Strength and Stiffness of Soils Under Salinity Conditions

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Abstract. Salinity of soil is the total concentration of soluble salts in the soil. Salinity influence the geotechnical properties of soils. In this study, the effect of water salinity on strength and stiffness of clayey soil, lateritic soil and marine clay were studied. Soil specimens were prepared using different concentrations of sodium chloride solution (0M, 0.1M, 0.25M etc.) and tested using triaxial compression apparatus. From the results of triaxial test the strength and stiffness of all the three type of soil under different salinity conditions were studied. It is observed that shear strength parameters and stiffness of the soil considerably increases with increase in the salt content.

Keywords: Salinity, Triaxial test, Marine clay, Shear strength.

1 Introduction

Engineering characteristics of fine-grained soils especially clayey soils are subject to several factors including density, porosity, structure, consistency, history of method of formation, amount and type of clayey minerals, plasticity characteristics, properties of pore water etc. Any change in each of these characteristics will change the physical and mechanical characteristics of soil. Shear strength of a soil is equal to the maximum value of shear stress that can be mobilized within a soil mass without failure taking place. The shear strength of a soil is a function of the stresses applied to it as well as the manner in which these stresses are applied. A knowledge of shear strength of soils is necessary to determine the bearing capacity of foundations, the lateral pressure exerted on retaining walls, and the stability of slopes. The shear strength of a soil is derived from two parameters - called shear strength parameters - which are inherent properties of the soil. They are cohesion (c) and the angle of internal friction (ϕ). Coarse-grained soils are cohesionless and the shear strength of such soil is mainly due to their property of internal friction. Fine-grained soils are free from internal friction and the shear strength of fine-grained soil is mainly due to cohesion. In mixed soil, the shear strength of soil is due to the presence of both properties like internal friction and cohesion. The chemistry of Pore liquid effects the geotechnical properties of soil. From sea water intrusion or from the leachate coming out from rocks containing several mineral saline water enters into in-situ soil. For the proper understanding of the behavior of soil when reacted with saline water, it must be mixed in proper concentration and their effect on the geotechnical properties of soil must be studied. In this study, the strength and stiffness of clayey soil, lateritic soil and marine clay under different salinity conditions [NaCl solution: 0.01M, 0.1M, 0.5M, 1M etc.] were studied. In order to investigate the strength properties, unconsolidated-undrained triaxial compression test were performed under confining pressures of 50 kPa, 100 kPa and 150 kPa.

2 Experimental Program

The unconsolidated- undrained triaxial tests were conducted to evaluate the effect of water salinity on strength and stiffness of clayey soil, lateritic soil and marine clay. The test variables were confining pressures and salt contents.

2.1 Materials used

Soil. Clayey soil, lateritic soil and marine clay were used for this study. The clayey soil was collected from a paddy field in Chalissery, Pattambi taluk of Palakkad Dist, Kerala and lateritic soil was from a quarry in Chalissery, Pattambi taluk of Palakkad Dist, Kerala and marine clay was collected from Vytilla, Kochi, Ernakulam Dist, Kerala. The geotechnical properties of clayey soil, lateritic soil and marine clay are given in Table 1. The clayey soil, lateritic soil and marine clay were classified as high plastic clay (CH) by IS classification system.

Table 1. Geotechnical properties of soils

Properties	Results		
	Clayey soil	Lateritic soil	Marine clay
Specific gravity	2.7	2.8	2.62
Percentage of gravel (%)	2	1	0.2
Percentage of sand (%)	26	44	11
Percentage of fines (%)	72	55	88.8
Liquid limit (%)	55	53	61
Plastic limit (%)	25	27	28
Shrinkage limit (%)	16	8	17
Plasticity index (%)	30	26	33
Soil classification system	CH	CH	CH
Optimum moisture content (%)	24	23	26
Maximum dry density (kN/m^3)	17	16	15
Undrained cohesion (kN/m^2)	43	19	25
Angle of internal friction ($^{\circ}$)	22	29	17

Common salt (NaCl). Common salt is a mineral composed primarily of sodium chloride (NaCl), a chemical compound belonging to the larger class of salts. Salt is present in vast quantities in seawater, where it is the main mineral constituent. The open ocean has about 35 grams of solids per litre. It was collected from a shop in Kunnamkulam, thrissur district, Kerala.

