Geotechnical Properties of Shedi Soil Affected by Alkali Contamination

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Abstract- **The paper brings out the effect of interaction of shedi soil containing both kaolinite and smectite minerals with alkali on various geotechnical properties such as the index properties, compaction characteristics, volume change behaviour, strength characteristics and hydraulic conductivity. It has been shown that though the plasticity index of soil decreases and optimum moisture content increases with increasing concentration of alkali content in the fluid. However the swell pressure and the compressibility of soil decrease. The shear strength of soil decreases essentially due to decrease in the cohesion of the soil particles. The hydraulic conductivity of the soil increases with higher concentrations of alkali solution. These changes in geotechnical properties of soil which are not consistent with changes in index properties are explained based on structural changes in soil particles due to alkali interaction.**

***Keywords**- Alkali solution, Plasticity, Shear strength, Volume Change Behaviour*

I. INTRODUCTION

Increasing number of instances of geotechnical failures due to heaving and settlement cracks and contamination of ground water are being reported almost from every part of the world. Conventional design of foundations to various types of structures is based on soil properties assessed in the presence of pure water. However soil-pollutant interactions that occur alter almost all geotechnical properties of soils. The extent of change in geotechnical properties of foundation soil depends not only on the nature and concentration of the pollutants but also influenced by mineral structure, such as particle size, bonding characteristics between particles ion exchange capacity, specific surface, etc. The smaller the soil particle more will be the chance for a soil particle to interact with the environment. The weaker the bonding energy between the particles (or higher the ion exchange capacity), the higher will be the change in the properties of soil. Therefore montmorillonite is potentially more sensitive to the environment than illite and kaolinite. Many attempts have been made to understand the effect of different types of pollutants on these extreme types of clays. In nature, most soils contain more than one clay mineral. But, little is known about the mechanism of change in the properties of soils containing extreme types of clays. Several studies have shown that geotechnical failures such as tilting of storage tanks and ground soil heave below industrial structures can occur due to changes in soil properties [1-3] Lukas and Gnaedoger, 1972; Sridharan et al., 1987; Assa'ad, 1998). Of the various pollutants, it is the alkali contaminations have considerable effect on the behaviour of soil[4-5] (Rao and Rao, 1994; Rao and Reddy, 1997). Hydroxides are released into the soil environment from various industries such as (i) Textile industry (ii) Paper and pulp industries (iii) In alumina production industry (iv) For making washing soaps and detergents (v) Refining of petrol and vegetable oils and so on. The effect of the hydroxide on the swelling of some soils is well known [6](Ingles, 1970). This can be due to clay-alkali interaction. Alkali at lower concentration can cause changes due to changes in the soil structure [7](Mitchell, 1993). At higher concentration clay- alkali interaction can produce new compounds and also can affect the clay structure. These different effects influenced by concentration of alkali on soils containing extreme types of clay minerals are not known. The main object of the present investigation is to study the soil contaminant interaction effects, especially with alkali on Shedi soil. The changes in geotechnical behaviour have been examined in terms of chemical and mineralogical changes. The changes in the basic properties such as Atterberg limits, Compaction characteristics, volume change, strength and hydraulic conductivity behaviour by alkali – soil interaction are expected to throw more light on the mechanism and effects on behaviour of soils in any other environment also.

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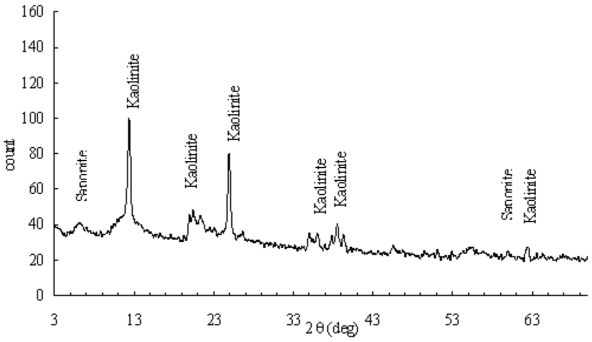
II. SOIL USED

For this experimental investigation, naturally occurring shedi soil has been procured from the MRPL-BASF industrial area of Surathkal, about 6 kms from National Institute of Technology Karnataka (NITK), India. The soil was collected by open excavation from a depth of two meter from natural ground level. Sufficient quantity of pure shedi soil was collected after removing the top lateritic soil. The soil was hand sorted to remove stones and vegetative matter if any. The soil was further dried and pulverized and sieved on 4.75mm sieve to eliminate gravel fractions if any. Finally the soil was sieved through 425-micron sieve and this sieved soil was stored in tin containers ready for use as per I.S: 2720 (Part – I)[8]. X-ray diffraction studies of Shedi soil (Fig. 1) indicated peaks 7.14, 3.57, 2.34, 2.5 A0 pertaining to 1:1 (1 silica sheet and 1 alumina sheet) Kaolinite mineral (PDF No 29 – 1488) and peaks 14.4, 1.54 A0 that are characteristic peaks of saponite, a smectite group mineral (PDF No 13 – 0086). Scanning electron microscopic image of the shedi soil is shown in Fig. 2. The micrograph depicts cluster of flakes having edge-to-edge orientation. Geotechnical properties of the soil are presented in Table 1.

