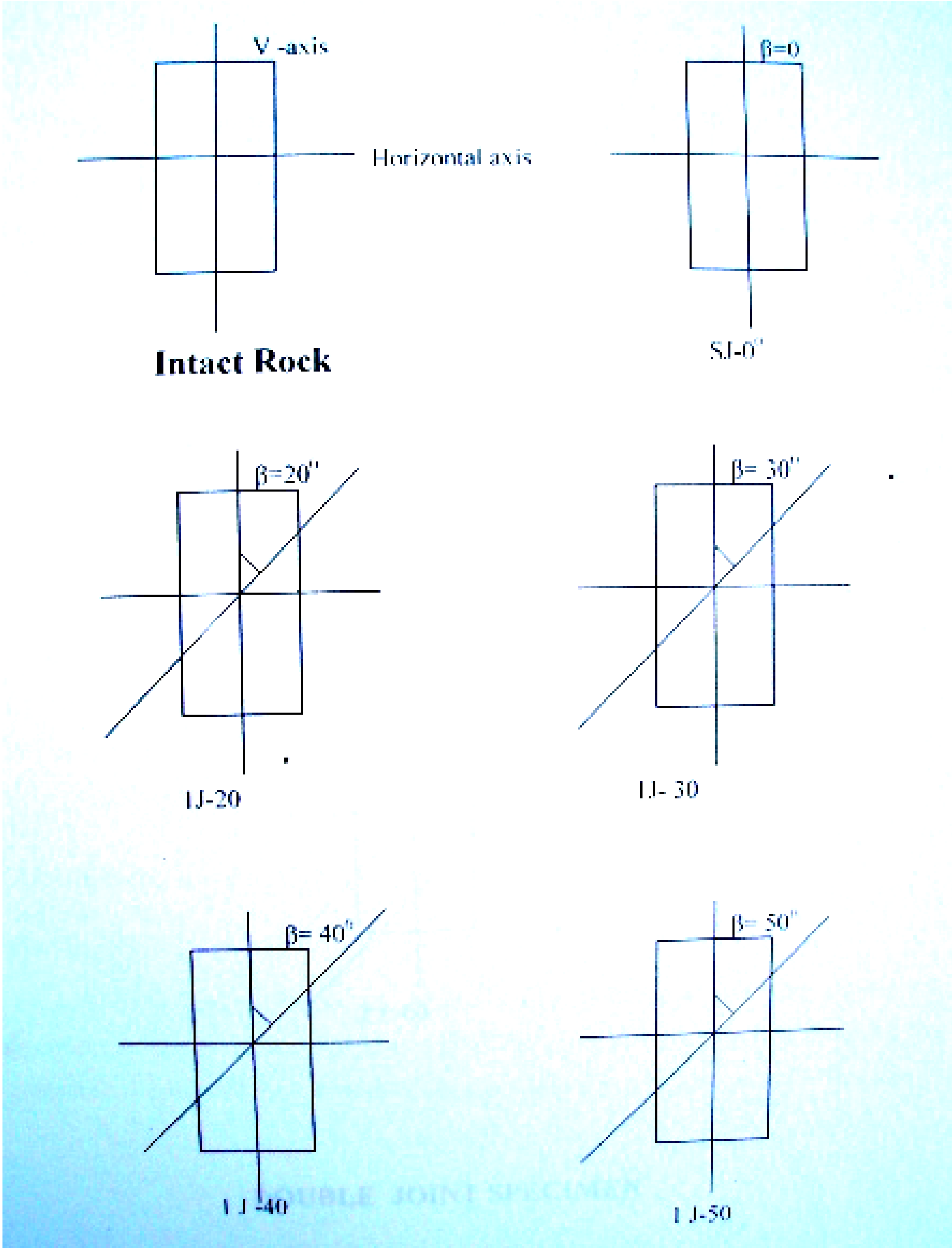
2) Light weight Hammer

3) Chisel

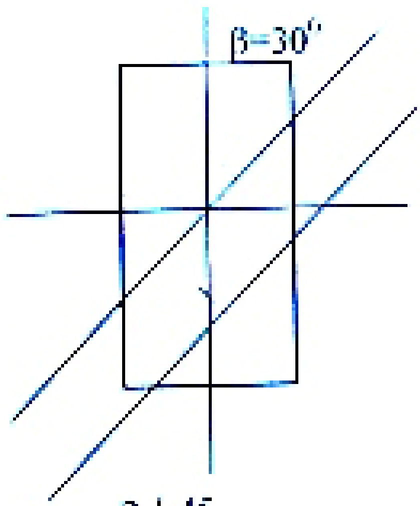
4) Scale

5) Pencil

6) Protractor



Single Joint Specimen



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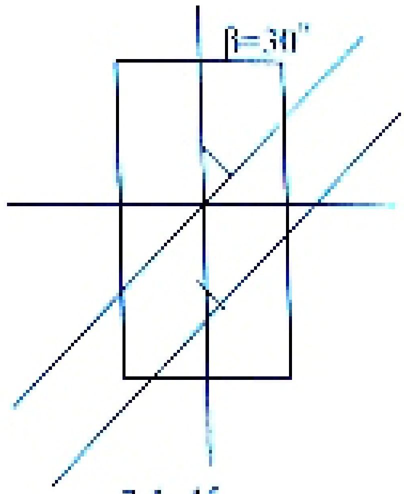

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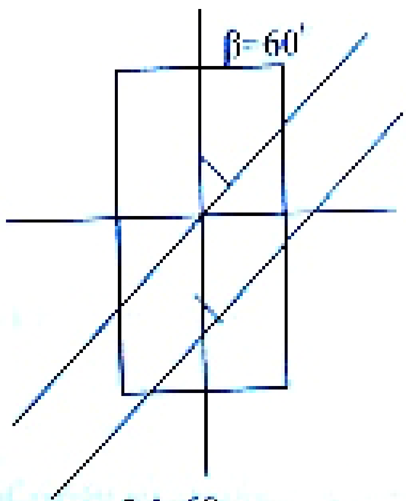


2 J -60

Double Joint Specimen

Chapter 4

RESULTS AND DISCUSSION

Result and Discussions

The strength characteristics of intact and jointed specimen of plaster of Paris has been presented and discussed. The experimental finding has been compared with the empirical relationship suggested by Arora (1987). The findings of laboratory tests conducted under unconfined conditions have been extended to predict the strength of jointed mass.