Fig. 1. (A) clayey soil, (B) lateritic soil, (C) marine clay, (D) sodium chloride salt

2.2 Sample preparation

The collected natural soils in the form of wet condition placed in an oven for 24 hours and then crushed into dry powder form in a mortar pan. The light compaction tests were conducted to determine the optimum moisture content and maximum dry density of two samples. Soil sample passing through 425 microns IS sieve was taken by considering its maximum dry density (including the weight of soil and weight of NaCl (based on the concentration of NaCl content required)) and thoroughly mixed with saline water (varying from 0.1 to 2.25 molar concentrations of salt) equal to the optimum moisture content of soil. Properly mixed soil was filled in the split mould. Extracted the cylindrical sample from the mould and measured its length and diameter. A membrane suction stretcher can be used to place the rubber membrane around the soil. Unconsolidated - undrained test was performed on the soil specimen.

2.3 Testing specimen

UU triaxial tests were performed on three types of soils with and without salt content for 0 days and 7 days curing with different confining pressure (50, 100, 150 kPa). The triaxial compression test was carried out by as per IS:2720, Part XI-1993. In this test, a cylindrical specimen is stressed under conditions of axial symmetry. In the first stage of the test, the specimen is subjected to a confining pressure on the surrounding and at the top and the bottom. This stage is known as the consolidation stage. But in the unconsolidated undrained test the specimen is not allowed to consolidate in the first stage. In the second stage of the test, called the shearing stage, an additional axial stress, known as the deviator stress, is applied on the top of the specimen. During the second stage drainage is not allowed. Thus, the total stress in the axial direction at the time of shearing is equal to confining pressure plus deviator stress. When the axial stress is increased, the shear stresses are developed on inclined planes due to compressive stresses on the top. In unconsolidated undrained tests, drainage from the soil specimen is not permitted during the application of chamber pressure σc. The test specimen is sheared to failure by the application of deviator stress Δσd. The desired three-dimensional system is achieved by initial application of confining pressure through water. While this confining pressure was kept constant throughout the test, axial loading was increased gradually at the rate of 1.2 mm/ minute. The loading was continued until strain level of reinforced specimen reached 20 %. This strain is known as strain at failure.

3 Results and discussions

3.1 Failure type

Fig. 2 shows photos of deformed failure specimens after tests. In clayey soil all around cracks were found for specimens without salt and for specimens with salt, crack was observed around the center of the specimen. In lateritic soil a slight bulging along with cracks were found for specimens without salt and for specimens with salt, only bulging at center was observed. In marine clay bulging was observed for all specimens with and without salt content, but the bulging reduces with increase in salt.

(a) (b) (c)

Fig. 2. Failure observed after loading with and without salt (a) clayey soil (b) lateritic soil (c) marine clay

3.2 Stress strain behavior

The deviator stress (σd) is equal to (σ1 – σ3), where σ1 is major principal stress and σ3 is minor principal stress.

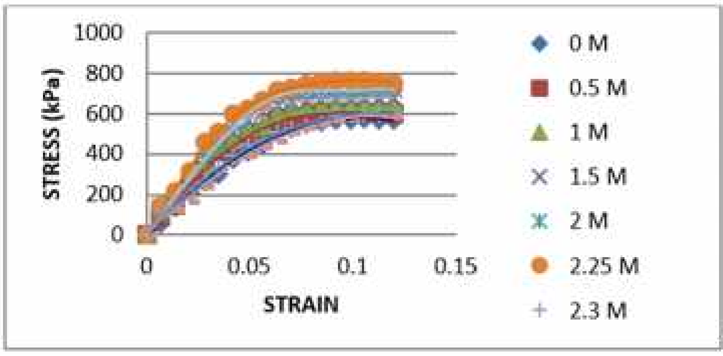
Table 2. Deviator stress at failure for clayey soil, lateritic soil and marine clay

CLAYEY SOIL				LATERITIC SOIL				MARINE CLAY			
Variation in salt content (molar)	Confining pressure (kPa)			Variation in salt content (molar)	Confining pressure (kPa)			Variation in salt content (molar)	Confining pressure (kPa)		
	50	100	150		50	100	150		50	100	150
0	569	650	673	0	358	389	555	0	222	256	342
0.5	602	673	713	0.1	389	442	716	0.1	279	326	362
1	645	696	739	0.5	410	447	724	0.25	298	358	411
1.5	678	726	764	0.75	439	479	768	0.45	318	383	445
2	719	746	789	0.8	447	513	834	0.5	285	313	401
2.25	754	772	802	0.85	381	421	689	0.6	227	254	326
2.3	597	681	693	1	368	405	634	0.65	183	231	306
2.5	584	625	678	1.5	345	358	516				

