Effect of Artificial Jointed Orientation on Strength Parameters of Carbonate Sedimentary Rocks Using Triaxial System

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Abstract : In rock strata, there are numbers of hair cracks and fissures are present. It degrades the physical and engineering properties of rock. Hence, problem occurs while excavation during tunneling and mining operations. Jointed rock masses comprise interlocking angular particles or blocks of hard brittle material separated by discontinuity surfaces which may not be jointed with weaker materials. Three types of carbonate sedimentary rock viz. Limestone, building stone and Marl procured from Porbandar,Gujarat (India). Samples are having different amount of calcite mineral. Chemical analysis is being done in order to get the exact amount of mineral present. its mineral effect is also be taken care. Matrix. The main Objective is to compare the strength of intact rock with their proposed rock matrix pattern and variation due to decrease in amount of calcium carbonate. secondary to know the behavior of rock specimens under confining pressure & plot stress vs. strain curve for the same.

***IndexTerms* - Calcium carbonate, Rock triaxial test, Jointed orientation, Rock matrices, Shear parameters.**

1 INTRODUCTION

Sedimentary rock formed on or near the surface of the earth by the insertion and replacement of particles of sediment or by the precipitation from the solution at normal temperatures (chemical rocks). These are the most common rocks exposed on the surface of the earth but are just a small area of the entire crust, governed by igneous and metamorphic rocks. Limestone is a sedimentary rock formed mainly by the mineral calcite (calcium carbonate, $CaCO_3$). This calcite comes from the shells of marine animals. It also emerges from seawater. Calcite is a $CaCO_3$ mineral of carbonate and a very stable polymorph of calcium carbonate. Gravity of 2.71 g/cm3. Pure calcite contains 56.03% CaO and 43.97% CO_2. Role of mineral is to increase the hardness of rock. The ground is composed of soil and rock which have different physical, mechanical and chemical properties. There is a constant need of searching the solution to complex problems involving the behaviour of rock masses. Rock masses are discontinuous containing cracks, fissures, joints, faults and bedding planes with varying degrees of strength along these planes of weakness; these planes which are often present in a rock mass, control its strength and deformational behavior. Thus, estimation of the strength of the rock mass came into picture.

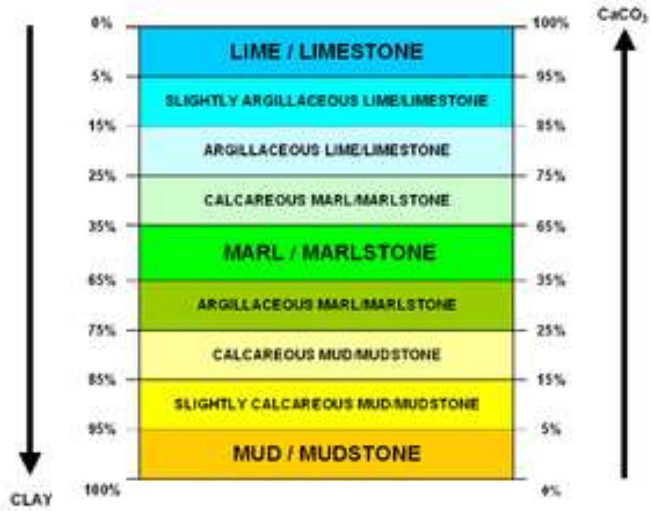


Fig.1 Elementary compositions of rock

In present investigation three types of rock viz. Carbonate rock, Marl and Building stone are used for laboratory investigation to know the shear and compression capacity of this rock samples with different matrix pattern viz. (1) intact (2) horizontal cut (3) vertical cut (4) inclined cut with 45˚ at H/2 distance (5)inclined cut with 60˚ at H/2 distance (6) 2 inclined cut with 30˚ at H/3 distance (7) 3 inclined cut with 30˚ at H/4 distance are adopted.

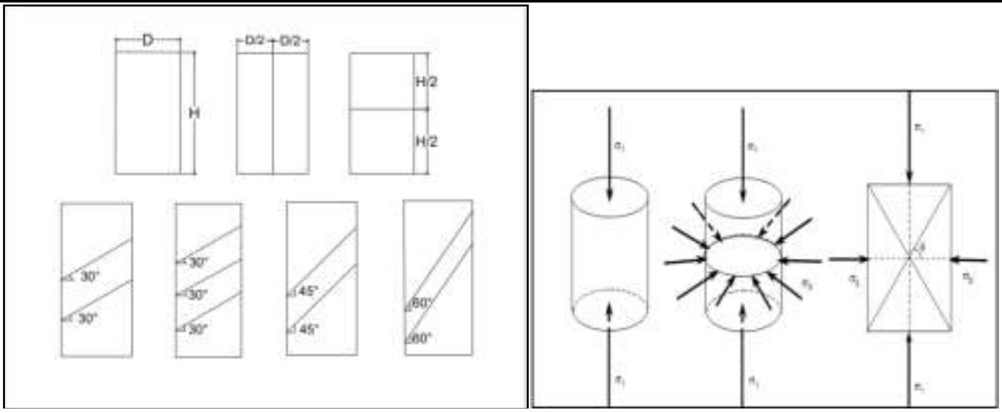


Fig.2 types of rock matrix

2 MATERIALS AND EXPERIMENTAL SETUP

2.1 Rock Sample:

Source of the Carbonate sedimentary rocks viz Carbonate rock, Marl, Building stone was procured commercially from Saurashtra coastal area, and Chotta-Udaipur,Baroda, Gujarat respectively.

