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Geomechanical properties of volcanic rocks from Deccan Traps, India.

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SUMMARY: Volcanic rocks (Basaltic flows and pyroclastic deposit) have different geotechnical behavior as compared to non-volcanic rocks due to their more materials heterogeneity in nature. The variability of the composition, presence of voids, variable degree of cementing material and the geotechnical characteristics of inter bed unit in volcanic episode makes analysis and design of structures in volcanic rock more problematic. The aim of the present study is geotechnical characterization of Deccan trap volcanic rocks namely Compacted Basalt (CB), Volcanic Breccia (VB) and Tuff through laboratory teting and analysis. Block and core samples were collected from Deccan trap and then specimens prepared for petrographical studies and geotechnical property determinations as per standard protocols. The specimen prepared for petrographical studies analysed under Scanning Electron Microscope (SEM) with Energy Dispersive X-ray (EDX) to measure the microstructure and material composition of the three rocks. In addition to that the Index properties example density, specific gravity, porosity and water content were determined according to international society of rock mechanics (ISRM) protocols. The mechanical behaviour including compressive, tensile and triaxial strengths were also experimentally measured. The geotechnical property obtained through testing and analysis compared with literature and presented here in. The present work contributed geotechnical property of three volcanic rocks that can be used in primary design parameters assessment for the study area and in similar volcanic rocks elsewhere.

KEYWORDS: Geotechnical Property, SEM, EDX, Volcanic rocks, Deccan trap.

1. INTRODUCTION

The Deccan traps are a large volcanic 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 lava fissures that are few meters to more than 2,000 m thick and cover an area of more than 500,000 km^2, (Duncan and Pyle 1988; Courtillot et al. 1988; Venkatesan et al. 1993; Baksi, 1994).

In the pre-historic era huge construction of forts, caves took place over Deccan traps whose traces still continues to exist.

The famous Ajanta Caves in Maharashtra built in 2nd Century B.C. by carvings on the basalt. Many major projects like Koyna hydropower project, communication tunnels (railway and highways), and high rise buildings of Mumbai and Pune cities have been built in/and on of Deccan traps volcanic rocks in the past century. Between Mumbai-Pune cities alone 10 communication tunnels are there, and more than a dozen sites where excavation, quarrying and construction were ongoing.

Deccan Trap still continues to be an important site for many construction projects and Basalt as an important construction material. Recently many construction activities are going on and the scale and scope of construction is going to increase in future.

Not only with respect to construction activities the study of Deccan traps is also important to understand various problems like landslides, slope failures, earthquakes etc. That are arising causing danger and damage to life and property. This reveals the importance of the geotechnical studies and investigations to evaluate the geotechnical properties of volcanic rocks.

However, geotechnical properties of Deccan trap volcanic rocks are very scarce. The available literature on engineering properties and behaviour of Deccan trap rocks focusing on compacted basalt only. Engineering behaviour of fresh and weathered of these rocks exposed at Nagpur extensively studied by Gupta (1997); Gupta and Rao (2001); and similarly Tugrul and Gurpinar (1997) reported on the effect of weathering on compacted basalt.

The effect of moisture content on (UCS and young's modulus of Compacted Basalt also performed by Gu et al. (2008) and presented the correlation between geo-mechanical properties with their moisture content for the Compacted Basalt of Melbourne.

The influence of moisture content on geotechnical properties (UCS, Point load, tensile strength, shear strength parameters) of compacted basalt near the Mahabaleshwar area, Satara district, Maharashtra conducted by Verma et al. (2014).

Limited studies have been performed on vesicular basalt by Franzone (1980) and Kelsall et al. (1986). The later scholar correlated the porosity of vesicular basalt determined using the procedure suggested by Brown (1981), with its uniaxial compressive strength and deformability. However because of the volcanic environment the volcanic rocks in Deccan trap heterogeneous that is found in random deposition. Most abundantly occurring Deccan trap rock are Basalt.

Figure 1: Quarry site on Mumbai-Nashik Highway 10 km from Mumbai city.

Figure 2: Dumping Site of Koyna Dam Volcanic Rocks.

Figure 3:Quarrying Site Just Outside the Satara district.