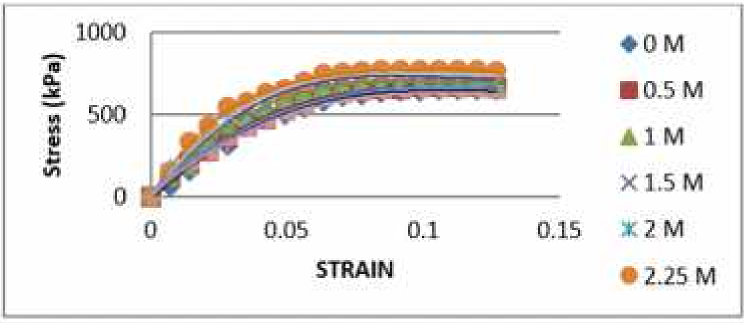
All the three soils selected for the study have different optimum range of salt content. After this range the deviator stress is decreasing.

3.3 Stress v/s strain graph

The y-axis shows the deviator stress ($\sigma 1 - \sigma 3$) and x-axis, the axial strain(ξ)



(A)



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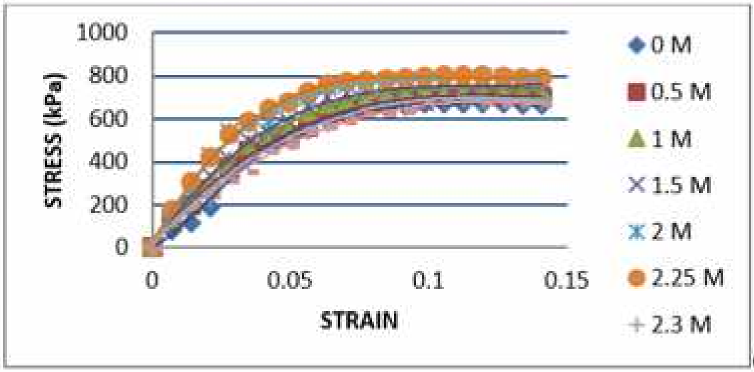
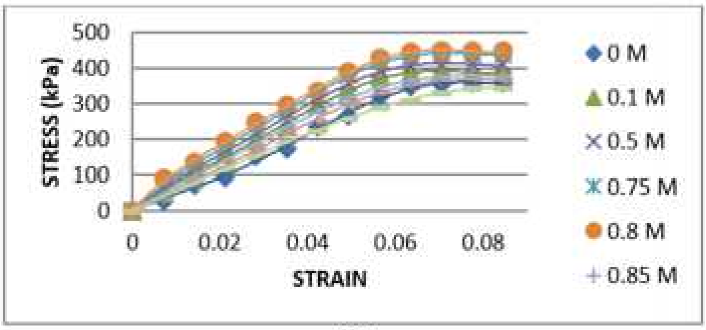
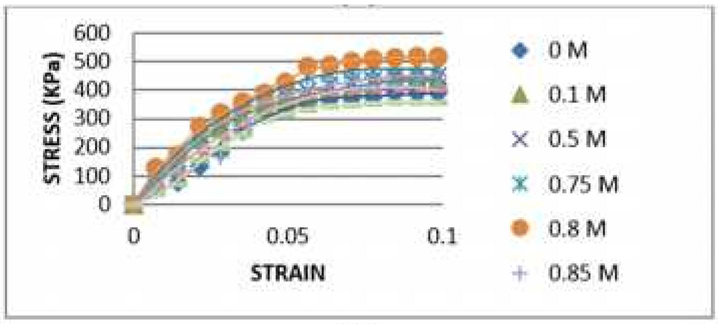


(C)