TABLE 1 GEOTECHNICAL PROPERTIES OF SHEDI SOIL

1.	Particle size distribution	
	Sand size, %	34
	Silt size, %	38
	Clay size, %	28
2.	Consistency limits	
	Liquid limit, %	60.6
	Plastic limit, %	37.3
	Shrinkage limit, %	27.0
	Plasticity Index, %	23.3
3.	Specific gravity	2.49
4.	Compaction characteristics	
	Optimum moisture content, %	27
	Maximum dry density, kN/m^3	14.23
5.	Consolidation characteristics	
	Coefficient of consolidation $c_{v,}$ cm^2/min	0.403
	Compression index, C_c	0.104
6.	Coefficient of permeability (k), m/sec	$2.71x10^{-9}$
7.	Swell potential, %	0.5
8.	Strength parameters	
	Cohesion, c_{uu} (kPa)	101
	Angle of internal friction, (ϕ_{uu})	17.9°
	Cohesion, c_{cu} (kPa)	36
	Angle of internal friction, (ϕ_{cu})	1.54°
9.	pH	4.30



Pattern of Shedi Soil
Kaolinite – $Al_2Si_2O_5(OH)_4$; Saponite – $Mg_3(Si,Al)_4O_{10}(OH)_2$. 4 H_2O;

Fig. 1 X-Ray Diffraction

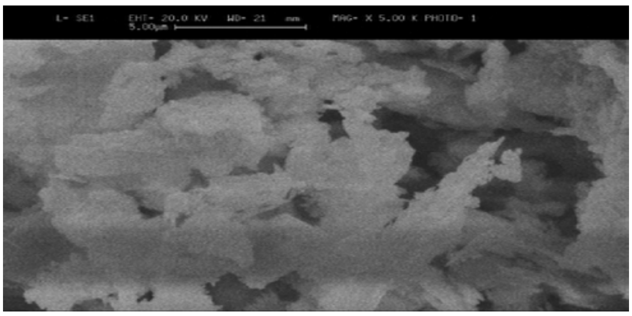


Fig. 2 SEM of Shedi Soil Indicating Clusters of thin Flakes having Edge-to-Edge Orientation

III. ALKALI SOLUTIONS

Different concentration of alkali, sodium hydroxide solutions of varying concentrations are prepared by dissolving known amounts of sodium hydroxide pellets in distilled water to have weight percentages varying form 1.5% to 12% in increments of 1.5%.

Air dried Shedi soil passing 425 micron is used for performing various tests as mentioned. The optimum moisture content and maximum dry density were determined for pure shedi soil. Knowing the optimum moisture content for pure soil, optimum moisture content for contaminated soils for varying percentage of alkali have been obtained by contaminating soil at the desired percentage and at a nominal water content say about 10%.

Standard proctor test were conducted on this contaminated soil after the curing period of 10 days and optimum moisture content of contaminated soil was obtained. This optimum moisture content is used to contaminate the soil for different tests. The procedure is repeated for varying percentage of sodium hydroxide. The soil sodium hydroxide mixtures were mixed thoroughly in to a soft easily remouldable state the mixtures were transferred to polythene bags to cure for ten days before testing.

IV. EXPERIMENTAL INVESTIGATIONS

Randomly oriented samples were prepared by manual grinding the shedi soil specimen in a porcelain mortar and pestle to powder form and subsequently pressing the material lightly into rectangular glass holders (Klug and Alexander, 1974). Samples were scanned from 3°2θ to 70°2θ using X1 Advanced Diffraction System, Scintag Inc, U.S.A, having provision to interchange X-ray tube. CuK∝ and scan rate of 3°/min radiation was used for uncontaminated soil.

The soil is mixed with desired amount of moulding fluid and placed in polythene bags and stored in airtight container for desired periods in order to achieve equal distribution of moisture, prior to testing.

The liquid limit of soil specimen mixed with sodium hydroxide were determined according to Cone penetration method because of its simplicity, quickness and reproducibility of test results, especially with high concentration of alkali solution. The Plastic limit test according to the conventional 3mm thread method ASTM D 4318–05 [9] and Shrinkage limit test of uncontaminated and contaminated soil specimen were determined as outlined in the ASTM procedure (ASTM D 427-493)[10]. In the shrinkage limit test, while working the wet soil into the shrinkage dish, care has been taken to expel entrapped air by thoroughly compacting the specimen. Cracking during drying was prevented by first allowing the soil to dry in air followed by oven-drying to a constant mass. The shrinkage limits reported are the average of three determinations.

