STUDY OF SHEAR STRENGTH CHARACTERISTICS OF GROUTED MODELLED ROCK

A DISSERTATION
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE
OF

MASTERS OF TECHNOLOGY
IN
GEOTECHNICAL ENGINEERING

Submitted by

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CANDIDATE'S DECLARATION

I **KOMAL SINGH** (2K23/GTE/02) hereby certify that the work which is being presented in the thesis entitled **"STUDY OF SHEAR STRENGTH CHARACTERISTICS OF GROUTED MODELLED ROCK"** in partial fulfillment of the requirements for the award of the Masters of Technology, submitted in the **Department of Civil Engineering**, Delhi Technological University is an authentic record of my own work carried out during the period from January 2025 to May 2025 under the supervision of **Prof ANIL KUMAR SAHU**.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

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CERTIFICATE BY THE SUPERVISOR

Certified that **KOMAL SINGH (2K23/GTE/02)** has carried out their search work presented in this thesis entitled **"Study of shear strength characteristics of grouted modelled rock"** for the award of **Master of Technology from Department of Civil Engineering**, Delhi Technological University, Delhi, under my supervision. The thesis embodies results of original work, and studies are carried out by the student herself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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ABSTRACT

Grouting is the widely used technique for compacting, stabilizing and strengthening weak soils and fractured rock masses. Although various studies have investigated grouting techniques and materials, several admixtures remain unexplored. This study investigates the effectiveness of cement – Dr. Fixit Pidiproof LW+ as a grout material for strengthening the fractured rock at different angles.

Modelled rock was prepared using a poorly graded sand collected from Delhi Technological Campus, stabilized with ordinary Portland cement (OPC) of grade 43, cylindrical samples were cast with dimensions of diameter 50mm and height 100mm, considered as standard sample. Artificial fractures were created in the standard samples by splitting the entire sample into two parts at mid depth at different angles including $0°, 30°, 45°, 60°, 90°$ considered as a fractured rock, three specimens were prepared for each angle. A 1mm thick cement-Pidiproof by weight mix was applied in the fractured rock referred to as fractured – grouted rock. Samples were left to dry for 24 hrs then placed in a tank for curing up to 28 days in normal water. After 28 days the samples were tested in unconfined compressive strength (UCS) test.

This study reveals the effectiveness of "Dr. Fixit Pidiproof LW+" as a grout material to enhance the strength of fractured rock, it showed the 45° fractured – grouted rock exhibited the maximum strength while 0° rock exhibited the lowest strength. This helps in optimizing grouting techniques for geotechnical applications and provides insights into the mechanical behaviour of grouted soils.

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Last but not least, I send my familiarization to the family for all the overriding affection, care, and patience as well as their strength. Their expectations for me have been useful most of the time and at critical periods of this journey.

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List of Abbreviations

OPC – ordinary Portland Cement

UCS – unconfined Compressive Strength

IS – Indian standards

OMC – optimum moisture content

SP – PL – Poorly graded sand with low plasticity

E - Modulus of Elasticity

% - percentage

CHAPTER – 1

INTRODUCTION

1.1 General

In rock masses presence of cracks, fissures and joints leads to reduction in strength and overall stability of the rock masses. To overcome these grouting is one of the most commonly used technique. Injection of grout material in the rock enhances the strength of the rock and prevents failure to some extent. Grouts consist of binder, such as cement, polymers mixed with water and other additives to achieve the desired strength or properties. It reduces the permeability, increases strength and stabilizes the soil or rock masses.

- **Various methods of grouting:**
  - (i) Permeation Grouting
  - (ii) Compaction Grouting
  - (iii) Rock/fissure Grouting
  - (iv) Jet grouting, and many more

  This study uses the **Rock/Fissures grouting** to fill the gaps of artificial fractures created in the modelled rock.

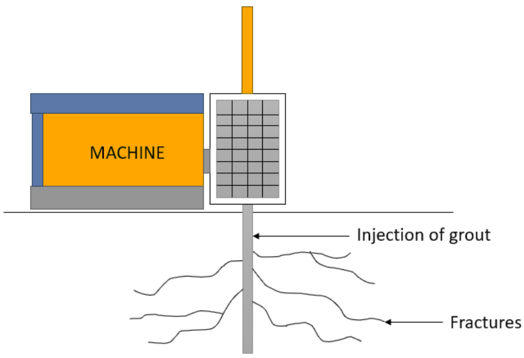


Fig 1.1: Rock/Fissure Grouting

- **Various types of grouts:**

  Various Grout were used depending the type of soil and desired property

(i) Cement based grouts

(ii) Epoxy grouts

(iii) Polymer based grouts (eg, Acrylic, polyester, furan grouts)

(iv) Other types (eg, chemical based, resin based, bentonite based)

- In this study **Cement – Dr Fixit Pidiproof LW+** mix as a grout material, which is cement based grout.
- Despite of wide use of grouting in tunneling, ground improvement, and many more, still various were left unexplored.
- **Dr. Fixit Pidiproof LW+** is adopted for the study, being widely used for strengthening, decreasing permeability and waterproofing can be a great material when mixed with cement,
- **The objectives of this study are:**

(i) Varying the angle of injection of grout material

(ii) To study shear strength characteristics of modelled rock

Concluding Remarks:

This chapter concludes the type of grouting method and the type of grout material adopted for the study, objective has been stated, further studies will be done to find out the efficiency of the Pidiproof as a grout material.

CHAPTER – 2

LITERATURE REVIEW

Deng, C., Li, L, etal (2025)

This research explores how magnetized water influences the properties of cement-based grouting materials. The study assesses parameters such as fluidity, setting time, and compressive strength when magnetized water is used in the grout mix. Findings reveal that magnetized water can improve the fluidity and early strength development of the grout, suggesting potential benefits for construction practices requiring efficient grouting solutions

Liao, C., Lin, B., etal (2024)

This paper shows the effect of Graphene oxide and fly ash on cementitious grout material was studied. On the basis of flowability, setting time, bleeding rate, performance tests including compressive strength, flexural strength test was performed. The 28 days strength of GO-FA paste was higher than pure cement hardened paste.

Qin, Xiangrui, et al. (2024)

The paper presents the behavior of grouted rock masses during failure by studying their mesostructure and macroscopic behavior. Through experiments the research studies the variation of strength and deformation on the interaction of grout materials with rock masses. The results show the impact of grout in improving the structural stability of fractured rock. These results helped in understanding the effectiveness of grout in rock stabilization and prevention of failure in engineering applications.

Zhang, Lianzhen, et al. (2024)

The paper presents the influence of slurry with water in the fractures and how it affected the grout efficiency and distribution. This study helps in understanding the importance of slurry viscosity, fracture geometry, and injection pressure affecting the grout penetration.

Zhang, Junwen, et al. (2024)

The research reveals the mechanical properties, flowability, and setting behavior of cementitious grouts under different conditions to determine their suitability for reinforcing fractured rock environments. Results showed that the selection of grout composition, including water-to-cement ratio and additives, significantly affects the grout performance in terms of penetration, strength, and durability. The study also focusses on the problems such as void filling and load redistribution in broken rock masses, identifying the effectiveness of cement-based grouts for improving safety and stability in coal mining operations.

Yalei, Z., Kepeng, H, etal (2024)

This study showed the mechanisms of grout diffusion and plugging within these rocks, with a particular emphasis on how time-varying yield stress and viscosity characteristics of the grout influence the process. The study develops a model that considers for these properties for better understanding how grout pressure and grout characteristics impact sealing effectiveness. This research gives valuable results in optimizing grouting techniques for complex jointed rock masses, where the diffusion behavior and mechanical properties of grout play a significant role in achieving stable sealing and enhancing the effectiveness of ground improvement methods.

Zhe, Y., Hou, K., etal (2024)

The research shows the variation of grout performance on yield stress with time, whose impact depends on its interaction with fractures and joints in the rock. The authors propose a model that incorporates the changing yield stress of grout over time, providing a more accurate representation of grout diffusion and flow in difficuilt geological environment. This study helps in understanding of grout behavior in dynamic environments, showing how varying grout viscosity and yield stress can influence the effectiveness of grouting for sealing and stabilizing rock formations.

Pengshuai, W., Zhengsheng, etal (2024)

This paper presents the plugging performance of grout slurry containing significant amounts of fly ash. By orthogonal testing and numerical simulations, the research shows how varying fly ash content affects the mechanical properties of the grout. The findings suggest that incorporating fly ash can enhance the plugging efficiency and mechanical strength of the grout, giving a cost-effective and environmentally friendly alternative for construction applications.

Li, Tan, et al. (2023)

The research is on optimizing the composition and properties of the grout and how it enhances its mechanical strength, flowability, and bonding capability. Experimental findings show that the improved grout gives better penetration and filling efficiency, making it suitable for complex fractured rock masses. Also, the material exhibits high strength and durability, effectively reducing deformation and enhancing the stability of broken surrounding rock masses.

Ruan, W., Liao, etal (2023)

The research finds the material's mechanical properties, flowability, and bonding mechanism with coal rock. Results revealed that red mud improves the grouts performance by enhancing its strength and durability while maintaining good flowability. The bonding mechanism analysis reveals strong interfacial adhesion between the grout and coal rock, providing strong reinforcement. This study highlights the potential of utilizing red mud for sustainable and efficient grouting applications in mining and underground engineering.

Zhu, Xianxiang, et al. (2023)

This research presents the diffusion mechanisms of solid waste product utilization in fracture network grouting. The study finds the behavior of grout materials such as solid waste when they penetrate and stabilize fracture networks. Results reveal that the material showed efficient diffusion and filling capabilities, significantly enhancing the stability and load-bearing properties of fractured rock. The study focuses the environmental benefits and engineering potential of using solid waste-derived grouts for sustainable geotechnical applications.

Shu, Benan, et al. (2021)

The study focuses on the performance and engineering applications of grouting materials with high quantity of solid waste. The research evaluates the mechanical, flowability, and environmental properties of these grouts to determine their suitability for large-scale construction projects. Results show that grouts with high solid waste content maintain efficient performance while promoting sustainability by reducing environmental impacts.

Field applications demonstrate the material's effectiveness in soil stabilization and structural reinforcement. This work supports the integration of waste materials into grouting practices, aligning with sustainable construction goals.