Most Basalts are:Compact Basalt (Basalt without gas cavities), Vascular Basalt (Basalt with empty gas cavities), Amygdaloidal Basalt (Basalt with gas cavities filled with white secondary minerals such as calcite, quartzite or zeolite or dark green coloured chlorophaetite) these volcanic rocks predominently found at mumbai-pune –Satara and Koyna region and other common Deccan trap volcanic rocks are volcanic Breccia, Tuff, Trachyte, and Rhyolite underlain Bombay city and laterite commonly found at Koyna region.

The aim of the present study are to contribute on geotechnical charcaterization of deccan trap volcanic rocks namely Compacted Basalt, Volcanic Braccia and Tuff of Mumbai, Pune-satara-koyna region through laboratoy analiysis and testing.

2. LOCATION AND DESCRIPTION ROCK SAMPLES

2.1 Location of the rock sample

The three lithology of Deccan trap volcanic rocks studied in the present work collected from Mumbai-Pune –Satara-Koyna area. Compacted Basalt from stone quarrying on West Thane, Godhbundur, and 10 Km from the Mumbai-Nashik Highway. Tuff from already drilled bore hole for subsurface investigation of Imperial 3 tower (The proposed Structure are G + 80 to 100 storey residential tower with six levels of podium) at M.P.Hill Compound at Tardeo, Mumbai and Volcanic Breccia from rock outcrops on the Outskirts of Lonavala and around Koyna Hydropwer project.

2.2 Description of the lithology

2.2.1. Compacted Basalt (CB)

The compacted basaltic volcanic rocks are exposed at the surface in Deccan Trap. This compacted basalt exposed at west Thane Gondhbundur have a concrete appearance with very fine grained. The rock is compact and dense in nature (Fig.4a and b).

For detailed petrographic analysis, Scanning electron microscope (SEM) with energy dispersive X-ray (EDX) was employed to measure its surface topography, microstructure and chemical composition. Fig.4a and b shows the SEM images of typical compacted basalt sample at magnification factors 1000x and 10000x respectively. Similarly for Tuff at 1000x and 2000x (Fig. 4 e and f).

As increasing magnification the clarity of microstructures, grain surface and arrangement is increased. The SEM image clearly shows that the crystal structure of compacted basalt is laminated, glossy and more orderly structured surface (Fig.4 a and b). These features show that the Compacted Basalt is formed by immediate cooling of lava flows.

While Volcanic Breccia and Tuff shows fragments of irregular minerals (Fig.4c and d) and presence of dull surface and cavities (Fig.4e and f). This type of pyroclastic material (Volcanic Breccia and Tuff) formed when fragments of volcanic material cemented together by fine materials during volcanic episode.

On hand inspection of specimens of Volcanic Breccia characterized by having large size fragmented of volcanic material cemented with fine matrix while Tuff are characterized by poorly/well cemented volcanic materials.

Element composition of the sample was analyzed with EDX module and the results are presented in Table 1. This table indicates that oxygen (O), silica (Si), ferrum (Fe), aluminum (Al) and calcium (Ca) are the primary elements in the Compacted Basalt, accounting for nearly 90% of the gross weight. Other elements, such as magnesium (Mg), Sodium (Na), potassium (K) and titanium (Ti), can also be observed but with low content.

The chemical element constitution of compacted basalt and tuff are same. However the amount of oxygen (O), aluminum (Al) and Sodium (Na) of Tuff is more than that of compacted basalt in gross weight percentage while the amount of Mg and Fe is more in Compacted Basalt with compared to that of Tuff (Table 1). It is conformed during hand specimen examination of Compacted Basalt and Tuff that the Tuff has light color and less density than Compacted Basalt due to the presence of magnesium (Mg) and ferrum (Fe) which gives dark color and heavier weight for compacted basalt.

2.2.2 Volcanic Breccia (VB)

This black grey color rock is coarse grained with white spots distributed all over the specimens. Large size fragments are seen distinctly. The rock is very clastic (Fig.4c and d).

