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Applicability of Size-strength Rippability Classification System for Laterite Excavation in Iron Ore Mines of Goa

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Abstract

Goa is a small state situated at the western ghats of India, with a large number of Iron ore mines, where Ripper-dozers are used for excavation. It was observed during mine visits and discussion with mine officials that, selection and performance monitoring of Ripper-dozers is a challenging task, due to variation in the rock material, affecting cost of excavation..

Present study focuses on the applicability of size-strength rippability classification system for laterite excavation in iron ore mines of Goa. To fulfill the objective six open pit iron ore mines were chosen where lateritic material is being removed by single shank ripper dozers. The field and laboratory investigations were performed and found that the ore rock is having uniaxial compressive strength between 5.09 to 22.65 MPa, point load strength between 0.54 to 3.22 MPa and discontinuity spacing between 14 to 37 cm. Laterite formations observed in the all six mines were rock-soil type of weathered earth material in which core stone (hard boulders) were firmly surrounded by soil. The tests were performed on these hard boulders because these boulders are affecting the rippability of whole lateritic material. Based on the observations a new size strength graph is suggested which can be helpful for laterite excavation and selection of ripper dozers.

Key word

Ripper dozer, Laterite, Excavation, Iron ore mines.

1. Introduction

Rippability is described as the process of ground breaking by dragging tines attached to the rear of a bulldozer. The tines penetrate the rock surface as the bulldozer moves forward and the rock material is displaced by the tines of rippers [13].

Rippability can also be explained as a measure of the ease with which earth materials can be broken by mechanical ripping equipment to facilitate their removal by other equipment like wheel loaders & shovels [2]. Church (1981) defined ripping as the fragmentation of rock by bulldozers equipped with ripper shanks and points or tines. Ripping rocks or weather rock material differs from other excavation methods which involves cutting down of the natural ground surface through digging or blasting or a combination of the two [6].

Today, because of advances in technology and ripping techniques, more detailed classification systems are used to describe the rippability of a site, but there is no one system that is generally accepted. Rippability classification systems vary substantially.

Franklin in 1971published a size-strength graph that narrates discontinuity spacing and rock strength to the method of excavation required. The graph is sub-divided into area of digging, scraping, ripping, blasting to loosen and blasting to fracture based on a research conducted in the United Kingdom between 1968 and 1970. In his assessment, Franklin (1971) suggested two parameters explicitly discontinuity spacing and point load index (Is50) as very important factors in ripper excavation. Discontinuity spacing is defined as the average spacing of fractures in a rock mass whereas the value of point load index is obtained by using force to break rock samples.

Based on research in different surface mines of Turkish Coal Enterprises, Bozdag (1988) modified the Franklin et al. (1971) chart. Bozdag (1988) divided the graph boundary into four parts and suggested the type of equipment to be used.

Pettifer and Fookes (1994) proposed a graphical revision of Franklin (1971) graph based on data collected from case studies in Africa, Hong Kong, United Kingdom and through conversation with site staff and observations obtained from a hundred sites. The size strength graph given by him allows the excavation assessment to be assessed more rapidly, and is particularly suited to rippability assessments with equipment selection for mining and civil engineering works.

Rippability equipment manufacturers have their own rippability classification systems, plotting rippability versus the seismic velocity of the rock mass. The first classification scheme using a complete array of geological parameters that affect rippability was proposed by [20], based on the Rock Mass Rating System of Bieniawski (1984). Many researchers developed different rippability or excavatability classification systems considering different rock mass properties [1, 3, 8, 10, 11, 12, 16, 17, 18, 19] while other systems have tried to predict the productivity of a bulldozer [13, 14].

For research purpose, scientific article, based on discontinuity of rock mass was referred [9] for developing understanding regarding lateritic rock mass. The most common rippability estimation methods are with the aim of finding the most appropriate methods for use in characterizing the rippability of the surface mines and civil construction site.

The present research will be helpful for Mining and Civil engineers, for categorization of lateritic formation and selection of appropriate ripper-dozer for excavation purpose as per proposed new classification system.

2. Field Description and Research Methodology

To fulfill the objective six iron ore mines were selected from the Goa Group of Dharwar Super Group of the Archaean-Proterozoic ageas shown in Fig.1, where laterite was removed by ripper dozers. For the ease of the identification the studied mines were shown as A, B, C, D, E and F, along the complete mineralized zone (iron ore) of Goa.

