



Full Length Research Paper

Influence of water content on Geotechnical Properties of Deccan Basalt, Maharashtra, India

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ABSTRACT

A number of civil projects are coming up in the hilly areas of the Maharashtra state, which gets adversely affected in the rainy season as document by the cases of slope failures, land subsidence etc. The present study on geotechnical properties of Deccan Basalt from Mahabaleshwar area, Maharashtra were studied to analyze the effect of moisture content. The important geotechnical parameters like, uniaxial compressive strength, point load strength, tensile strength, cohesion and angle of internal friction have been studied experimentally as well as the results have been analyzed numerically for verification of the same.

Keywords: Civil projects, Land subsidence, Geotechnical, Tensile strength

INTRODUCTION

Basalt is a grey to brown coloured, fine-grained, volcanic igneous rock, popularly known as Deccan Basalt in India, covers an area of 500,000 km² area in central region. Basalt finds its use as building material and ballast; crushed basalt is added to many construction jobs including asphalt paving, mixed with concrete, and as a rock filtering agent in many drain fields. It can also be cut into dimensional form and used as tiling for floors, producing veneers. A number of highways, underground and other civil projects are coming in the state of Maharashtra, India. The safety and sustainability of these engineering works is affected by the geotechnical properties of the basalt which get affected during the rainy season. Water plays an important role in influencing the geotechnical properties of Basalt.

Various important parameters that influence the geotechnical properties of basalt are grain size, grain shape, density, porosity, anisotropy, moisture content, confining pressure, temperature, weathering grade and alteration zones and joint properties (roughness, filling material, water, dip and strike, etc.) (Kahraman, 2001; Khandelwal and Singh, 2009). The knowledge of these properties of basalt are essential for the construction of engineering project like tunnels, dams, caverns, bridges,

cut bench slopes, deep trenches etc (Dubey and Singh, 2000; Monjezi and Singh, 2000). The properties of basaltic rocks have not been thoroughly characterized although the elastic and strength properties of intact samples of basaltic rock are well known. This deficiency can be attributed to the fact that the assessment of geotechnical properties of any rock

Geotechnical Investigations are mostly financed by large-scale engineering projects, relatively very few of which are located in the basaltic rocks (Dietz, 1985; Gupta and Daemen, 1988). Rigorous field and laboratory testing of basaltic rock and rock masses has been done as part of the large-scale Basalt Waste Isolation Project at the Hanford site, Washington State, during the late 1980's (U.S. Department of Energy, 1988; Cramer et al. 1987). The project report has provided a valuable new data base on the deformation properties of basaltic rock masses that can be used in geotechnical design, studies and construction activities. Basalts have also been studied at the Hanford site occur in central Washington State as part of the Columbia River Basalt Group (Reidel et al., 1989a). Extensive documentation of the igneous rock and structural settings of these rocks exists in the literature (Lumb, 1983; Reidel et al., 1989b) as well as some

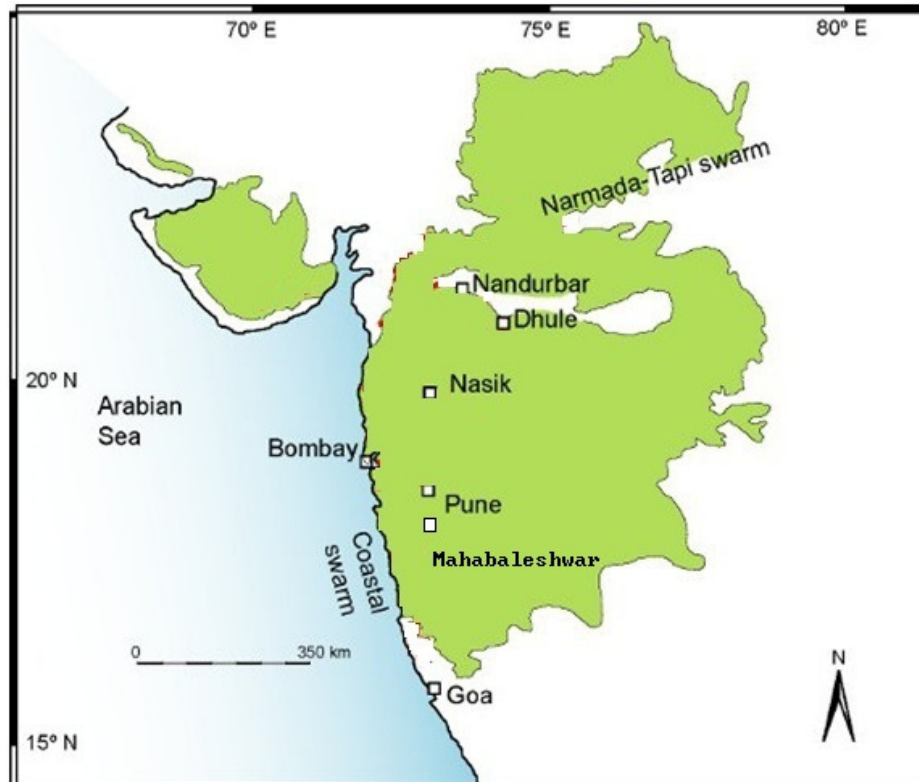


Figure 1: Schematic map of the Deccan Traps (Shaded), Modified after Hooper (1990) and Deshmukh & Sehgal (1988)