Table 1. Chemical element constitution

Element	Deccan Trap Volcanic Rock					
	Compacted Basalt		Volcanic Breccia		Tuff	
	Wt (%)	Atom (%)	Wt (%)	Atom (%)	Wt (%)	Atom (%)
O	48.67	65.99	56.06	70.64	50.04	66.81
Si	16.61	12.83	12.35	8.86	18.18	13.83
Fe	11.12	4.32	7.31	2.64	10.51	4.02
Al	7.09	5.70	6.40	4.78	7.96	6.30
Ca	6.62	3.58	7.66	3.86	4.80	2.56
Mg	3.73	3.33	3.70	3.07	2.05	1.80
Na	2.77	2.61	2.25	1.97	3.42	3.17
C	-	-	1.82	3.05	-	-
Ti	2.42	1.09	1.36	0.57	1.46	0.65
K	0.96	0.54	1.10	0.57	1.58	0.87

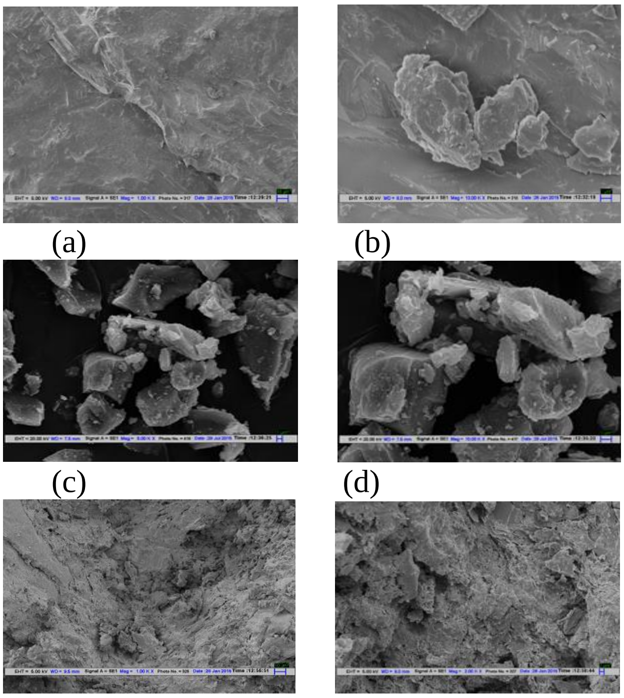

Figure 4: SEM images of Compacted Basalt (a and b), Volcanic Breccia (c and d) Tuff (e and f) at different magnification factors.

Figure 4c and d shows the SEM images of typical Volcanic Breccia sample at magnification factors (5000x) and (10000x). From these SEM images, fragment of rocks and elongated and surrounded quartz clearly visible (Fig.4c and d).

The element composition of the sample was analyzed with EDX module and the results are presented in Table 1. This table indicates the amount of oxygen (O), silica (Si), calcium (Ca), ferrum (Fe) and aluminum (Al) in decreasing order.

Like Compacted Basalt the amount of magnesium (Mg) and ferrum (Fe) is more than that of Tuff. Unlike Compacted Basalt and Tuff, in this rock new mineral containing carbon (C) is observed in less than 2% in gross weight.

2.2.3 Tuff

This greenish brown color volcanic rock primarily contains ash and fragments of very fine to medium size (Fig.4 e and f). This (Fig.4e and f) shows the development of voids, which indicates the porous nature of the Tuff rock. The EDX analysis for this rock is presented in Table 1. The detail chemical element constitutes analysis given under compacted basalt with comparison.

3. EXPERIMENTAL DESIGN FOR MECHANICAL TESTS

3.1 Specimen preparation

Three types of specimens were prepared for physical and engineering property determination (Fig.5).

Figure 5: Specimens prepared for different types of mechanical tests.

The rock specimens required for different strength tests i.e. tensile (L/D=0.5), uniaxial and triaxial (L/D=2) were prepared as per ISRM protocols. The tolerance limit suggested by ISRM (1981) were adhered while preparing individual specimens for all three varieties of rock samples (Fig.5).

From each categories of rocks i.e. Compacted Basalt,Volcanic Braccia and Tuff, the samples are prepared for determination of physical properties. The physical properties includes the dry density, specific gravity and porosity. The average and representative values of physical properties for the three volcanic roks of deccan trap are presented in table 2.

4. EXPERIMENTAL RESULTS AND ANALYSIS

4.1 Tensile Strength (σ_t)

The Brazilian strength (indirect tensile strength) test results for the specimens tested and the mean values for the three volcanic rocks types are presented in (Table 2). The Brazilian strength for Comacted Basalt specimens is 19.67 MPa which is much higher than the others two volcanic rock types, followed by tuff and volcanic breccia. These values are comparable with values form the literature for the respective catagories (Table 3). The failure modes in Brazilian test for the rocks tested are shown in the Fig 6. It is to be noted that there is a considerable variations of strength values in each categories in this type of tests.

