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Characterization and evaluation of continental basalts from two sites in Maharashtra using ultrasonic measurements in the laboratory

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ABSTRACT

The Deccan volcanic province comprises ~3.4 km thick ~65 Ma tholeiitic basalt flows with subordinate amount of alkaline and picritic basalts. The flows show a wide range of texture and microstructures. These rocks are widely used as a main construction material in various engineering structures in India, where these rock formations are exposed. Therefore, understanding of their physico-mechanical properties is useful to determine their suitability as the construction material. We studied basalt samples from the Khadakpurna link canal project site and the Koyna borehole. Density, ultrasonic P-wave velocity (V_p) and Uniaxial Compressive Strength (UCS) of these samples were measured and Schmidt's hardness and United Alteration Index (UAI) were derived. The results show that the Khadakpurna samples show a wide range of V_P from 3578 m/s to 5163 m/s, while the Koyna samples show a narrow range, from 5617 m/s to 5789 m/s, indicating the effect of weathering on the ultrasonic P-wave velocity. Accordingly, the other properties such as density, uniaxial compressive strength, Schmidt's hardness, United Alteration Index (UAI) are also found to vary significantly. When the results of these two sites are compared, the Koyna rocks can be used for building heavy engineering structures.

INTRODUCTION

Physical, mechanical and engineering properties of rocks are very important in civil engineering works such as underground structures, dams, foundations on rock, canals and rock slopes. The Deccan basalt province (Fig.1) is spread over an area of ~500,000 km^2, which consists predominantly of tholeiitic basalts, with subordinate amounts of alkaline and picritic basalts. The total thickness of the entire Deccan basalt sequence is ~3.4 km, containing three subgroups and eleven formations, of which the basalts of Ambenali Formation are largely exposed on the southern part of the Deccan province (Senthil Kumar, Rajeev Menon & Koti Reddy 2007). The basalts flows are largely exposed in the Indian states such as Maharashtra, Madhya Pradesh, and Gujarat, where these rocks are largely used as the construction material for various geo-engineering structures. It is also well known that basalts are used as aggregate in engineering materials such as portland cement, concrete and asphaltic concrete, rock fill for dams and breakwaters, material for roads (Goodman 1993). The quality of the aggregates depends on the physico-mechanical properties of source rock (Hartley 1974; Ramsay, Dhir & Spence 1974). The geo-mechanical properties of the basalts are influenced by weathering (Kocbay & Kilic 2006). The engineering properties of basalts can vary significantly due to the weathering and the presence of vesicles (Harthi, Amri & Shehata 1999). Hence, it is essential to characterize the basalts of interest. Ultrasonic P-wave velocity (V_p) is one of the non-destructive methods to characterize the rock samples. Therefore, we have carried out density and ultrasonic P-wave velocity measurements and uniaxial compressive tests on basalts from two engineering project sites namely, Khadakpurana link canal project and a borehole drilled near Koyna reservoir (Fig.1) for characterization and estimation of the engineering properties of basalts.

EXPERIMENTAL DETAILS

The rock samples of the Khadakpurna are weathered basalts. The borehole samples of Koyna are massive basalts. The sample locations of Khadakpurna link canal and borehole drilled at Koyna are shown in Figure 1.The test samples have been prepared in the form of right circular cylinders (30 mm diameter and

