Comparison between the soil properties of the Coastal and Interior regions of Gujarat

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Abstract. Constructions in the coastal region have been a huge challenge in the civil engineering world for long years and so a solutions for the same has to be devised. To study this problem, this paper deals with the soil properties of some coastal belt places of Gujarat region and the soil properties of the non-coastal region of Gujarat. Gujarat's soil type has a wide range of classification and so the different properties like the N-value, type of sample, the depth at which the sample is obtained, type of soil in that region, depth of water table, moisture content, field dry density, the Atterberg Limits are studied. After studying these properties from the soil reports obtained from various laboratories, a comparison is made between the soil at Coastal belt region and Non-Coastal belt region of Gujarat and the variation is observed in the various properties. Considering, a school building at Hathab, which a coastal belt location the N-Value varies from 10 to 20 blows in a 6m considered depth. While considering a building at Bhavnagar district, which is away from the coastal area, the N-Value varies from12 to 23 blows in a 6m, considered depth. While considering the Dry Density at Hathab, it varies from 1.48 to 1.62 gm/cm^3 and the Dry Density at Bhavnagar district varies from 1.47 to 1.49 gm/cm^3, considering 6m depth. These differences need to be studied and it will helpful in designing suitable design solutions. Thus this paper may contribute in future research studies to improve and strengthen soil properties of the coastal region.

Keywords: Coastal region, Non coastal soil, N-values, Dry density, silica, Atterberg limits, design solutions.

Table 1. List of symbols

Group Symbol	Group Name
GW	Well Graded Gravel
GP	Poorly Graded Gravel
GM	Silty Gravel
GC	Clayey Gravel
SW	Well Graded Sand
SP	Poorly Graded Sand
SM	Silty Sand
SC	Clayey Sand
ML	Silt
CL	Clay of Low Plasticity
OL	Organic Silt, Organic Clay

MH	Silt of High Plasticity
CH	Clay of High Plasticity
OH	Organic Clay, Organic Silt
Pt	Peat

1 Introduction

From the evolution of the construction industry, new challenges have always emerged and the solutions to it have always been tried out. One of the major problems in the construction industry is the construction of structures in coastal region by constantly providing challenges to the industry due to complex and vexed behavior of soil in these regions. Thus to give a direction to design solution to the problems this paper is written after analyzing the geotechnical properties of the soil like Plasticity Index, Field Dry Density, Cohesion Factor, Internal Angle of Friction, Moisture Content, Bearing Capacity and SPT Value from the soil reports of different places in coastal region and some in the region away from coast, in the state of Gujarat from different laboratories of the state. The places in coastal region of whose the soil reports were analyzed are Tarsamiya, Sidsar, Akwada, Popatnagar and Hathab region of Bhavnagar, Pipavav region of Amreli district, Bhatar Road region of Surat district and Riverfront in Surendranagar district. The places in non-coastal region whose soil reports were analyzed are Vejalpur region of Ahmedabad district and Haripura region of Vadodara district. Finally the result and conclusions have been provided in the graphical form, from which we can interpret the variations that follows along the coastal and non-coastal belt of Gujarat.

Fig.1: Places of which the soil reports have been analyzed.

2 Geotechnical Properties

2.1 Plasticity Index (%)

Plasticity index gives an idea about the range in which the given soil shows plastic behavior. The range of water content basically indicates the plastic property of the soil.
0: non plastic
0-7: slightly plastic
7-17: medium plastic
>17: highly plastic
The data is given in Table.1 for Coastal and in Table.2 for Non-coastal Soil.

2.2 Field Dry Density (FDD in g/cc)

The maximum dry density possible is obtained by performing the laboratory standard proctor test on a given field soil and then the compaction ability of the layers of soil is determined from the field dry density of that particular soil. So the compaction degree can be obtained by dividing the field dry density by the maximum dry density. So more will be the field dry density more will be the compaction degree. This in-turn will be fruitful for the construction purpose as it will be a much hard surface strata. The data is given in Table.3 for Coastal and in Table.4 for Non-coastal Soil.

2.3 Cohesion Factor (C in Kg/cm^2)

Cohesion factor is an engineering shear strength parameter. This represents the cohesion between the soil particles and it is more prominent in the case of clay soil. Considering the soil consistency, the cohesion factor plays an important role. More cohesive the soil is, the more the shear strength of soil is, as it will hold the particles more firmly. The data is given in Table.5 for Coastal and in Table.6 for Non-coastal Soil.