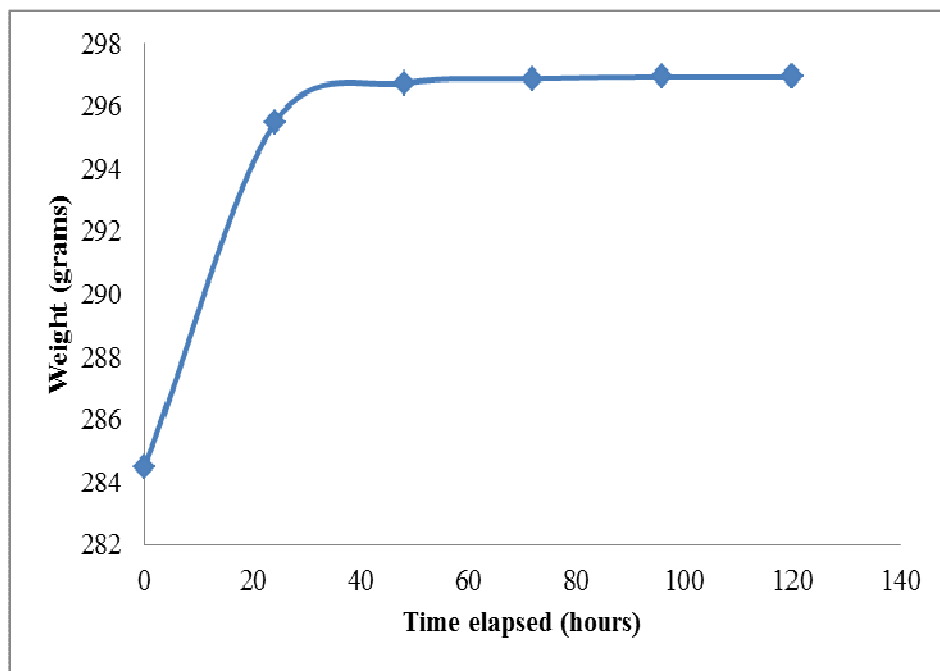


Figure 2: Increase in weight of a representative sample vs time under submergence in water.

Table 1. UCS of various samples of Basalt

Sr. No.	UCS (MPa), Dry	Moisture content (%)	UCS (MPa), Wet
1	58.67	1.26	55.23
2	59.01	1.2	57.01
3	55.02	1.52	50.56
4	50.23	1.88	48.96
5	45.36	2.22	38.27
6	47.39	3.12	32.09
7	45.02	3.52	31.85
8	44.27	3.75	32.29
9	56.02	1.39	53.39
10	55.02	1.45	51.08
11	59.26	1.27	55.52
12	57.06	1.96	52.89
13	58.09	1.86	53.9
14	65.26	1.39	59.97
15	55.96	1.71	47.2
16	70.26	1.29	68.34
17	72.09	1.19	69.91
18	71.23	1.25	68.08
19	69.33	1.18	67.47
20	65.29	1.21	63.54
21	60.11	1.28	57.85
22	45.23	2.12	38.9
23	46.28	2.23	39.28
24	47.45	2.46	40.56
25	44.98	2.39	37.95
26	48.23	2.29	42.12
27	47.24	3.22	33.01
28	44.02	3.59	30.81
29	43.27	3.85	31.29

Table 2. Tensile Strength of various samples of Basalt

Sr. No.	Tensile Strength (MPa), Dry	Moisture content (%)	Tensile Strength (MPa), Wet
1	8.29	1.32	7.81
2	7.85	2.11	6.37
3	7.52	2.45	6
4	6.66	3.61	5.85
5	8.56	1.19	8.01
6	7.6	2.29	6.29
7	7.57	2.35	6.09
8	8.32	1.25	7.85
9	6.77	3.49	5.92
10	7.82	2.19	6.25
11	6.98	3.09	6.06
12	6.89	3.28	6.01
13	8.45	1.21	7.9
14	8.28	1.31	7.8
15	6.95	3.2	6.15
16	6.9	3.25	6.07

Table 3. Point Load Index of various samples of Basalt.

Sr. No.	Moisture content (%)	PLI (MPa), Dry	PLI (MPa), Wet
1	3.33	2.85	2
2	3.35	2.75	1.95
3	3.31	2.38	1.72
4	2.25	3.12	3.02
5	2.2	3.23	3.11
6	2.15	3.29	3.23

Table 3. Continued

Sr. No.	Moisture content (%)	PLI (MPa), Dry	PLI (MPa), Wet
7	1.15	4.42	3.85
8	1.35	4.59	3.95
9	1.45	4.3	3.41
10	1.5	4.65	3.55
11	1.47	4.72	3.68
12	2.25	3.57	2.99
13	2.59	3.25	3.09
14	2.5	3.35	2.95
15	3.55	2.96	1.08
16	3.45	2.91	1
17	3.49	2.89	1.98
18	2.35	3.09	2.89
19	1.2	4.35	3.89
20	1.3	4.2	3.81