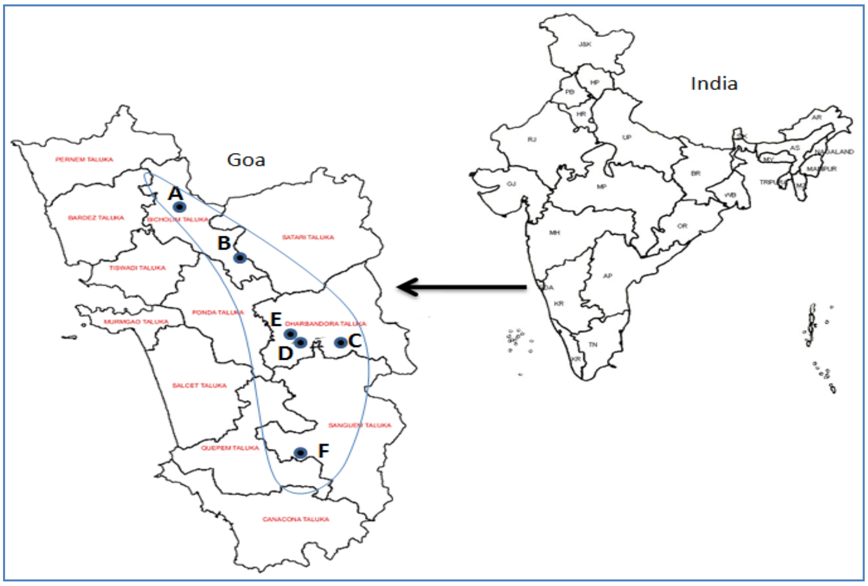

Fig.1. Location Map of the study Area Showing Different Mine Locations

The area is covered by rocks of the Goa Group of Dharwar Super Group of the Archaean-Proterozoic age. The Goa Group, which includes roughly the upper half of Dharwar Super Group, is comparable to the Chitradurga Group in the Karnataka region. The Goa Group consists of eugeosynclinal assemblage of rocks and is divided into four formations that in the order of superposition are Barcem Formation, Sanvordem Formation, Bicholim formation and Vageri Formation. Barcem Formation includes essentially meta-volcanic rocks with minor meta-sedimentary.

The rocks have been subjected to at least three generations of folding. The intensity of different generations of folding and degree of expression of their effect are however observed to vary widely from place to place.

Iron Ore in the region was formed from Banded Hematite Quartzite's and Ferruginous Phyllites through a specific process which cannot be attributed, the process of leaching away silica, replacement by iron and concentration of iron is the one looks suitable. The possible two stages in the process of iron ore formation can be:

1. Rocks of iron ore series have been variously metamorphosed, repeatedly folded and considerably altered by weathering and action of circulating waters and solutions of magmatic/meteoric origin in the zone of oxidation. Secondly changes brought about by circulating waters resulting in leaching away of Ca, Mg and Al oxides from ferruginous phyllites with consequent concentration of iron and silica giving rise to banded hematite quartzite's.
2. Further action of circulating water was responsible for leaching away of silica from banded hematite quartzite's, replacement and concentration of iron.

The general lithological sequence seen in the mining areas is as given in Table 1.

Table 1. Lithological sequence of Goa Group of Dharwar Super Group

Rock Type	Depth from surface, m
Laterite	0-5
Lateritic lumpy iron	0-25
Powder iron ore	15-35
Silicious iron ore	20-35
BHQ	30-50
Dyke/Intrusives	10-30
Phyllitic Clay	15-35
Mangniferrous Clay	10-30

Iron ore occurs as reefs as on the crests and slopes of the hill at and near the surface, above and below ground water table. The deposits have resulted essentially by residual concentration in the banded ferruginous quartzite by leaching of silica and concentration of iron.

As seen from the exposed sections of mine faces (Fig.2), the iron ore bearing bands occupy the crest and slopes of hill range and also depending on the topographic position enrichment of formations i.e. concentration of iron content varies from upper to lower layers.