2.4 Angle of Internal Friction (¤)

Internal friction angle or the angle of internal friction, a shear strength parameter, is the angle between the resultant shear stress and the applied normal effective stress. It is the angle at which shear failure occurs. This, shear strength parameter is more prominent in case of granular cohesion less soil like sand and gravel. This can be obtained by both Direct Shear test and Tri-axial shear test. The data is given in Table.7 for Coastal and in Table.8 for Non-coastal Soil.

2.5 Moisture Content (%)

Moisture content is the percentage of water present in the soil by weight with respect to the dry weight of the soil. This water is present in the voids between the soil particles and this does not include the water present in molecular double layer. It can be measured by doing the oven dry test in the laboratory at 105^{o}C to 110^{o}C. Moisture content is useful in finding the bearing capacity and settlement. It will also give you an idea of the state of the soil. The data is given in Table.9 for Coastal soil and in Table.10 for Non-coastal Soil.

2.6 Bearing Capacity (t/m2)

Bearing capacity is the ability of the soil to bear the loads coming from the foundation. It can be obtained by the equation

$$Q = C\, N_c S_c\, d_c + q\,(N_q - 1)\, S_q d_q + 0.5\gamma B N_\gamma S_\gamma d_\gamma \qquad (1)$$

Where,
C=Cohesion = Overburden Pressure, γ= Density, B = Width of the Footing, N_c,N_q,N_γ= Bearing capacity Factor
S_c,S_q,S_γ= Shape Factor, d_c,d_q,d_γ= Depth factor, Q_u= ultimate bearing capacity, Q_{ns}= net safe bearing capacity
The data is given in Table.11 for Coastal soil and in Table.12 for Non-coastal Soil.

2.7 SPT Value (N)

It is the number of vertical blows applied on a standard split spoon sampler per a given standard penetration value and it shows the resistance provided by the soil strata. This number (N) gives us an indication of the relative density of the soil and various other correlations are used to obtain different geotechnical properties like shear strength, cohesion factor, bearing capacity, etc. The data is given in Table.13 for Coastal and in Table.14 for Non-coastal Soil.

3 Tabulation of the Geotechnical properties

Table1. Plasticity Index for Coastal Soil

Location	Soil Classification	Depth (m)	Plasticity Index (%)
Hathab	CH	2.5	35
	CH	4	34
	CH	5.5	40
	CH	7	38
Pipavav	SC	1.5	9
	CH	2.5	37
	CH	4	36
	CH	5.5	38
	CH	7	35

Table 2.Palsticity Index for Non-Coastal Soil

Location	Soil Classification	Depth (m)	Plasticity Index (%)
Vejalpur Bh-1	CH	3	32
	SC	4.5	13
	SC	6	12
	SM	7.5	NP
	SM	9	4
Haripura	CL	2.5	16.8
	SC	4	11.3
	SC	5.5	16.5
	SC	7	17.2

Table 3.FDD (g/cc) for Coastal Soil

Location	Soil Classification	Depth (m)	FDD (g/cc)
Hathab	CH	2.5	1.64
	CH	4	1.66
	CH	5.5	1.80
	CH	7	1.82
Pipavav	CH	2.5	1.12
	CH	4	1.18
	SC	5.5	1.22
	CH	7	1.27

Table 4.FDD (g/cc) for Non-Coastal Soil

Location	Soil Classification	Depth (m)	FDD(g/cc)
Vejalpur Bh-1	CH	3	1.70
	SC	6	1.73
	SM	9	1.76
Haripura	CL	2.5	1.521
	SC	4	1.574
	SC	5.5	1.651
	SC	7	1.689

Table 5. Cohesion Factor (C in Kg/cm2) for Coastal Soil

Location	Soil Classification	Depth (m)	Cohesion Factor (C in Kg/cm2)
Hathab	CH	2.5	0.32
	CH	4	0.32
	CH	5.5	0.34
	CH	7	0.34
Pipavav	CH	2.5	0.4
	CH	4	0.45
	CH	5.5	0.6
	CH	7	0.5