Table 4. Cohesion and Angle of Internal Friction of various samples of Basalt

Sr. No.	Moisture content (%)	Cohesion (MPa), Dry	Angle of Internal Friction (ϕ), Dry	Cohesion (MPa), Wet	Angle of Internal Friction (ϕ), Wet
1	3.23	13.5	39	12.01	37.7
2	3.26	13.2	38	11.98	36.5
3	3.25	13.29	38.3	12.25	36
4	2.25	14.82	38.98	14.91	39.6
5	1.23	16.99	42.9	16.01	42
6	1.89	15.29	40.24	15.1	38.4
7	1.59	16.65	42	15.99	40.08
8	1.33	16.75	42.2	15.93	41.35
9	1.39	16.74	42.5	15.92	41
10	3.5	13.01	37	10.92	35.01
11	2.29	14.21	39	12.08	36.41
12	2.12	14.58	40.46	14.99	41
13	2.19	14.45	40.35	14.85	39.85
14	2.33	14.92	40	14.1	39.05

Table 5. Young's Modulus of various samples of Basalt

Sr. No.	Moisture content (%)	Young's Modulus (GPa), Dry	Young's Modulus (GPa), Wet
1	1.69	44.26	44.01
2	1.21	49.36	48.2
3	1.3	48.29	46.29
4	1.29	47.19	46.01
5	1.23	50.19	49.02
6	1.18	54.26	53.39
7	1.13	53.16	52.95
8	2.29	42.1	40.02
9	2.2	45.15	43.09
10	1.23	51.26	49.9
11	3.11	38.29	35.07
12	3.09	38.67	36.2
13	3.1	38.6	34.91
14	3	39.26	36.49
15	1.81	43.96	42.51
16	1.65	44.58	41.02
17	1.29	48.3	46.85
18	1.59	46.29	43.95
19	3.15	39.56	36.09
20	3.2	39.26	36.5
21	1.26	49.11	48.05
22	2.25	45.24	43.23
23	2.28	44.12	40.09
24	2.3	43.19	41.11
25	2.45	43.08	41.89
26	3.21	38.49	36.07
27	3.15	39.67	37.12

geotechnical data on attributes such as fracture density and spacing (DOE, 1988). Limited studies have been performed on vesicular basalt by Franzone (1980) and Kelsall et al. (1986). Kelsall et al. (1986), correlated the porosity of vesicular basalt determined using the procedure suggested by Brown (1981), with its uniaxial compressive strength and deformability. However for weathered basalt, Tugrul and Gurpinar (1997) and Gu et al. (2008) have studied the geotechnical properties of the Basalts.

The aim of the present study is to examine the effect of variation in moisture content on the geotechnical properties of Deccan basalts of near the Mahabaleshwar area, India as numerous civil engineering activities are presently going on in Deccan basalts viz. road cutting, tunnels etc. In the rainy season various sliding activities occurs in road cut, in tunnel and various other construction works due to increase in the moisture content in the basalt and hence weakening the rock mass. All these mishaps call for a rigorous and intensive study of various geotechnical properties of Deccan basalts with varying moisture content. The basalt rock samples have also been numerically simulated in a finite element code at different moisture content to study the variation in deviatoric stress with material strength.

Geo-Tectonics of Deccan Basalt

Deccan volcanism, representing incredible eruption of volcanic activity, results an important episode in Indian geological history. It encompasses nearly two-thirds of peninsular India. The Deccan volcanic province is one of the most important and largest flood basalt provinces of the world. It has grabbed the attention of geologists because it coincided with the Cretaceous–Tertiary boundary ~65 million years ago (Duncan and Pyle 1988; Courtillot et al. 1988; Venkatesan et al. 1993; Baksi, 1994). The Deccan Traps are a large igneous province located on the Deccan Plateau of west-central India between 17–24N, 73–74E and one of the largest volcanic features on Earth surface erupting from large fissures (Figure 1). Deccan basalt consists of multiple layers of solidified flood basalt that together are more than 2,000 m thick and cover an area of 500,000 km². The original volume of the province has been estimated at approximately 1.5×10^6 km³ (Wadia, 1975; Eldholm and Coffin, 2000). The lava flows are dominantly tholeiitic basalts, with notable picritic and alkalic occurrences in the northwestern Deccan (Krishnamurthy and Cox, 1977). Several alkalic, acidic and carbonatitic complexes occur in scattered areas, often cutting through or overlying tholeiitic lavas (Mahoney, 1988).

Laboratory experimentation

Representative rock blocks were collected from the plateau region in the Satara district, Maharashtra, India,

from the road cuts for their analysis of geotechnical properties. The cores were drilled from the block using NX size drill bit for determination of physico-mechanical properties as per ISRM (1981a) specifications. All geotechnical properties like UCS, Tensile Strength (TS), Point Load Index (PLI), Cohesion, Angle of internal friction (AIF) and Young's Modulus were measured in dry as well as saturated conditions (Table 1,2,3,4 and 5). The samples were saturated for 120 hours and the increase in weight was measured periodically to replicate the effect of wet conditions in the rock (Figure 2).