Iron ore deposits are mostly covered by laterite. The laterite at places appears to be very hard and compact. At some places, the laterite is having hard lumpy ore pieces. The chemical composition of the laterite ranges from 20 to 38% Fe and alumina ranging from 2 to 30%. Ferruginous/Phyllitic clay is exposed at very small place. It is very fined grained and soft. The chemical composition of clay ranges from Fe 30 to 35% and Al2O3 from 10 to 25%.

The ore body is generally found below the laterite capping. The total thickness of the ore body is about 20 to 40 meters. Out of which the top portion of the ore body is lateritized and the grade is +45% Fe.

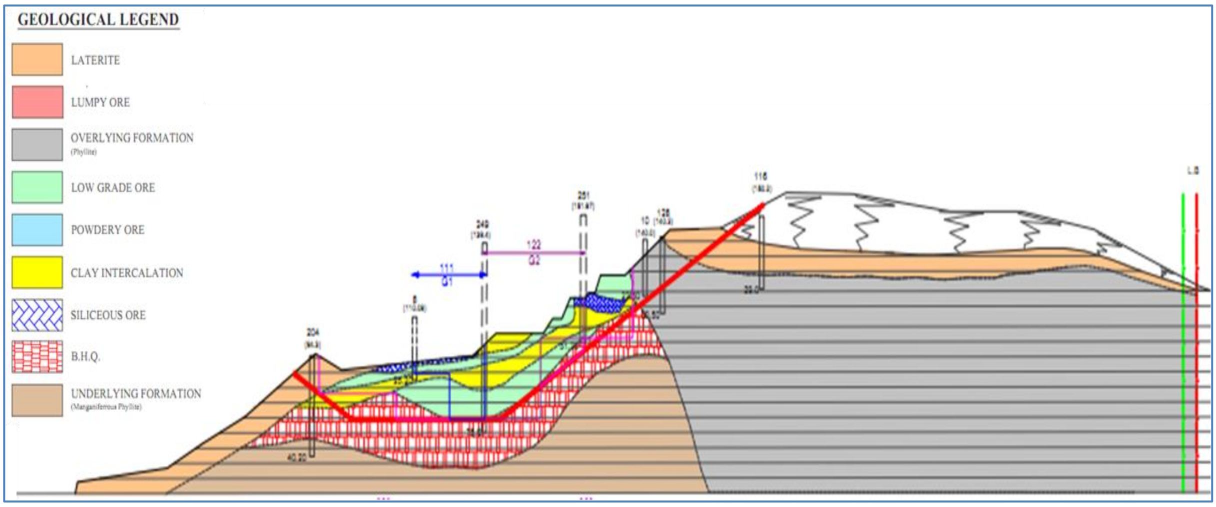

Fig.2. General Geological Section for Iron Ore Deposits in Goa

2.1 Research Methodology

Earth material considered for present study is laterite found in iron ore mines of Goa. To complete the objective the following methodology was adopted:

Step-I: Engineering properties of discontinuities in laterite at excavation site were determined by measurement of prominent vugs, fissures and joints present in boulders.

Step-II: Cylindrical shaped-samples were prepared from boulders, collected during field works, in the laboratory. The uniaxial compression tests and point load tests were determined using these samples as per ISRM standards.

Step-III: After obtained data from field and laboratory tests, applicability of size-strength excavation classification systems was validated and a rippability chart is proposed.

3. Results and Discussions

Field visits were conducted at six different iron ore mines A, B, C, D, E and F. At every mine ripper excavation in laterite was observed at four different places, generating a data set for 24 locations. Field observations for discontinuity spacing and laboratory tests (Uniaxial compressive strength (UCS), point load strength (PLS), Discontinuity Spacing (DS) results are shown in Table 2.

