

Index properties of sediments off Narsapur, east coast of India and their importance for offshore construction

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A large number of soil engineering and index tests (shear strength, Atterberg limits, unit weight, water content, etc.) were carried out on the 12 piston cores obtained during a cruise of *R.V. Samudra Kaustubh* to determine various physical parameters of sediments collected from the shelf area of the Bay of Bengal off Narsapur. Maximum penetration depth of the core was 4.71m (PC-12). Correlations were made between undrained shear strength and liquidity index, saturated unit weight with water content and porosity, and shear strength with water content, by drawing the lines of best fit curves. Comparison of above mentioned parameters as determined, clearly reveals that many of these quick and inexpensive tests adequately describe the general characteristics and behaviour of the sediments.

Designing of offshore installation of various nature requires knowledge of engineering properties as well as geological history of foundation sediments. The present study gives a profile of shear strength, Atterberg limits, water content, bulk density etc. of sediments collected off Narsapur.

Narsapur, a small but prominent township of East Godavari district of Andhra Pradesh, is situated about 15 km inside the river mouth on the right bank of Vasistha Godavari which carries during its journey to the Bay of Bengal, a large volume of terrigenous sediments and gets deposited there in the shelf area. An area of about 225 km² south-west of Vasistha Godavari mouth, has been studied for evaluation of geotechnical properties of the seabed sediments¹.

Materials and Methods

The following treatise has been made on the basis of studies made on 104 subsamples taken generally at 50 cm interval from the 12 piston cores (Fig. 1) collected during a cruise of *R.V. Samudra Kaustubh* during February-March 1988. Locations of these piston cores vary in water depth from 10 to 18 m, the farthest one being about 17 km from the shore. The cores were cut approximately at 1 m interval on board the vessel and both ends were sealed. Immediately on arrival in the laboratory, all tests were carried out simultaneously on each of the subsample. Undrained shear strengths were determined first, by hand tor-

vane. The water content is expressed as percentage of dry weight. Atterberg limits were determined according to Lambe². The saturated unit weight was measured straightway in the laboratory. Porosity and void ratio were calculated from the water content and grain specific gravity using

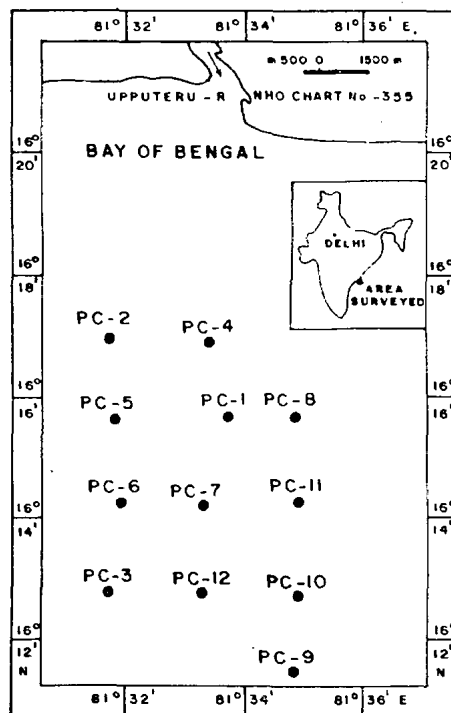


Fig. 1—Location of the piston cores

standard formulae and technique²⁻⁴. Liquidity index is denoted by the ratio of the excess natural water content above the plastic limit to the plasticity index.

Results

Results are presented in Table 1. Plasticity indices show that 89% of samples fall on either side of A-line but on right hand side of B-line (Fig. 2). The results of undrained shear strength when plotted against liquidity index show that the values are restricted within a narrow zone of maximum and minimum limits (Fig. 3). The original fabric of sediments has been assumed to have been retained as there is very little possibility of samples being disturbed during transportation from the port to the laboratory. A best fit curve has been constructed utilising the data, on the basis of which an empirical model between these 2 variables has been proposed. The plot of the data indicates that a power function can be used to express their relationship as:

$$S_u = 0.095 \times e^{-1.21 LI}$$

where S_u = undrained shear strength and LI = liquidity index.