Table 6. Cohesion Factor (C in Kg/cm2) for Non-Coastal Soil

Location	Soil classification	Depth	Cohesion Factor (C in Kg/cm2)
Vejalpur Bh-1	CH	3	0.72
	SC	6	0.19
	SM	9	0.00
Haripura	CL	2.5	0.37
	SC	4	0.14

Table 7. Angle of Internal Friction (ϕ in degree) for Coastal Soil

Location	Soil Classification	Depth (m)	Angle of Internal Friction(ϕ in degree)
Hathab	CH	2.5	6
	CH	4	6
	CH	5.5	4
	CH	7	4
Pipavav	CH	2.5	0
	CH	4	0
	CH	5.5	0
	CH	7	0

Table 8. Angle of Internal Friction (ϕ in degree) for Non-Coastal Soil

Location	Soil Classification	Depth	Angle of Internal Friction (ϕ in degree)
VejalpurBh-1	CH	3	5
	SC	6	27
	SM	9	31
Haripura	CL	2.5	13
	SC	4	20

Table 9. Moisture Content for Coastal Soil

Location	Soil Classification	Depth (m)	Moisture Content (%)
Hathab	CH	2.5	11.3
	CH	4	12.3
	CH	5.5	12.24
	CH	7	12.90
Pipavav	CH	2.5	28.5
	CH	4	30.2
	CH	5.5	30.9
	CH	7	31.2

Table 10. Moisture Content for Non-Coastal Soil

Location	Soil Classification	Depth (m)	Moisture Content (%)
Vejalpur Bh-1	CH	3	7.34
	SC	6	13.59
	SM	9	15.31
Haripura	CL	2.5	21.8
	SC	4	23.4
	SC	5.5	22.7
	SC	7	24.3

Table 11.Bearing Capacity for Coastal Soil

Location	Depth of Footing (m)	Qun (t/m2)	Qns (t/m2)
Akwada	2	33.8	13.52
	2.5	37.875	15.15
	3	42.11	16.84
Bhatar Road	8	77.5	31
	8.5	80	32
	9	82.5	33

Table 12. Bearing Capacity for Non-Coastal Soil

Location	Depth of Footing(m)	Qun (t/m2)	Qns (t/m2)
Vejalpur	8.5	150	60
	9	182.5	73
	9.5	215	86
Haripura	1.5	35.2	14.08
	2	37.5	15
	2.5	39.88	15.94

Table 13.SPT Value for Coastal Soil

Location	Soil classification	Depth (m)	SPT Value (N)
Hathab	CH	1.5	10
	CH	3	15
	CH	4.5	20
	CH	6	26
	CH	7.5	32
	CH	9	38
Pipavav	SC	1.5	3
	CH	3	8
	CH	4.5	10
	CH	6	11
	CH	7.5	12
	CH	9	15

Table 14.SPT Value for Non-Coastal Soil

Location	Soil Classification	Depth (m)	SPT value (N)
Vejalpur Bh-1	CH	1.5	19
	SC	4.5	38
	SM	7.5	56
Haripura	CL	2	14
	CL	3.5	24
	SC	5	27
	SC	6.5	31

4 Analysis of the Results obtained from Soil Reports:

The soil reports of six different coastal and non-coastal places of Gujarat were collected, the geotechnical properties were analyzed and then the graphical results are plotted for the geotechnical property analyzed against the depths, depicting significant trends differing in coastal and non-coastal soil. There are some complexities observed from the graph due to the different soil type present and location of ground water table. The water table was encountered at the depth of 6m at Vejalpur. The borehole depth for investigation was 20m.The borehole depth was excavated for 9m and the water table was encountered at the depth of 1.5m below ground level.These trends are shown for each property in the graphical form below.