2.2 Test Methodology:

The Triaxial tests was performed as per IS 13047-2010 and sample preparation was made as per IS 9179- 2001. The strain rate used for present research work is 0.315 mm/min and confining pressures 10 N/mm2 , 15 N/mm2 , 20 N/mm2 for both types of rock samples. The self-compensating mercury control device is used for keeping cell pressure constant throughout the test. The usual procedure for conducting a tri-axial compression test is first to apply the confining pressure σ3 all around the cylinder is held constant & then to apply axial load σ1 (Figure 2). Through plunger vertical load is applied which causes failure in the sample.

3 LABORATORY TESTING

3.1 Index Properties:

Index properties of the rock used for the current study are described below in table 4.3. There was a certain requirement that the rock should be homogeneous. Testing for index properties were preferred to carry out for all the samples due to possibility of unevenness of the rock. The rock used for the current project did not large unevenness for water content, density and void ratio.

Table1: Index properties of Building stone

Type of matrix	Sample No.	Height (mm)	Dia (mm)	Water Content (%)	Porosity $n=v_v/v$	Density kN/m³ (ρ =M/V)
B_IR	1	84	42	1.98	25.84	16.77
	2	84	42	1.95	24.35	16.78
	3	84	42	1.95	24.95	16.77
BI_45°_ H/2	4	84	42	1.84	25.62	16.72
	5	84	42	1.85	25.30	16.78
	6	84	42	1.89	25.94	16.75
BI_60°_ H/2	7	84	42	1.93	24.60	16.76
	8	84	42	1.85	23.95	16.75
	9	84	42	1.86	23.88	16.73
BH_H/ 2	10	84	42	1.91	25.31	16.73
	11	84	42	1.92	25.95	16.73
	12	84	42	1.91	24.36	16.75
BV_D/2	13	84	42	1.88	24.96	16.72
	14	84	42	1.83	25.30	16.78
	15	84	42	1.92	25.30	16.75
B2I_30° _H/3	16	84	42	1.93	24.65	16.76
	17	84	42	1.96	25.20	16.75
	18	84	42	1.95	25.30	16.73
B3I_30° __H/4	19	84	42	1.88	24.89	16.73
	20	84	42	1.86	25.67	16.73
	21	84	42	1.90	24.69	16.74

Table2: Index properties of carbonate rock

Type of matrix	Sample No.	Height (mm)	Dia (mm)	Water Content (%)	Porosity $n=v_v/v$	Density kN/m³ (ρ =M/V)
C _IR	1	84	42	1.12	18.46	16.72
	2	84	42	1.12	18.56	16.78
	3	84	42	1.13	18.62	16.75
CI_45°_ H/2	4	84	42	1.15	17.33	16.76
	5	84	42	1.13	18.24	16.75
	6	84	42	1.15	17.32	16.73
BI_60°_ H/2	7	84	42	1.10	18.64	16.73
	8	84	42	1.10	18.83	16.73
	9	84	42	1.11	17.69	16.75
CH_H/ 2	10	84	42	1.16	18.23	16.75
	11	84	42	1.13	18.56	16.75
	12	84	42	1.15	18.23	16.75
CV_D/2	13	84	42	1.14	18.62	16.77
	14	84	42	1.12	17.33	16.72
	15	84	42	1.12	18.24	16.73
C2I_30° _H/3	16	84	42	1.13	17.32	16.73
	17	84	42	1.13	18.64	16.73
	18	84	42	1.19	18.65	16.75
C3I_30° _H/4	19	84	42	1.13	17.66	16.73
	20	84	42	1.15	18.21	16.71
	21	84	42	1.16	18.42	16.69