A similar relation with different constants has been reported for the remoulded clays⁵. The values of the shear strength are very much akin to those of sediments in East Bay Area, Mississippi delta⁶.

The saturated unit weights of sediments range

from a maximum of 1.87 g.cm^{-3} at 48.19% to 1.39 g.cm^{-3} at 71.9% porosity. The unit weight obtained mathematically from water content and grain specific gravity was slightly lower than that obtained in the laboratory. An inverse relationship is indicated between the unit weight and the water content (Fig. 4). The regression analysis shows the model to be:

$$\gamma = 1.89 - 0.399 W$$

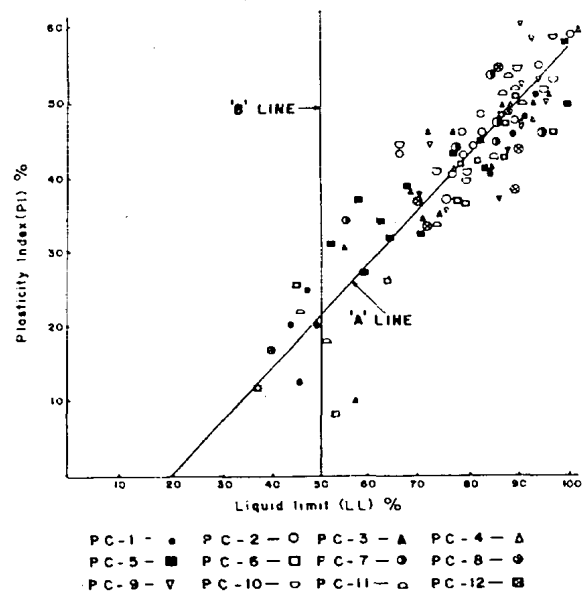


Fig. 2—Plasticity Chart

Table 1—Range of a few index and geotechnical properties with their average values
Core No.

Parameter		PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7	PC-8	PC-9	PC-10	PC-11	PC-12
Water content (W) %	Min.	55.00	65.90	36.78	34.71	27.14	44.00	35.31	32.82	59.19	60.59	40.42	69.77
	Max.	101.24	102.11	111.17	102.56	91.78	97.08	98.59	116.71	102.05	106.26	125.62	104.00
	Av.	75.21	87.13	81.21	79.46	66.67	75.22	72.64	81.06	84.92	85.60	86.02	86.15
Unit weight (γ) g.cm^{-3}	Min.	1.49	1.47	1.48	1.47	1.49	1.50	1.48	1.48	1.49	1.46	1.39	1.48
	Max.	1.85	1.66	1.61	1.77	1.76	1.85	1.87	1.78	1.60	1.56	1.68	1.66
	Av.	1.62	1.55	1.54	1.56	1.64	1.61	1.59	1.55	1.52	1.52	1.55	1.54
Porosity (n%)	Min.	49.50	64.41	47.64	42.92	41.18	53.70	48.19	47.09	58.33	59.02	35.90	64.03
	Max.	70.76	71.91	72.30	70.68	69.33	71.91	71.02	74.75	71.18	71.35	74.03	71.67
	Av.	65.07	69.12	65.74	64.79	61.11	65.67	62.96	65.49	67.11	66.70	64.31	67.30
Liquidity index (LI)	Min.	0.37	1.00	0.25	0.34	0.18	0.84	0.44	0.54	0.28	0.55	0.77	0.74
	Max.	1.70	1.42	3.51	1.23	1.57	1.67	1.17	1.54	1.20	1.32	2.51	5.48
	Av.	1.15	1.11	1.28	0.95	1.00	1.20	0.88	0.95	0.92	1.01	1.36	1.55
Shear strength (S_u) kPa	Min.	1.60	1.60	0.80	0.40	2.80	0.40	2.00	0.40	1.00	1.20	1.20	2.60
	Max.	5.60	4.80	8.00	7.80	10.00	5.20	9.00	4.80	5.20	6.60	9.00	4.80
	Av.	4.13	3.30	4.26	2.82	4.65	3.27	3.85	2.86	3.13	3.53	4.28	3.72