Table 2. Field and Laboratory Investigation Result

Location	**Rock type**	**Depth from Surface, m**	**UCS, MPa**	**PLS, MPa**	**DS, cm**	**Ripper Dozer Model**	**Capacity of Ripper dozer**		**Remark on rippability**
							kW	**HP**	
A1	Laterite	2	15.00	2.66	37	Komatsu’ D275A	337	452	Very Difficult
A1	Laterite	2	15.00	2.66	37	Cat D11R	634	850	Moderate
B1	Laterite	1.5	14.89	2.27	35	Komatsu’ D275A	337	452	Very Difficult
B1	Laterite	1.5	14.89	2.27	35	Cat D10R	425	570	Difficult
C1	Laterite	1	12.14	2.05	33	Komatsu’ D275A	337	452	Difficult
D1	Laterite	1.5	12.68	2.2	30	Cat D9R	302	405	Difficult
E1	Laterite	1	12.90	2.35	29	Cat D9H	310	410	Difficult
F1	Laterite	2	11.02	2.04	26	Komatsu’ D355A-3	305	410	Difficult
A4	Laterite	15	22.65	3.22	33	Komatsu’ D275A	337	452	Difficult
A4	Laterite	15	22.65	3.22	33	Cat D11R	634	850	Moderate
B4	Laterite	18	20.07	2.84	32	Komatsu’ D275A	337	452	Very Difficult
B4	Laterite	18	20.07	2.84	32	Cat D10R	425	570	Difficult
C4	Laterite	15	19.08	2.1	32	Komatsu’ D275A	337	452	Difficult
D4	Laterite	20	20.07	2.46	33	Cat D9R	302	405	Very Difficult
E4	Laterite	20	18.41	2.66	30	Cat D9H	310	410	Very Difficult
F4	Laterite	12	17.97	2.37	25	Komatsu’ D355A-3	305	410	Difficult
A2	Laterite	5	9.50	1.9	24	Komatsu’ D275A	337	452	Moderate
A2	Laterite	5	9.50	1.9	24	Cat D11R	634	850	Easy
B2	Laterite	3.5	11.69	1.67	24	Komatsu’ D275A	337	452	Moderate
B2	Laterite	3.5	11.69	1.67	24	Cat D10R	425	570	Easy
C2	Laterite	4	9.93	1.58	19	Komatsu’ D275A	337	452	Moderate

D2	Laterite	6	10.70	1.54	20	Cat D9R	302	405	Moderate
E2	Laterite	6	9.81	1.64	19	Cat D9H	310	410	Moderate
F2	Laterite	6	8.08	1.38	18	Komatsu' D355A-3	305	410	Easy
A3	Laterite	8	5.09	0.92	18	Komatsu' D275A	337	452	Easy
A3	Laterite	8	5.09	0.92	18	Cat D11R	634	850	Easy
B3	Laterite	10	5.29	0.68	19	Komatsu' D275A	337	452	Easy
B3	Laterite	10	5.29	0.68	19	Cat D10R	425	570	Easy
C3	Laterite	7	6.40	0.6	15	Komatsu' D275A	337	452	Easy
D3	Laterite	9	6.17	0.75	16	Cat D9R	302	405	Easy
E3	Laterite	12	6.06	0.6	14	Cat D9H	310	410	Easy
F3	Laterite	10	6.39	0.54	15	Komatsu' D355A-3	305	410	Easy

Field observations and sample test data were compared with the size strength classification systems developed by Franklin (1971), Bozdag (1988) and Pettifer and Fookes (1994) to check there applicability for ripper excavation in laterite.

The data set is further divided in to four Sets based on point load strength and uniaxial compressive strength namely Set1 (A1, B1, C1, D1, E1, and F1), Set2 (A2, B2, C2, D2, E2 and F2), Set3 (A3, B3, C3, D3, E3 and F3) and Set4 (A4, B4, C4, D4, E4 and F4) where A, B, C, D, E and F denoting the mine identity. Test data for mine A, B, C, D, E and F were fitted into the chart (Fig. 3, 4 and 5) proposed by Franklin, Bozdag and Pettifer and Fookes, it was observed that uniaxial compressive strength and point load strength data for laterite samples were not matching suitable on both lower and upper scale, so uniaxial compressive strength and discontinuity spacing were considered for observations.

Table 3. Detailed Field Observation Regarding Remark on Rippability at Different Location

Remark on Rippability	Field observations
Easy	Smooth and uninterrupted ripping, with occasional jerk because of boulders. Boulders present were crushed or displaced by ripper shank and crawler chain.
Moderate	Less interrupted ripping, with frequent jerk because of boulders and occasional slip of crawler chain.
Difficult	Interrupted and disturbed ripping with frequent jerk because of hard boulders, slipping and lifting of crawler chain at the rear side of Machine. Increased ripping time. Metal to metal rubbing/cutting smell can be felt, giving signs of hard ripping.
Very Difficult	Very interrupted and disturbed ripping with frequent jerk because of hard boulders, slipping and lifting of crawler chain at the rear side of Machine. Occasional adjustment in shank length required which reduces shank penetration. Increased ripping time. Sparks can

	be seen because of metal to metal rubbing due to presence of solid iron lumps present in ore. Sometime machine will stuck and require adjustment in ripping direction.

