Geotechnical Properties of Lateritic Rocks in North Goa

Mrudula Ingale and Purnanand P. Savoikar

Abstract Laterite rock is rich in iron and aluminium and is thought to have formed in tropical warm and humid regions like Goa. Generally, all laterites are of rusty-red colouration due to high content of iron oxide. Owing to difficulties in construction of foundations on the lateritic strata, geotechnical investigations of such areas has drawn considerable attention. In the present study, samples of laterite rock were obtained from boreholes at Dona Paula and Porvorim Goa sites. All these sites are closer to the coastal belt in North Goa. Various tests were conducted on these rock samples to study the geotechnical properties of the lateritic rocks in Goa and also the geology of laterites in Goa. These tests include, UCS, unit weight, water absorption test, etc. were also studied. Correlation is obtained about variation of UCS with *L*/*D* ratio for the sites under consideration.

Keywords Geotechnical · Lateritic rock · UCS · *L*/*D* ratio

1 Introduction

The landforms of Goa exhibit a polycyclic landscape that has evolved largely during Cenozoic under humid tropical climatic conditions. The State of Goa is largely categorised as follows:

- The coastal tract
- Sub-Ghat region and
- The high ranges of the Western Ghats.

Laterites are deposits that are more recent. Laterite covers the major portion of Goa and typically occurs as plateau landforms. In Goa, only the laterite and the younger sand, soil and alluvium deposits are of era comparable to the advent of human beings.

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Over the past few million years, the laterite, sand and soil seen today have developed [15]. Laterite, alluvium and sand cover most of the geological formations in Goa, as one expect in the wet tropical climate (Fig. 1).

The study of geotechnical properties of laterites is important because of its uncertain behaviour. Laterite may be considered as a soft rock as compared to other rocks. Geotechnical properties of laterites in Goa are not yet studied by the researchers. The study of characterization and evolution of primary and secondary laterites in north-western Bengal basin was studied by Ghosh and Gucchait [6]. Kasthurba et al. [9] determined the in situ features of laterite such as colour, texture, composition and hardness by field research of laterite in Kerala for construction purposes. Meshram and Randive [10] reported on the geochemical study of laterites of the Jamnagar district. Widdowson [14] studied the evolution of laterites in Goa. The work summarised the incidence of laterites in Goa, distribution and development. Goan laterite development is positioned within the geomorphological and geological (i.e. morphotectonic) development of India's western continental margin.

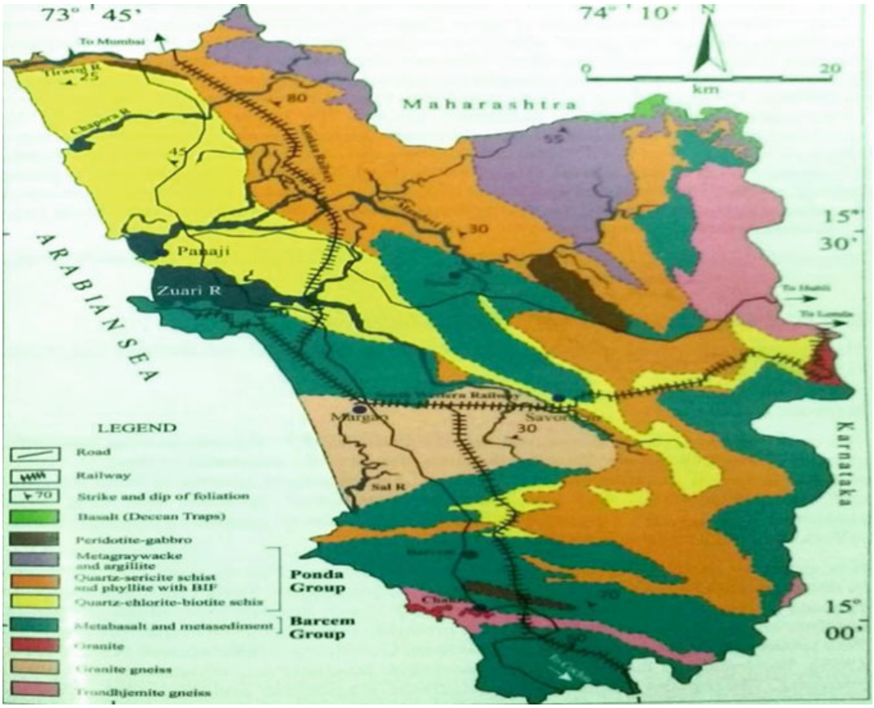


Fig. 1 Geological sketch map of Goa revised after Geological Survey of India, 1996 (modified after Dessai [4])

Turk and Dearman [13] proposed an equation for correlation of UCS test results to *L*/*D* ratio of 2. An equation was given for normalisation of test results to a length-to-diameter ratio of two and 50 mm diameter. Within the range of 1–4 of *L*/*D* ratio error was found to be less than 10%.