Table3: Index properties of Marl

Type of matrix	Sample No.	Height (mm)	Dia (mm)	Water Content (%)	Porosity $n=v_v/v$	Density kN/m³ (ρ =M/V)
M_IR	1	84	42	0.93	3.95	20.20
	2	84	42	0.92	3.84	20.21
	3	84	42	0.93	3.95	20.20
MI_45°_H/2	4	84	42	0.98	3.93	20.23
	5	84	42	1.01	3.89	20.21
	6	84	42	0.98	3.91	20.20
MI_60°_H/2	7	84	42	0.98	3.92	20.23
	8	84	42	0.96	3.90	20.24
	9	84	42	0.92	3.90	20.21
MH_H/2	10	84	42	0.93	3.81	20.25
	11	84	42	0.98	3.93	20.24
	12	84	42	0.95	3.89	20.21
MV_D/2	13	84	42	0.92	3.91	20.23
	14	84	42	0.93	3.92	20.21
	15	84	42	0.95	3.90	20.20
M2I_30°_H/3	16	84	42	0.97	3.90	20.23
	17	84	42	0.95	3.81	20.24
	18	84	42	1.02	3.93	20.21
M3I_30°_H/4	19	84	42	0.03	3.89	20.25
	20	84	42	0.98	3.98	20.24
	21	84	42	0.95	3.93	20.21

3.2 Chemical analysis

3.2.1 Sample Building stone

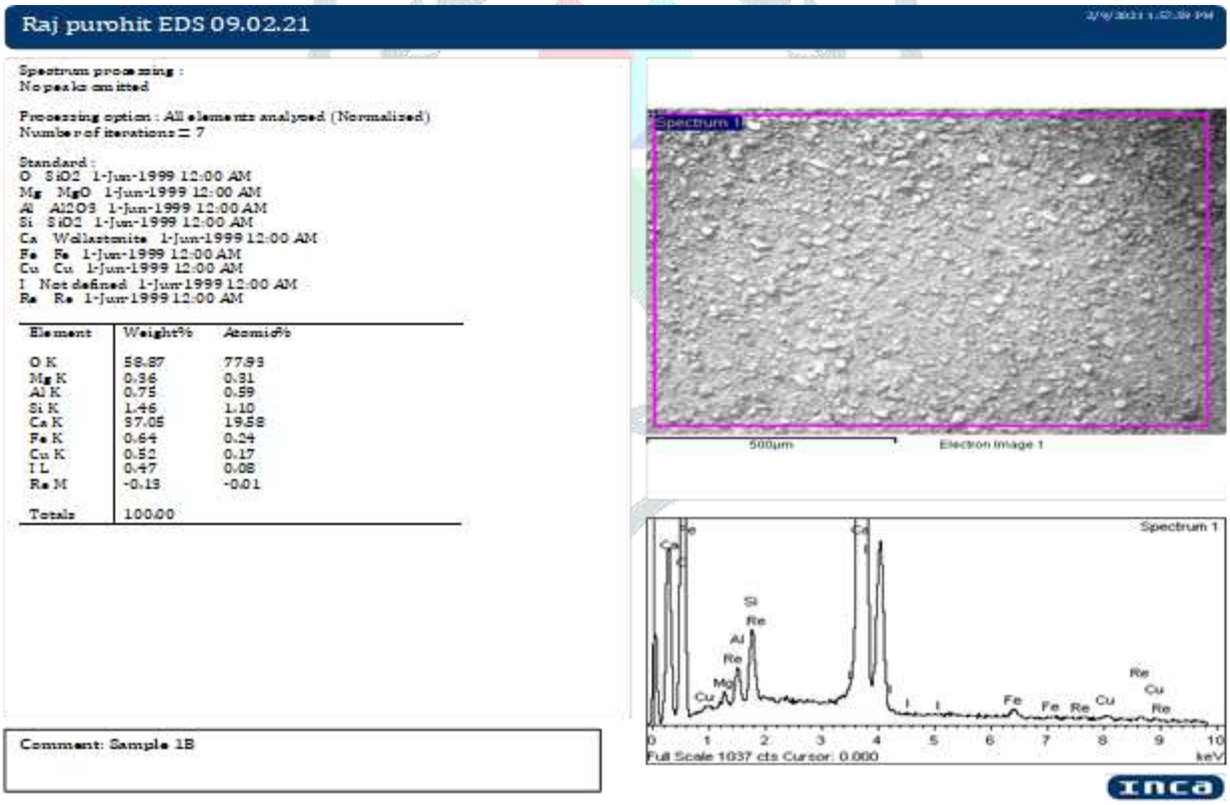


Fig. 3

3.2.2 Sample Carbonate rock

Raj purohit EDS 09.02.21

Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 6

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Mg MgO 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
Ca Wollastonite 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	11.24	18.56
O K	50.25	62.31
Mg K	0.31	0.26
Al K	0.40	0.30
Si K	0.76	0.53
Ca K	35.80	17.72
Fe K	0.31	0.11
Cu K	0.41	0.13
Sn L	0.50	0.08
Totals	100.00	