3.1 Assessment of Excavability of Lateritic Rock Material with Reference to Rippability Chart (Franklin, 1971)

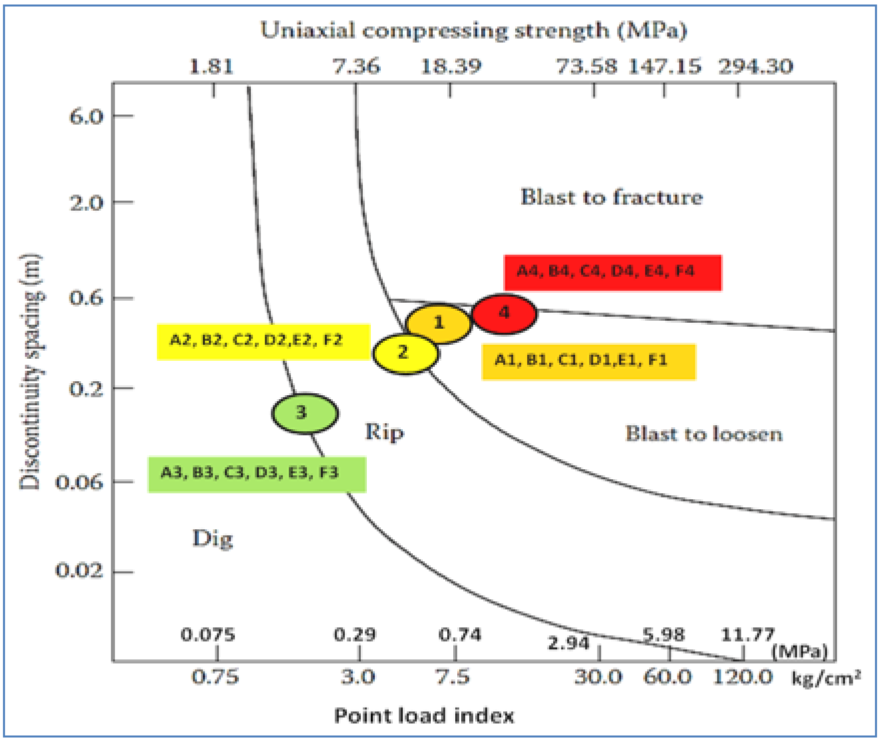

Fig.3. Assessment of Lateritic Rock Material with Reference to Rippability Chart **(**Franklin, 1971)

From the chart (Fig. 3) it is evident that the laterite Set 4 and 1 were falling under the blast to lose portion of graph, but it was observed while ripping at mine bench that Set 4 and 1 can be ripped with some difficulty (by ripper dozers D11R and D10R) which may not require blasting prior to ripping. Set 2 rock material is partially falling between blast to loose and rip, and also it was observed in field that such laterite material can be ripped (using D275A, D9R and D355A-3). Set 3 laterite materials falling between digging and rip zone in chart which were found easy to rip material even for low capacity ripper dozers. All three categories and 24 locations are shown in Fig.3 for quick understanding.

So rippability chart cannot be fully applicable to Set 4 and 1 laterite material. Set 2 and 3 laterite material fitting partially into the chart zone also the suggested excavation method is partially correct.