Wang, Xiaochen, et al. (2021)

This paper shows the grouting behavior in rock fissures with rough surfaces using a designed apparatus for experimental testing. The research showed the grout flow behavior, penetration depth, and mechanical reinforcement effects under various conditions. Results indicate that fracture surface roughness, grout viscosity, and injection pressure significantly affect grout distribution and stabilization performance. The study gives the practical guidelines for optimizing grouting techniques in rock engineering, particularly for rough and irregular fractures.

Jiang, H., & Qiu, X. (2021).

This paper studied the effectiveness of cement slurry with varying ratios for stabilizing the dam foundations. It helped in enhancing the strength, durability, and overall behavior of the foundation when it is subjected to critical environmental and mechanical conditions. The study focuses to provide valuable contribution into the application of cement slurry in dam engineering, mainly in improving foundation stability in challenging environmental conditions.

Li, Z., Liu, H., etal (2020)

This paper presents the effects of grouting on rock fractures by using shear and seepage assessments. The study analyzes how grouting impacts the mechanical behavior of fractured rock. Results shows that grouting improves the shear strength and reduces seepage and improved the overall stability of the rock masses. The study reveals the importance of grout composition and injection techniques to achieve effective sealing in fractured rock formations. These findings are particularly beneficial for applications in tunneling and where fracture stability is critical.

Xu, Z., Liu, C, etal. (2019)

This paper presents the study of fissure grouting in rocks at greater depths. Experiments were conducted in finding the impact of grout penetration, distribution and its effectiveness in sealing gaps. The results revealed grouting pressure and viscosity along with that it also studies grout pattern and its mechanism in stabilization of deeper rocks.

This work helps in the design and optimization of grouting methods for improving structural integrity in underground construction.

Li, Shucai, et al. (2019)

This paper presents the development and practical application of a cementitious anti-washout grouting material used for difficuilt underwater or high-flow environments. The anti-washout properties of the grouts were attained by the addition of specific admixtures, which prevents grout dilution and loss during its application. Experimental and field tests showed how the material maintains its strength and cohesiveness under difficuilt water conditions, making it highly effective for sealing leaks and reinforcing structures in dams, tunnels, and other hydraulic engineering projects.

Zheng, J. (2018)

This paper studies the problems in detecting voids under semi-rigid road bases and finding the effectiveness of grouting. Using Ground Penetrating Radar (GPR), the research studies the characteristics of different void types (air-filled, water-filled, or grout-treated) and dimensions on GPR images. The results suggest methods for detecting voids, analyzing their sizes, and identifying grout effectiveness in road maintenance and repair.

Salimian, M. H., et al. (2017)

This paper presents how grouting affects the shear strength of rock masses under varying conditions. Experiments analyzed the effectiveness of grout in rough joints or high normal stresses This study revealed the role of grouting in optimizing the joints in various engineering applications in tunneling, mining and slope stabilization.

Pei, Jianzhong, et al. (2016)

This paper presents the effect of high – performance cement pastes for semi flexible pavements. It studies how paste flowability, setting time and its mechanical properties affects in pavement applications. Result showed material's crack resistance, durability and effectiveness for semi- flexible pavement systems.

Dayakar, P., Raman, etal (2012)

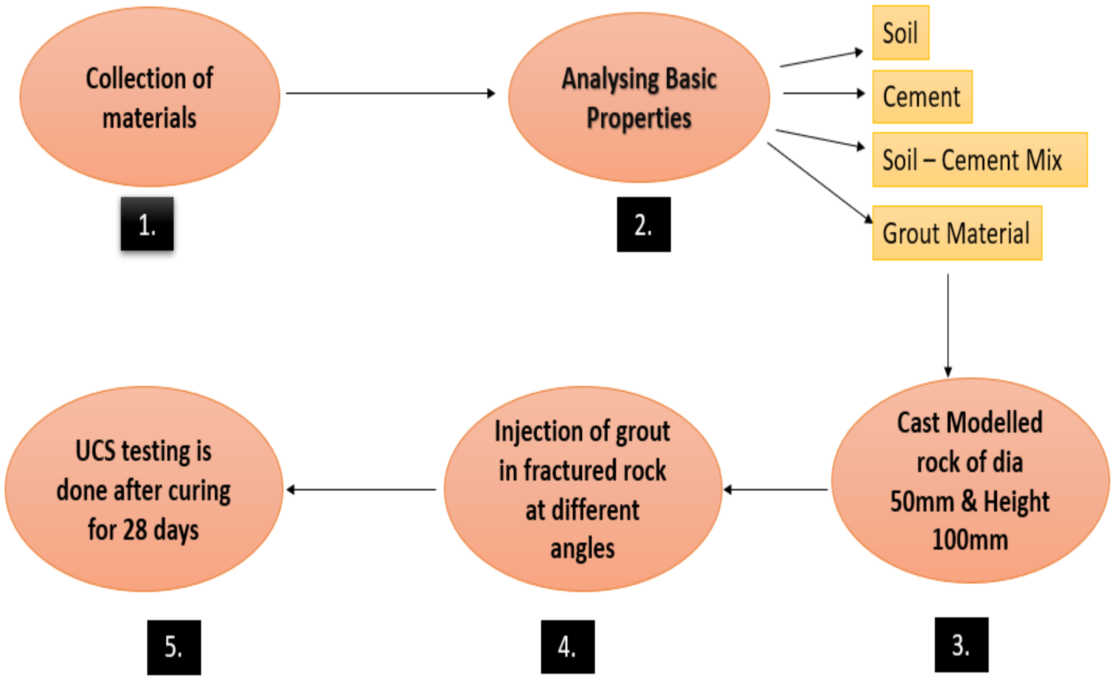
This paper presents the enhancement of bearing capacity of sandy soils by cement grouting. Experiments were conducted to evaluate how cement grout penetrates in sandy soils and how it affects its strength. The results showed that cement grouting enhance the load bearing capacity of sandy soils.

Concluding Remark:

The reviewed literature highlights significant advancements in grouting techniques, materials, and their applications for soil and rock stabilization. However, notable gaps exist in understanding the impact of injection angles and material composition on grout performance, which this study aims to address. This provides a critical foundation for optimizing grouting methods in geotechnical engineering.

CHAPTER - 3

METHODOLOGY



3.1 Collection of materials:

- Cement – Ordinary Portland Cement (OPC) Grade 43
- Water – free from impurities
- Soil – From DTU campus
- PVC pipes – 18 (dimensions: Dia 50mm, Length 100mm)
- Grout material – Dr. FixitPidiproof LW+

3.2 Analyzing basic properties:

3.2.1 TESTS ON SOIL

A. Specific gravity Using Pycnometer:

- Weight of empty pycnometer is taken as W_1
- Pour 200 gm dry soil in the above pycnometer, take its weight as W_2
- Pour water in above pycnometer up to the tip take its weight as W_3

- Now empty the pycnometer then add water, take its weight as W_4

Fig3.1: Pycnometer with soil and water

Table 1: Observations obtained from pycnometer

Sno	W1(gm)	W2(gm)	W3(gm)	W4(gm)
1.	688	886	1676	1556
2.	688	886	1672	1556
3.	688	888	1670	1556

- Specific Gravity (G) = $\frac{(W_2 - W_1)}{((W_4 - W_1)-(W_3 - W_2))}$…………………(3.1)

A. Sieve Analysis:

- Sieves as per IS code (sieve 10mm, 4.75mm, 2.36mm, 1.18mm, 600μ, 300μ, 150μ)
- The oven dried soil sample was passed through a series of IS sieve sizes arranged from bigger to smaller sieve sizes. Cumulative weight retained was noted:

Fig3.2: Sieve analysis of soil sample

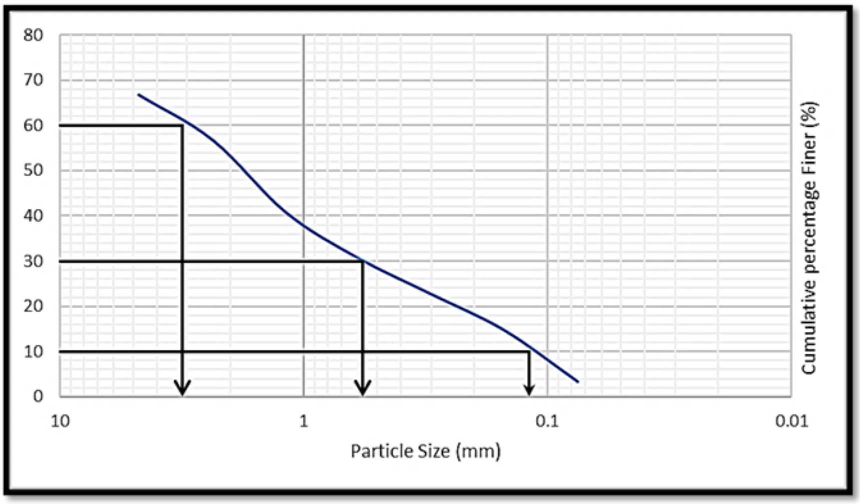


Fig3.3: PARTICLE SIZE DISTRIBUTION CURVE

Table2: values obtained from graph

D_{60}	3.155
D_{30}	0.574
D_{10}	0.110
C_U	26.50
C_C	0.879
% Fines	0.01

- Based on above data, it is poorly graded sand – SP
- $C_u > 6$, $C_c > 1$

C. Standard Proctor Test:

- **Optimum Moisture content:** is that amount of water in soil at which soil attains maximum dry density.
- **Maximum Dry Density:** Maximum dry unit weight is the unit weight at optimum moisture content.

Procedure

- 3kg oven dried sample is taken, soil passing through 4.75mm is taken, 25 number of blows in 3 layers with hammer weight 2.6kgs and 305mm height.