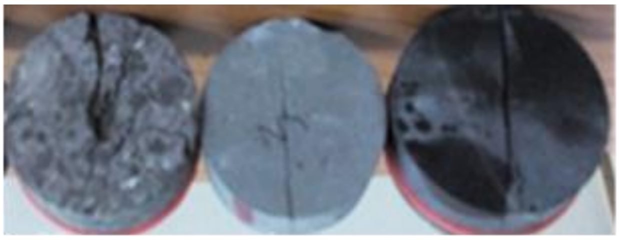

Figure 6. Typical failure patter under indirect tensile test.

4.2 Uniaxial Compressive Strength (σ_C)

The Uniaxial Compressive Strength test is conducted on (L/D = 2) specimens for the three deccan trap volcanic rocks. Table 2 gives the tangent modulus (E_t) values determined at 50% of ultimate load and UCS values for different rocks. The UCS values are ranging for Compcated Basalt from 55.24 to 97.26MPa, for Tuff from 31.8 to 41.59MPa, and Volcanic Breccia from 20 to 43.38Mpa.

Similar to the UCS values and Modulus values are very high for the Copacted Basalt, followed by Tuff, and Breccia.

Figure 7.Typical failure patterns under uniaxial compression tests.

4.3 Triaxial Shear Behaviour

A large number of triaxial compression tests at different confining pressures where conducted on specimens from the three catagories of deccan trap Volacanic rocks. The test result are summarized in Table 2 for all the three volcanic rocks. As expected failure stress increases with increasing confining pressure for all specimens. The strength envelopes i.e. σ_1 vs. σ_3 for all the rocks are given in Figures 8, 9, and 10.

They are fairly linear within the range of confining pressures adopted in the testing. The shear strength parameters c and ϕ values are obtained from ploting Mohr envelopes (Fig.11,12 and 13) and p-q plots (Fig.14) for Compacted Basalt, (Figure 15) for Tuff and volcanic breccia.

The c and ϕ values are indicated in the tables as well as Fig.11-15. Compcated Basalt specimens registered very high value of ϕ as expected.

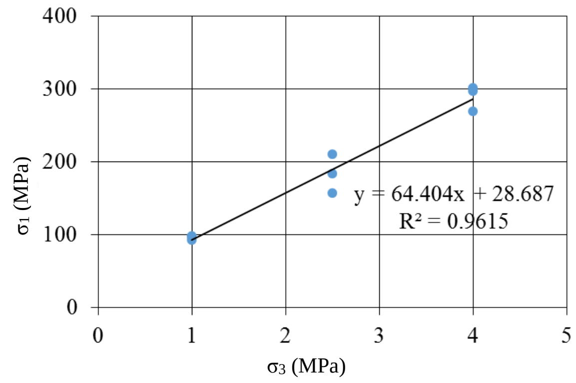

Figure 8: σ_1- σ_3 Plot of CB.

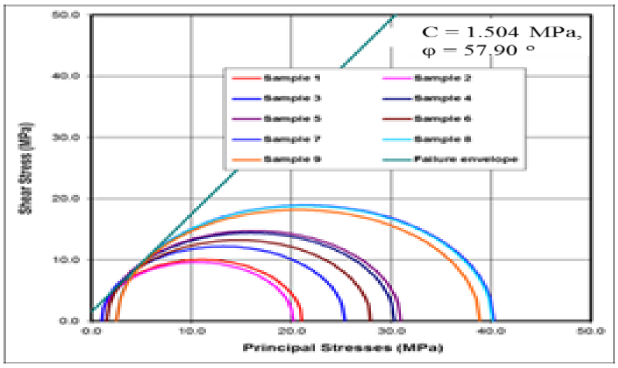

Figure 12: Mohr Envelopes for VB.

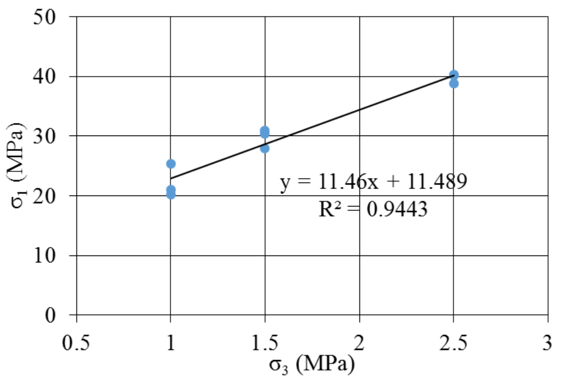

Figure 9: σ_1- σ_3 Plot of VB.