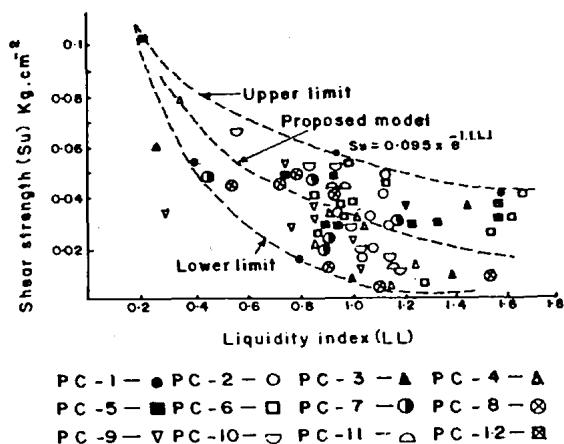


Fig. 3—Relation of shear strength with liquidity index

where γ = saturated unit weight and W = water content.

Porosity in a saturated sediment reflects directly the water content, and the unit weight will naturally be inversely proportional to these proportions⁷. This is because higher the unit weight, there will be more packing of the grains and hence less space will be available for the water. Figure 5 shows inverse relation between porosity and unit weight. It is expressed as:

$$\gamma = 2.55 - 1.5 n$$

where γ = saturated unit weight, and n = porosity.

It is reported that laboratory values of porosity are generally not far from the values obtained by *in situ* measurement⁸ and are comparable to those reported by Richards⁷.

The sediments investigated are largely cohesive and contain significant amount of clayey particles that possess plasticity. These saturated fine sediments when stressed without any appreciable change in water content ($\phi=0$ analysis) give the values of shear strength expressed here as cohesion that range from 0.004 to 0.1 $\text{kg}\cdot\text{cm}^{-2}$, i.e. 0.4 to 10 kPa and these values are having a variable relation with depth (Fig. 6) although about 71% of the data show an increase in value with depth. At around 1 and 2 m below the mudline, there is however sudden increase in the values of shear strength as seen in the case of PC-2, 7, 8, 10 and 11 and PC-2, 3, 4, 5, 9 and 10 respectively¹ (Fig. 6).

Attempt has been made to find relation between water content and the undrained shear strength. Figure 7 shows the lines of average water content against shear strength for each core and it is found that except for the core PC-12, an inverse