Compaction test was carried out in the Standard Proctor's mould, having an internal diameter of 10 cm and height of 11.7 cms as per IS: 2720 (Part – VII) – 1974 method.

One – dimensional consolidation test were conducted in conventional Oedometer using different concentration of chemical contaminants as per standard procedure for consolidation test IS: 2720 (Part – XV) – 1986 method. In the experiment extreme precautions were taken to minimize the errors due to side friction. To reduce the side friction between the rings and specimen, the inner surface of the rings were lubricated with silicon grease. Shedi soil and shedi soil contaminated with varying concentrations of contaminants were statically compacted to the Proctor's maximum dry density in a 60 mm. diameter and 20 mm. high consolidation ring, to a thickness of 14 mm. The ring was then mounted in a consolidation cell and positioned in the loading frame. All consolidation tests were performed at a room temperature of 25oC ± 1oC. At a nominal pressure of 5 kPa, the sample was inundated with water. A load increment ratio of one was adopted and the load increment duration was kept as 24hours or until primary consolidation was complete. The void ratios have been obtained for different consolidation pressure increments of 10 kPa, 20 kPa, 50 kPa, 100 kPa, 200 kPa, 400 kPa and 800 kPa. For each increment of loading compression dial gauge readings were recorded for the elapsed time of 15 sec., 1, 2.25, 4.6, 6.25, 9, 12.25, 36, 49, 64 and 1440 min. as per Indian standards.

Swell potential was measured during the initial stages of the consolidation test. Having mounted in the consolidation cell and positioned with loading frame the soil sample was inundated with water under the seating load of 5 kPa and the dial gauge readings were noted. The swell potential is defined as the ratio of increase in height (ΔH) from heave under a given surcharge to the initial height (H) of the soil sample and is expressed as a percentage.

The conventional Oedometer test equipment and procedure was adopted to perform falling head permeability. Besides the simplicity of the equipment and procedure, the great merit of this test lies in the possibility of measuring not only the permeability under the initial site condition, but also the variation of permeability with the void ratio under increasing consolidation pressure. Having mounted the specimen in the Oedometer cell test is started applying the pressure increment ratio of unity up to a consolidation stress of 800 kPa. At the end of consolidation under the applied pressure the falling head permeability test is carried out. The falling head test is continued for 24 hours observing the variations with time of the water level. The consolidation test is then resumed. Constant dial gauge readings have been noticed well with in 12 to 18 hours for all the chemicals even at varying concentrations. An observation period of 24 hours is used for the permeability measurement.

At the end of consolidation stage of the conventional step-loaded Oedometer test the permeability test is started by connecting the base of the specimen to the glass tube filled with water. An initial head in the order of 100 cm is thus applied between the base and top of the 20 mm high specimen. The void ratio of the specimen was constant for about 24 hours to ensure that the height of the specimen was constant.

The soil samples for shear test were prepared by mixing varying concentration of alkali solutions at optimum moisture content and compacting statically to their respective optimum dry densities. The specimens obtained were of height 7.62 cm and diameter 3.81 cm.

Conventional triaxial testing system was used for carrying out strength tests. The test was conducted under a constant strain rate of 062 cm/min. Reading of deviator load and axial deformation was taken. The test was repeated on three identical specimens under a different cell pressure of 49, 98, and 147 kPa. Using the test data, deviator stress and axial strains were computed. Plots of deviator stress versus axial strain were plotted and peak deviator stress was determined. Knowing the values of peak deviator stresses for three cell pressures, cohesion intercept and angle of shearing resistance were obtained by plotting the test results in the form of modified failure envelope. The advantage of this method of plotting the failure envelope is that the averaging of scattered test results is facilitated to a great extent, giving the mean value of the parameters.

The alkaline characteristics of soils have been determined by measuring pH of soil with different alkali solutions using the standardized pH meter. The soil fluid ratio of 1:2 is used for suspensions.

V. RESULTS AND DISCUSSIONS

In this investigation shedi soil - containing both kaolinite and smectite has been selected for the study. The effect of alkali on the basic properties, volume change behaviour, strength characteristics and hydraulic conductivity of soil has been explained and the changes have been explained based on clay - pollutant interaction. The relative importance of cation and anion exchange, flocculation, diffuse double layer forces, surface forces on different properties of kaolinite and montmorillonitic soils can be easily assessed from this information.