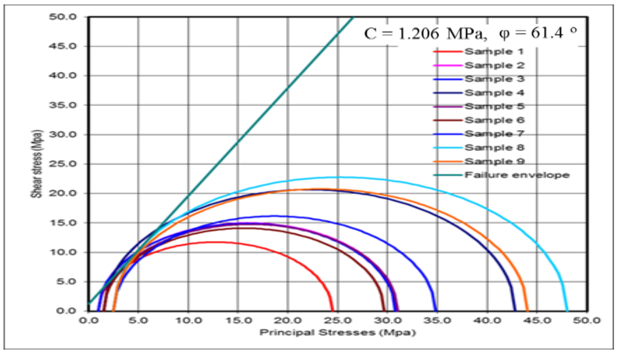

Figure 13: Mohr Envelopes for TUFF

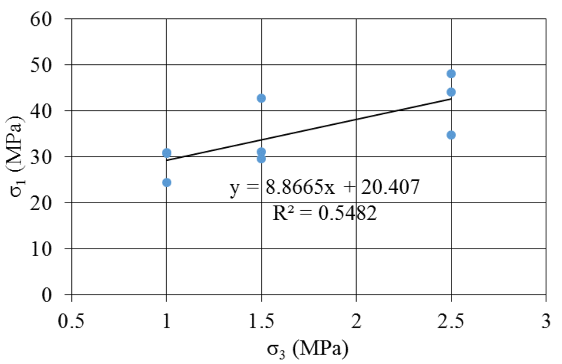

Figure 10: σ_1- σ_3 Plot of Tuff.

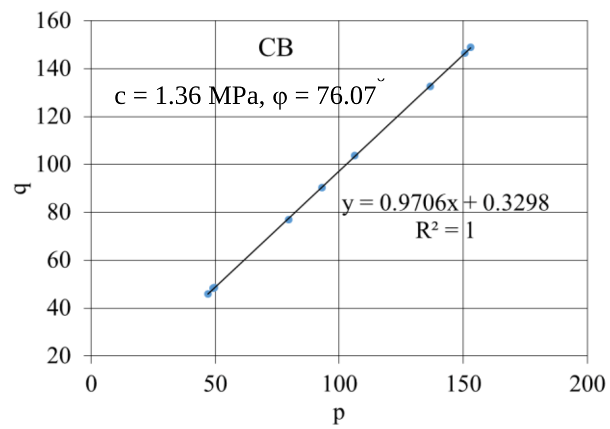

Figure 14.: p-q Plot of CB. Values in Mpa

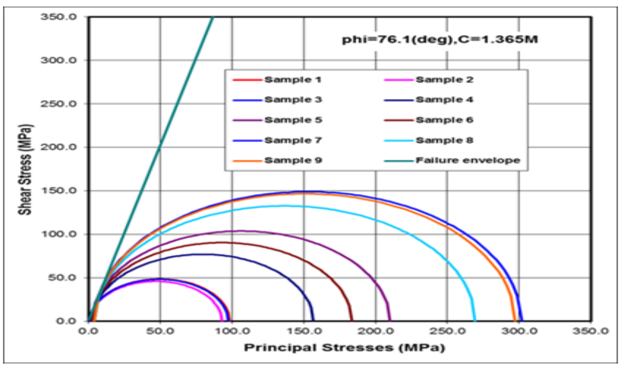

Figure 11: Mohr Envelopes CB.

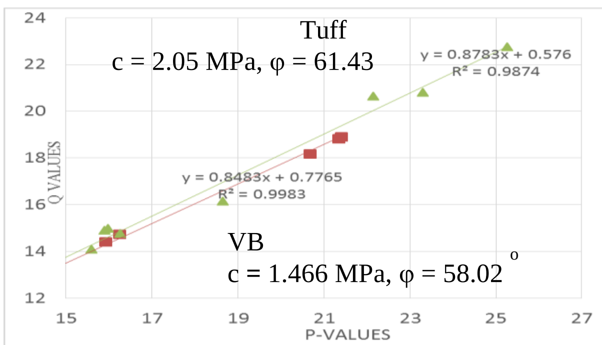

Figure 15: p-q Plot of Tuff and VB. Values in MPa

Table 2. Summary of Geotechnical properties of Deccan Trap rocks.