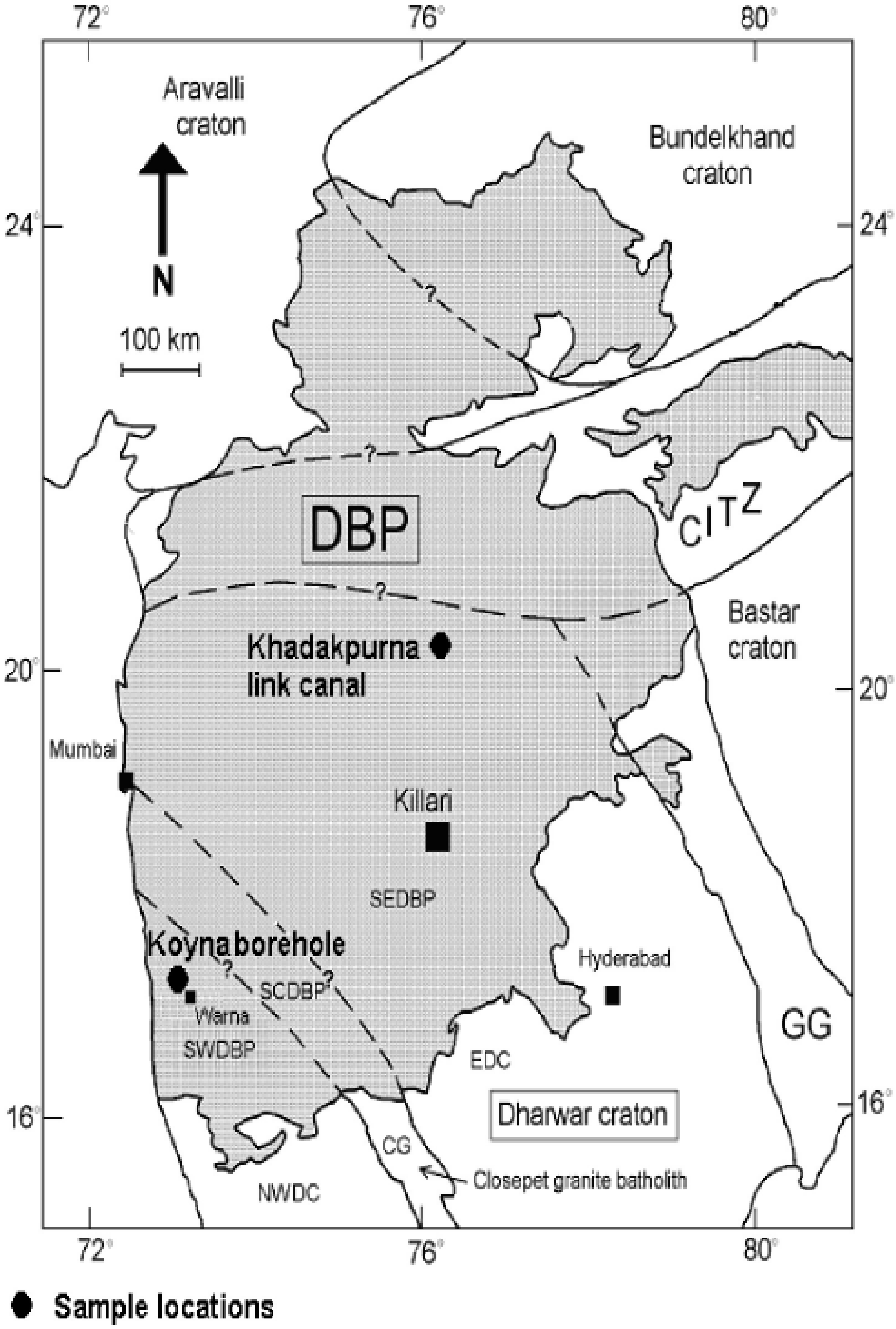

Figure 1. Sample locations of the Khadakpurna link canal project site and the borehole drilled at Koyna are shown in the geological map with the boundary of Deccan basalt province, surrounding cratons and the Proterozoic fault systems (Senthil Kumar, Rajeev Menon & Koti Reddy 2007). Abbreviations used: NWDC – Northwestern Dharwar Craton, CG – Closepet Granite, EDC – Eastern Dharwar Craton, SWDBP – southwestern Deccan basalt province, SCDBP – Southcentral Deccan Basalt Province, SEDBP – Southeastern Deccan Basalt Province, GG – Godavari Graben, DBP – Deccan Basalt Province, and CITZ – Central Indian Tectonic Zone.