3.2 Assessment of Excavability of Lateritic Rock Material with Reference to Rippability Chart (Bozdog's, 1988)

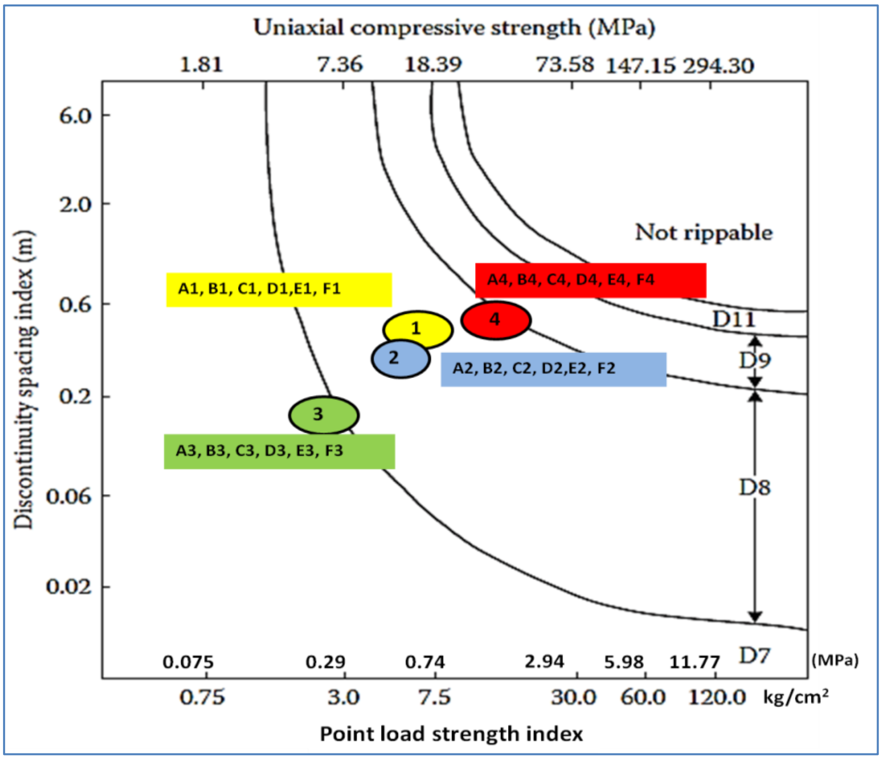

Fig.4. Assessment of Lateritic Rock Material with Reference to Rippability Chart (Bozdag, 1988)

From the chart (Fig. 4) it is evident that the laterite Set 4 falling under the portion of chart which require either D9 ripper or D8 ripper as per Bozdag's rippability chart, but it was observed while ripping at mine site that Set 4 laterite material were rippable using high capacity ripper dozers D11R and D10R. As per the rippability chart Set 1 require D8 ripper machine but again it will be miss fit as it was observed during field ripping run that, it require D10 or D11 ripper machine to rip the material. Set 2 and 3 laterite material will require D8 and D7 ripper machine which is correctly matching field observations, hence applicability of Bozdag rippability chart is perfect for Set 2 and 3 material. All four categories and 24 locations are shown in Fig.3 for quick understanding.

3.3 Assessment of Excavability of Lateritic Rock Material with Reference to Rippability Chart (Pettifer and Fooke's, 1994)

From the chart (Fig. 5) it is evident that the laterite Set 4 and 1 are fairly fitting into the graph zone suggesting very hard and hard ripping, but equipment selection shown is improper for Set 4 the classification suggests Caterpillar D9R ripper dozer which should not be a proper choice and based on field observations it is felt that for ripping laterite material of Set 4 Caterpillar D11R must be chosen. Similarly for Set 1 laterite Caterpillar D9R must be chosen in place of Caterpillar D8R.

Set 2 and 3 laterite are also fitting properly in graph zone but again equipment selection suggested by Pettifer and Fookes is of lower capacity and for ripping laterite of Set 2 and 3, D9R and D8R must be chosen respectively. If discussed in totality rock classification and equipment selection suggested by Pettifer and Fookes can be applicable for laterite material.