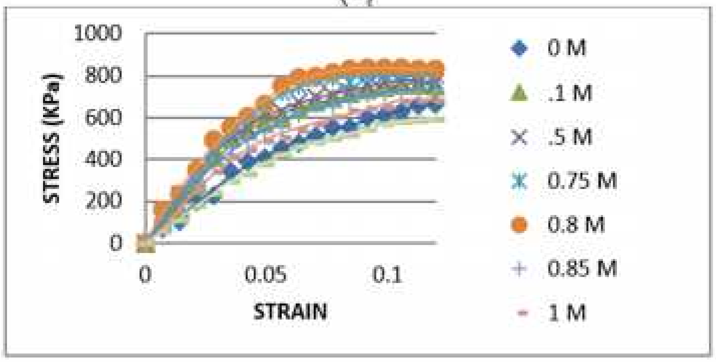
Fig. 3. (A), (B) and (C) are stress strain curve of clayey soil for confining pressures 50 kPa, 100 kPa and 150 kPa respectively



(D)

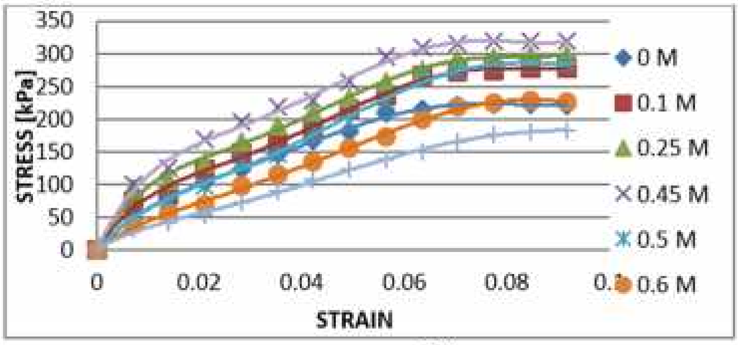


(E)

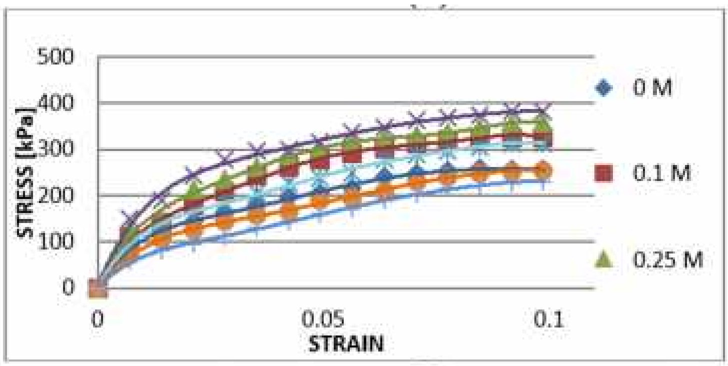


(F)

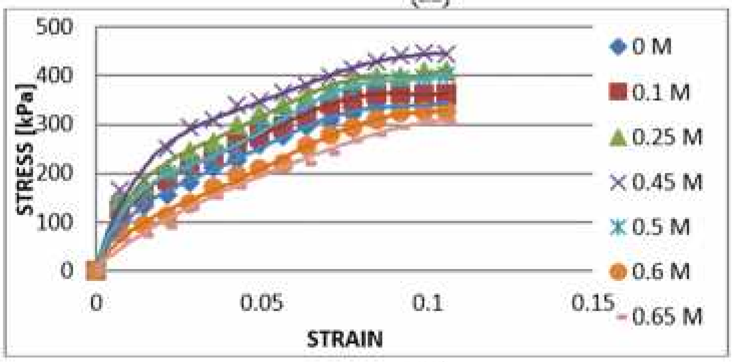
Fig. 4. (D), (E) and (F) are stress strain curve of lateritic soil for confining pressures 50 kPa, 100 kPa and 150 kPa respectively



(G)



(H)



(I)

Fig. 5. (G), (H) and (I) are stress strain curve of marine clay for confining pressures 50 kPa, 100 kPa and 150 kPa respectively

The deviator stress at failure increased as the salt content and confining pressure were increased. And this increase in deviator stress is only up to the optimum range of salt, there after it is decreasing. This optimum range is different for different soils.

3.4 Variation in strength

Tables given below shows the variation in strength of soils with change in concentration of salt content.