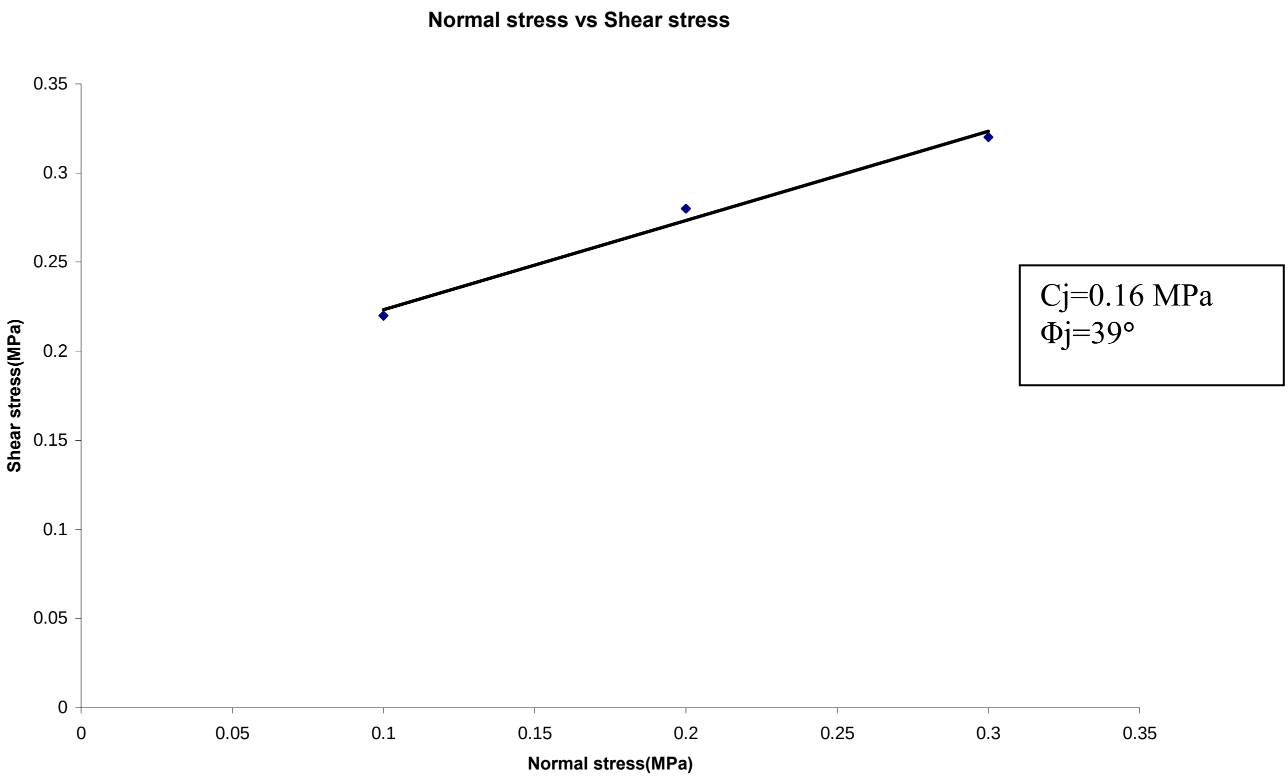
Roughness Parameter

Shear test was conducted at different normal stresses. The value of shear stress for different values of normal stress on jointed specimen of Plaster of Paris in direct shear test is given below:

Table 3.1

Normal stress(MPa)	0.1	0.2	0.3
Shear stress(MPa)	0.22	0.28	0.32

Fig. 3.1



The values for cohesion Cj for jointed specimen of Plaster of Paris was found to be 0.16 MPa and the value of friction angle Φj was found to be 39°. Hence the roughness parameter (r= tan Φj) comes out to be **.809** for the specimen of Plaster of Paris tested.

Uniaxial Compression Test Results:

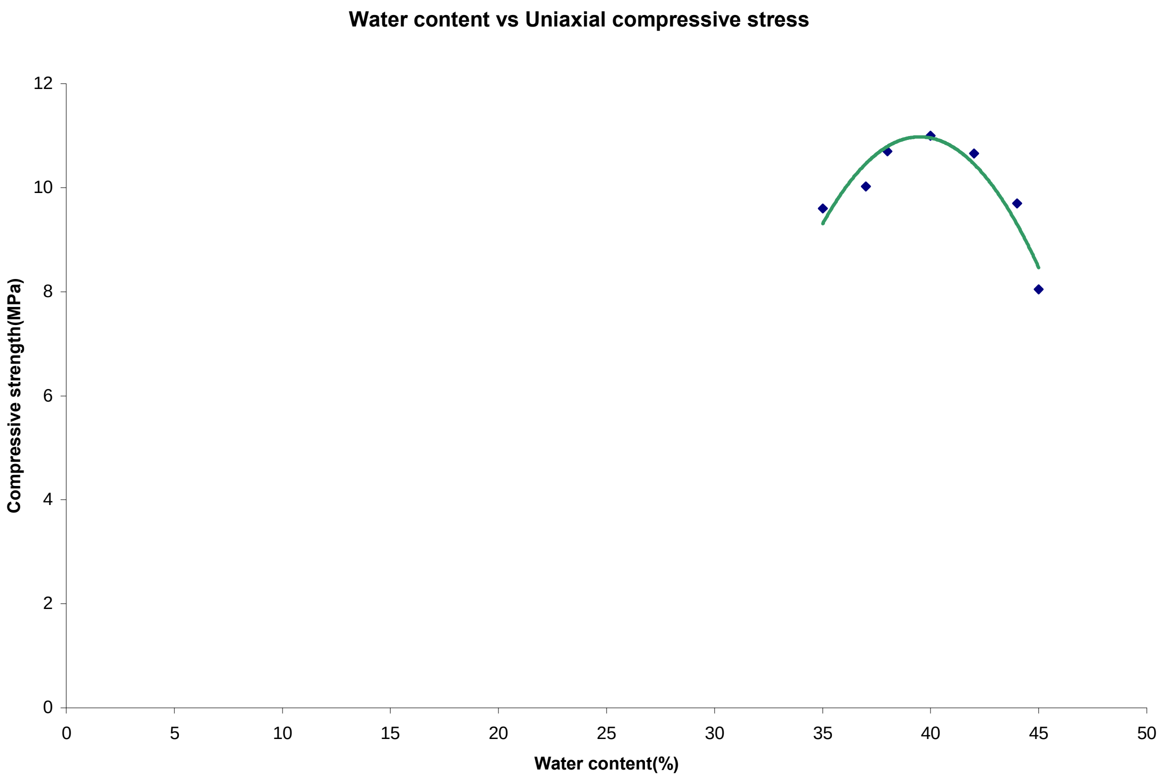
Intact Specimen

The variation of stress as obtained in uniaxial compression test for the intact specimen of Plaster of Paris for different values of water content is illustrated below:

Table 3.2

Water content (%)	35	37	38	40	42	44	45
Uniaxial Compressive Strength(MPa)	9.60	10.02	10.70	11.00	10.66	9.70	8.05

Fig 3.2



The optimum value of uniaxial compressive strength (σ_{ci}) evaluated from the above test was found to be 11.00 MPa.

Jointed Specimen

The uniaxial compressive strength for jointed specimen (σ_{cj}) is evaluated .After obtaining the values of σ_{cj} it was observed that the strength of Plaster of Paris was minimum for orientation angle β=30°. The values of σ_{cr} with different joint orientation angles (β) were obtained by using the relationship:

$$\sigma_{cr} = \sigma_{cj} / \sigma_{ci}$$

The value of joint factor (J_f) has been evaluated by using the relationship:

$$J_f = J_n/(n.r)$$

Arora(1987) has suggested the following empirical relationship between J_f and σ_{cr} :

$$\sigma_{cr} = e^{-.008 J_f}$$

The variation between σ_{cr} and J_f is illustrated for single joints. Also a comparative study of the experimental tests and the empirical relationship given by Arora is provided.

Table 3.3

Joint type in degrees	J_n	n	r= tan Φj	$J_f = J_n/(n.r)$	σ_{cj} (MPa)	σ_{ci} (MPa)	$\sigma_{cr} = \sigma_{cj} / \sigma_{ci}$
0	13	0.81	0.809	19.83	9.23	11.00	0.83
10	13	0.46	0.809	34.93	8.85	11.00	0.80
20	13	0.105	0.809	153.04	4.30	11.00	0.39
30	13	0.046	0.809	349.33	3.24	11.00	0.29
40	13	0.071	0.809	226.32	4.65	11.00	0.42
50	13	0.306	0.809	52.51	7.32	11.00	0.66
60	13	0.465	0.809	34.55	8.33	11.00	0.75
70	13	0.634	0.809	25.34	8.98	11.00	0.81
80	13	0.814	0.809	19.74	9.54	11.00	0.86
90	13	1.00	0.809	16.06	10.12	11.00	0.92

It is clear that for β increasing from 0º to 90° the value of σ_{cr} goes on decreasing and attains a minimum at β=30° and then increases again to attain a maximum value at β=90º.