Comment: Sample 2C-1

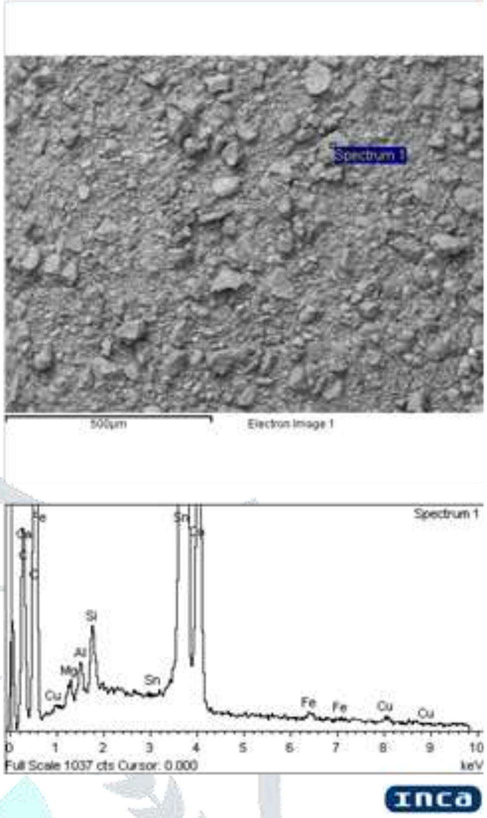


Fig. 4

3.2.3 Sample Marl

Raj purohit EDS 09.02.21

Spectrum processing :
Peaks possibly omitted : 4.510, 0.845, 0.620 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 6

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Na Albite 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Ca Wollastonite 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	8.02	12.91
O K	50.56	61.12
Na K	0.69	0.58
Al K	6.75	4.84
Si K	19.04	13.67
K K	6.94	3.43
Ca K	6.98	3.37
Fe K	0.21	0.07
Totals	100.00	