Before understanding the effect of contaminant on the properties of shedi soil, the mechanism of soil behaviour has been explained from fundamental considerations. Particle size distribution of shedi soil indicates (Table 1) that soil is finer than 425 micron. Also it has been reported that particle size coarser than silt size grade is about 30%. The fine grained shedi soil has a liquid limit of 60.6% and plasticity index of 23.3%. This indicates MH-CH type of classification for the soil used in this investigation from the plasticity chart. Hence as per IS soil classification system, shedi soil used in this investigation can be grouped as highly compressible, inorganic, silty – soil. The shrinkage limit of soil is about 27%, which is higher than normally expected from its liquid limit. Expansive soil with a corresponding liquid limit would have a shrinkage limit of about 12%. The medium value of specific gravity 2.49 indicate the absence of iron and presence of organic content to a smaller extent and considerable amount of alumina in shedi soil. Optimum moisture content and maximum dry density were found to be 27 % and 14.23 kN/m3 respectively. This implies that higher water is needed for compaction process and closer packing of this type of soil. X-Ray diffraction patterns of shedi soil have indicated kaolinite and smectite as major clay minerals present in the soil. Also quartz usually present in soil is almost absent in this soil. Thus the index properties of shedi soil and the compaction characteristics of soil reflect the soil with predominant kaolinitic clay with smectite minerals. High liquid limit and high shrinkage limit probably indicate that the clay mineral is predominantly kaolinite and the smectite particles are accommodated within the flocculated skeleton formed by kaolinite. pH of the shedi soil has been reported as 4.3 which indicates the acidic nature of soil.

A. Index and Compaction Characteristics

a) Consistency Limits

The variation in consistency limits for various soil sodium hydroxide mixes is presented in Table 2 and in Figs. 3 and 4. The liquid limit of soil generally decreases with increasing concentration of sodium hydroxide. The decrease is more marked up to 9.0% of sodium hydroxide concentration.

On treatment with sodium hydroxide, the pH of soil which has been very low at 4.3 increases to about 11 with a alkali concentration of 1.5%.

This decrease in liquid limit with increase in the concentration of sodium hydroxide might be due to the predominant influence of increase in electrolyte concentration. If the effect of increase in the repulsion of clay particles due to increase in the negative charge on clay particle was predominant, the liquid limit would increase. Also formation of zeolites by soil kaolinite interaction was predominant; the liquid limit would have increased (Sivapullaiah and Manju, 2005)[11]. The liquid limit decreased with increasing concentration of sodium hydroxide up to 12%. This study indicates the formation of new minerals is negligible.

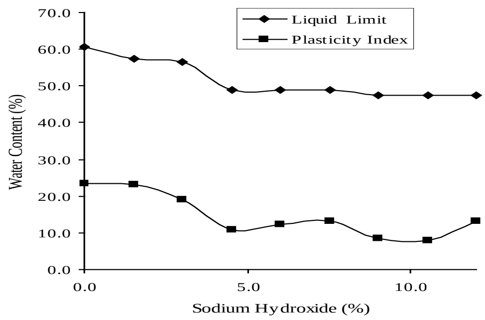


Fig.3 Effect of Alkali Concentration on Liquid Limit and Plasticity Index of Soil

TABLE 2 INDEX PROPERTIES OF SHEDI SOIL CONTAMINATED WITH SODIUM HYDROXIDE

Sodium Hydroxide (%)	Plasticity Characteristics				Specific Gravity	pH	Compaction Characteristics	
	Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit (%)	Plasticity Index (%)			Optimum Moisture Content (%)	Maximum Dry Density (kN/m^3)
0.0	60.6	37.3	27.0	23.3	2.49	4.30	27.00	14.50
1.5	57.4	34.2	29.1	23.2	2.45	11.21	27.00	14.50
3.0	56.5	37.5	33.7	19.0	2.37	11.42	27.50	14.20
4.5	49.0	38.2	34.4	10.8	2.30	11.62	28.00	14.10
6.0	49.0	36.7	35.1	12.3	2.28	10.55	28.15	13.90
7.5	48.9	35.9	35.0	13.1	2.25	10.34	29.00	13.70
9.0	47.5	35.7	33.4	8.6	2.20	10.48	30.00	13.50
10.5	47.5	34.4	32.9	7.8	2.19	10.55	30.00	13.30
12.0	47.3	34.3	32.7	13.1	2.16	10.85	32.00	12.70

This further confirmed by increase in the shrinkage limit of soil. There is no definite trend of variation in the plastic limit. However, the plasticity index generally decreased with increase in the concentration of sodium hydroxide. Only small decrease in liquid limit with increasing concentration of sodium hydroxide might be due to relatively less amount of smectite in the soil and predominance of kaolinite.