Fig 3.4: Standard Proctor Test mould

Table3: Value obtained from proctor test

Sno.	Weight of Mould (kg) W_1	Wt of compacted soil + mould (W_2) Kg	Volume of mould (cm^3)	Water added (%)	Bulk Density KN/m^3	Moisture content (%)	Dry Density (KN/m^3)
1	4.184	5.881	964.21	0	17.59	8.97	16.14
2	4.184	6.112	964.21	4	19.97	10.12	18.13
3	4.184	6.121	964.21	8	20.08	13.12	17.75
4	4.184	6.042	964.21	12	19.30	16.45	16.57
5	4.184	6.221	964.21	16	18.75	19.12	15.74

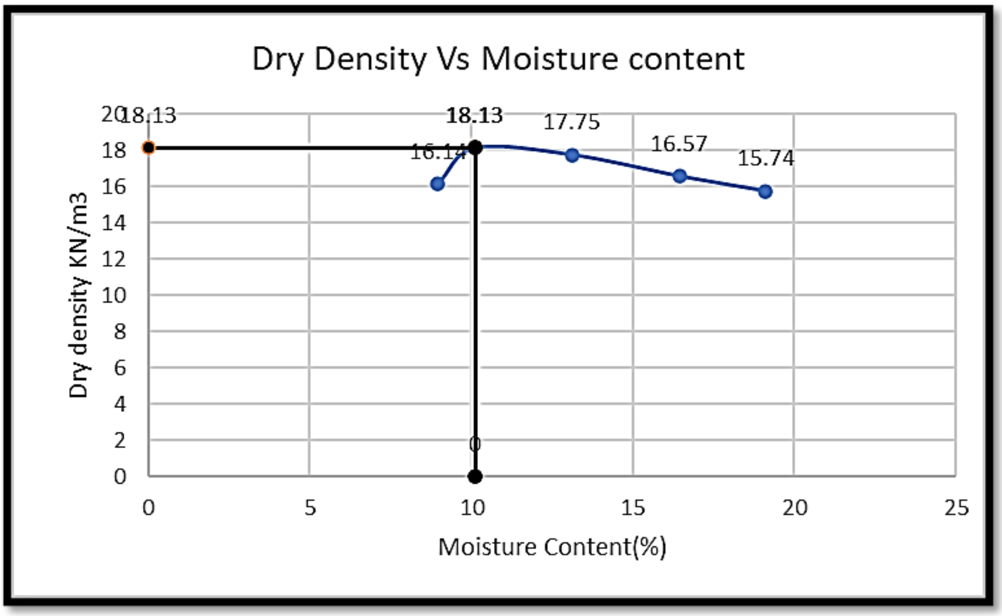


Fig 3.5: Standard Proctor Graph

D. Liquid Limit of soil:

- The moisture content at which soil losses its plasticity and started behaving as a liquid is known as its liquid limit.

Procedure:

1. Take 30 to 40 gm of soil sample passing through 425 microns IS sieve.
2. Add water to the soil sample to form a paste then pour the paste in the Casagrande apparatus.
3. Mark a groove of 10mm at the middle of the poured sample
4. Now start rotating the handle of the device to give blows to the soil sample
5. Note the no. of blows at which give blows by rotating crank of the standard device at which the groove close.
6. Repeat the experiment by varying water percentage ranging from 17 to 34.

Fig 3.6: Casagrande's apparatus with soil sample

Table4: Liquid Limit readings obtained

Container Number	**1**	**2**	**3**	**4**
Weight of container, W_1 gm	20.41	24.29	21.38	20.19
Weight of container + wet soil W_2 gm	39.59	40.13	36.11	38.25
Weight of container + dry soil W_3 gm	35.31	36.42	32.45	33.50
Weight of water ($W_2 – W_3$) gm	4.25	3.70	3.65	4.71
Moisture Content (%) = $\frac{W_2 - W_3}{W_3 - W_1}$	14.8	12.14	11.08	13.33
	28.58	30.51	32.81	35.39
No. of blows	34	27	23	17

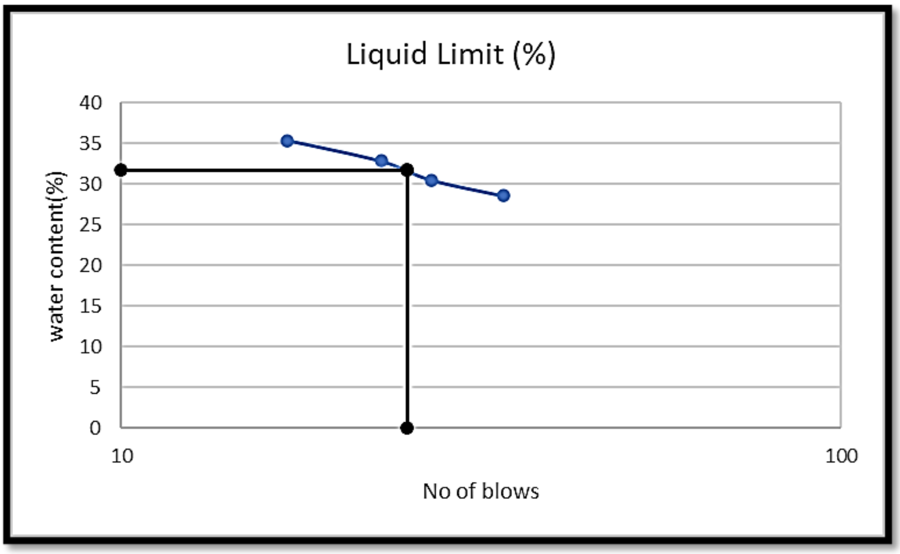


Fig 3.7: Liquid Limit graph

E. Plastic Limit

- The moisture content at which soil started behaving as a plastic is known as its plastic limit.

Procedure:

1. Take around 8 gm of soil sample add some quantity of water to it.
2. Make a ball by the soil water paste, then roll the ball on the glass plate to form a thread of 3 mm.
3. Continuously roll the thread until it starts crumbling.
4. The water at which the thread of dia 3 mm got crumbled is noted as its plastic limit.
5. Collect the crumbled soil for water content determination.

Table5: Observation Table of Plastic limit

Weight of container	23.10	21.86
Weight of container + wet soil	32.29	34.74
Weight of container + oven dried soil	31.20	32.51
Weight of water	1.09	2.23
Weight of oven dried soil	5.10	10.65

Fig 3.8: Crumbled thread of 3mm diameter

3.2.2 TESTS ON CEMENT:

A. Initial and Final setting of time Cement

- The initial setting time of the cement is the time at which cement losses its plasticity and cannot be disturbed by additional force.
- The final setting time of cement is the time taken by the cement paste to reach a state of complete hardening and development of strength.

Procedure:

1. Pour the cement paste in the mould, lower the needle till it touches the top surface of the cement paste. Release the needle to allow it to penetrate in the cement paste.
2. Repeat the same steps until the needle shows 5-7 mm penetration from the top.

Fig 3.9: Vicat's Apparatus

- Needle Dia: 1.13 mm (Initial setting time)
- Plunger Dia = 10 mm (final setting time)

B. Normal Consistency of Cement:

- The standard consistency of cement paste is defined as the percentage water added to the 300gm weight of cement which will permit a Vicat plunger having a 50 mm length and 10 mm diameter to penetrate in cement paste to a depth of 33-35 mm from the top of the mold.

Procedure:

- Take about 300 gm of cement into a tray and is mixed with a known percentage of water by weight of cement. Prepare cement paste by adding 26% of water to 300 gm of cement and mixing it well taking care that the time of mixing is not less than 3 minutes, nor more than 5 min. Lower the plunger such that it touches the top surface of mould filled with paste, and quickly release, allowing it to sink into the paste. It should be around 33 to 35 mm from the mould filled with cement paste

C. Compressive Strength Test:

- Compressive Strength = $\frac{Maximum\ load\ at\ time\ of\ failure}{Area\ of\ Specimen}$ N/mm^2

Procedure:

- Mix 200gm cement and 600gm sand with water of (P/4+3) %, P is standard consistency of cement. Pour cement in the cube mould by tampering with rod 20times in 8 second.
- After 24 hours remove the cubes from the mould. Keep the cubes for curing up to 7 days. Then cubes were placed in the Compressive strength machine.

Fig 3.10: Casted cubes before and after testing

3.2.3 Basic tests on soil – cement mix

A. Normal Consistency

Procedure:

- Take 240gm of soil and 60gm cement, water is added at different % varying from 26% - 33%
- Lower the plunger just it touches the top surface and release it. The reading at which it shows 33-35mm from the top is the percentage of standard consistency.

Fig 3.11: Normal consistency for soil cement mix

- Normal consistency for soil-cement mix is 19.2%

B. Compressive strength test

Procedure:

- 500gm soil sample is mixed with 125gm of cement, 60ml of water is added and mixed thoroughly
- Then this mix is placed and compacted in a 70.6mm × 70.6mm × 70.6mm cubes.
- Cubes were placed in curing tank for 28 days
- Testing of cubes are done after 28 days in universal testing machine.

Fig 3.12: Cement stabilized cubes with varying %

3.2.4 Properties of Grout material

A. Compressive strength, σ_g

Procedure:

- 500gm cement, 250ml water, 2ml Pidiproof are mixed together
- Cast the cubes of 70.6mm × 70.6mm × 70.6mm
- Cubes are placed for curing for 28 days
- After 28 days cubes are tested in universal testing machine

(i)

(ii)

Fig 3.13: (i)Cement – Pidiproof mix cubes (ii) Testing of cubes

METHOD OF APPLICATION:

- Charge cement & aggregates to concrete mixer as per the mix design, mix in dry state for 1–2 minutes.
- Start addition of 75–80% mixing water & mix for 2-3 minutes.
- Dr. Fixit Pidiproof LW+ is added as per the recommended dosage into the remaining mixing / gauging water,
- Then add to concrete mixer & mix for another 2 minutes.
- Place the concrete or apply plaster, as needed.

CURING AND STORAGE OF SPECIMEN

- Keep the specimen at a temperature of 27 + 2°C in an atmosphere of at least 90 percent relative humidity for 24 h. At the end of that period submerge the specimen in clean fresh water and keep there for 20 days, and take it out just prior to testing.
- The water in which the specimens are submerged shall be changed every 7 days and shall be maintained at a temperature of 27 + 2°C.

3.3 Preparation of Modelled Rock

3.3.1 Preparation of standard sample

3.3.1.1 Optimum percentage of Ordinary Portland Cement used,

- Stress for soil sample should be calculated for 0% cement

Fig 3.14: UCS on soil sample with 0% cement content

- Samples with different percentage of cement is taken varying from 10%, 15%, 20%, 25% and 28%
- Cast of cylinders were done, soaked the cylinders for 28days
- UCS testing was done, the cylinder gives maximum strength will give the optimum value of cement for a given soil.