Agustawijaya [1] conducted UCS on the number of samples of soft rock considering dry and saturated conditions. From the results, it was observed that the strength reduced remarkably on saturation. One of the causes of strength reduction is weathering. Distinctly weathered rock gives less strength than partially weathered rock. UCS values for the soft rock were found to be lesser than 20 MPa, while for some samples value approached as low as 1 MPa, which is very low for rock material. An equation relating UCS and *L*/*d* ratio was also proposed. It was also reported that *L*/*D* ratio has no significant influence on UCS values. As regards, influence of dry density on UCS, it was reported that UCS increases with dry density.

Ergun and Nilsun [5] investigated the effect of *L*/*D* ration and shape on UCS for the dry cores of seven rocks with *L*/*d* ratios of 1–2.5. For the tested rocks, correlation formula was obtained. UCS values obtained for lesser loading time did not show significant difference as compared to loading time of 8–10 min. Derived equation for conversion of UCS values obtained on different *L*/*d* ratios to standard value of 2.5 was applicable to the nine rock types such as basalt, pink andesite, grey andesite, limestone, marble, siltstone, dubham dolomite, westerly granite and mizuho trachyte which were tested during the study.

2 Occurrence and Distribution of Laterites

In 1807, Buchanan [3] first defined and named in Southern India a laterite formation. He named it from the Latin term Later laterite, meaning bricks. Laterites are iron and aluminium rich residues of chemical decomposition and leaching of parent rocks in situ under warm, humid tropical climate. Alternatively, they could be described as low temperature and pressure alteration products of weathering of rocks under warm, monsoon climate. The process of prolonged chemical weathering of rock is called as lateralisation.

Figure 2a shows distribution of laterites in Goa in the various plateaux as shown below:

Pernem taluka: Harmal—Keri and Mandre—Morji Plateaux

Bardez taluka: Mapusa—Assagao, Saligao, Porvorim, Vernem and Aguada Plateux

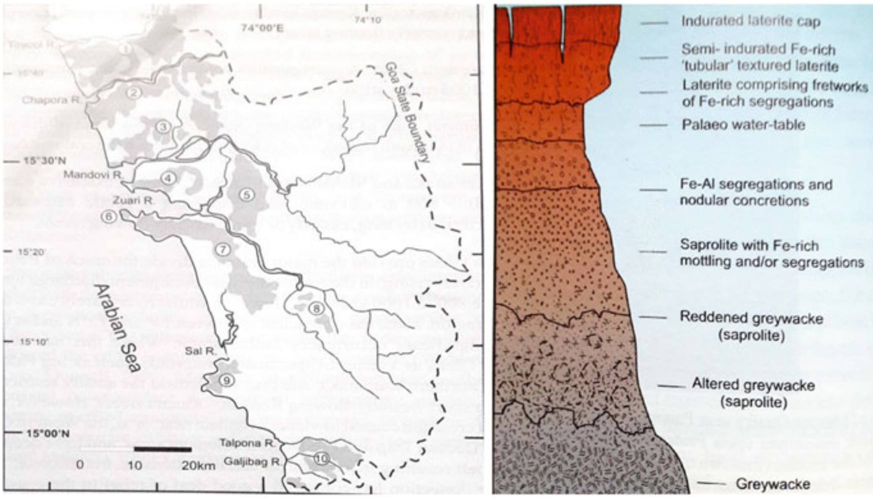
Tiswadi taluka: Dona Paula—Taleigao, Bambolim, Kadamba and Merces Plateaux

Ponda taluka: Ponda area Plateaux

Mormugao taluka: Vasco de Gama headland, Dabolim and Mormugao plateaux

Quepem taluka: Quepem area Plateaux

Canacona taluka: Cabo de Rama and Canacona area Plateaux.