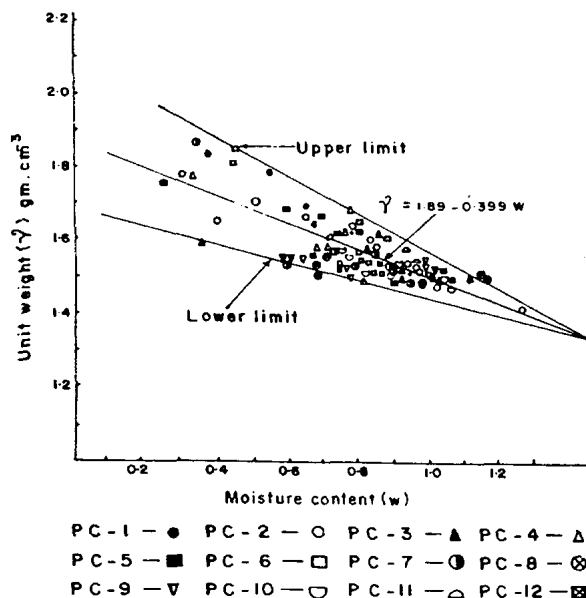


Fig. 4—Relation of unit weight with water content

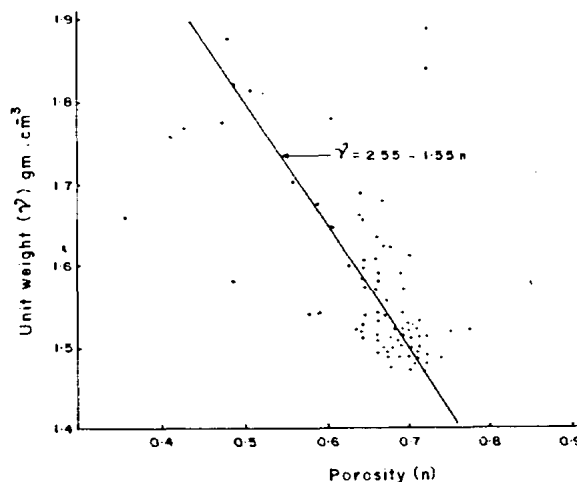


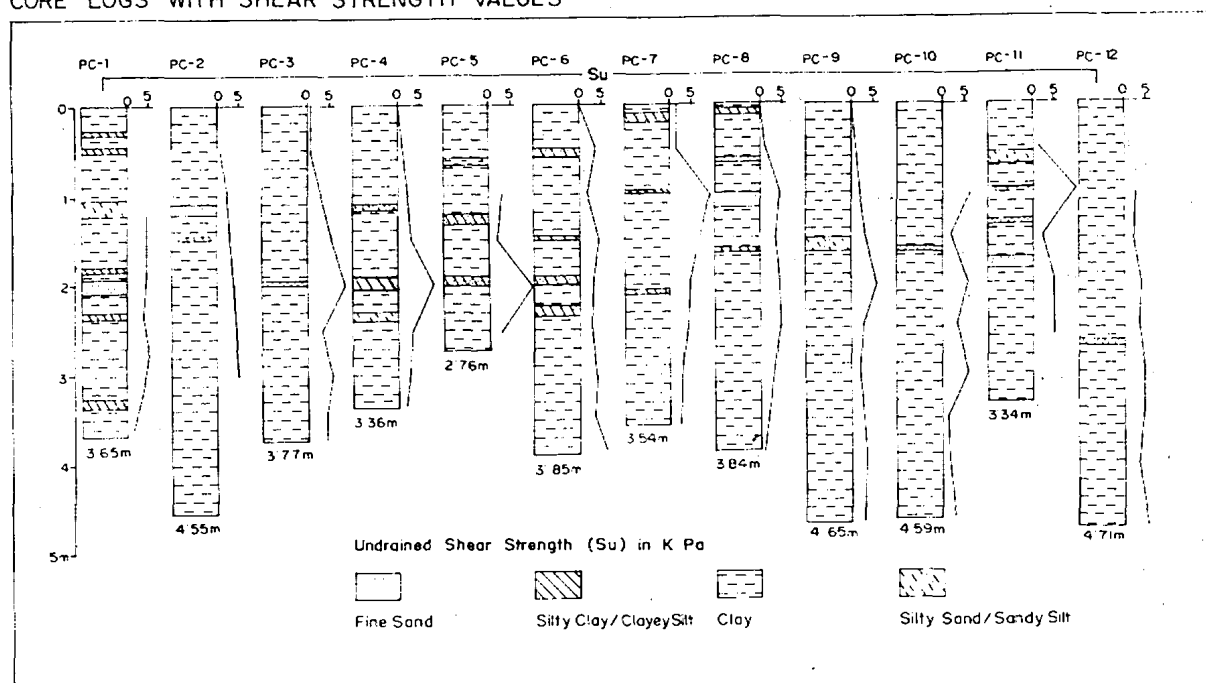
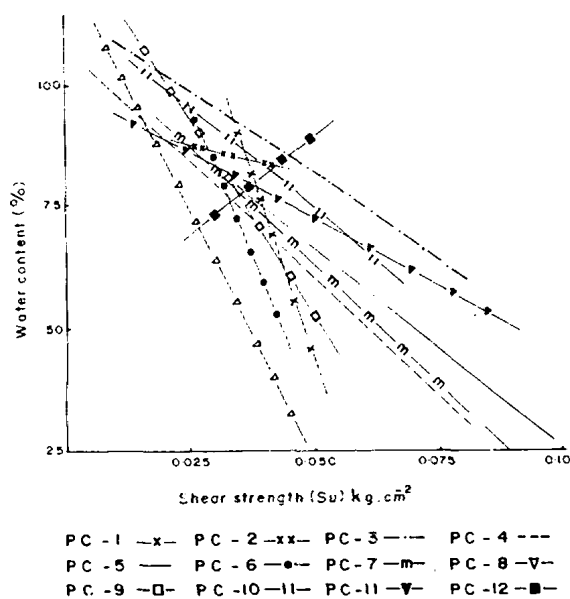
Fig. 5—Relation of unit weight with porosity