4.1 Plasticity Index:

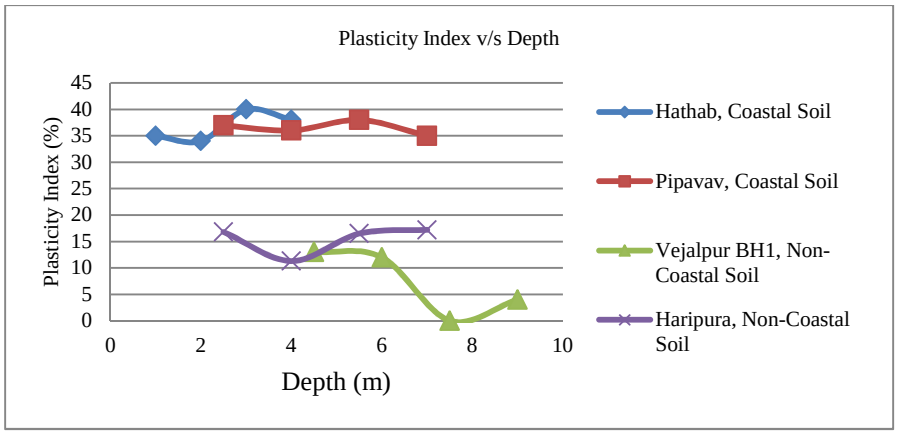

Fig 2.Graph of Plasticity v/s depth for stated coastal and non-coastal soil.

The soil at Hathab ranges from 35%to 38% and it increases as the depth increases. The same trend is also observed for the Pipavav. So we can analyze that the higher plasticity in coastal soil may raise the in-stability nature of the soil. On comparing the soil at Vejalpur, the plasticity index is much lower than at the coastal soil region and at a depth of 7.5m the soil becomes non-plastic. In Vejalpur we can see that as we excavate deeper the plasticity index decreases. And at a depth of a 7.5m the soil becomes non plastic. While neither at Hathab nor at Pipavav the soil becomes non-plastic. This provides an insight to the problems in coastal area. At Vejalpur, the plasticity index above the ground water level decreases up to depth 6m where the groundwater level is observed. Here this decrease is

drastic but as you go deep below the water table it increases up to depth of 15m but then on it decreases but not as drastically as it did above the water table. For Haripura, it is observed that as excavating further below the ground water table the plasticity index increases. From the two different soil strata, the CL and the SC, the SC posses more plasticity. In Hathab the soil type found was CH for the entire excavated bore and the plasticity index with increase in depth increases. This trend was similar in the Pipavav region where the two soil types were found, SC at 1.5m and CH from 2.5m. Here the SC had lower plasticity compared to CH and in CH same trend is observed as in Hathab. Thus CH type soil posses more plasticity for both coastal and no-coastal soil. At higher depths the SM layer soil is found which posses lowest plasticity and also becomes non plastic at depth of 9m at Vejalpur.

4.2 Field dry density:

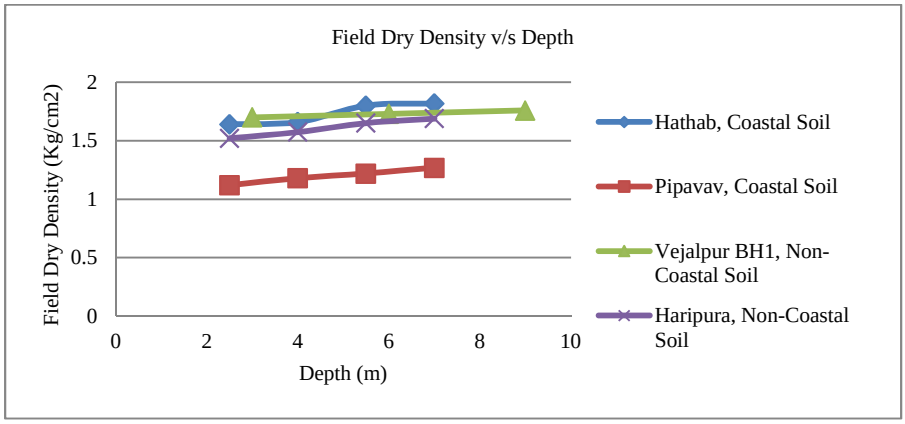

Fig 3.Graph of Field Dry Density v/s Depth for stated coastal and non-coastal soil

From the above graph it can be observed that non-coastal soils at Vejalpur and at Haripura have high Field Dry Density ranges from 1.7g/cc to 1.76g/cc for Vejalpur and it ranges from 1.52g/cc to 1.69g/cc for Haripura. It can be seen that the Field Dry Density at Hathab ranged 1.64gm/cc to 1.82gm/cc, which is higher than non-coastal soil at Haripura. This exception can be affirmed by difference in the water holding capacity of the soil, 12.9%, at Hathab which was CH at 7m, while soil encountered was SM at 9m. Considering at Vejalpur the soil encountered was SM at 9m. The field dry density both above and below the water table increase with depth from 1.70g/cc to 1.83g/cc at Vejalppur. For Haripura, the FDD for the SC strata is more than the CL strata and the SC

has a higher degree of compaction. At the coastal areas the FDD was found higher at a great depth of 7m, while the FDD for non-coastal area was found higher a shallow depth of 3m. But for FDD at coastal area of Pipavav, it was found much lower though having the same soil type, CH of that at Hathab. It was because the moisture content here was also enough more to that of Hathab and the moisture content at CH layer at depth 3m at Vejalpur.