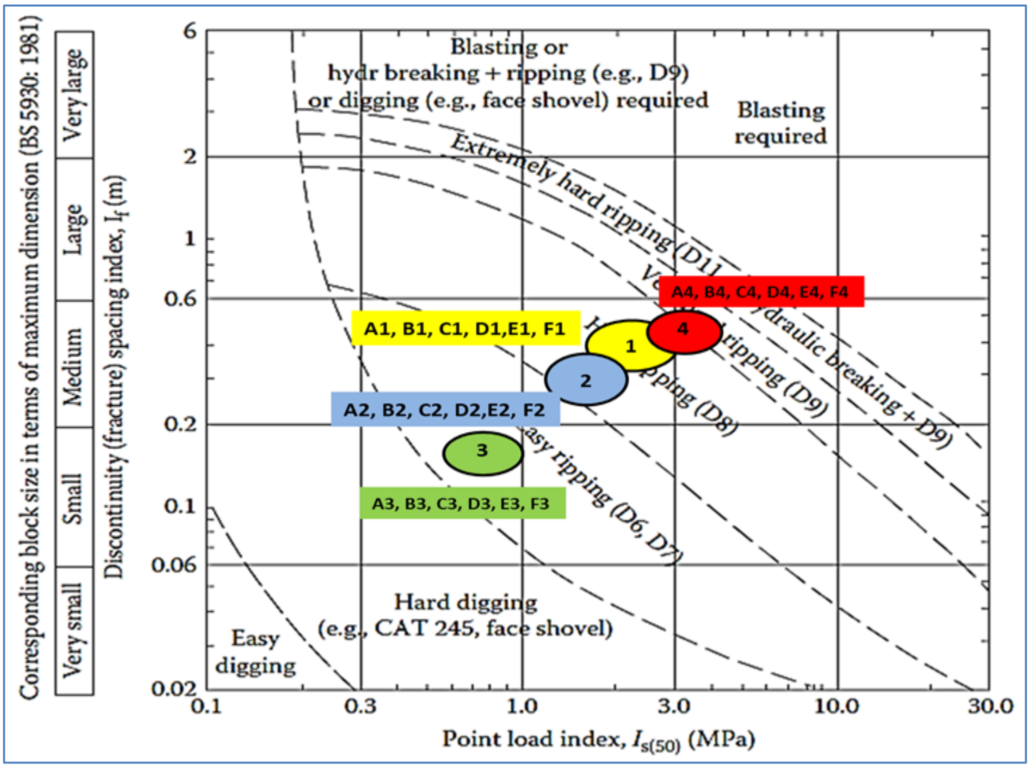

Fig. 5. Assessment of Lateritic Rock Material with Reference to Rippability Chart (Pettifer and Fookes, 1994)

Conclusions

Above discussed size strength rippability charts are found suitable and can give rough idea about rock class, excavation method and equipment selection, but have partial applicability for lateritic material where ripping is mainly affected by the presence of hard boulders.

Based on literature survey and data collected from iron ore mines, a new size strength graph is proposed showing four different class of laterite (Fig.6 and Fig.**7**) and which will be helpful in ripper dozer selection for lateritic materials as shown in Table 5.