Comment: Sample 3K

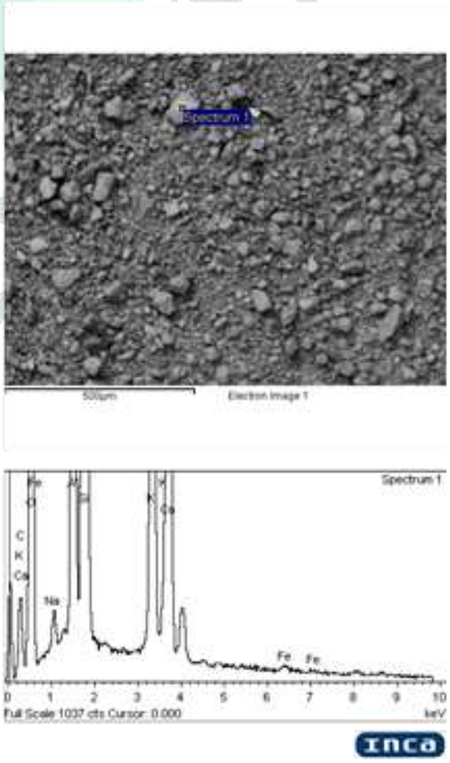


Fig. 5

4 ANALYSIS

4.1 Failure pattern of rock matrix

4.1.1 Carbonate rock

Fig. 6 Failure pattern of Carbonate rock matrix

4.1.2 Marl

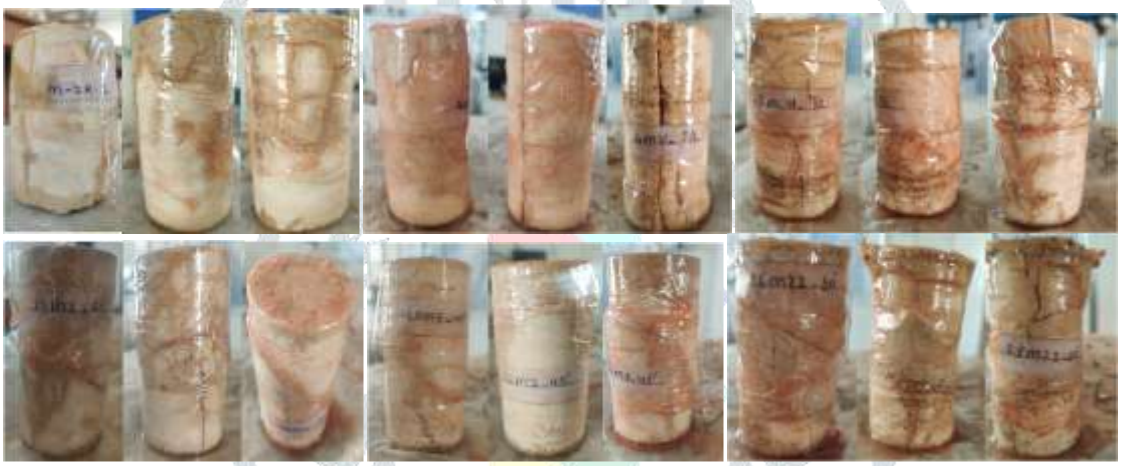


Fig. 7 Failure pattern of Marl rock matrix

4.1.3 Building stone

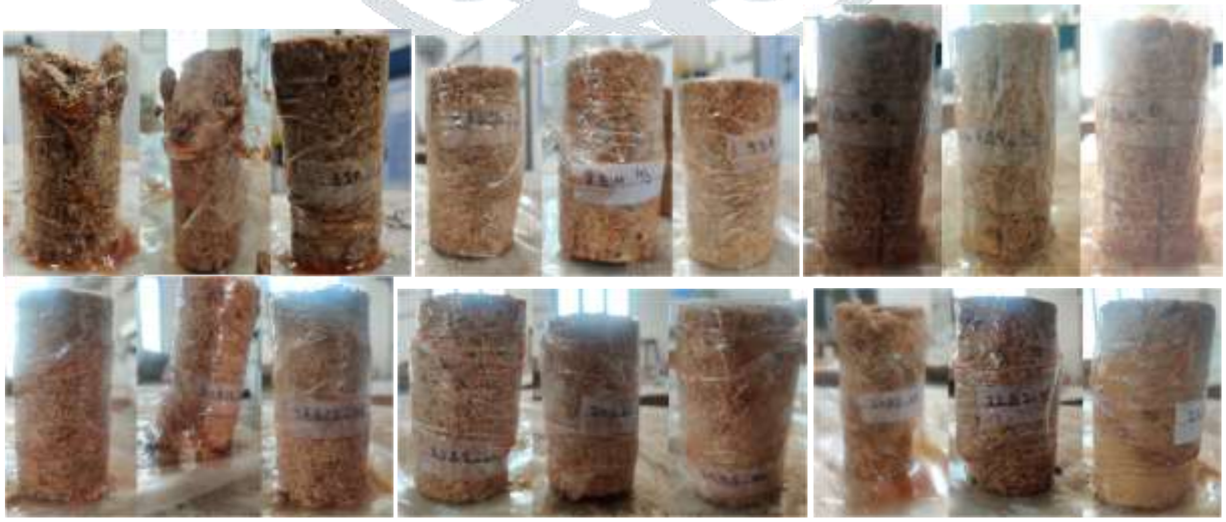


Fig. 8 Failure pattern of Building stone rock matrix

4.2 Stress strain relationship

Graphical representation of stress strain relationship is shown in figure 5.69 for carbonate rock 5.70 for marl and 5.71 for building stone. which shows stress-strain curve for rock shows average value of major principle stress under confining pressure and different orientation of joints. As the number of joints increases and orientation of cuts changes the values of major principle stress decreases. Intact rock specimen of all the samples viz C_IR, M_IR and B_IR shows the highest value of major principle stress as compared to the samples which has joints. it is also observed that as the amount of calcium carbonate increases the value of major principle also increases as the mineral plays vital role in the hardness of the rock. Value of C_IR is found to be more than M_IR and B_IR as it contains more calcium carbonate than others.