Evaluation of experimental data

The presence of geographic barrier controls the rainfall in the state of Maharashtra, which is in the order of 400-6000 mm per years. To characterize the effect of water absorption during the months of monsoon on the geotechnical properties of basalt viz, UCS, Tensile Strength (TS), PLI, Cohesion, AIF and Young's Modulus a total of 127 samples were tested for both dry and wet conditions. The minimum and maximum values as well as the standard deviation for both in dry and saturated condition are given in Table 6.

The Basalt core samples with variable moisture content were tested in a UTM for their uniaxial compressive strength. The values of UCS have shown to decrease exponentially with the increase in moisture content for the rocks (Figure 4a). The UCS values are quite sensitive to the amount of water absorption (Figure 4b).

The behaviour was similar for tensile strength too where the relation was linear w.r.t the water absorption (Figure 5a). Basalt's tensile strength is clustered into three distinct zones which is due to their extent of weathering i.e. normal, moderately weathered and extremely weathered. The results here show maximas of Tensile strength at the minimas of moisture content and vice versa (Figure 5b).

The point load index and cohesion values shared a liner relation with the water absorption characteristics of the rock. (Figure 6a and 7a). In line with the previous observations, the highest peaks of point load index are those which have lowest moisture content and vice versa (Figure 6b and 7b).

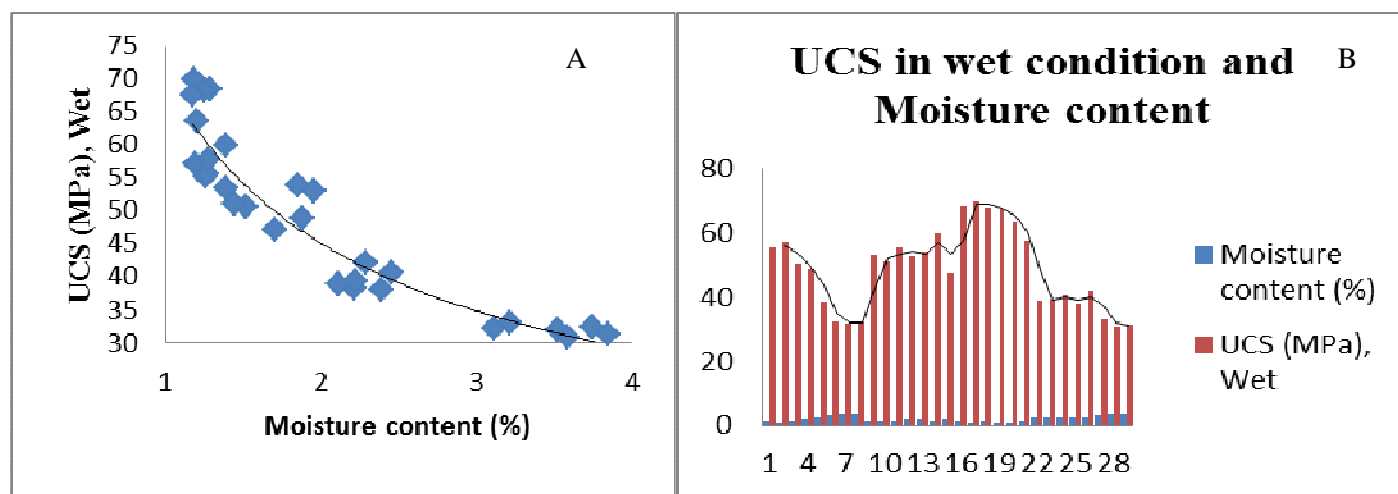
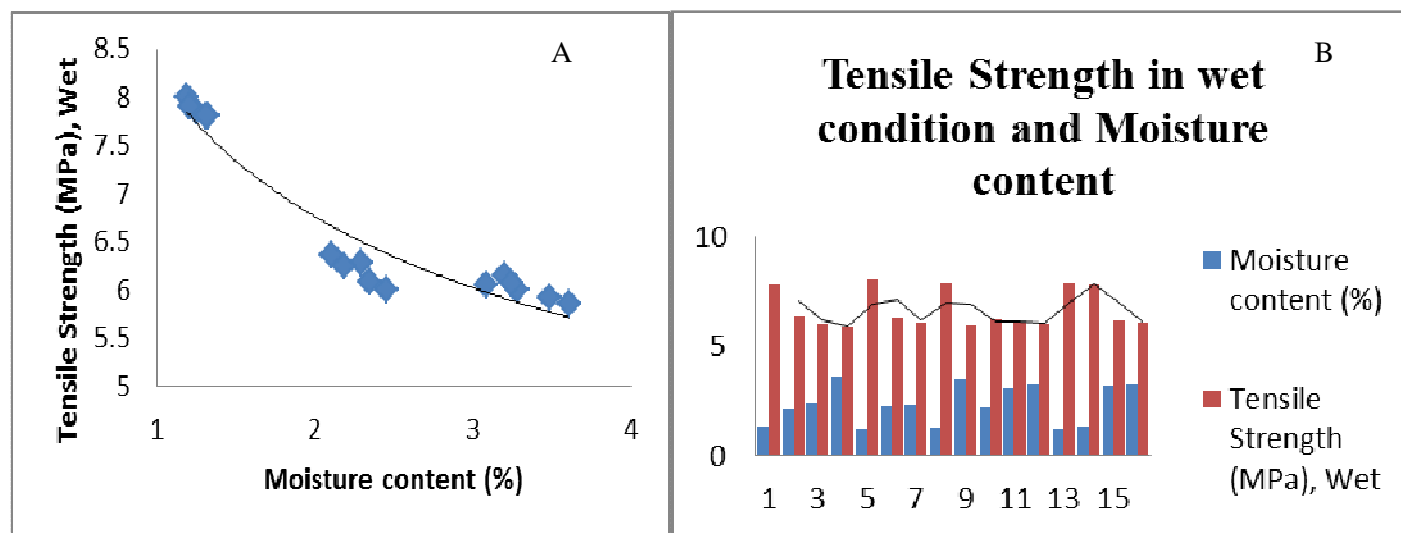
The angle of internal friction and youngs modulus values were tested to be decreasing exponentially with increase in moisture content (Figure 8a & 9a). From the histogram it can be scrutinized that the values angle of internal friction and Youngs modulus is maximum for the samples whose moisture content is minimum (Figure 8b and 9a).