(a) (b)

Fig. 2 **a** Map of distribution of key laterite-capped plateaux of Goa and **b** Idealised profile of an 'in-situ' laterite [14]

3 Geology of Laterites in Goa

3.1 Laterite Profile

A laterite profile is a typical field-section of a laterite (Fig. 2b), from surface to the parent rock. The term 'profile' refers to an 'outline' and not a 'cross-section' of an outcrop. The upper part of the section is generally red, hard and massive, which is referred to as 'lateritic crust'. It consists of a fretwork of oxides and hydroxides of iron and aluminium. The lower part of it is vermiform in nature and grades into a tubular, semi-indurated laterite. Below this there is a prominent thick horizon of variegated colours and is dominated by clay minerals is called as 'lithomarge'. It is generally nodular concretionary at the top and mottled below. The mottled portion consists of kaolinite along with patches and accumulations of iron oxyhydroxides. The saprolite beneath the mottled zone is relatively impermeable and corresponds to 'plasmic zone' of the profile. A significant portion of the saprolite shows bleaching and constitutes the 'pallid zone'.

3.2 Geotechnical Properties of Laterites in North Goa

In the present study, four lateritic rock sites were selected from North Goa district which is along or near to the coastal belt of Goa. Undisturbed lateritic rock samples were collected from the boreholes driven for soil investigations at two sites in Donapaula Goa and two sites in Porvorim Goa. All the four sites are located along the coastal belts of Goa (200–1500 m from the coast). Unconfined compression test (IS:9143), bulk density and water absorption test (IS:1124-1974) were conducted on the rock samples collected.

3.3 Borehole Details

Boreholes were driven up to the depth of 12.5 m. The rock samples collected from all the four sites were analysed for mineral content. It was observed that for depth up to 6 m, the laterite rock with mineral composition of Limonite ($Fe_2O_3 \bullet nH_2O$) followed by brown/red coloured laterite with high iron content (gibbsite/kaolinite) and very less hematite content (brownish red/yellow in colour) was observed up to 6 m depth. The structure of rock was porous/concretionary. For the depth of 6–12.5 m, the mineral composition varied from Goethite and Limonite (brown/red colour) for depth up to 7.5 m followed by laterite rich in limonite (brownish yellow) with gibbsite/kaolinite was also observed. Goethite/haematite was not present in appreciable quantities. More or less same profile was observed at all the four boreholes. The Rock Quality Designation (RQD) value varied from 7 to 26% for top 6 m and up to 7% for remaining half depth was observed. Table 1 shows the geotechnical properties of rock such as UCS, bulk density and water absorption at the Porvorim sites for different *L*/*D* ratios while Table 2 shows the corresponding properties at Dona Paula sites. The variation of UCS with *L*/*D* ratio is plotted in Fig. 3 while variation of UCS with bulk density is shown in Fig. 4. The all lateritic rocks exhibited the water absorption of 5–10%.

4 Results and Discussions

4.1 Influence of L/D *Ratio on UCS*

Figure 3 shows variation of UCS with *L*/*D* ratio for rock specimens with different *L*/*D* ratios. It can be seen that the scatter of UCS values is large indicating that there is no significant influence of *L*/*D* ratio on UCS of rock samples collected from all four sites. Similar conclusions were also drawn by Agustawijaya [1].

Table 1 Geotechnical properties of Porvorim sites 1 and 2

L/*D* ratio	UCS (kN/m^2)	Density (kN/m^3)	Water absorption (%)
1.15	3156	20.3	4.92
1.15	883	19.7	6.08
1.8	2777	20.3	5.58
2.1	3871	21.6	5.93
2.5	1370	17.4	11.26
3	2447	19	6.82
3	1388	21.7	4.59
3.2	3038	20.3	6.32
3.3	3903	21.3	5.21
3.5	2300	20.9	6.62
1.8	5238	20.3	5.36
1.9	295	18.4	6.3
1.9	3143	20.4	7.82
2	1262	17.9	7.77
2.2	4698	20.5	6.88
2.3	1742	10.5	4.99
2.6	2313	18.9	6.65
2.6	5481	20.2	7.61
3.4	2104	20.2	5.82

Table 2 Geotechnical properties of Dona Paula sites 1 and 2

L/*D* ratio	UCS (kN/m^2)	Density (kN/m^3)	Water absorption (%)
1.06	1270	20.7	4.92
1.11	6375	22.8	3.2
1.29	2542	22	4.83
1.57	2919	22.8	4.73
1.6	4193	23.9	5.43
1.66	2644	21.4	3.63
1.11	1235	21.1	3.43
1.2	1335	20.7	2.92
1.26	3599	23.2	4.72
1.6	1890	22.1	6.31
1.73	5779	24	4.29