(i)

(ii)

Fig 3.15: Samples with different percentage of cement (i)unsoaked (ii) soaked condition

3.3.1.2 Standard sample was prepared for 20%

- PVC pipes of dimension 50mm × 100mm are collected
- 250 gm soil sample, 63 gm cement are dry mixed in a pan, 32ml water is added to the mix and mixed thoroughly.
- Now Pipes with oil coating inside is filled with the mix in three layers, tamping each layer with 20 blows per 8 seconds,
- Now samples are left to dry for 24hrs
- After 24 hrs. samples were placed for curing for 28 days

Fig 3.16: Cylindrical samples considered as standard rock

3.3.2 Preparation of grouted modelled rock

- Samples were prepared in the similar way but fractures were created at 0°,30°,45°,60°,90°, fractured rock is created.

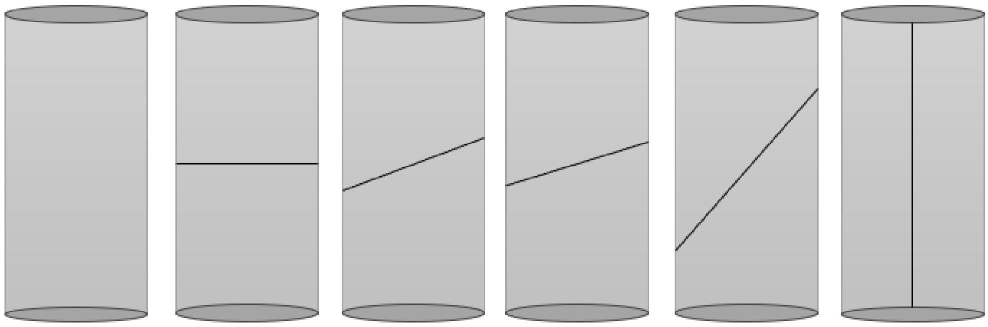


Fig 3.17: Standard sample, fractured rock at 0°,45°,30°,60°,90°

3.3.4 Injection of grout in fractured rock

- Now Grout material were prepared by mixing 50gram cement with 20 ml water and 2-3ml Dr. Fixit Pidiproof LW+
- Grout was placed in the crack developed of thickness nearly 1mm
- This grouted modelled rock is left to dry for 24hrs, after 24hrs these were kept in curing tank for 28 days

Fig 3.18: Grouted modelled rock 60°,45°,30° respectively

Fig 3.19: Soaked sample for 28 days

3.3.5 Testing of sample

- All samples were tested in UCS machine
- Axial load and deformation were collected

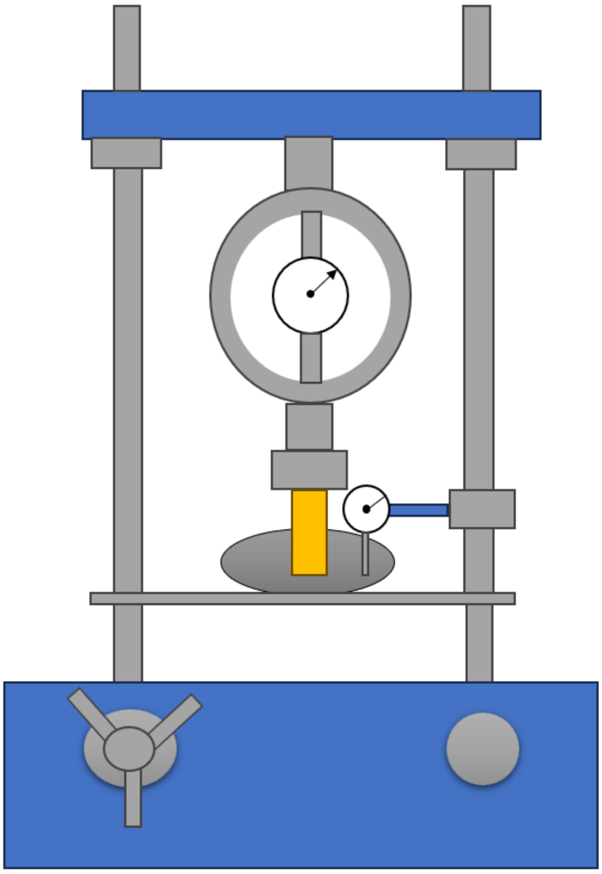


Fig 3.20: Unconfined compressive strength testing of sample

Concluding Remarks:

This methodology established the approach to find the strength of grouted modelled rock, starting from the collection of materials to the final testing of specimen. Each step ensures precise evaluation of the effects of grout composition and injection angles.

CHAPTER - 4
OBSERVATIONS AND CALCULATIONS

4.1 Data obtained from UCS testing of Samples

- Ac (Corrected Area) - $\frac{Actual/True\ area}{(1-\in_a)}$....................(4.1)
- $\in_a$ = Axial strain %

4.1.1 Table 6: Standard sample readings of sample 1

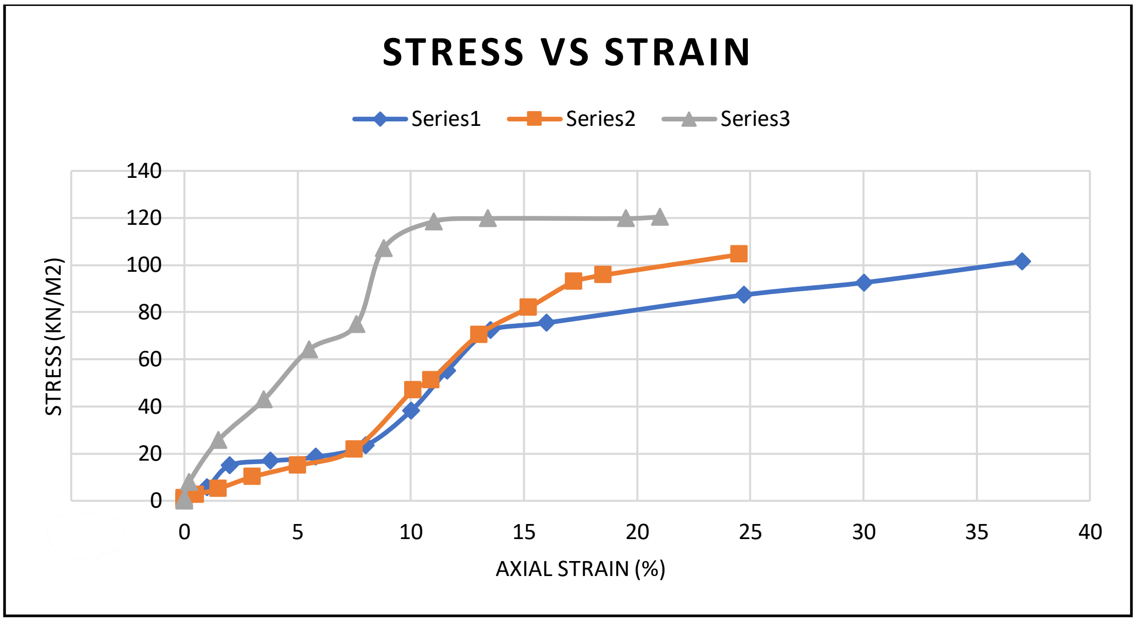
Axial Load (N)	Corrected Area (mm^2)	Deformations (mm)	Stress (KN/m^2)	Strain (del L/L) %
0	1963.5	0	0	0
2.05	1963.5	0	1.044	0
11.275	1983.33	0.1	5.628	0.001
30.75	2003.57	0.2	15.04	0.002
35.875	2041.06	0.38	16.908	0.0038
41	2084.39	0.58	18.529	0.0058
54.325	2134.24	0.80	23.417	0.008
92.25	2181.67	1	38.055	0.01
138.375	2221.15	1.16	55.072	0.0116
189.625	2269.94	1.35	72.259	0.0135
210.125	2337.5	1.60	75.510	0.016
302.375	2607.57	2.47	87.318	0.0247
404.875	2930.6	3.30	92.563	0.033
502.25	3116.67	3.70	**101.524**	0.037

4.1.2 Standard sample 2

Axial Load (N)	Corrected Area (mm^2)	Deformations (mm)	Stress (KN/m^2)	Strain (del L/L) %
0	1963.5	0	0	0
2.05	1963.5	0	1.0441	0
5.125	1973.367	0.05	2.597	0.05
10.25	1993.401	0.15	5.142	0.15
20.5	2024.227	0.3	10.127	0.3
30.75	2066.842	0.5	14.877	0.5
46.125	2122.703	0.75	21.729	0.75
102.5	2184.093	1.01	46.930	1.01
112.75	2203.704	1.09	51.164	1.09
158.875	2256.897	1.3	70.395	1.3
189.625	2315.448	1.52	81.895	1.52
220.375	2371.377	1.72	92.931	1.72
230.625	2409.202	1.85	95.726	1.85
271.625	2600.662	2.45	**104.445**	2.45

4.1.3 Standard sample 3

Axial Load (N)	Corrected Area (mm^2)	Deformations (mm)	Stress (KN/m^2)	Strain (del L/L) %
0	1963.5	0	0	0
2.05	1963.5	0	1.044	0
15.375	1967.43	0.02	7.814	0.02
51.25	1993.4	0.15	25.709	0.15
87.125	2034.72	0.35	42.819	0.35
133.25	2077.78	0.55	64.131	0.55
158.875	2125	0.76	74.765	0.76
230.625	2152.96	0.88	107.12	0.88
261.375	2206.18	1.1	118.474	1.1
271.625	2267.32	1.34	119.8	1.34
292.125	2439.13	1.95	119.766	1.95
299.3	2485.44	2.1	**120.421**	2.1



(i)

(ii)