Numerical Simulation of the Saturated Basalt rock samples

The NX sized basalt rock core sample was also simulated numerically in a 2D finite element code. The

Table 6. The Statistical observation of the experimental data

Sr. No.	Parameter	UCS (MPa)	Tensile Strength (MPa)	Point load Index (MPa)	Cohesion (MPa)	Internal Angle of Friction(ϕ) ($^{\circ}$)	Young Modulus (MPa)
1	No. of samples	29	16	20	42	42	27
2	Maximum Value (Dry)	72.09	8.56	4.72	13.99	42.9	54.26
3	Minimum Value (Dry)	43.27	6.66	2.38	13.01	37	38.29
4	Maximum Value (Wet)	69.91	8.01	3.95	16.01	42	53.39
5	Minimum Value (Wet)	30.81	5.85	1	10.92	35.01	34.91
6	Average (Dry)	54.71	7.59	3.54	14.88	40.07	44.62
7	Average (Wet)	48.59	6.65	2.86	14.07	38.85	42.59
8	Standard Deviation (Dry)	9.21	0.66	0.74	1.42	1.81	4.76
9	Standard Deviation (Wet)	12.0	0.86	0.92	1.83	2.22	5.52

**Figure 4:** Plot between UCS and Moisture content**Figure 5:** Plot between Tensile Strength and Moisture content

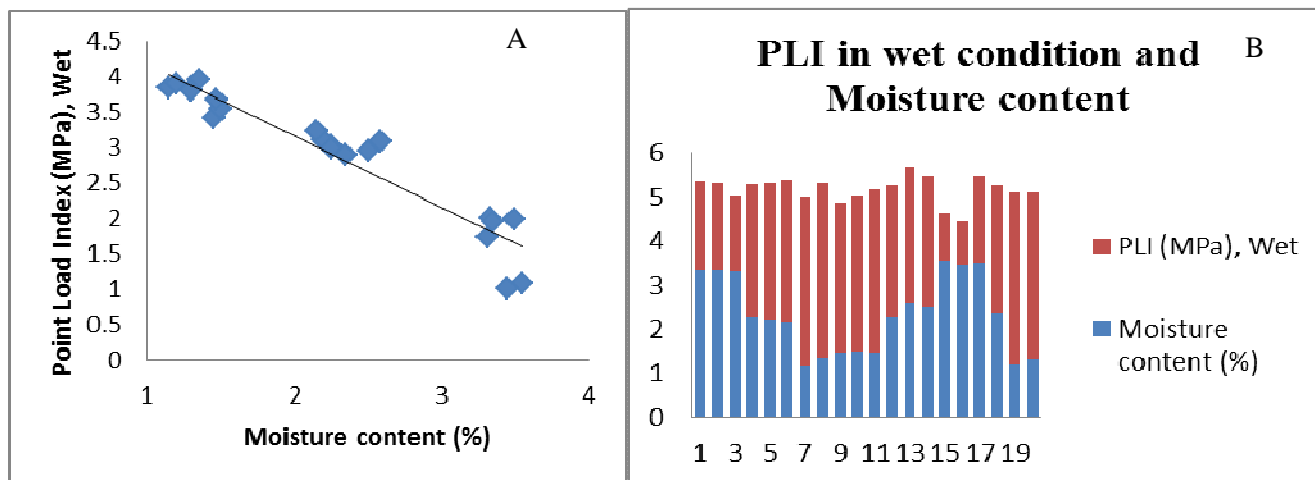


Figure 6: Plot between Point Load Index and Moisture content

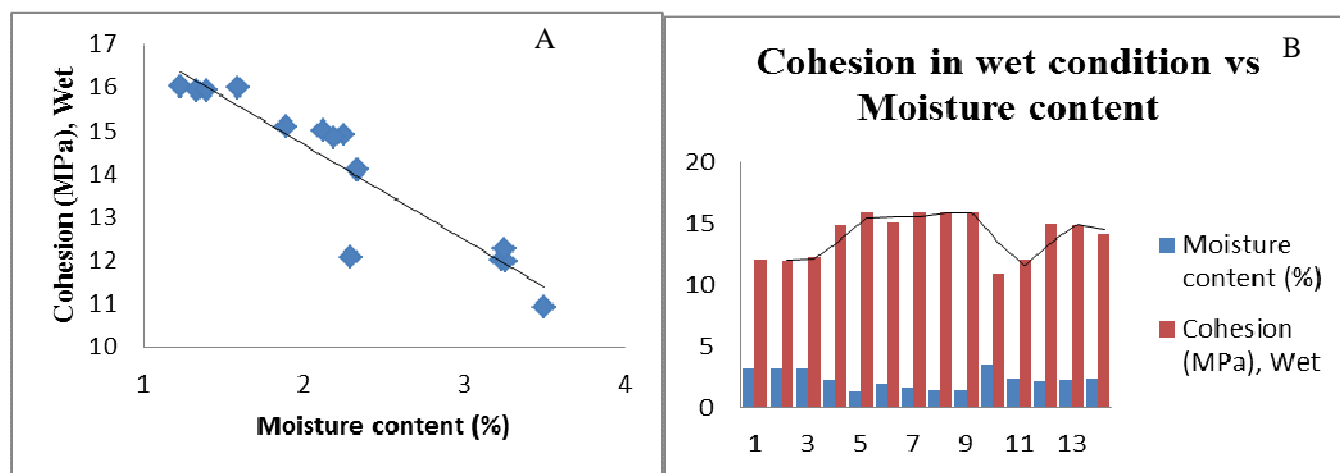


Figure 7: Plot between Cohesion and Moisture content

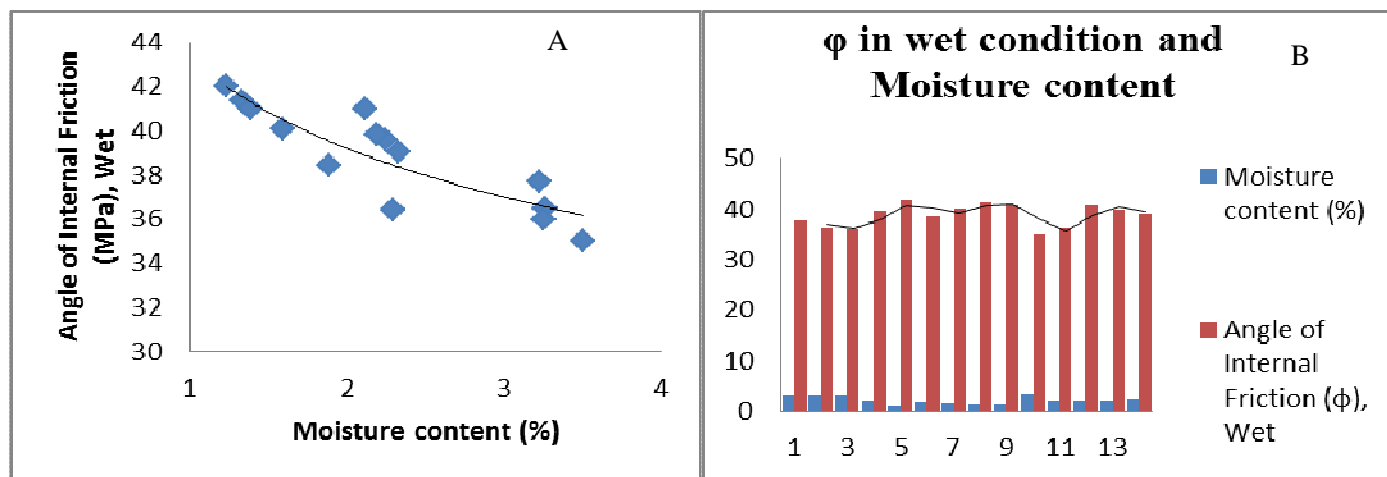


Figure 8: Plot between Angle of Internal Friction and Moisture content

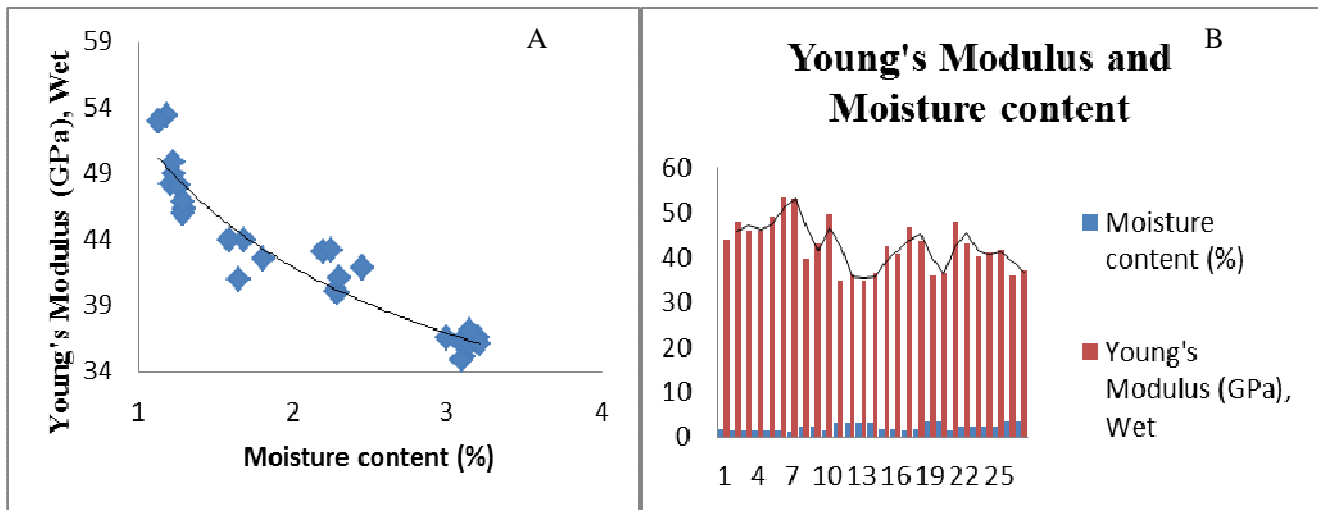


Figure 9: Plot between Young's Modulus and Moisture content

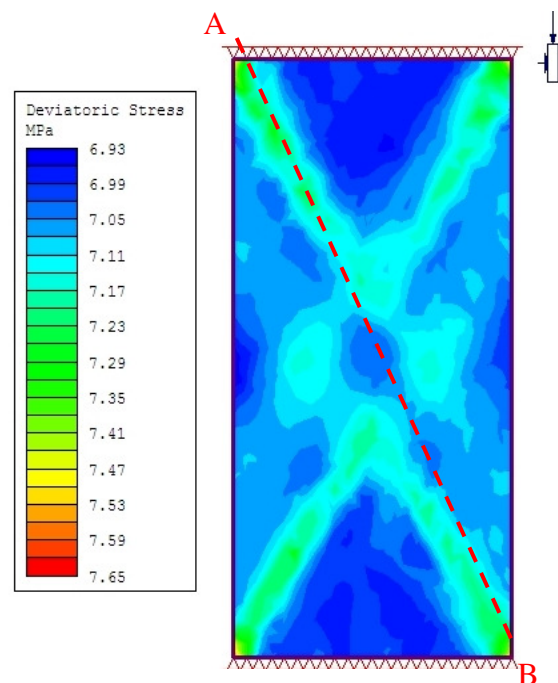


Figure 10. Deviatoric stress generation under compression at 2.75 % moisture content (24 hour's saturation).

study was undertaken to analyze the effective shear stress generation with augmented water content to verify the mechanical experiment. A two-dimensional four-noded quadrilateral mesh was generated for better