4.3 Cohesion Factor:

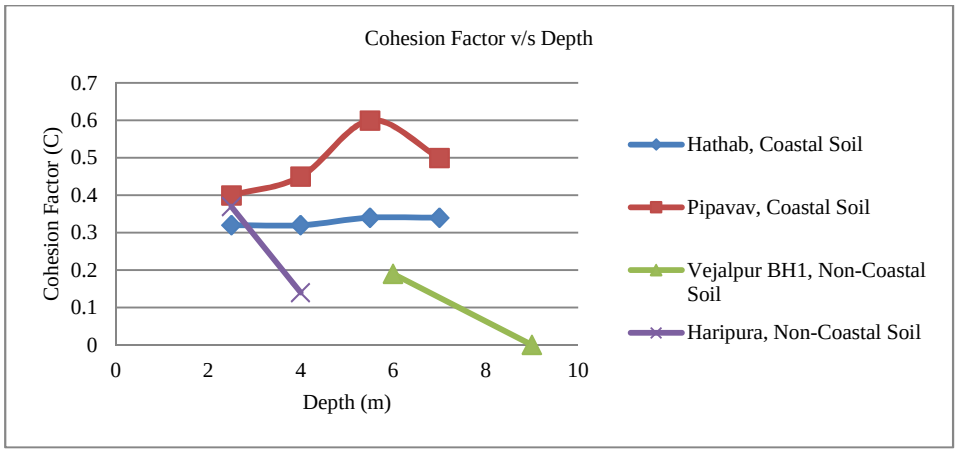

Fig 4.Graph of Cohesion v/s Depth for stated coastal and non-coastal soil

From the above graph it can be inferred that the cohesion for Vejalpur soil decreases with the depth from 0.19kg/cm^2 at 6m depth to 0kg/cm^2 at a depth of 9m. The cohesion factor for Haripura seems to follow the same trend. While in the coastal soil the Cohesion is much higher. In Hathab it ranges from 0.32kg/cm^2 to 0.34kg/cm^2. At Pipavav, the same trend of increase in cohesion factor with depth follows. Also as the cohesion increases the shear strength increases. For Vejalpur it was found that above the water table level the cohesion value decreases with depth up to the depth of water table. For Haripura it decreases below the ground water level and is 0.14Kg/cm2 at depth of 4m. The soil also changes from CL to SC with increase in depth, which decreases the cohesive nature of soil as you go deeper. At both the coastal site, CH soil type was excavated and tested and the Cohesion factor value varies between 0.32Kg/cm^2 to 0.5Kg/cm^2 at 4m depth which compared to the CH at the non-coastal area is 0.72Kg/cm^2 for CH soil type at 3m depth at Vejalpur. So the coastal area has less cohesive soil compared to the non-coastal area. The highest cohesion factor value is obtained for CH type of soil for both coastal and non-

coastal soil. While the SC type has lower than CH type soil and the lowest is found for the SM type soil.