Addition of sodium hydroxide decreases the specific gravity continuously with increase in the concentration of sodium hydroxide. This may be due to the lower specific gravity (2.13) of sodium hydroxide than changes in the mineralogy or formation of new compounds due to soil alkali interaction.

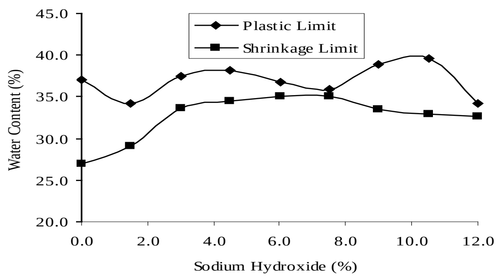


Fig 4.Effect of alkali concentration on the plastic and shrinkage limit

B. Compaction Characteristics

Sodium hydroxide increases optimum moisture content (Table 2) and decreases the maximum dry density of shedi soil with increase in concentration of sodium hydroxide. It has shown earlier that the liquid limit of soil decreases in the presence of sodium hydroxide. Normally one would expect that optimum moisture content would decrease and maximum dry density would increase. The opposite trend may be due to flocculation of particles when they are compacted at lower water contents. However, when the soil mixed thoroughly with high water contents in the range of liquid limit, the effect of flocculation is not seen and the liquid limit decreased. Thus the particles are more in flocculated structure with lower water contents.

C. Volume Change Behaviour of Shedi Soil with Alkali Solution

The effect of sodium hydroxide on the volume change behaviour of shedi soil is presented in this section. The volume change behaviour of soil has been studied in terms of variation in the swelling potential and changes in the consolidation behaviour.

a) Effect of Sodium Hydroxide

In general the swelling property of a clayey soil follows the same pattern as their plasticity properties. The potential expansion of the soils follows closely their relative plasticity indices; i.e., the higher the plasticity index, the greater the swelling potential. Attempts have been made to calculate the swelling potential of soils based on their plasticity index. However, no single relationship is suitable for all conditions. This is due to influences of compositional factors. The actual amount of swell as a result of wetting depends on factors in addition to mineralogy, such as particle arrangement, initial water content and confining pressure etc. and Table 3 present the variation in the swelling potential of Shedi soil with different amounts of sodium hydroxide. It was shown earlier that the plasticity index of soil decreases continuously with increase in the amount of sodium hydroxide contamination. However, it is seen that the swell potential of soil, which is about 0.5, marginally increases with small amounts of sodium hydroxide.

The swelling potential decreases with further increase in the amount of sodium hydroxide. The initial increase in swelling potential may be due to particle repulsion caused by increased negative charges on soil particles. This with decrease in the plasticity as observed earlier might be due to change in the particle arrangement. At higher concentration of sodium hydroxide both swelling potential and plasticity have decreased.

Figure 5 shows the void ratio - pressure relationships for shedi soil with different concentrations of sodium hydroxide. The shedi soil itself shows reasonably high compressibility due to the presence of smectite minerals. It can be seen that the compressibility of soil treated with any amount of sodium hydroxide is generally lower than that of untreated soil. The total compressibility, as the pressure is increased from 10kPa to 800kPa, increases with increase in the concentration of sodium hydroxide from 1.5% to 4.5% from Δe of 0.222 to 0.39.

TABLE 3 SWELL POTENTIAL AND COMPRESSION INDEX OF SHEDI SOIL CONTAMINATED WITH SODIUM HYDROXIDE

Sodium Hydroxide (%)	Swell Potential (%)	Compression Index
0	0.50	0.104
1.5	0.55	0.104
3.0	0.65	0.107
4.5	0.60	0.118
6.0	0.57	0.122
7.5	0.55	0.118
9.0	0.53	0.107
10.5	0.50	0.092
12.0	0.30	0.088

It was earlier noticed that during this range of concentration, the swelling potential of soil increased. Thus the relatively higher compression than expected is due to repulsion of soil particles with increase in pH. However, the effect of increase in the electrolyte concentration overtakes the effect due to increased pH. Thus the total compressibility decreases and the compressibility is least with the highest concentration of 12% of sodium hydroxide studied as the percentage of sodium hydroxide increases the compressibility decreases.

The effect of amount of sodium hydroxide on the compression index of shedi soil is shown in Table 3 and Fig. 6. The compression index remains fairly constant with addition of sodium hydroxide up to about 3%. Then it increases steeply with the increase in the amount of sodium hydroxide up to 7.5% and then decreases continuously with increase in the amount of sodium hydroxide. With addition of small amounts of sodium hydroxide up to about 3%, it was shown that the swelling potential of the soil increases which is also responsible for lower decrease in the total compressibility. This is also is the reason for almost constant compression index. But with increase in the concentration of alkali solution, the effect of electrolyte concentration overtakes. Also the effect of small increase in swelling potential, if any, is seen only at smaller effective pressures and the compression is steeper at higher applied effective pressures. Thus the swelling potential of the soil decreases and the soil undergoes higher compression index. This compression is particularly at higher pressures, which is responsible for higher compression index. The rate of decrease in the compression index is particularly high at sodium hydroxide concentration of up to 10.5 % of sodium hydroxide.