discretization of the rock sample (Cook et al., 1974). Three different models with different rock cohesion and angle of friction based on the reduction of these properties as a function of moisture content. A uniform 60 MPa was applied on the rock core samples.

A maximum deviatoric stress of 7.47 MPa was generated in the rock core towards the edge when rock sample with 24 hours saturation having a moisture content of 2.75%, was numerically examined (Figure 10). Deviatoric stress divulges the information about the probable failure mechanics as well as the failure planes in the rock body (Figure 11 and 12).

The effective shear stress which has decreased with the increase in moisture content which invariably leads to

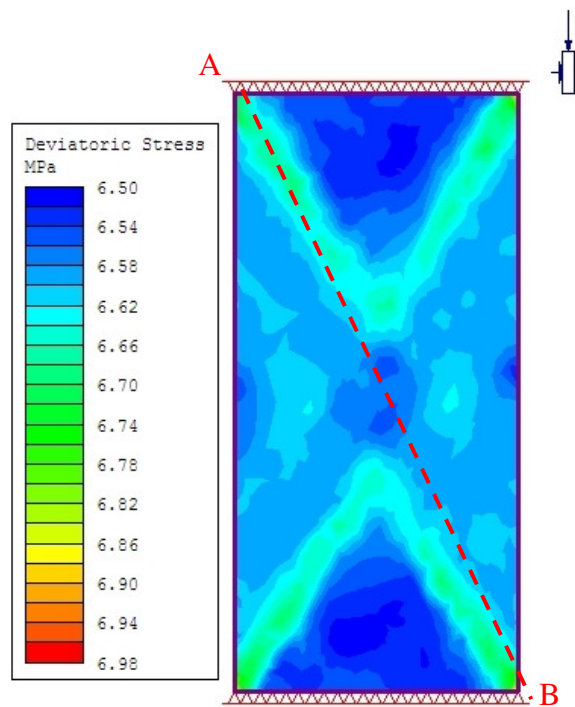


Figure 11: Deviatoric stress generation under compression at 3.45 % moisture content (48 hour's saturation).