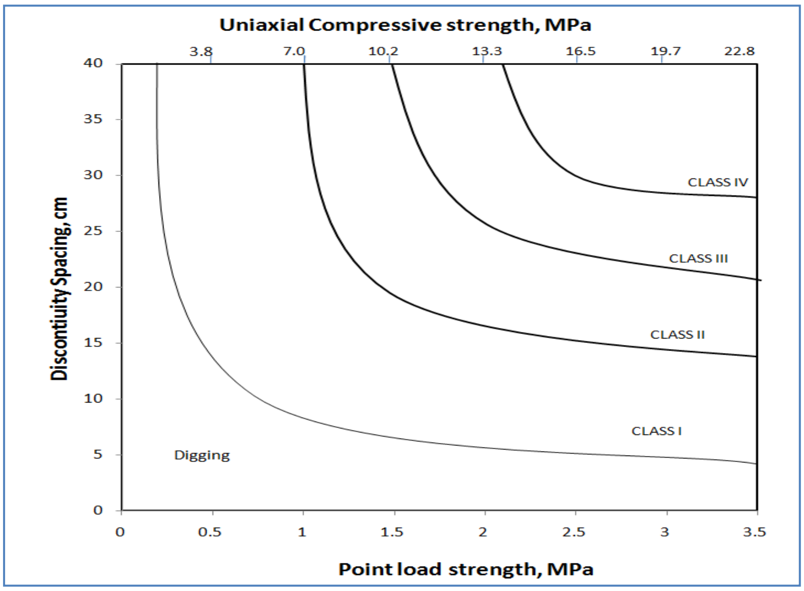

Fig.6. Proposed Modified Size Strength Rippability Chart for Laterite Material

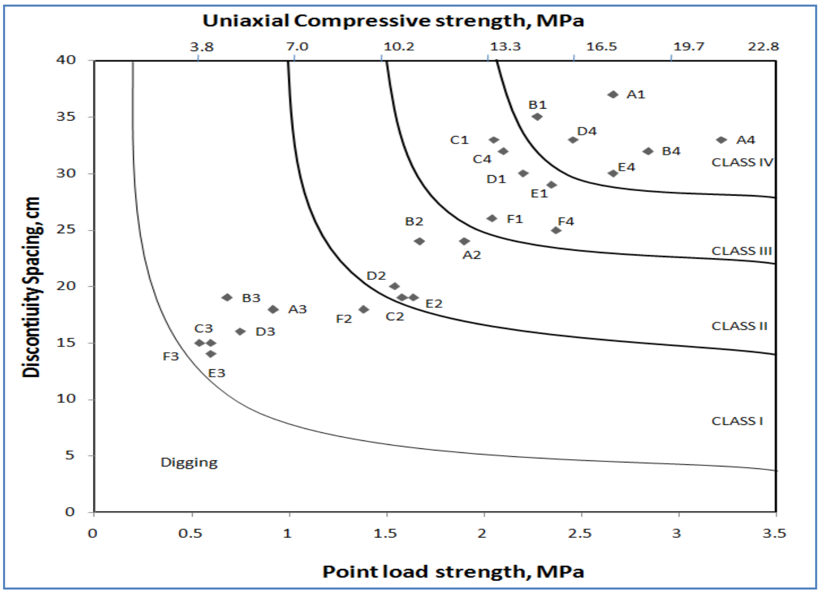

Fig.7. Assessment of Lateritic Rock Material from Iron Ore Mines of Goa with Reference to Proposed Rippability Classification System

Table 4. Field Observations Based on Laterite Class and Ripper Machine Capacity

Machine Capacity (kW) ↓	Comment on Rippability			
600-650	Easy	Easy	Easy	Moderate
400-450	Easy	Easy	Moderate	Difficult
300-350	Easy	Moderate	Difficult	Very Difficult
200-250	Easy	Moderate	Very Difficult	Very Difficult
Laterite Class →	I	II	III	IV

Upper limits of uniaxial strength, point load strength and discontinuity spacing require other means of excavation like hydraulic breaker, Eccentric ripper/Vibro rippers/Impact rippers and ultimately drilling & blasting. Lower limits of uniaxial strength, point load strength and discontinuity spacing require direct digging by power shovel.

Fig.7 shows different rock properties present at 24 locations and are bifurcated in different class as per new classification chart. Classification of lateritic rock material can be further utilized for selection of appropriate ripper dozer when observations from Table 2 are considered regarding remark on field rippability of each excavation site (Table 4).

It is marked from Table 2 that lateritic material falling under to Class IV (D4, B4, E4, A4, B1 and A1)) which require D11R or equivalent capacity ripper dozer (600-650 kW/850 HP), as D9R, D10R and D275A were struggling to rip the mine bench floor.

Similarly laterite material belonging to Class III (C1, C4, D1, E1, F1 and F4) where D275A, D9R, D355A-3 (capacity 300-340 kW/ 400-450 HP) were used for rippability found to be less effective in ground ripping, which require D10R or equivalent capacity ripper machines to rip comfortably.

Table 5. Selection of Ripper Dozer with Respect to Laterite Class Shown in Fig.7

Laterite Class	Suitable Machine		
	Capacity	Caterpillar	Komatsu’s
I	200-250 kW / 300-350 HP	D7R or D8R	D155A-6
II	300-340 kW/ 400-450 HP	D9R	D275A-5
III	400-450 kW / 500-550 HP	D10R	D375A-6
IV	600-650 kW / 850 HP	D11R	D475A-5E

Considering the same concept for Class II and Class I suitable ripper dozer machines are mentioned in Table 5. For Class I and II at some locations (A3, B3, A2 and B2) D11R and D10R ripping trials proves very easily ripping, underutilizing the machine. So selection of appropriate ripper dozer machine becomes important to avoid overutilization and underutilization of machine, also to get appropriate ripping performance. Considering above discussed facts selection of ripper dozer is suggested for different laterite class in Table 5.

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