Fig 4.1: (i) Combined graph (ii) Failed rock for standard sample

4.2.1 Table 7: Sample grouted at 0° for sample 1

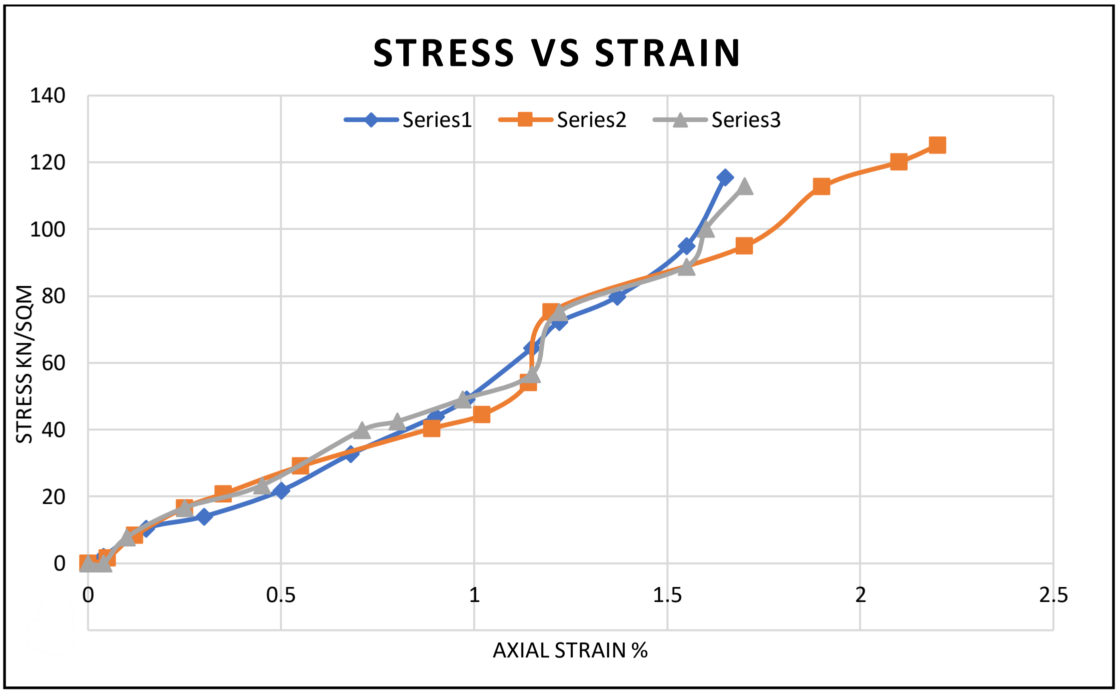
Axial Load (N)	**Corrected Area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (Del L/L) %**
0	1963.5	0	0	0
0	1964.281	0.04	0	0.04
15.375	1965.46	0.1	7.82	0.1
32.8	1968.416	0.25	16.66	0.25
46.125	1972.371	0.45	23.38	0.45
78.925	1977.536	0.71	39.91	0.71
84.05	1979.33	0.80	42.46	0.80
97.375	1982.73	0.97	49.11	0.97
112.75	1986.34	1.15	56.76	1.15
149.65	1987.745	1.22	75.28	1.22
177.325	1994.408	1.55	88.911	1.55
199.88	1995.42	1.60	100.167	1.60
225.5	1997.45	1.70	**112.894**	1.70

4.2.2 Grouted at 0° of sample 2

Axial Load KN	**Corrected Area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (del L/L) %**
0	1963.5	0	0	0
4.1	1964.28	0.04	2.087	0.04
20.5	1966.44	0.15	10.424	0.15
27.675	1969.40	0.3	14.052	0.3
43.05	1973.36	0.5	21.815	0.5
64.575	1976.94	0.68	32.66	0.68
87.125	1981.32	0.9	43.97	0.9
97.375	1982.93	0.98	49.106	0.98
128.125	1986.34	1.15	64.503	1.15
143.5	1987.75	1.22	72.192	1.22
158.875	1990.77	1.37	79.805	1.37
189.625	1994.41	1.55	95.08	1.55
230.625	1996.44	1.65	**115.52**	1.65

4.2.3 Grouted at 0° of sample 3

Axial Load (N)	Corrected Area (mm^2)	Deformations (mm)	Stress (KN/m^2)	Strain (Del L/L) %
0	1963.5	0	0	0
3.075	1964.48	0.05	1.57	0.05
16.4	1965.85	0.12	8.34	0.12
32.8	1968.42	0.25	16.66	0.25
41	1970.4	0.35	20.8	0.35
57.4	1974.35	0.55	29.07	0.55
79.95	1981.13	0.89	40.35	0.89
88.15	1983.73	1.02	44.44	1.02
107.625	1986.14	1.14	54.18	1.14
149.65	1987.34	1.20	75.30	1.20
189.625	1997.45	1.70	94.93	1.70
225.5	2001.52	1.90	112.65	1.90
240.875	2005.61	2.10	120.1	2.10
251.125	2007.66	2.20	**125.08**	2.20



(i)

(ii)

Fig 4.2: (i) Combined graph (ii) Failed rock for 0°

4.3.1 Table 8: Sample grouted at 30° of sample 1

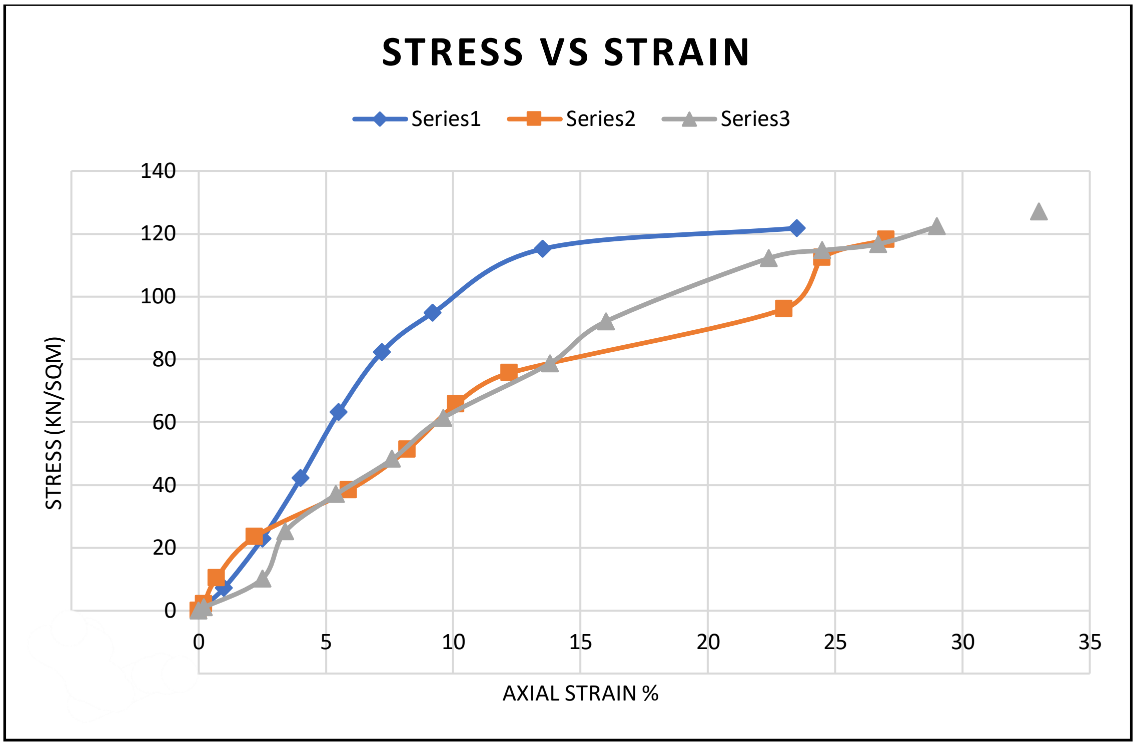
Axial load (N)	**Corrected area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (Del L/L) %**
0	1963.5	0	0	0
2.05	1967.43	0.02	1.042	0.02
20.5	2013.85	0.25	10.18	0.25
51.25	2032.61	0.34	25.214	0.34
76.875	2075.58	0.54	37.04	0.54
102.5	2125	0.76	48.24	0.76
133.25	2172.01	0.96	61.35	0.96
179.375	2277.84	1.38	78.75	1.38
215.25	2337.5	1.6	92.08	1.6
283.93	2530.28	2.24	112.21	2.24
298.275	2600.66	2.45	114.69	2.45
312.625	2678.72	2.67	116.707	2.67
338.25	2765.49	2.9	**122.31**	2.9

4.3.2 Grouted at 30° of sample 2

Axial Load KN	**Corrected Area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (del L/L) %**
0	1963.5	0	0	0
3.075	1967.43	0.02	1.56	0.02
14.35	1983.33	0.1	7.24	0.1
46.125	2013.85	0.25	22.90	0.25
86.1	2045.31	0.40	42.096	0.4
131.2	2077.78	0.55	63.14	0.55
174.25	2115.84	0.72	82.35	0.72
205	2162.44	0.92	94.80	0.92
261.375	2269.94	1.35	115.146	1.35
312.625	2566.67	2.35	**121.802**	2.35

4.3.3 Grouted at 30°of sample 3

Axial Load KN	**Corrected Area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (del L/L) %**
0	1963.5	0	0	0
4.1	1967.43	0.02	2.08	0.02
20.5	1977.34	0.07	10.36	0.07
47.15	2007.66	0.22	23.48	0.22
79.95	2086.61	0.59	38.32	0.59
109.68	2138.88	0.82	51.27	0.82
143.5	2184.09	1.01	65.70	1.01
169.125	2236.33	1.22	75.62	1.22
244.975	2550	2.30	96.06	2.30
292.125	2600.66	2.45	121.33	2.45
317.75	2689.73	2.70	**118.135**	2.70



(i)

(ii)

Fig 4.3: (i)Combined graph (ii) Failed rock for 30°

4.4.1 Table 9: Sample grouted at 45° of sample 1

Axial Load KN	Corrected Area (mm^2)	Deformations (mm)	Stress (KN/m^2)	Strain (del L/L) %
0	1963.5	0	0	0
2.05	1967.43	0.02	1.04	0.02
5.125	2003.57	0.2	2.55	0.2
20.5	2045.31	0.4	10.02	0.4