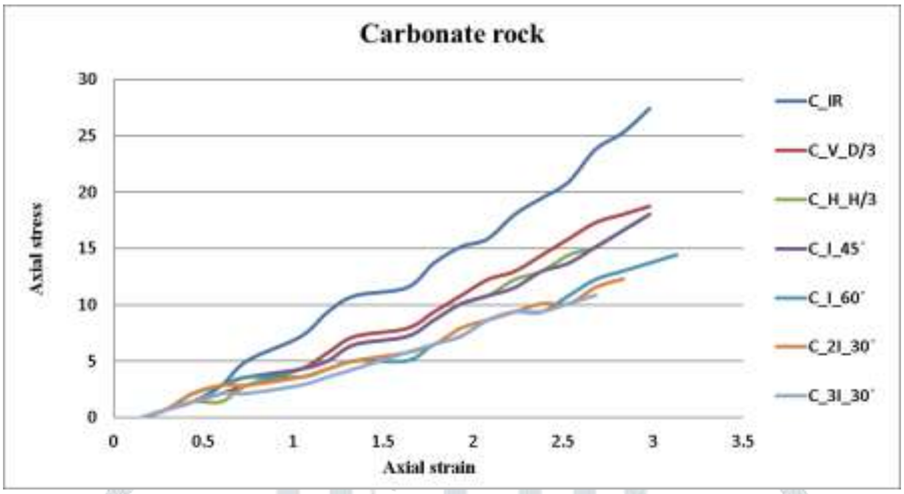


Fig 9. Stress vs strain relationship for carbonate rock

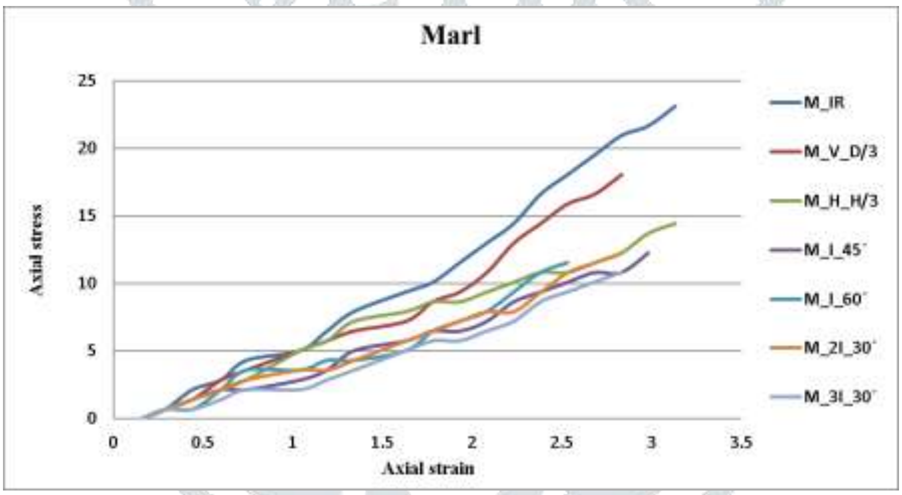


Fig 10. Stress vs strain relationship formarl

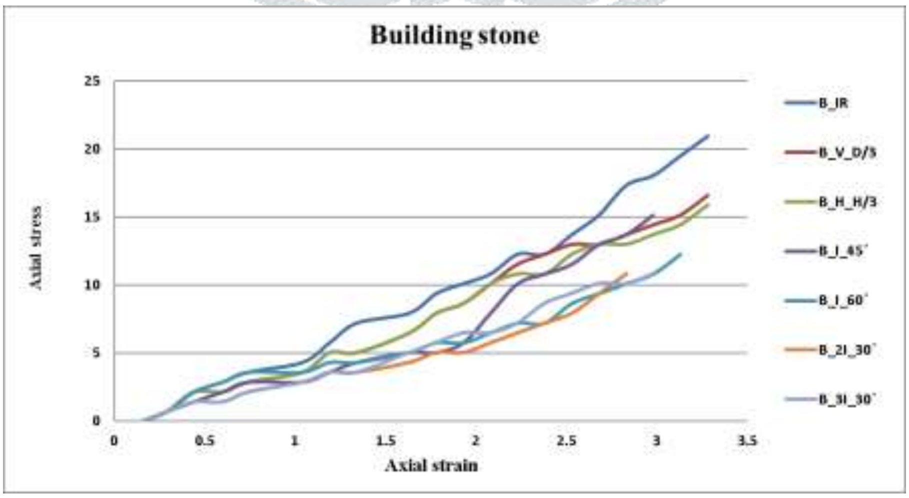
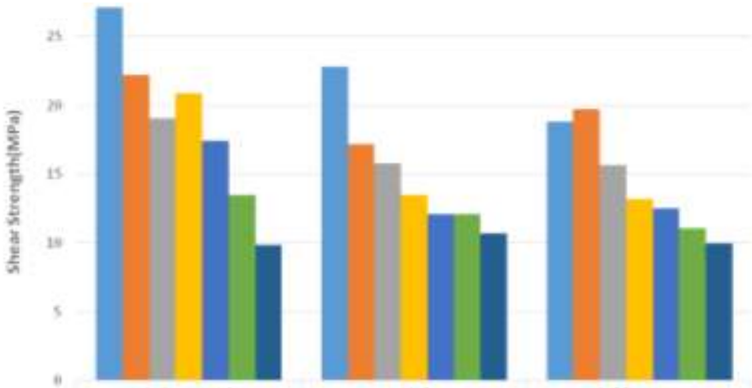


Fig 11. Stress vs strain relationship forbuilding stone

The behavior of rock mass under triaxial compressive stresses and confining stresses is simulated through this experimental work. In situ natural rock mass is confined by various types of stresses is mainly due to material density, geological composition and physicalchemical bonding of rock particles. A cylindrical intact specimen when substitute by various rock matrix. The transformation of stresses from one joint to other with this complex phenomenon amount of energy which the intact specimen possesses is very high even if it is compared to smaller rock matrix. The dissipation of energy creates more number of failures into rock masses either through joints, fissures, bedding planes, hair cracks etc. and the resistance to this energy is simulated into various rock matrix patterns. It is noted that rock matrix and its orientation both with respect to vertical and horizontal direction are playing vital role in development of deformation shapes and sliding of tiny rock blocks into weakest plane of failure.

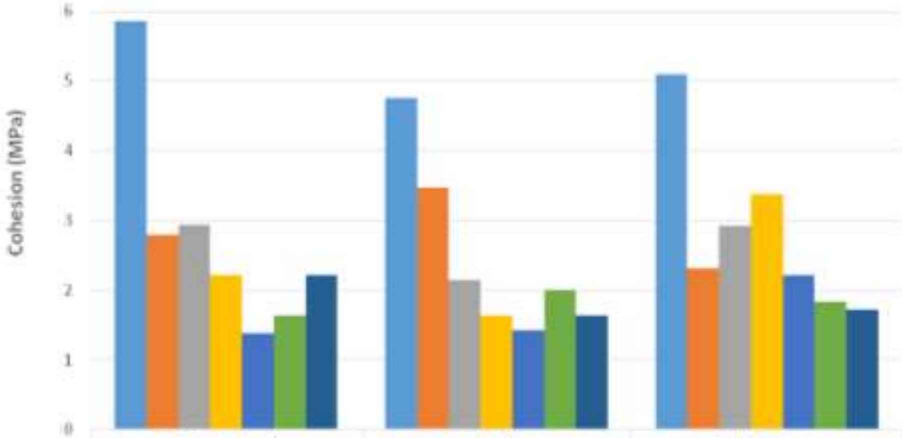
4.3 Comparison of shear parameter of different rock specimen