Fig 3.3

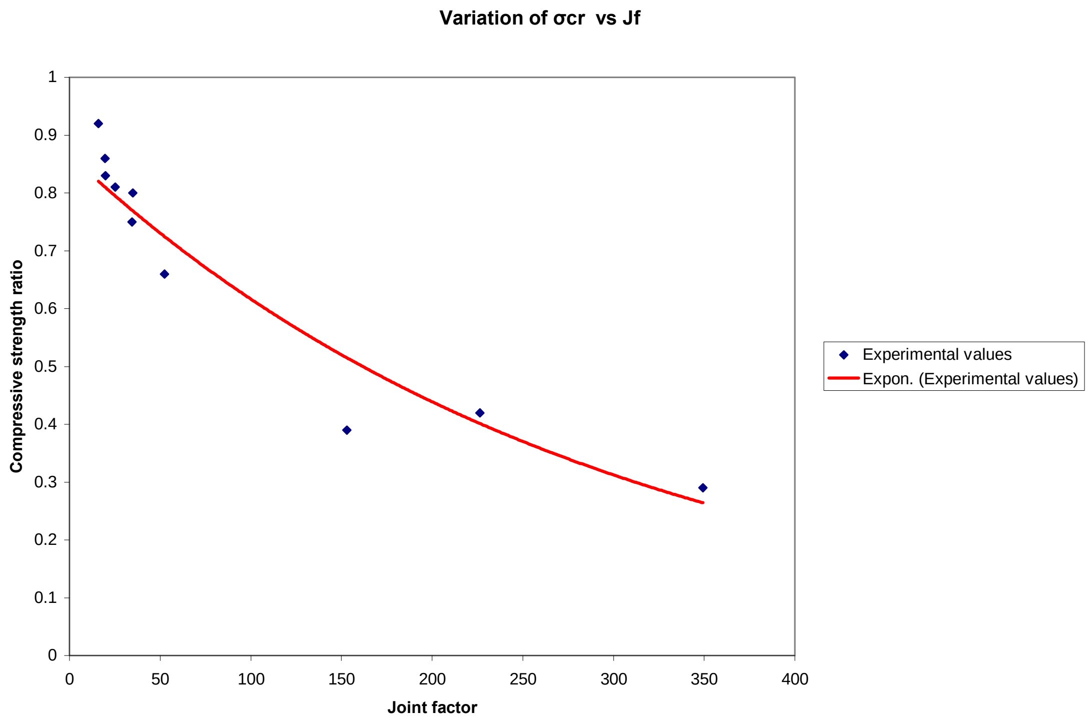

Variation of σcr vs Jf
Compressive strength ratio
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
Joint factor
Experimental values
Expon. (Experimental values)