Table 3. variation of strength with salt content in clayey soil, lateritic soil and marine clay

CLAYEY SOIL				LATERITIC SOIL				MARINE CLAY			
Variation in salt content (molar)	Confining pressure (kPa)			Variation in salt content (molar)	Confining pressure (kPa)			Variation in salt content (molar)	Confining pressure (kPa)		
	50	100	150		50	100	150		50	100	150
0	0	0	0	0	0	0	0	0	0	0	0
0.5	6	4	6	0.1	9	13	29	0.1	26	28	6
1	13	7	10	0.5	15	15	36	0.25	34	40	20
1.5	19	12	14	0.75	23	23	38	0.45	43	50	30
2	26	15	17	0.8	25	25	50	0.5	28	22	17
2.25	32	19	19	0.85	7	7	24	0.6	2	-1	-5
2.3	5	5	3	1	3	3	4	0.65	-17	-10	-11
2.5	3	-3	1	1.5	-4	-4	-7				

The strength was increased as the salt content increases. Marine clay shows greater improvement in strength compared to other two soils selected for the study. But after the optimum salt content, strength is decreasing.

3.5 Modulus of elasticity

Modulus of elasticity is an elastic soil parameter and a measure of soil stiffness. It is calculated by taking the slope of initial tangent drawn to the stress v/s strain curve. Modulus of elasticity is represented by the letter E.

Table 4. Variation in Modulus of elasticity of clayey soil, lateritic soil and marine clay

CLAYEY SOIL				LATERITIC SOIL				MARINE CLAY			
salt content (molar)	Confining pressure (kPa)			salt content (molar)	Confining pressure (kPa)			salt content (molar)	Confining pressure (kPa)		
	50	100	150		50	100	150		50	100	150
0	10000	12000	13000	0	6000	9000	11000	0	6000	11000	10000
0.5	12000	13000	13500	0.1	7000	11000	16000	0.1	8000	13000	12000
1	14000	16000	15000	0.5	8000	12000	17000	0.25	12000	31250	14000
1.5	14500	18000	17000	0.75	9000	13000	18000	0.45	15000	18000	20000
2	15000	19500	20000	0.8	9500	14000	18500	0.5	8000	11000	13000
2.25	16000	24000	20500	0.85	6500	8500	14000	0.6	4500	7000	8000

2.3	10000	20000	14000	1	6000	8000	12000	0.65	3500	6000	5500
2.5	9500	17000	12000	1.5	5500	7000	7500				

3.6 Undrained cohesion and angle of internal friction

A modified failure envelope is a plot between p and q values at failure, Where, P= (σ1 +σ3)/2 and q= (σ1 –σ3)/2. Cohesion and angle of internal friction is obtained from the plot between p and q.

Table 5. Variation in undrained cohesion and angle of internal friction of clayey soil, lateritic soil and marine clay

Salt content (molar)	Cohesion (c)	Angle of internal friction (ϕ)	Salt content (molar)	Cohesion (c)	Angle of internal friction (ϕ)	Salt content (molar)	Cohesion (c)	Angle of internal friction (ϕ)
0	43	22	0	19	29	0	25	17
0.5	49	25	0.1	28	28	0.1	74	15
1	70	30	0.5	34	27	0.25	90	11
1.5	70	30	0.75	39	26	0.45	94	11
2	75	34	0.8	45	26	0.5	72	17
2.25	97	48	0.85	43	27	0.6	48	22
2.3	40	41	1	39	27	0.65	33	24
2.5	24	34	1.5	33	27			

4 Conclusions

A series of UU triaxial compression tests were performed to investigate the effect of salinity on strength and stiffness of soils. The main objective of this work is stabilization of soil by mixing it with low cost material that will makes construction work economical and improves the shear strength as well as the engineering properties of soil. The conclusions of this study can be summarized as follows.

- For clayey soil, lateritic soil and marine clay strength of soil increases with increase in NaCl salt content. Optimum amount of NaCl salt for three soils were found out. For clayey soil it is 2.25 molar, for lateritic soil it is 0.8 molar and for marine clay it is 0.45 molar. For all three soils, shear strength parameters and modulus of elasticity increases upto its optimum value and there after it decreases.

- For clayey soil strength increases to 32 , 19 and 19 percentage of plain soil as the concentration of salt increases to 2.25 molar for confining pressure of 50 kPa, 100kPa and 150 kPa, respectively; For lateritic soil strength increases to 25 , 25 and 50 percentage of plain soil as the concentration of salt increases to 0.8 molar for confining pressure of 50 kPa, 100kPa and 150 kPa, respectively and for marine clay strength increases to 43 , 50 and 30 percentage of plain soil as the concentration of salt increases to 0.45 molar for confining pressure of 50 kPa, 100kPa and 150 kPa, respectively.

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