D. Shear Strength of Contaminated Shedi Soil

It is known that the shear strength of shedi soil varies with moulding water content. To avoid the effect of variation in the moulding water content in the consideration of the effect of sodium hydroxide on the shear strength of shedi soil, the moulding water content has been kept at the respective optimum water content of the contaminated soil. It has been observed that as the percentage of sodium hydroxide is increased, the optimum moisture content increases and maximum dry density decreased. To consider the effect of varying percentage of sodium hydroxide on the shear strength of shedi soil, consolidated undrained strength of soil mixed with varying amount of sodium hydroxide has been determined. The effect of sodium hydroxide has been considered in terms of stress strain behaviour and variations in the shear strength parameters.

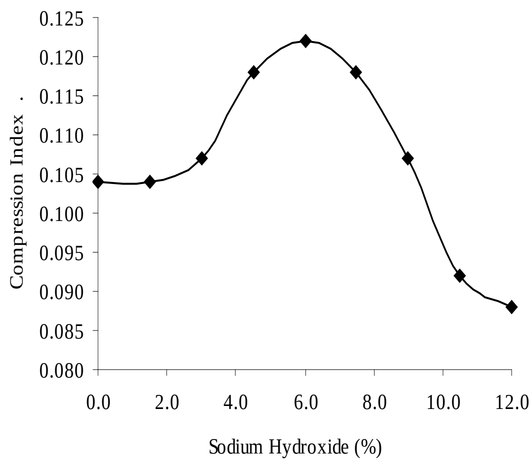


Fig. 5 Void ratio Versus Pressure Relationship for Sodium Hydroxide Treated Soil

The effect of varying percentages of sodium hydroxide on the stress strain relationship of shedi soil at a cell pressure of 49 kPa is shown in Fig. 7. It can be seen that the peak stress of the soil increases with a small percentage of sodium hydroxide of 1.5%. However, with further increase in the amount of sodium hydroxide, the peak stress continuously decreases. It has been shown earlier that the plasticity and compressibility of soil decreases.

This may be due to variations in the shear strength parameters. Similar behaviour is observed from the stress strain relationship of soil at a cell pressure of 98 kPa (Fig. 8). However the effect of sodium hydroxide is substantially reduced at cell pressure of 147 kPa (Fig. 9). The peak stress of contaminated soil is almost the same as that of uncontaminated soil. The stiffness of the soil reduces with increase in moisture content and percentage contaminant.

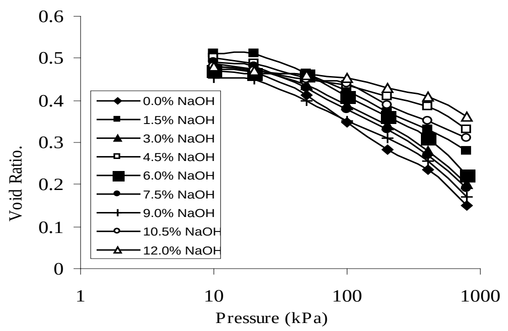


Fig.6 Effect of concentration of Sodium Hydroxide solutions on Compression Index of Soil

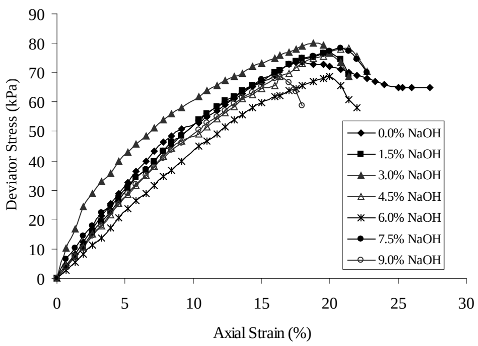


Fig.7. Stress - Strain Curves of Soil Compacted with Different Alkali Concentrations at a Cell Pressure of 49 kPa

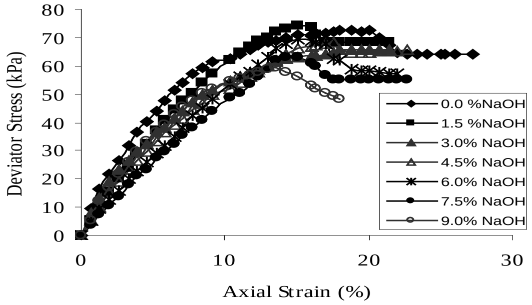


Fig.8. Stress- Strain Curves of Soil Compacted with Different Alkali Concentrations at a Cell Pressure of 98 kPa