	Carbonate rock	Marl	Building stone
Intact	27.07	22.8	18.8
vertical cut	22.2	17.18	19.71
horizontal cut	19.04	15.78	15.67
inclined cut with 45º	20.85	13.46	13.18
inclined cut with 60º	17.4	12.07	12.49
Two inclined cut with 30º	13.47	12.11	11.08
Three inclined cut with 30º	9.84	10.69	9.96

Fig 12. Comparison of shear strength

As shown in the graph decrement in Shear Strength of carbonate rock is observed. the value of shear strength decreases by 17.99%, 29.66%, 22.97%, 35.27%, 50.27% and 63.64% for C_V_D/2, C_H_H/2, C_I_45°, C_I_60°, C_2I_30° and C_3I_30° as compared to intact rock specimen. Similarly for marl the value of shear strength decreases by 21.88%, 30.78%, 40.96%, 47.06%, 46.88%, and 53.11% for M_V_D/2, M_H_H/2, M_I_45°, M_I_60°, M_2I_30° and M_3I_30° as compared to intact rock specimen. Similarly for building stone the value of shear strength decreases by 4.84%, 16.64%, 29.89%, 33.56%, 41.66% and 47.02% for B_V_D/2, B_H_H/2, B_I_45°, B_I_60°, B_2I_30° and B_3I_30° as compared to intact rock specimen.



	Carbonate rock	Marl	Building stone
Intact	5.85	4.76	5.09
Vertical cut	2.8	3.47	2.32
horizontal cut	2.94	2.15	2.92
inclined cut with 45º	2.21	1.64	3.38
inclined cut with 60º	1.38	1.42	2.22
Two inclined cut with 30º	1.64	2.01	1.84
Three inclined cut with 30º	2.21	1.64	1.72

Fig 12. Comparison of cohesion

From the above graph value of cohesion is observed for carbonate rock to be decreasing by 52.21%, 49.74%, 62.22%, 76.41%, 71.96%, and 62.22% for C_V_D/2, C_H_H/2, C_I_45°, C_I_60°, C_2I_30° and C_3I_30° as compared to intact rock specimen. Similarly for marl the value of cohesion decreases by 27.10%, 54.83%, 65.55%, 70.16%, 55.88% and 65.55% for M_V_D/2, M_H_H/2, M_I_45°, M_I_60°, M_2I_30°and M_3I_30° as compared to intact rock specimen. Similarly for building stone the value of cohesion decreases by 54.42%, 42.63%, 33.59%, 56.38%, 63.85%, and 66.20% for B_V_D/2, B_H_H/2, B_I_45°, B_I_60°, B_2I_30° and B_3I_30°as compared to intact rock specimen.

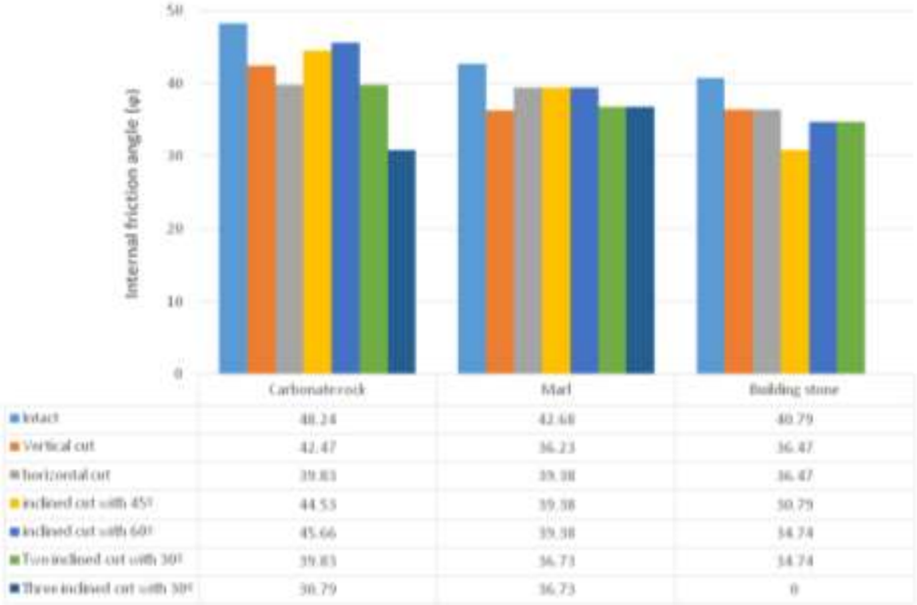


Fig 13. Comparison of internal friction.