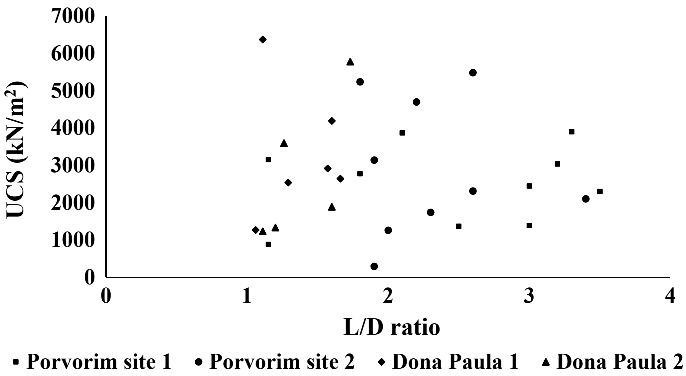


Fig. 3 Influence of *L*/*D* ratio on UCS

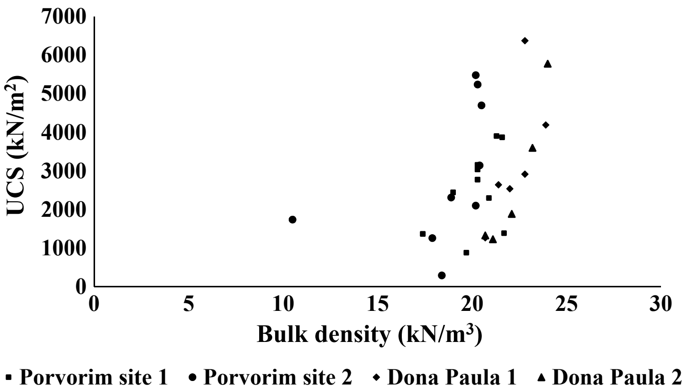


Fig. 4 Influence of bulk density on UCS for all four sites

4.2 Influence of Dry Density on UCS

Figure 4 shows variation of UCS with dry density. It can be seen that as dry density increases, UCS also increases. The values of UCS may be seen clustered around the value of density in the range 16–25 kN/m^3 since for lateritic rock sites, the density varies from 16 to 25 kN/m^3.

4.3 Comments on UCS Values

It is evident from plot of UCS with *L*/*D* ratio that there is wide scatter of values. Also, for the same site and for same *L*/*D* ratio, the value of UCS may be different. In general, *L*/*D* ratio of 2 is assumed to be the standard ratio for testing the rock

Table 3 Correlation equations for non-standard *L*/*D* ratios

Equation	Applicability	References
$\frac{\sigma_c}{\sigma_m} = \frac{1}{0.848+0.304\frac{D}{L}}$	Coal measures rocks in UK	[7, 12]
$\frac{\sigma_c}{\sigma_m} = \frac{1}{0.88+0.24\frac{D}{L}}$	For non-standard *L*/*D* ratios other than 2	[2]
$\frac{\sigma_c}{\sigma_m} = \frac{1}{0.875+0.25\frac{D}{L}}$	For non-standard *L*/*D* ratios other than 2	[11]

specimens. Very few number of samples of *L*/*D* ratio of 2 were available in the present case to comment on influence of *L*/*D* ratio.

Change in *L*/*D* ratio gives different values of UCS which may sometimes be misleading. The factors on which UCS may depend are shape and size of specimen, rate of loading, degree of saturation, etc. which are termed as external factors while defects, porosity, mineralogy, degree of weathering are termed as internal factors [13]. According to ISRM [8] the test specimen shall not be less than 54 mm in diameter and *L*/*D* ratio of 2.5–3, while ASTM (D2938-79) specifies test specimen of diameter not less than 48 mm and *L*/*D* ratio of 2–2.5.

Various co-relation equations have been suggested for correction in UCS values in the case of non-standard *L*/*D* ratios (other than 2) as shown in Table 3, where σ_c is the corrected UCS value and σ_m is measured UCS value for non-standard *L*/*D* ratios.

5 Conclusions

In the present study, water absorption, unconfined compressive strength and unit weight of the rock samples collected from different sites of Goa was obtained. The mineral composition of all rocks indicated the presence of Limonite in higher quantities followed by Gibsite and Kaolinite. Hematite and Goethite were observed in very less quantities. It can be concluded that the unconfined compressive strength of the laterite rock not necessarily increases with the increasing depth, sometimes it reduces for the intermediate layer of soil and again increases. This reduction in UCS values may be due to the porous and concretionary structure of the laterites found at different depths, varying mineral contents and degree of lateritization/alteration. It is required to develop standard correlation equation for UCS for non-standard *L*/*D* ratios as many times UCS is used in determining safe bearing pressures on rocks.

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