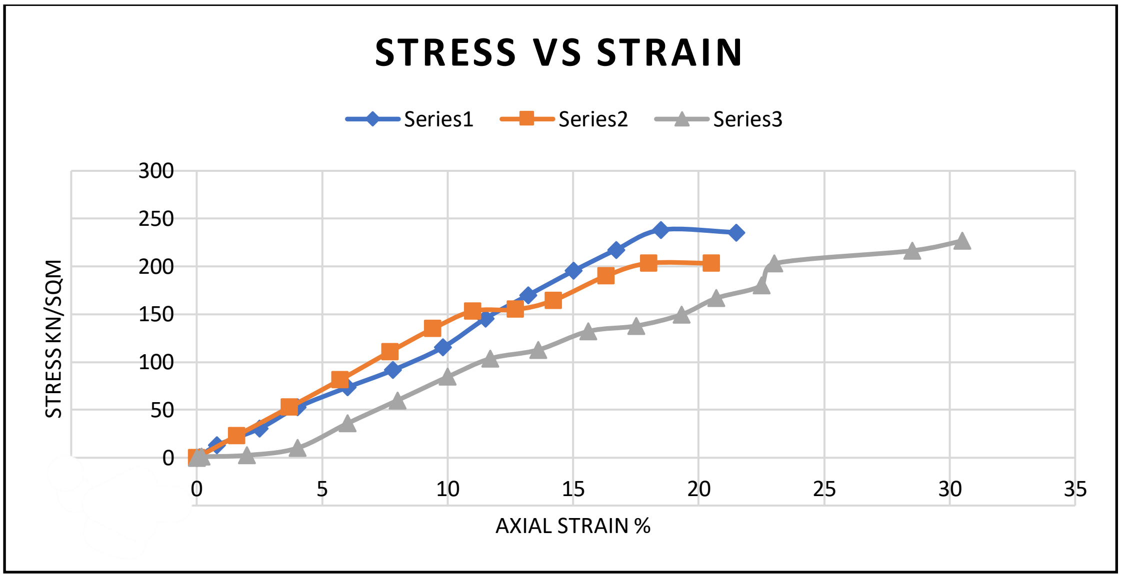
74.825	2088.83	0.6	35.82	0.6
128.125	2134.24	0.8	60.03	0.8
184.5	2181.67	1	84.57	1
230.625	2223.67	1.17	103.71	1.17
256.25	2272.57	1.36	112.75	1.36
307.5	2326.42	1.56	132.17	1.56
328	2380	1.75	137.82	1.75
363.875	2433.09	1.93	149.5	1.93
413.075	2476.04	2.07	166.83	2.07
456.125	2533.55	2.25	180.03	2.25
517.625	2550	2.3	202.9	2.3
594.5	2746.15	2.85	216.49	2.85
640.625	2825.18	3.05	**226.75**	3.05

4.4.2 Grouted at 45° sample 2

Axial Load KN	**Corrected Area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (del L/L) %**
0	1963.5	0	0	0
46.125	1995.43	0.16	23.12	0.16
107.625	2038.94	0.37	52.78	0.37
169.125	2082.185	0.57	81.22	0.57
235.75	2127.302	0.77	110.82	0.77
292.125	2167.32	0.94	134.8	0.94
338.25	2206.18	1.1	153.32	1.1
348.5	2249.14	1.27	154.95	1.27
376.175	2288.46	1.42	164.38	1.42
445.875	2345.878	1.63	190.06	1.63
486.875	2394.512	1.80	203.33	1.80
502.25	2469.81	2.10	**203.35**	2.10

4.4.3 Grouted at 45° of sample 3

Axial Load KN	**Corrected Area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (del L/L) %**
0	1963.5	0	0	0
1.025	1965.47	0.01	0.52	0.01
25.625	1979.33	0.08	12.94	0.08
61.5	2013.85	0.25	30.54	0.25
107.625	2045.31	0.4	52.62	0.4
153.75	2088.83	0.60	73.61	0.6
194.75	2129.61	0.78	91.45	0.78
251.125	2176.83	0.98	115.36	0.98
322.875	2218.64	1.15	145.53	1.15
384.375	2262.1	1.32	169.92	1.32
451	2310	1.5	195.24	1.5
512.5	2357.14	1.67	217.42	1.67
574	2409.2	1.85	**238.25**	1.85
589.375	2501.27	2.15	235.63	2.15



(i)

(ii)

Fig 4.4: (i) Combined graph (ii) Failed rock for 45°

4.5.1 Table 10: Sample grouted at 60° of sample 1,2,3

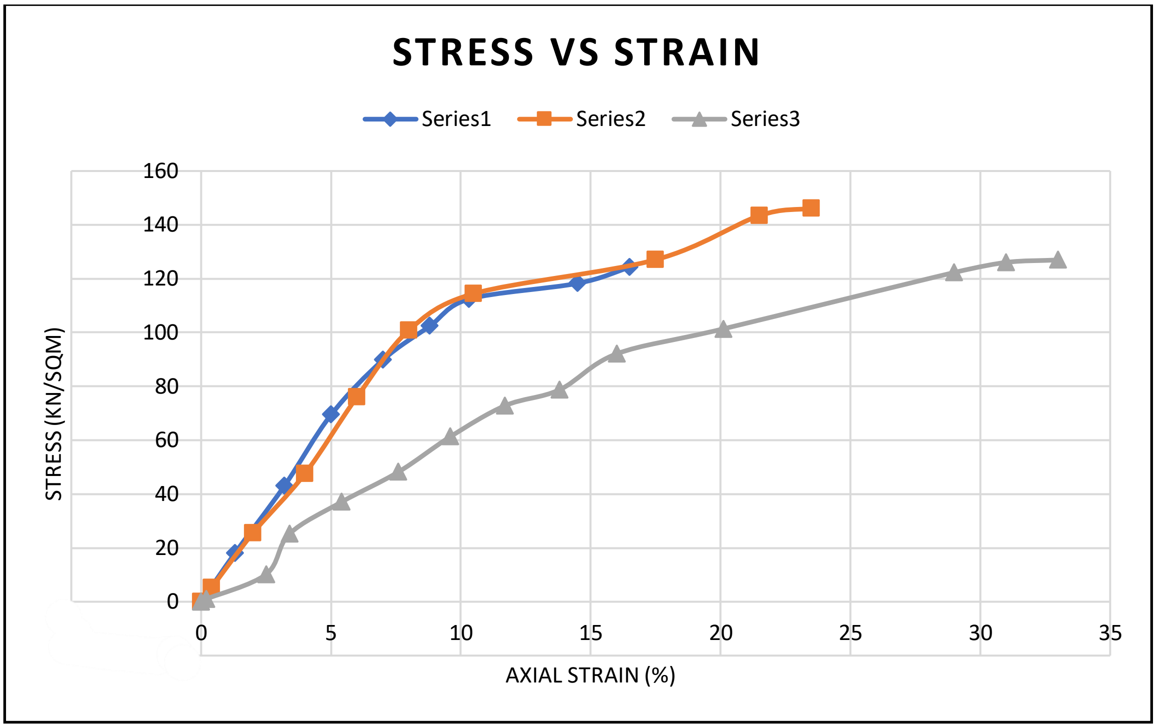
Axial Load KN	**Corrected Area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (del L/L) %**
0	1963.5	0	0	0
35.875	1989.362	0.13	18.03	0.13
87.125	2028.41	0.32	42.95	0.32
143.5	2066.84	0.50	69.43	0.50
189.625	2111.3	0.70	89.814	0.70
220.375	2152.96	0.88	102.36	0.88
246	2188.96	1.03	112.38	1.03
271.625	2296.49	1.45	118.278	1.45
292.125	2351.5	1.65	**124.23**	1.65

4.5.2 Grouted at 60° of sample 2

Axial Load KN	**Corrected Area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (del L/L) %**
0	1963.5	0	0	0
10.25	1971.38	0.04	5.19	0.04
51.25	2003.57	0.2	25.58	0.2
97.375	2045.31	0.4	47.61	0.40
158.875	2088.83	0.6	76.06	0.60
215.25	2134.24	0.8	100.85	0.80
251.125	2193.85	1.05	114.46	1.05
302.375	2380	1.75	127.04	1.75
358.75	2501.27	2.15	143.43	2.15
375.15	2566.66	2.35	**146.16**	2.35

4.5.3 Grouted at 60° of sample 3

Axial Load KN	**Corrected Area (mm^2)**	**Deformations (mm)**	**Stress (KN/m^2)**	**Strain (del L/L) %**
0	1963.5	0	0	0
0	1963.5	0	0	0
2.05	1967.435	0.02	1.042	0.02
20.5	2013.85	0.25	10.18	0.25
51.25	2032.61	0.34	25.22	0.34
76.875	2075.58	0.54	37.04	0.54
102.5	2125	0.76	48.24	0.76
133.25	2172.013	0.96	61.35	0.96
161.95	2223.67	1.17	72.83	1.17
179.38	2277.84	1.38	78.75	1.38
215.25	2337.5	1.6	92.08	1.6
249.08	2457.45	2.01	101.355	2.01
338.25	2765.5	2.9	122.31	2.9
358.75	2845.65	3.1	126.07	3.1
372.08	2930.6	3.3	**126.96**	3.3



(i)

(ii)

Fig 4.5: (i) Combined graph (ii) Failed rock for 60°

4.6.1 Table 11: Sample grouted at 90° of sample 1

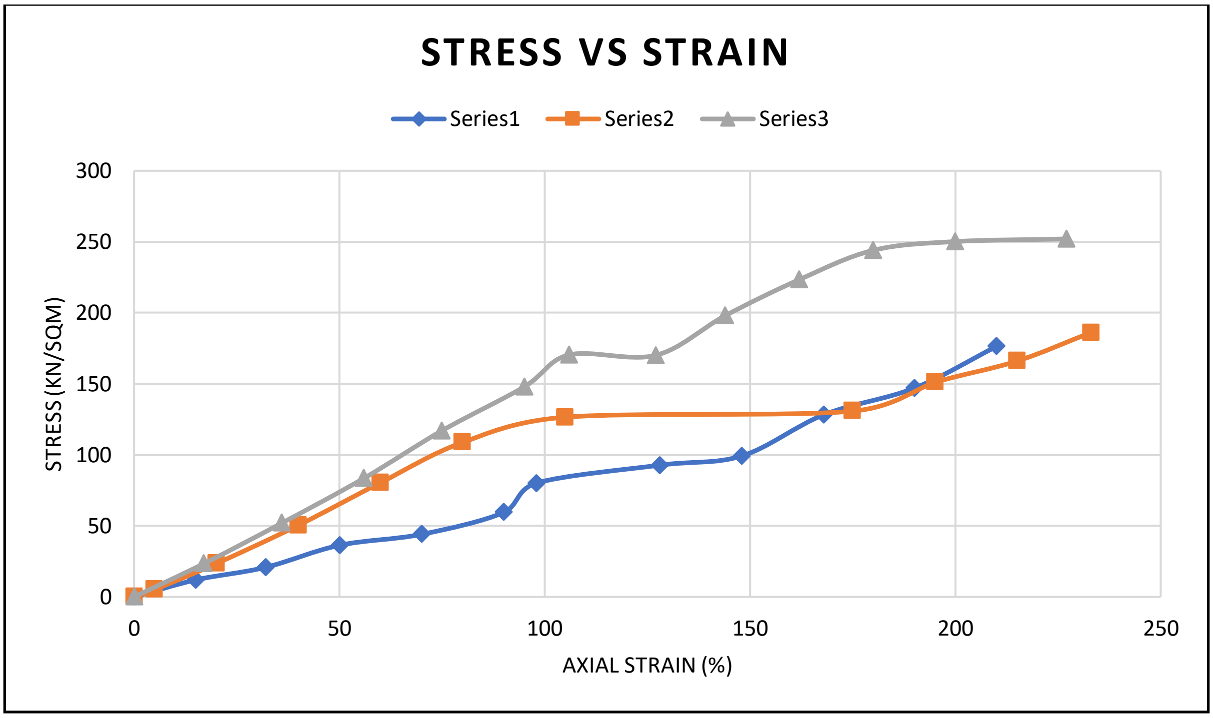
Axial Load KN	Corrected Area (mm^2)	Deformations (mm)	Stress (KN/m^2)	Strain (del L/L) %
0	1963.5	0	0	0
23.575	1966.44	0.15	11.98	0.15
41	1969.79	0.32	20.81	0.32
71.75	1973.36	0.5	36.36	0.5
87.125	1977.33	0.7	44.06	0.7
117.875	1981.32	0.9	59.5	0.9
158.875	1982.92	0.98	80.121	0.98
184.5	1988.95	1.28	92.76	1.28
197.825	1992.99	1.48	99.26	1.48
256.25	1997.04	1.68	128.31	1.68
294.175	2001.52	1.9	146.98	1.9
353.625	2005.61	2.1	**176.32**	2.1