4.4 Angle of Internal Friction:

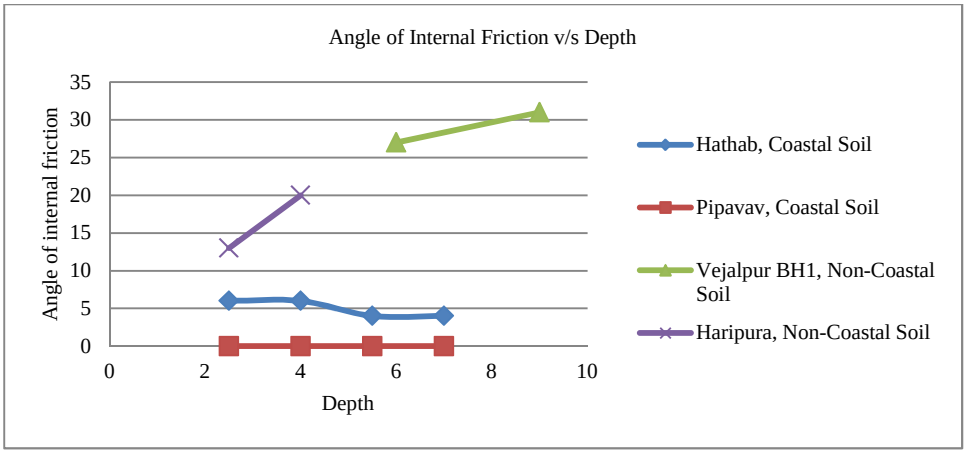

Fig 5.Graph of Angle of Internal Friction v/s Depth for stated coastal and non-coastal soil

From the above graph we can infer that the angle of internal friction for coastal soil is lower than that of non-costal soil. So the shear strength at the non-coastal soil with higher internal angle of friction is higher and it provides more stability to the soil. The angle of internal friction is highest at Vejalpur with 31 degree at a depth of around 9m and compared to that in the coastal soil of Pipavav region, the angle of internal friction is lowest with 0 degree at all the depths which were taken. Therefore the shear strength is lowest at this region and the soil has very low stability in this region. The angle of internal friction increases and becomes maximum of 31 degree at the depth of 9m at Vejalpur. For Haripura, the angle of internal friction for SC was more than the angle for the CL, which makes clear that the shear strength for the CL is more compared to the SC. In both the places, Hathab and Pipavav, coastal area in the soil type CH was found and comparing this soil type with the CH type of soil at non coastal area the ϕ value does not increase beyond 6 degree. Though in Pipavav, the ϕ value found is 0 degree. So for CH type soil the angle of internal friction was found maximum to be 6 degree at both coastal and non-coastal area While for other soil type, SC and SM, found at Vejalpur, it is 27 degree and 31 degree respectively at deeper depths.

4.5 Moisture Content:

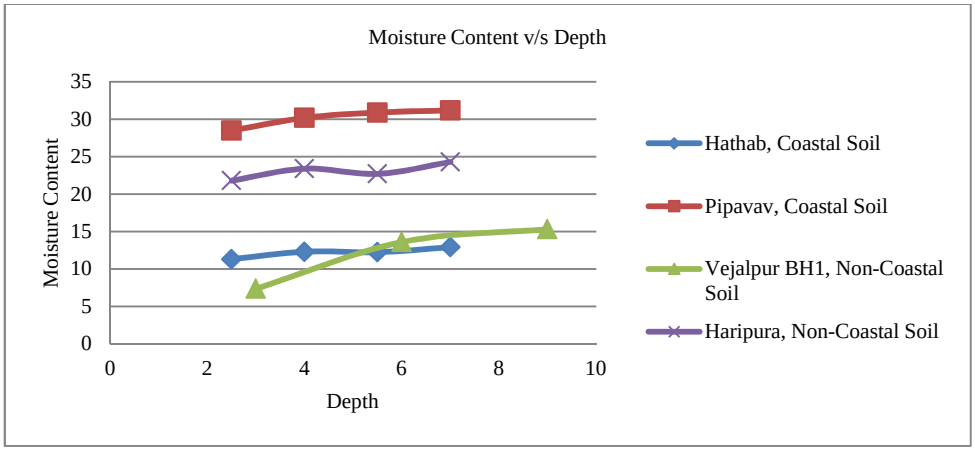

Fig 6.Graph of Moisture Content v/s Depth for stated coastal and non-coastal soil

For the coastal soil the natural moisture content will be higher compared to the non-coastal soil, but the result plotted after the analysis shows some twists in the pattern. We can see that Hathab, has lower moisture content and Haripura has higher moisture content compared to Hathab. This is because from the soil reports it was found that the water table level was encountered at an early depth of 1.5m at Haripura. While at Pipavav the normal trend of high moisture content was observed and at Vejalpur, water table depth of 6m was encountered, the moisture content was low. For existing, clayey soil (SC and CL) below the depth of water table, the moisture content increase at Vejalpur. For Haripura, the moisture content going deeper increases and the CL holds less moisture than the SC. Hathab and Pipavav, coastal area both have CH type soil and in both the soil type the moisture content increases excavating deeper. Though for same type of soil CH, Vejalpur the moisture content was found very less compared to coastal area and this tells how even the same soil type differ in moisture content at coastal and non-coastal area on the basis of water table depth and soil type.