Geotechnical property	Compactd Basalt	Volcanic Beraccia	Tuff	No.of Tests
δ_{dry} (KN m^3)	28.452	21.882	20.408	12
G	2.80	2.78	2.58	12
n (%)	1.3	16.40	10	12
σ_t	17-22	33-5	4-9	10
σ_C (MPa)	55-100	20-44	24-34	16
E (Gpa)	17-21	2-15	2-13	16
c (MPa)	1.365	1.504	1.206	9
ϕ (°)	76	57	61	9

Where: δ = Density,G = Specific gravity, n = porocity , E =Youngs modulus.

5. COMPARISION OF THE RESULT

Volcanic rocks have different geotechnical behavior as compared to other non-volcanic rocks. There are two types of volcanic rocks (1) lava flow (Basalt) and (2) pyroclastic rocks such as volcanic Breccia and Tuff.

The unique geotechnical behaviour of volcanic rocks is given by Menénde et al. (2010). Accordingly, the behavior of the lava flow depends mainly on presence of vesicular in intact and rock mass where as the pyroclastic rocks are mainly dependent on resistant characteristics of the rock matrix that cemented together the material. These behaviors are observed during the present mechanical testing on Compacted Basalt and pyroclastic material (Volcanic Breccia and Tuff) of Deccan trap rocks. Compacted Basalt is the most reported volcanic rocks in literature (Table 3) as compared to the other volcanic rocks such as Volcanic Breccia and Tuff.

However, as discused above in volcanic enviorment the heteroginity of rocks in terms of stregth is more, which ranges from low strength (28 MPa) to very high starength (224 MPa) as per Deere and Miller clasification sysytem. Therefore while desgning structures in volcanic enviorment, each and every volcacnic rocks should be charecterized differently and their respective engineering properties should be estimated properly. However, in most of the heavy rock engineering practcise such as Roller-compacted concrete (RCC) and deep and long tunnel in volacnic rocks the generalized engineering properties of volcanic material are used for numerical modeling and designing. In the present stage of rock mechanics development the practice on the ground are old traditional for such material.

Table 3:Comparesion of test result with literature

Rocks	σ_c (MPa)	c (MPa)	ϕ (°)	E (GPa)	Refrences
CB	55-100	1.365	76	17-21	Present work
	43-73	14.88	40	38-43	Varma et al. (2014)
	25-160 (40-80)	-	40-55	15-30	González de Vallejo et al.(2008)
	169-174	-	-	32-59	Gupta and Rao (2000)
	25-400 (50-100)	-	-	20-70	Deere and Miller 1966
VB	20-44	1.504	57	(2-15)	Present work
Tuff	31-42	1.206	61	(2-13)	Present work
	1-50	0-1.45	12-30	0.1-22	González de Vallejo et al.(2008)

Note:The values in the bracket are the most frequently registared test result values.CB:Compacted Basalt,VB: Volcanic Breecia .

6. CONCLUSIONS

This paper studied the geotechnical characterization of three volcanic rocks namely compacted Basalt, Volcanic Breccia and Tuff from Deccan Trap, India. The compression, tensile and triaxial strengths were measured by uniaxial compression system, indirect tensile testing and triaxial compression tests. From these, crushing strength, tensile strength and shear strength parameters at different confining pressure were obtained. The UCS values are ranging for Compcated Basalt from 55.24 to 97.26 MPa, for Tuff from 31.8 to 41.59MPa, and Volcanic Breccia from 20 to 43.38 MPa The mean Tensile strength for Comacted Basalt specimens is 19.67 MPa which is much higher than the others two volcanic rock type, followed by Tuff and Volcanic Breccia (Table 2). Compcated Basalt specimens registered very high value of ϕ (76^0) as expected. In general, for Volcanic Breccia the geotechnical properties are more variable than Compacted Basalt and Tuff of Deccan Trap volcanic Rocks. Similarly the failure patterns of Volcanic Breccia is more complex than those observed in CB and Tuff.

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