Fig 3.4

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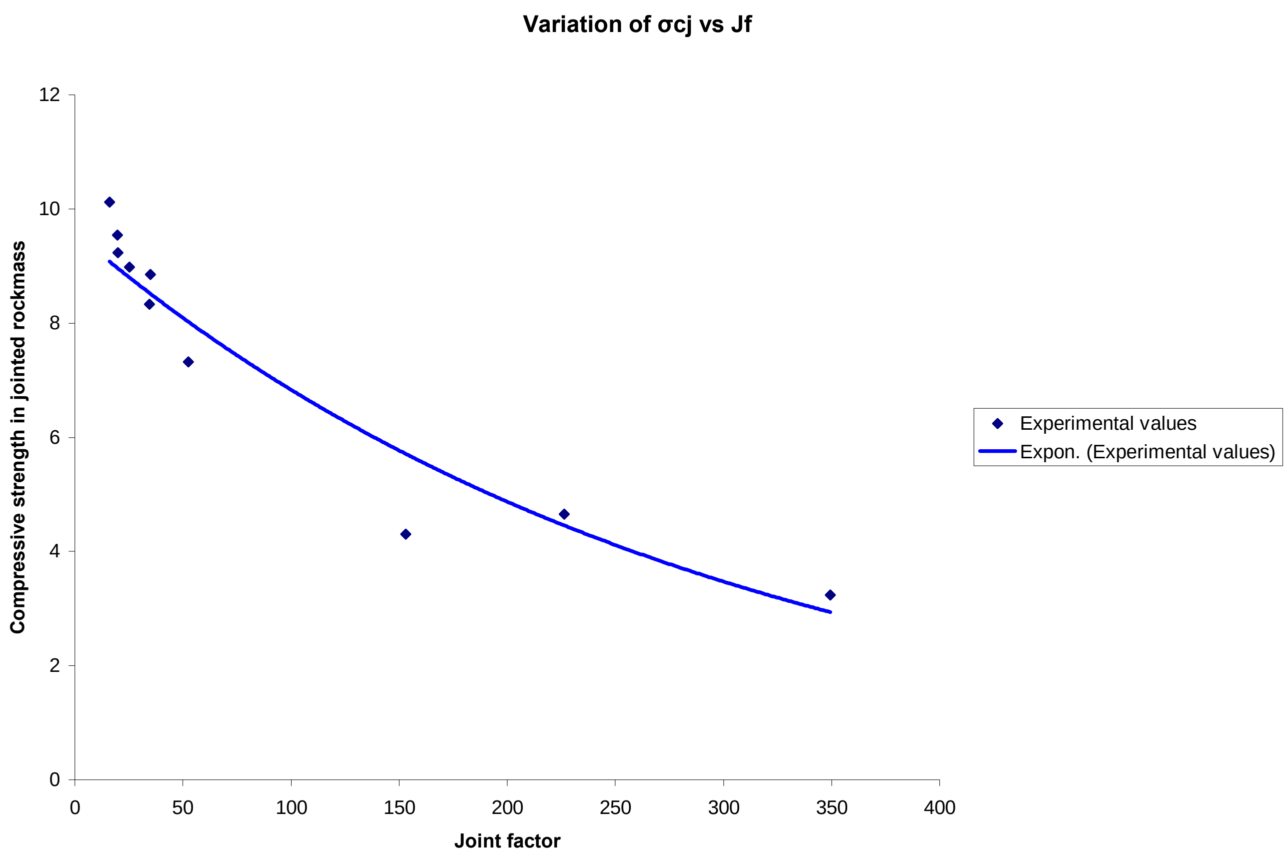
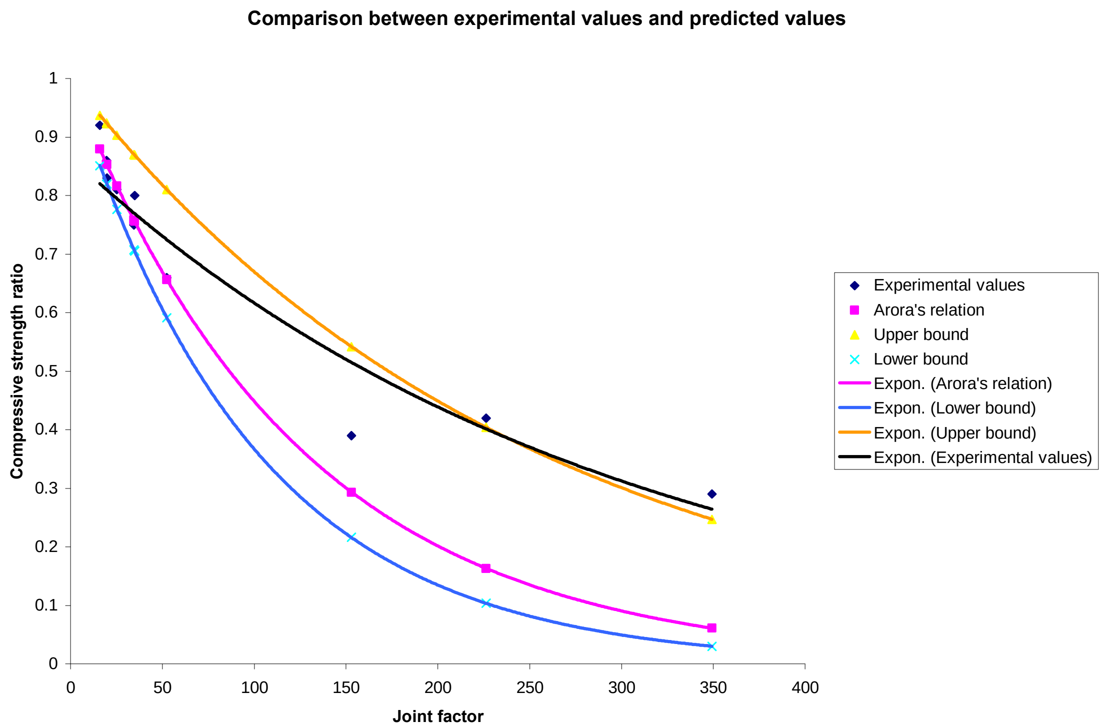