4.6 Net Safe Bearing Capacity:

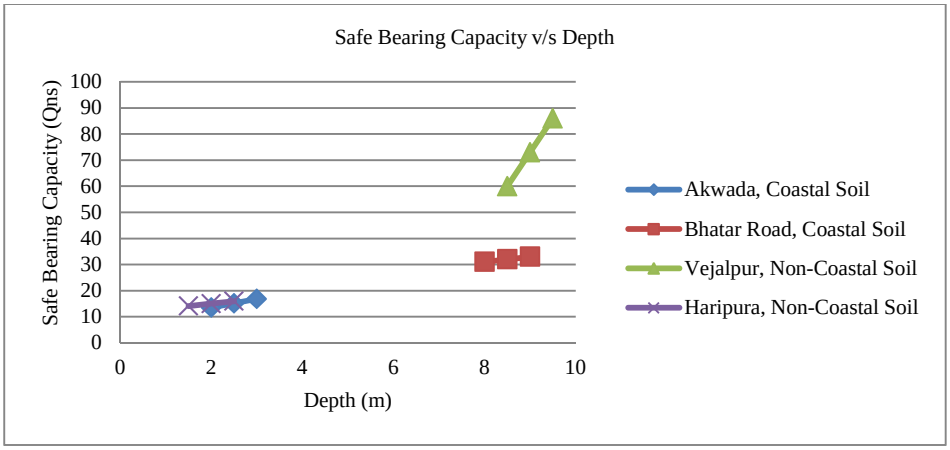

Fig 7.Graph of Net Safe Bearing Capacity v/s Depth for stated coastal and non-coastal soil

The results found from the plot of net safe bearing capacity v/s depth graph are not very conclusive. The net bearing capacity of the non-coastal soil is generally higher than the coastal soil but here from four places analyzed, two places, Akwada ranges from 13.52t/m^2 to 16.84t/m^2 and Vejalpur from 60t/m^2 to 86t/m^2, increases with depth shows normal trend and is acceptable. While considering Haripura, the water table was encountered at a shallow depth of 1.5m and the bearing capacity is lower and ranges from 14.08t/m^2 to 15.94t/m^2. Similar trend was obtained at Bhatar Road, a coastal soil, the safe bearing capacity ranged from 31t/m^2 to 33t/m^2, as the ground water table level was not encountered within 15m of excavation, so it can carry more load compared to other places on coastal soil. The net safe bearing capacity observed for Vejalpur increases on going down from 8.5m that is below the ground water table level. This can also be inferred from the N-value the N-value in this region is more than 100. Thus this region is good for foundation. The safe bearing capacity can be related with the N-value and so we can say that the SC has a higher safe bearing capacity as the N-value obtained here is higher. For bearing capacity we encountered the soil reports of other coastal places Akwada, Bhavnagar and Bhatar Road, Surat. Here a different trend is observed; Haripura being a non-coastal area still has a similar trend like that of Akwada. This is due to as discussed at Haripura the water table was just observed at a depth of 1.5m and bearing capacity was measured within 2.5m depth. Also the soil type found at both the places was similar, CL

and SC. For Bhatar road the safe bearing capacity was relatively higher than other coastal area as the soil type here found was SM which generally has higher bearing capacity, which is also found at Vejalpur, having high bearing capacity up to 86t/m^2