relation exists between them. The unusual behaviour of the PC-12 may be due to dessication and further collapse of sediment in the voids so created by some unknown factors (loss of water may be due to improper sealing of the ends of the core).

Discussion

All the above correlations have been developed relating the various index parameters with one another. These can be used to estimate the engineering properties of the marine clay off Narsapur. Physical properties including Atterberg limits and shear strength have demonstrated that all of them

CORE LOGS WITH SHEAR STRENGTH VALUES

Fig. 6—Core log with shear strength (S_u) valuesFig. 7—Relation of shear strength (S_u) with water content

are predominantly texture dependent. The plasticity chart (Fig. 2) shows most of the sediments to be of high compressibility type. The average values of liquid limit and plasticity index when plotted on the plasticity chart fall in the region of clays of moderately high plasticity. Values of li-

quidity index (average being > 1) indicate that the water content is marginally higher than the liquid limit. The soft nature of the sediment shows that the natural moisture content is closer to the liquid limit. Figure 3 shows that though the values of liquidity index increase with decrease of shear strength, the lower limit has an asymptotic base.

For most engineering purposes, cohesion or undrained shear strength in the fine grained cohesive sediments from an area can be estimated with reasonable accuracy from the knowledge of water content. The measurement of water content by conventional methods if made *in situ*, can be extended to estimate the shear strength directly, once the values have been calibrated from the laboratory study for its practical use while designing any offshore installation. The *in situ* measurements if feasible, however, will be helpful to cross check the data generated in the laboratory. The inverse relation between shear strength and water content as depicted in Fig. 7 can reasonably be used in the area with tolerable accuracy for any geotechnical purpose.

Figure 6 shows lithological description of core and values of shear strength against depth. The sudden increase in cohesion as seen around 1 and 2 m below the seabed may probably be due to change in lithological composition of the sediments at that depth. Silt content together with

moisture content play a dominant role in the variation of shear strength. It thus supports the contention that the physical properties are texture dependant. It may not be out of place to mention that the average ultimate bearing capacity for a footing of 1 m² at a depth of 2 m below the seabed has been found to be 3.14 tons with a safety factor of 2 as calculated by the theory of Prandtl and modified by Terzaghi (see ref. no. 3).

All these simplified soil tests have been made since their results depend precisely on the same physical factors which determine the resistance and permeability of sediments perhaps in a far more complex manner. It is clear that a preliminary estimate of the design of offshore construction can be made on the basis of Atterborg limits, shear strength and other index properties, so that sufficient care is taken before undertaking any constructional work considering the peculiar behaviour of the montmorillonite group of clay minerals. The correlation provides an insight regarding the engineering properties of sediment.

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