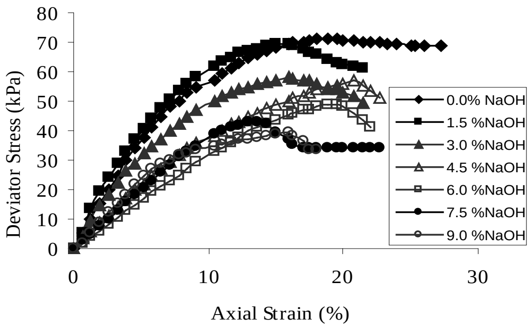


Fig.9 Stress - Strain Curves of Soil Compacted with Different Alkali Concentrations at a Cell Pressure of 147 kPa

The shear strength parameters of soil with different amounts of sodium hydroxide are calculated using modified Mohr's failure envelopes. It can be seen that the strength of soil with higher percentages of sodium hydroxide is reduced. With 1.5% of sodium hydroxide, the strength of soil is higher. The values of cohesion and angle of internal friction are given in Table 4. It can be seen that the cohesion of soil decreases (Fig. 10) and value of internal friction increases (Fig. 11) continuously with increase in the amount of sodium hydroxide.

TABLE 4 TOTAL AND EFFECTIVE SHEAR STRENGTH PARAMETERS OF SHEDI SOIL CONTAMINATED WITH SODIUM HYDROXIDE

Sodium Hydroxide (%)	**Total Cohesion (kPa)**	**Total Angle of Internal Friction (ϕ)**	**Effective Cohesion (kPa)**	**Effective Angle of Internal Friction (ϕ^1)**
0	34.44	1.20	34.95	0.60
1.5	30.71	4.10	32.30	2.50
3.0	21.44	5.80	21.85	6.80
4.5	20.90	5.70	21.30	6.00
6.0	19.41	5.30	19.25	6.20
7.5	11.13	8.80	11.37	9.00
9.0	9.32	8.00	11.60	7.50

However, the increase in the value of internal friction is relatively steep with 1.5 % and gradual subsequently. The net effect is that the strength of soil is high when contaminated with a small amount of sodium hydroxide but decreases steeply with increase in the amount of sodium hydroxide.

a) Effect of Sodium Hydroxide on the Shear Strength of Soil at High Water Contents

The effect of varying amounts of sodium hydroxide on the shear strength of shedi soil as determined by fall cone apparatus is presented in. The strength of soil varied depending on the amount of contaminant. Comparable strength of soil could be achieved at different range of water content. Generally, as the amount of contaminant increases, the same strength was achieved at lower water contents. This indicates that the strength of soil decreases in the presence of sodium hydroxide. For example, strength of 2 kPa was achieved for the soil alone at a water content of 58%, whereas the same strength is obtained at 56.8 % for the soil with 1.5%

of sodium hydroxide, 56 % for the soil with 3 % of sodium hydroxide.

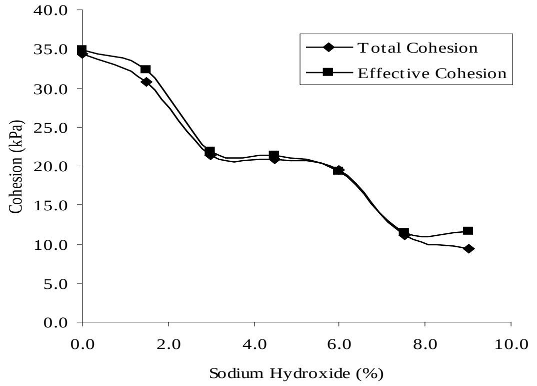


Fig.10 Total and Effective Cohesion for Soil with Alkali solutions of Different Concentrations

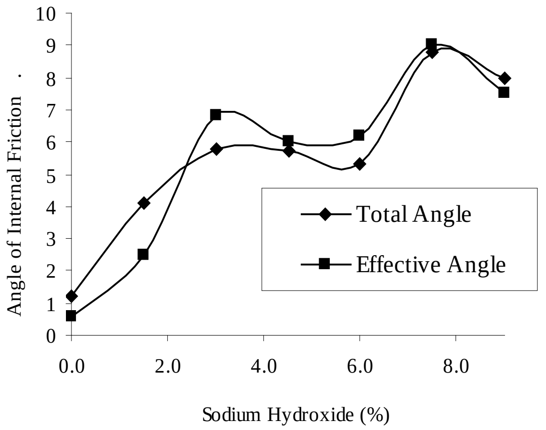


Fig.11 Total and Effective Angle of Internal Friction for Soil with Alkali solutions of Different concentrations