4.7 SPT N-Value:

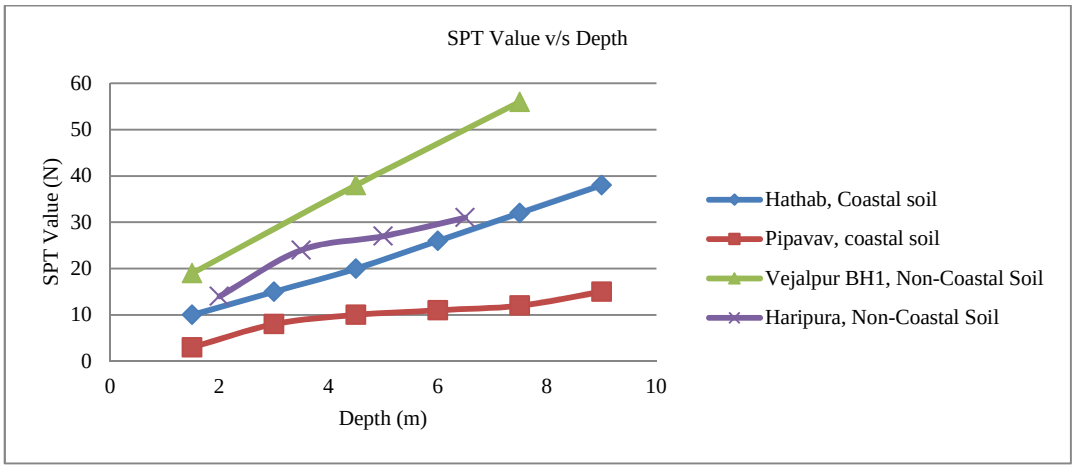

Fig 8.Graph of SPT Value v/s Depth for coastal and non coastal soil

The N-value seems to follow an obvious pattern. At coastal soil it can easily penetrate and so the blows required is lower compared to the non-coastal soil. The blows required for the non-coastal soil, Vejalpur reaches more than 50, which will ensure good strata and so the overburden pressure check is not required. On the other non-coastal soil, Haripara the blows do not reach up to 50 but the strata can be considered good. For the coastal soil due to the presence of ample moisture content the penetration becomes easy and lesser blows are required. Considering Pipavav coastal soil, the N-value hardly reaches 15. While seeing other coastal region, Hathab the blows increase after a depth of 6m, which suggests that strata gradually start to harden below a depth of 6m. Below the water table level the N value was 56 at 7.5m and varies to 100 on going to further depth up to 20m. The soil layer found beneath the water table is almost clay. And so the plasticity index decreases. This shows that the ground surface is becoming much harder with increase in depth. For Haripura, with increase in depth, the N-value increases up to 33. The soil varies from CL to SC. It infers that the SC strata offer more resistance to the hammer blows than the CL strata. For the soil type CH the N-value limits up to 20 for a depth of 4.5m but going further it even reached to N-value 38, for

both coastal and non-coastal soil. For non-coastal soil where during excavation even other soil layer like SC was encountered the N-value even exceeded 30 and for the SM type soil at depth of 7.5m the N-Value even crossed 50, and for CL it was beyond 80 and even reaches more than 100, which gives a high resisting strata.

5 Conclusions

The presence of different types of soil and the sourcing of the soil sample above the ground water table level or below the ground water table level affects the geotechnical properties of the soil and it varies from, their normal pattern or trend observed. The seasonal variation of the water table also affects the geotechnical soil properties. Considering the plasticity index for coastal soil it ranges from 35% to 38% and increases with depth while for non-coastal soil it decreases from 32% and reaches to 0% (NP). For the Field Dry Density for coastal soil should be low and non-coastal soil high but at Hathab it ranges to 1.82 gm/cc as the boring work took place at 8.5 m and the water table level was at shallow depth. The cohesion for non-coastal soil was much lower, ranged from 0 kg/cm^2 to 0.37 kg/cm^2 and for coastal soil it almost ranged twice to 0.6 kg/cm^2, where the water content played the role. The angle of internal friction for non-coastal soil is higher and ranges up to 31 degree and provides good shear strength and for the coastal soil due to presence of high moisture content, the angle of internal friction ranges from 0 degree to 6 degree only, having lower shear strength. The complex trend can also be observed in the moisture content of Hathab which ranges from 11.3% to 12.90% though being a coastal soil as the water table encountered at a shallow depth and for non-coastal soil at Haripura the water content was found higher up to 24.3% as the water table was encountered at a depth 1.5m where boring work took place apart from this the soil obtained here was SM while at Hathab the soil was observed to be SC. A mismatch trend was also seen in the bearing capacity. For coastal soil the net safe bearing capacity of Bhatar Road, ranging $31t/m^2$ to $33t/m^2$ was higher than that of non-coastal soil at Haripura ranging $14.08t/m^2$ to $15.94t/m^2$ as at Bhatar road the water table level was not observed up to 15m of boring works while at the Haripura the water table was observed at 1.5m. SPT Value follows a simple and normal trend and no complexions are observed. For coastal soil the N-values are less compared to the non-coastal soil. Thus this paper might be helpful for the further research in increasing the soil properties of coastal soil so that a healthy development in the infrastructure takes place at a sustainable level.

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