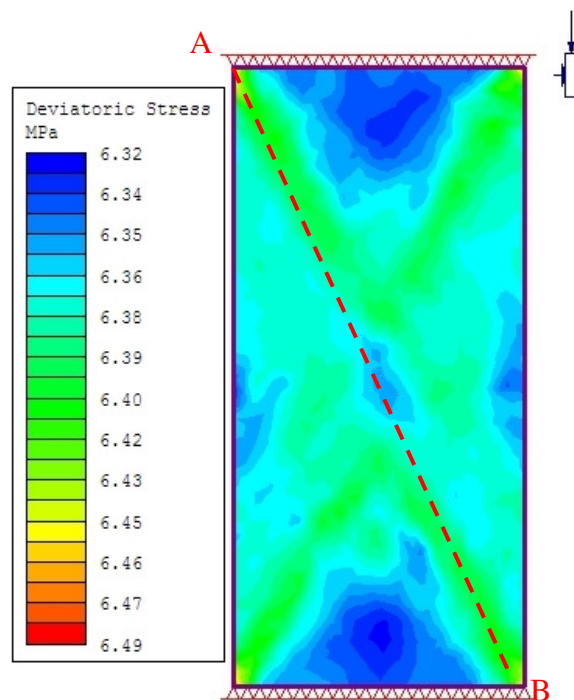


Figure 12: Deviatoric stress generation under compression at 3.85 % moisture content (72 hour's saturation).

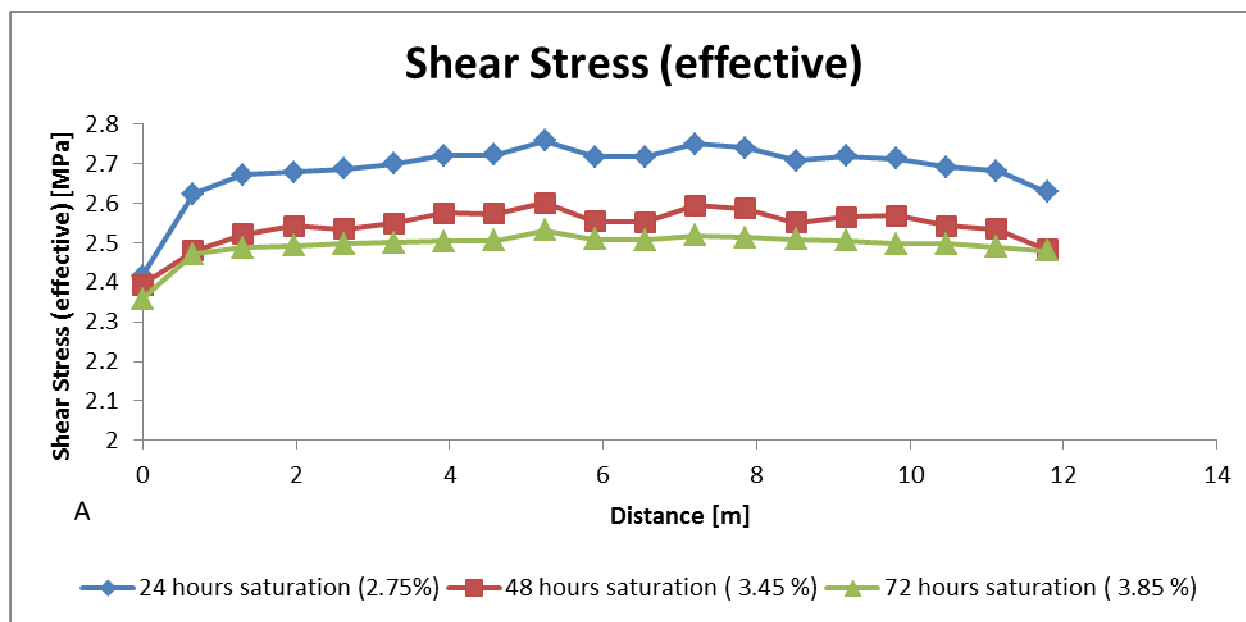


Figure 13: Variation of the effective shear stress generated along the line A-B with at varying moisture content

the reduction in strength (Figure 13). The effective shear stress has been measured along the shear plane A-B (Figure 10, 11 and 12).

Comparison with published data set

The Deccan basalts samples brought from the field were tested both dry and saturated for their different geo-mechanical properties. PLI and cohesion values varied linearly while UCS, TS, AIF and young's modulus altered exponentially. Results of the present findings for Basalt conform to that of Gu et al. (2008), who presented the correlation between geo-mechanical properties with their moisture content for the Basalt of Melbourne. He has correlated the properties like UCS, Young's Modulus and Point Load Index with moisture content.

Chiu (1981) also worked on the correlations between the intact rock strength (UCS) and intact rock modulus (E) with moisture content for siltstone (Melbourne Mudstone). A reasonable correlation between UCS, Young's modulus and moisture content had been found.

CONCLUSION

In the present study, for the first time the geotechnical properties of Deccan basalt were correlated with variation in their moisture content. With increase in moisture content, an exponential decrease was observed in case of UCS, Tensile Strength, Angle of internal friction and Young's modulus while the decrease was linear in the case of cohesion and Point load index. The scatter of the test results is probably indicative of the inclusion of test results biased by joint/fracture influences. Apart from that

the scatter can also be attributed to the inclusion of all available test data in the analysis without discrimination for possible non-representative data.

The numerical results also conform with the analytical results, showing a decreasing in load bearing capacity with increased moisture content.

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