4.6.2 Grouted at 90° of sample 2

Axial Load KN	Corrected Area (mm^2)	Deformations (mm)	Stress (KN/m^2)	Strain (del L/L) %
0	1963.5	0	0	0
10.25	1964.47	0.05	5.22	0.05
46.125	1967.43	0.2	23.44	0.2
99.425	1971.38	0.4	50.43	0.4
158.875	1975.34	0.6	80.43	0.6
215.25	1979.32	0.8	108.75	0.8
251.125	1984.33	1.05	126.55	1.05
261.375	1998.46	1.75	130.78	1.75
302.375	2002.54	1.95	150.9	1.95
333.125	2006.64	2.15	166.01	2.15
374.125	2010.34	2.33	**186.10**	2.33

4.6.3 Grouting at 90° of sample 3

Axial Load KN	Corrected Area (mm²)	Deformations (mm)	Stress (KN/m²)	Strain (del L/L) %
0	1963.5	0	0	0
46.125	1966.84	0.17	23.45	0.17
102.5	1970.58	0.36	52.01	0.36
165.025	1974.55	0.56	83.58	0.56
231.65	1978.33	0.75	117.09	0.75
293.15	1982.33	0.95	147.88	0.95
338.25	1984.53	1.06	170.44	1.06
338.25	1988.75	1.27	170.08	1.27
394.63	1992.18	1.44	198.08	1.44
445.88	1995.83	1.62	223.40	1.62
487.9	1999.83	1.80	244.01	1.80
501.23	2003.56	2	250.16	2
506.4	2009.10	2.27	**252.03**	2.27



(i)

(ii)

Fig 4.6: (i) Combined graph (ii) Failed rock of 90°

4.7 Combined Graph for all angles

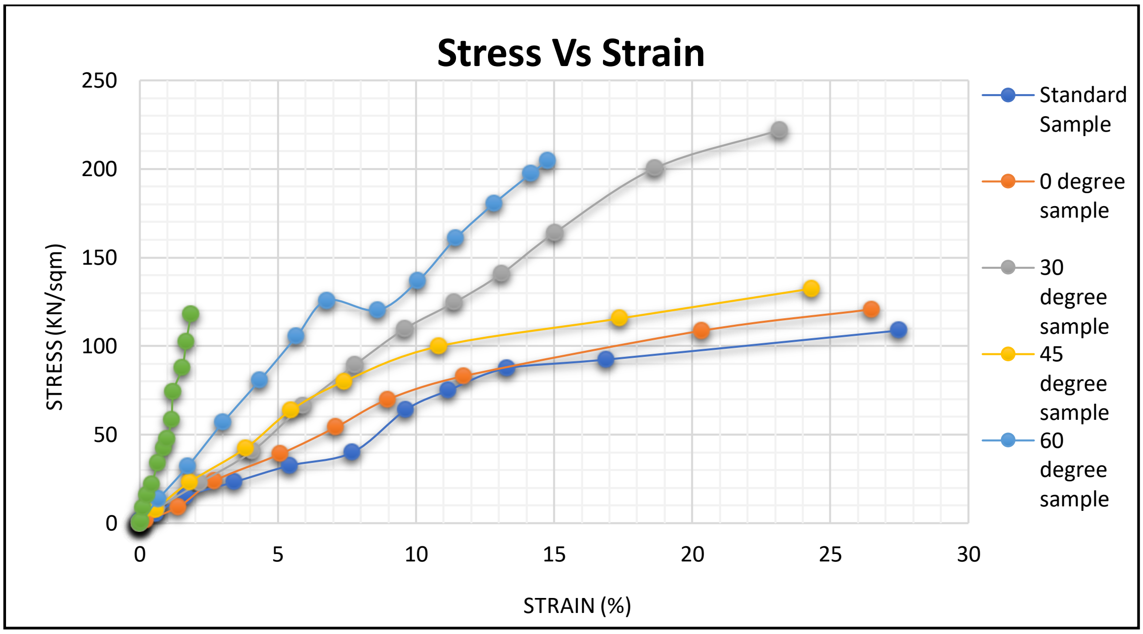


Fig 4.7: Stress Vs Strain Curve for all samples

Concluding Remarks:

This helps us in finding the modulus of elasticity for different samples and the peak values of stress obtained for various samples. It was observed that the value obtained was maximum for 45° and least for 0°, there is a drastic increase in stress value for grouted modelled rock compared to standard sample.

CHAPTER - 5
RESULTS AND DISCUSSIONS

5.1 Table 12: Properties of soil

Properties	Values Obtained
Specific Gravity of Soil, G	2.538
Moisture content, %	10.53%
Dry Density, KN/m^3	18.05KN/m^3
Liquid Limit, w_L	31.69%
Plastic Limit, w_P	21.16%
Plasticity Index	10.53%
Type of soil	Poorly graded sand with low plasticity SP - ML

5.2 Table 13: Strength of soil with varying % of cement

Percentage of Cement (%)	Strength of stabilized sample N/mm^2
10	1
15	1.42
20	1.86
25	1.92
28	1.96

5.3 Table 14: Properties of cement

Properties	Values Obtained
Initial setting time	30min
Final setting time	600min, 10hrs
Compressive strength	3 days – 23MPa 7 days – 33 MPa
Normal Consistency	33%

5.4 Properties of Grout material: Dr Fixit Pidiproof LW+

- It is an integral liquid waterproofing compound used to enhance the water-resistance and durability of concrete mortar.
- It makes cement cohesive and prevents segregation
- Prevents corrosion
- Compatible with mortar mixes, easily dispersible
- Reduces permeability
- Reduces shrinkage
- Improves workability
- It integrates well with the grout and enhances its performance in soil stabilization, structural repairs, or filling gaps.

Table15: Specifications of Dr. FixitPidiproof LW+

Properties	Specifications	Results
Appearance		Free flowing liquid
Colour		Wine red
Specific Gravity @ 25°C		1.05-1.070
Non - volatile liquid		13.5-14.5%
pH value		9-13
Initial setting time	IS: 2645: 2003	≮ 30 minutes
Final Setting time	IS: 2645: 2003	≯ 600 minutes
Chloride Content	IS:2645: 2003	≯2% by mass of product
Water permeability	IS: 2645: 2003	Equal to half of the permeability of cylinder prepared without Pidiproof
Compressive strength	IS: 2654: 2003	≮ 3 days and 7 days compressive strength of grade of OPC

5.5 Table 16: Compressive strength obtained for grout material

Compressive Strength KN/m^2	**Sample 1**	**Sample 2**	**Sample 3**
3 days	22.48	22.53	22.46
28 days	44.92	45.06	44.96

5.6 Table 17: Properties of Soil – cement mix

Properties	Values Obtained
Normal consistency	19.2%
Compressive strength (N/mm^2)	1.86

5.7 Results obtained from UCS testing

5.7.1 Table 18: Modulus of Elasticity from Graph

Sample Types	Modulus of Elasticity, E KN/m^2
Standard sample	7.19×10^3
0°	7.5×10^3
30°	10.22×10^3
45°	12.78×10^3
60°	10.56×10^3
90°	1.78×10^3

5.7.2 Table 19: Stress values obtained

Sample type	Ultimate Stress Value Obtained σ_{gr}, KN/m^2
Soil sample	4.83
Standard sample	108.795
0°	117.33
30°	122.29
45°	222.787
60°	132.438
90°	197.612

5.7.3 Table 20: Value of k obtained for various samples,

σ_g = Strength of grout material,

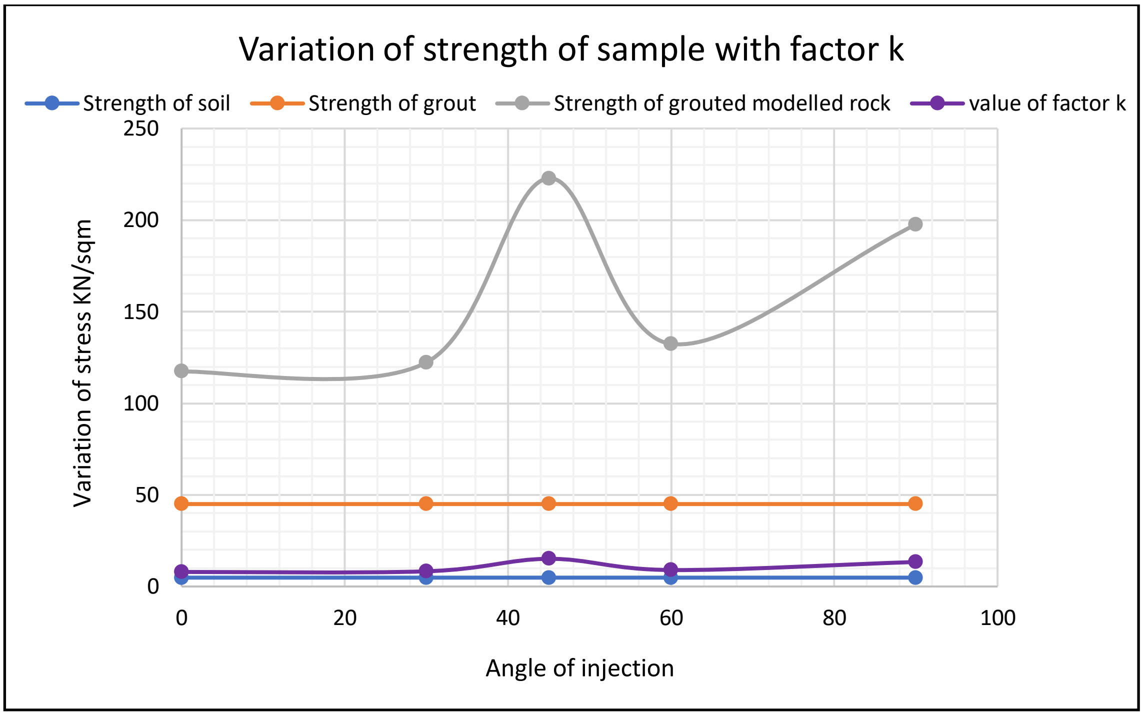
σ_s = strength of soil sample,

σ_{gr} = strength of grouted modelled rock,

K = strength comparison factor

$$\sigma_{gr} = k\sqrt{\sigma_g\,\sigma_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.1)$$