From the above graph it is observed that the value of angle of internal friction for carbonate rock decreases to 11.96%, 17.43%, 7.69%, 5.34%, 17.43%, 36.17%, for C_V_D/2, C_H_H/2, C_I_45°, C_I_60°, C_2I_30°, C_3I_30° as compared to intact rock specimen respectively. Similarly for marl the value of internal friction decreases by 14.90%, 6.67%, 6.67%, 6.67%, 15.11% and 15.11% for M_V_D/2, M_H_H/2, M_I_45°, M_I_60°, M_2I_30°and M_3I_30° as compared to intact rock specimen. Similarly for building stone the value of internal friction decreases by 10.59%, 11.11%, 24.51%, 14.83%, 14.83% and 14.83% for B_V_D/2, B_H_H/2, B_I_45°, B_I_60°, B_2I_30° and B_3I_30° as compared to intact rock specimen.

4.4 Comparison of shear strength by taking in to consideration of its mineral variation

Hardness of rock is depending upon the calcite mineral. As the percentage of calcium carbonate increases in rock its hardness also increases. The value of shear strength of C_IR, M_IR and B_IR is 27.07 MPa, 22.80 MPa, 18.80 MPa respectively. From the graph it is observed that the value of shear strength is maximum in C_IR rock matrix. C_IR is intact specimen of carbonate rock. As the amount of calcium carbonate decreases the value of shear strength also decreases. B_IR has less shear strength compared to C_IR and M_IR. B_IR is intact sample of building stone and it contains silica more than calcium carbonate so the value of shear strength is found to be less in this type of rock. The value of shear strength decreases by 15.77% for M_IR and 30.55% for B_IR. It is also seen that as the number of cuts are increase the value of shear strength decreases because of reduction in weight density.

5 CONCLUSION

The presence of rock matrixes of carbonate sedimentary rocks has different effects on the engineering properties of rocks. The effects mainly depend on the numbers of joins, direction of applied loading with respect to orientation of joints, confining pressure and the spacing of joints in the specimen. The rock properties of rock matrix samples have been influenced significantly with the increase of numbers of joints in particular direction, confining pressure and spacing of joints. The above results and discussion have justified that each rock matrix have significant effects on the rock properties. Significant variation is observed in engineering properties of Carbonate sedimentary rocks due to change in orientation of cuts of rock samples. It is also seen that the mineral calcite has a great influence on the strength parameters of the rocks. The change in the engineering relevance of these properties directly influences the load carrying capacity of Carbonate sedimentary rocks. Load carrying capacity of the sample for matrix pattern to their corresponding intact rock, have shown considerable effects on various parameters resulting long-term structural changes attributing major change in shear parameters of rock.

6 REFERENCES

[1] Quantifying Rock Weakening Due to DecreasingCalcite Mineral Content by Numerical Simulations Maria Wetzel 1,2, *ID, Thomas Kempka 1,2 ID and Michael Kühn 1,2 I

[2] Liu D., Shao A., Jin C. and Yang L., 2018. Healing technique for rock cracks based on microbiologically induced calcium carbonate mineralization. Journal of Materials in Civil Engineering, 30(11), p.04018286.

[3] Arzua J. et al. 2014. "Strength and dilation of jointed granite specimens in triaxial test. International Journal of Rock Mechanics" @ Science direct. 69,93–104.

[4] 4.Cai M. et al. 2003. "Estimation of rock mass deformation modulus and strength of jointed hard rock masses" @ International Journal of Rock Mechanics. Mining Sciences & Science direct. 14,3-19.

[5] Evert H. et al. 2002. "Hoek-Brown failure criterion" @ NARMS-TAC Conference. Toronto. 1,267-273.

[6] Rao K. et al. 2016. "Rock failure pattern under uniaxial, triaxial compression and brazilian loading conditions" @ Indian geotechnical conference. Chennai.

[7] Alber M, Heiland J. "Investigation of a limestone pillar failure part 1: Geology, laboratory testing and numerical modeling" @Rock Mechanics and Rock Engineering2001;34(3):167–186.

[8] Bewick RP, Kaiser PK, Amann F. "Strength of massive to moderately jointed hard rock masses" @Journal of Rock Mechanics and Geotechnical Engineering 2019;11:562-575.

[9] Brown E. "Strength of models of rock with intermittent joints" @Journal of the Soil Mechanics and Foundations Division 1970;96(SM6):1935-49

[10] Bruning T, Karakus M, Nguyen GD, Goodchild D. "Experimental study on the damage evolution of brittle rock under triaxial confinement with full circumferential strain control" Rock Mechanics and Rock Engineering 2018;51:3321–3341.