Table 1. The physical, mechanical and engineering properties of basalts from Khadakpurna and Koyna, Maharashtra.

Sample No	Weathering state	Density g/cm^3	V_P m/s	UCS MPa	Schmidt's hardness	UAI
Khadakpurna						
A 900	highly weathered	2.62	3587	41.95	**25**	0.618
B 900	highly weathered	2.62	3569	41.92	**25**	0.620
	Ave.	**2.62**	**3578**	**41.94**	**25**	**0.619**
1185 A	highly weathered	2.86	4934	74.24	34	0.429
1185 B	highly weathered	2.85	5024	32.69	20	0.417
	Ave.	**2.86**	**4979**	**53.47**	**27**	**0.423**
A 4800	basalt hard	2.90	5091	122.92	43	0.407
B 4800	basalt hard	2.89	5235	132.15	44	0.387
	Ave.	**2.90**	**5163**	**127.54**	**43**	**0.397**
6210 A	vesicular basalt	2.70	4131	44.85	27	0.542
6210 B	vesicular basalt	2.69	4016	46.41	28	0.558
	Ave.	**2.70**	**4073**	**45.63**	**28**	**0.550**
A 6945	highly weathered	2.51	3844	35.91	24	0.582
B 6945	highly weathered	2.52	3803	29.82	21	0.588
	Ave.	**2.52**	**3823**	**32.87**	**23**	**0.585**
A 7125	highly weathered	2.67	4456	48.39	28	0.496
B 7125	highly weathered	2.66	4523	46.13	26	0.487
	Ave.	**2.67**	**4490**	**47.26**	**27**	**0.491**
	Range	**2.52-2.90**	**3578 - 5163**	**33 - 128**	**23-43**	**0.397-0.619**
	poor to good quality rocks (a, b)			**medium strong to strong rocks (c, d)**		
Koyna						
51a	massive basalt	2.98	5652	137.72	43	0.329
51b	massive basalt	2.99	5789	158.21	47	0.310
51c	massive basalt	2.95	5617	---	---	0.334
103a	massive basalt	2.95	5740	110.21	39	0.316
103c	massive basalt	2.99	5748	66.63	32	0.315
	Ave.	**2.97**	**5709**	**118.19**	**40**	**0321**
	Range	**2.95-2.99**	**5617-5789**	**67-158**	**32-47**	**0.310-0.334**
excellent quality rocks (a, b)			**strong to very strong rocks (c, d)**			

V_P : P-wave velocity; UCS : Uniaxial Compressive Strength; UAI : United Alteration Index. **a** : Barton (2007), **b** : Zulfu Gurocak and Recep Kilic (2005), **c** : Miller (1965), **d** : ISRM (1981).

60 mm length) by core drilling of rock block samples. The two end faces of each test sample were ground flat and parallel to within ± 0.01 mm. The density of each core sample was measured after the removal of moisture from it. Length and diameter of each cylindrical sample was measured to obtain volume of the samples. An electronic balance was used for measuring the mass. The density is calculated from mass and volume of each sample. We used a high-energy ultrasonic pulser-receiver (Model No. Ultran HE 900) on the driving side and a Hewlett Packard digital storage oscilloscope (Model No. 54645 A) which is equipped with cursor facilities on the receiving side. The measurement of P-wave velocity has been carried out as described in detail in our earlier papers (Rao, Sarma & Prasanna Lakshmi 2002; Rao & Prasanna Lakshmi 2003; Rao et al., 2006). Pair of hard-faced direct-contact P-wave transducers of 1.0 MHz resonant frequency was used for carrying out the wave propagation measurements. The time-of-flight measurement was carried out with respect to the onset of the first received pulse for determining V_p in each rock sample.The uniaxial compressive strength was determined by subjecting each rock sample to incremental loading with the help of a Universal Testing Machine (UTM) of 100 ton capacity. The load value at final failure of core sample was obtained from this uniaxial compressive test. The UCS of the test sample is calculated by dividing the load value at failure of the rock by the cross sectional area of it.