Sample Type	σ_s , KN/m^2	σ_g, KN/m^2	k	σ_{gr}, KN/m^2
Standard Sample	4.83	45	7.38	108.795
0	4.83	45	7.95	117.33
30	4.83	45	8.29	122.29
45	4.83	45	15.11	222.787
60	4.83	45	8.98	132.438
90	4.83	45	13.40	197.612



- Using equation (5.1) the values of k have been calculated for all samples
- From the above table it is seen by the values that the **k is maximum for 45°** and **minimum for 0°**

- Strength increment of grouted modelled rock for 45° is **15.11** times the strength of individual constituents.

Concluding Remarks:

This chapter shows all the values obtained after individual testing of the constituents and the strength increment when they are combined together to form a grouted modelled rock, and the variation of strength with the addition of Pidiproof in the rock.

CHAPTER – 6
CONCLUSION

This study reveals the enhancement of fractured rock when grouted with cement – Pidiproof LW+ mix. The modelled specimens were prepared using poorly graded sand of (SP – PL) low plasticity with Ordinary Portland Cement of grade 43, grouted at 0°,30°,45°,60°,90° angles, cylinders casted were cured for 28 days and tested on UCS test.

The conclusions drawn from the testing:

- **Strength Enhancement -** On addition of cement Pidilite the strength is increased compared to the standard rock, maximum for 45° and minimum for 0°.
- **Modulus of elasticity, E** – obtained from stress – strain curve, maximum for 45° and minimum for 90°
- **Effect of different angle of injection of grout** – The strength varies with the injection angle, the value of stress increased by almost 50% for 45° when compared to standard rock,
- **Strength of modelled rock compared to individual constituents** – the strength varies for modelled rock when compared with strength of soil and grout material by the factor k, the value of k is attained **maximum for 45° and minimum for 0°**
- It can be concluded that the value of k may also increase with the variation of grout thickness.
- The use of Dr Fixit Pidiproof LW+ not only enhances the strength of fractured rock but also shows a drastic increase for 45° compared to standard rock.
- This showed the potential for using Dr Fixit Pidiproof LW+ for grouting purposes.

Scope of future work

- Variation of strength when Pidiproof is mixed with other grout materials
- Long term effect of Pidiproof on ground improvement
- Seepage of grout material (Pidiproof) from the soil with time

REFERENCES

[1] Compressive strength test of Grade 53 cement: IS 4031(Part-6)

[2] Consistency Test of Cement IS Codes – IS: 5513-1976, IS: 4031 (Part 4) – 1988

[3] IS: 2645: 2003 Integral waterproofing compounds for cement mortar and concrete

[4] Jiang, H., & Qiu, X. (2021). Performance assessment of a newly developed and highly stable grouting material for a completely weathered granite dam foundation. Construction and Building Materials, 299, 123956.

[5] Li, Shucai, et al. "Investigation and practical application of a new cementitious anti-washout grouting material." Construction and Building Materials 224 (2019): 66-77

[6] Liao, C., Lin, B., Li, M., Hu, S., Dai, G., Liu, D., & Huang, S. (2024). Study on the properties of graphene oxide cementitious grout materials and its cementing effect in reinforcing broken rock mass by grouting. Journal of Building Engineering, 96, 110458.

[7] Li, Tan, et al. "Experimental study of improved cement silicate grouting material for broken surrounding rock." Journal of Building Engineering 74 (2023): 106782

[8] Li, Z., Liu, H., Dun, Z., Ren, L., & Fang, J. (2020). Grouting effect on rock fracture using shear and seepage assessment. Construction and building materials, 242, 118131.

[9] Pei, Jianzhong, et al. "Design and performance validation of high-performance cement paste as a grouting material for semi-flexible pavement." Construction and Building Materials 126 (2016): 206-217.

[10] Qin, Xiangrui, et al. "Experimental investigation on the failure mechanism of grouted rock mass: Mesostructure and macroscopic mechanical behavior." Engineering Failure Analysis 161 (2024): 108304.

[11] Ruan, W., Liao, J., Mo, J., Li, F., Gu, X., Ma(2023). Effects of red mud on properties of magnesium phosphate cement-based grouting material and its bonding mechanism with coal rock. Ceramics International, 49(2), 2015-2025.

[12] Salimian, M. H., et al. "Effect of grouting on shear behavior of rock joint." International Journal of Rock Mechanics and Mining Sciences 98 (2017): 159-166.

[13] Shu, Benan, et al. "Performance study and engineering application of grouting materials with a large content of solid waste." Construction and Building Materials 312 (2021): 125464

[14] The initial and final setting time of cement is calculated using the VICAT apparatus - IS: 4031 (Part 5) – 1988

[15] Wang, Xiaochen, et al. "Grouting characteristics in rock fractures with rough surfaces: Apparatus design and experimental study." Measurement 184 (2021): 109870.

[16] Xu, Z., Liu, C., Zhou, X., Gao, G., & Feng, X. (2019). Full-scale physical modelling of fissure grouting in deep underground rocks. Tunnelling and Underground Space Technology, 89, 249-261.

[17] Yalei, Z., Kepeng, H., Zongyong, W., Shifei, Y., Yunlin, Y., & Yong, Y. (2024). The grouting plugging mechanism of layered jointed rock mass considering the time-varying yield stress of grout. Scientific Reports, 14(1), 23029.

[18] Zhang, Lianzhen, et al. "Characteristics of slurry-water mixing region in fractured rock mass grouting process: Experimental study." Construction and Building Materials 427 (2024): 136244.

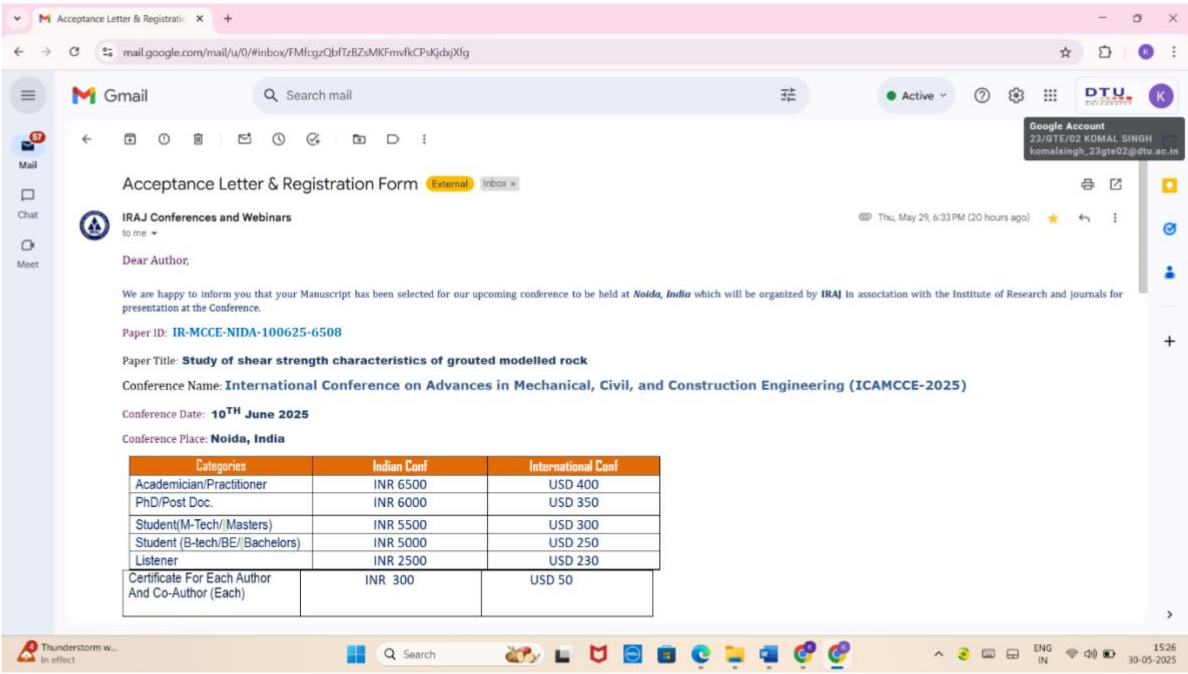
[19] Zhang, Junwen, et al. "Experimental study on cement-based materials for grouting/replacement of broken rock mass in coal mine." Construction and Building Materials 425 (2024): 135979.

[20] Zhu, Xianxiang, et al. "Diffusion mechanism of solid waste product utilization pulping and fracture network grouting." Construction and Building Materials 408 (2023): 133571.

[21] Zhe, Y., Hou, K., Wang, Z., Yang, S., Yu, Y., & Yang, Y. (2024). Research on the grouting plugging mechanism of layered jointed rock mass based on the time-varying yield stress of grout.

LIST OF PUBLICATIONS

Paper Tittle	Category	Presented In	Publishing In	Status
Study of shear strength characteristics of grouted modelled rock	Conference	International Conference on Advances in Mechanical, Civil, and Construction Engineering (ICAMCCE-2025)	Yet to be decided	Paper accepted for the conference



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