Variation of σcj vs Jf
Compressive strength in jointed rockmass
12
10
8
6
4
2
0
0
50
100
150
200
250
300
350
400
Joint factor
Experimental values
Expon. (Experimental values)

Comparison also has to be made between the observed experimental values and the empirical relations given by various researchers previously. Hence the experimental values of σ_{cr} vs J_f is compared with Arora's empirical relation and also with values given by Yaji's(1984), Einstein and Hirschfeld(1973), Brown (1970) and Roy(1993).

Table 3.4

Joint type in degrees	$J_f=J_n/(n.r)$	$\sigma_{cr}= \sigma_{cj} /\sigma_{ci}$	Arora's empirical relation $\sigma_{cr}=e^{-.008J_f}$	Upper bound $\sigma_{cr}=e^{-.004J_f}$	Lower bound $\sigma_{cr}=e^{-.01J_f}$
0	19.83	0.83	.853	.923	.820
10	34.93	0.80	.756	.869	.705
20	153.04	0.39	.293	.542	.216
30	349.33	0.29	.061	.247	.030
40	226.32	0.42	.163	.404	.104
50	52.51	0.66	.656	.810	.591
60	34.55	0.75	.758	.870	.707
70	25.34	0.81	.816	.903	.776
80	19.74	0.86	.853	.924	.820
90	16.06	0.92	.879	.937	.851

Fig. 3.5



Chapter 5

CONCLUSIONS

Conclusions

From the experimental analysis of the intact and jointed specimen of plaster of Paris the following conclusions are drawn:

1) The uniaxial compressive strength of intact specimen of Plaster of Paris is found to be 11.00 MPa.

2) The strength of jointed specimen depends on the joint orientation β with respect to the direction of major principal stress. The strength at $\beta=30^\circ$ is found to be minimum and the strength at $\beta=90^\circ$ is found to be maximum.

Scope of future work:

1) The effect of temperature, confining pressure and rate of loading on the strength characteristics can be studied.
2) The change in strength can be studied by introducing gouge in the joints.
3) Studies can be made by introducing multiple joints in varying orientation.

On the basis of above investigation one can find out the values of uniaxial compressive stress of jointed rock mass without conducting extensive tests in the field but by a few simple laboratory experiments.

It can also be possible to find out the values of σ_{cj} for different rock mass by conducting simple laboratory tests. For this we have to take a photograph of the rock mass by remote sensing or aerial photography and from that we can find out the nature of the joint and hence the values of σ_{cj} can be predicted.

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