RESULTS AND DISCUSSION

The results obtained from the above mentioned tests are presented in Table 1. The density of basalts from Khadakpurna link canal project varies from 2.52 to 2.90 g/cm^3 with an average value of 2.71 g/cm^3. The P-wave velocity shows a wide variation from 3578 m/s to 5163 m/s with an average value of 4351 m/s. The UCS value ranges from 32.87 MPa to 127.54 MPa with an average value of 58.12 MPa. On the other hand, the properties of Koyna basalts are different. The density varies from 2.95 to 2.99 g/cm^3 with an average value of 2.97 g/cm^3. The P-wave velocity shows a narrow range of 5617 m/s to 5789 m/s with an average value of 5709 m/s. The UCS varies between 66.63 MPa and 158.21 MPa with an average value of 118.19 MPa. When the results of these two areas are compared, the Koyna samples found to have higher density, P-wave velocity, uniaxial compressive strength, and Schmidt's hardness but lower united alteration index. These results clearly show that the amount of weathering in basalts can significantly affect the physical, mechanical and engineering properties of the basalt rocks.

The physical, mechanical and the engineering properties are essential for classification of rock materials and judgment about their suitability for various construction purposes (Yasar & Erdogan 2004). These properties are also helpful to determine probable problems and necessary precautions to be taken prior to construction (Kocbay & Kilic 2006). Many studies were carried out to correlate the engineering properties such as Schmidt's hardness, shore scleroscope hardness, with unconfined compressive strength and Young's modulus of various rock types (Griffith 1937; Wuerker 1953). Miller (1965) showed the relationship between the UCS and Schmidt's hardness for different densities, in the form of a correlation chart. Using the chart, the Schmidt's hardness can be determined with the help of known UCS and density of the rock samples (also see ISRM 1981). Zulfu Gurocak & Recap Kilic (2005) provided an empirical relationship between the united alteration index and P-wave velocity and UAI is found to increase with decreasing P-wave velocity.

$$\text{UAI} = 1.12 - [1.4 * (10^{-4}) * V_p] \qquad \text{——} \qquad (1)$$

Where, UAI = United Alteration Index; V_p = P-wave velocity.

Using the above methods, Schmidt's hardness and united alteration index of the Khadakpurna and Koyna samples were calculated and the results are presented in Table 1.

The Schmidt's hardness of Khadakpurna samples varies between 23 and 43 with an average value of 29; UAI ranges from 0.397 to 0.619 with an average value of 0.511. On the other hand, Schmidt's hardness of Koyna massive basalts varies from 32 to 47 with an average value of 40; UAI ranges from 0.310 to 0.334 with an average value of 0.321. According to the classification of Miller (1965) and ISRM (1981), using the Schmidt's hardness and UCS, the Khadakpurna samples can be classified as medium strong to strong rocks, while the Koyna samples as strong to very strong rocks. According to Barton (2007) and Zulfu Gurocak & Recep Kilic (2005), on the basis of V_p and UAI data, the Khadakpurna samples are considered to be poor to good quality rocks, while Koyna samples as excellent quality rocks.

CONCLUSIONS

The important engineering properties such as Schmidt's hardness and united alteration index are estimated from the density, ultrasonic P-wave velocity and uniaxial compressive strength data of basalts of two engineering project sites namely Khadakpurna link canal project and Koyna reservoir. The Khadakpurna basalts are medium strong to strong rocks while Koyna borehole basalts come under strong to very strong rock groups based on the UCS data. On the basis of V_P and UAI data, the Khadakpurna basalts come under poor to good quality rock groups, whereas the Koyna borehole basalts can be categorized as excellent quality rocks for engineering applications. When the results of these two sites are compared, the Koyna rocks can be used for building heavy engineering structures.

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