For example, strength of 2 kPa was achieved for the soil alone at a water content of 58%, whereas the same strength is obtained at 56.8 % for the soil with 1.5% of sodium hydroxide, 56 % for the soil with 3 % of sodium hydroxide. Gradually the water content required for the soil decreases to 44 % with sodium hydroxide concentration of 7.5%. There are slight variations in the order of decrease with increasing contaminant concentrations. However, it is established that the strength of shedi soil decreases in the presence of sodium hydroxide even at higher water contents.

b) Effect of Sodium Hydroxide on the Hydraulic Conductivity of Shedi Soil

The hydraulic conductivity of soils is the most important parameter involved in the assessment of contaminant migration in the sub surface. It is desirable to understand the parameters that influence the permeability characteristics of different types of contaminants particularly in the context of the soil for use as liner. It is generally known that permeability of remoulded soils depends on the moulding water content, compaction method and compactive effort. Further the properties of permeants, such as its concentration and duration of exposure also play very important role. The variations in the soil parameters are considered in terms of i) associated exchangeable cations; ii) adsorbed anions, and variations in permeating fluid in terms of i) acidity, ii) alkalinity, iii) electrolyte concentration and iv) dielectric constant. Significant increase in hydraulic conductivity may result from flocculation of clay particles due to interaction with electrolyte solutions, shrinkage of the soil matrix in the presence of concentrated organic solvents, and acid base dissolution of the soil. Guoy-Chapman theory has been used to describe the influence of aqueous solutions on the fabric and therefore on the hydraulic conductivity. However, swelling test results suggest that the Gouy-Chapman theory does not account properly for shrinkage effects, which have been observed to result in large increases in hydraulic conductivity upon permeation with concentrated organic solvents. Three mechanisms may contribute to an increase in the hydraulic conductivity of clay soils upon permeation with acid permeants: (1) flocculation of the clay, (2) dissolution of the clay minerals (aluminosilicates) and (3) dissolution of other minerals (e.g., CaCO3) in the clay soil. Dissolution and piping of clay minerals leads to increase in hydraulic conductivity. Dissolution of carbonates initially leads to buffering, re- precipitation, pore clogging, and a decrease in hydraulic conductivity. Depletion of the buffering capacity leads to a decrease in pH, dissolution of constituents, and a possible increase in hydraulic conductivity.

However, relatively little is known on changes in the hydraulic conductivity due strong interaction that occurs between the fluid and the shedi soil. The results presented in earlier sections had shown that the properties of shedi soil are altered to different extents. The effect of sodium hydroxide on the hydraulic conductivity of shedi soil is presented in the following sections.

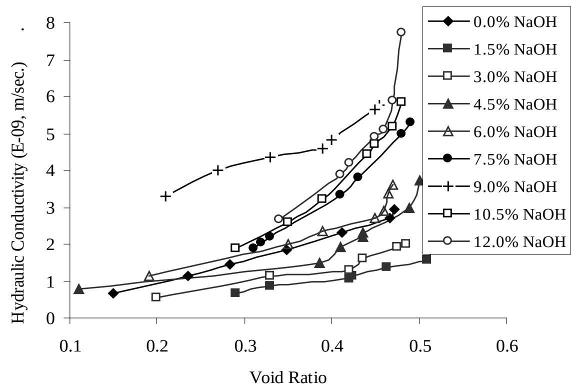


Fig.12 Effect of Alkali Concentration on the Hydraulic Conductivity of soil at different Void Ratios

E. Hydraulic Conductivity of Shedi Soil

The hydraulic conductivity of shedi soil has been determined using consolidation testing apparatus. It is well recognised that this method offers best means of measuring the changes in the hydraulic conductivity of soils with different chemicals. Also this method can be used to obtain hydraulic conductivity at different pressure and at different void ratios. Since the samples used for measuring the hydraulic conductivity were already compacted, the variations in the void ratios and consequently the hydraulic conductivity were restricted. Figure 12 shows the variation in the hydraulic conductivity at different void ratios.

It is seen that the hydraulic conductivity increases from 0.66 x 10-9 m/s to 2.96 x 10-9m/s as the void ratio is increased from 0.24 to 0.47. However, the hydraulic conductivity is in the range of 10-9 m/s. At the same void ratio, it is seen that the hydraulic conductivity of shedi soil with higher amount of sodium hydroxide (more than 6%) is much higher than soil with lower amount of sodium hydroxide (up to 6%). This clearly demonstrates that higher concentration of sodium hydroxide changes the nature of particle arrangement or produces some new minerals.

VI. CONCLUSIONS

The geotechnical properties of Shedi soil containing kaolinite and montmorillonite are altered due to interaction with alkali solutions.

1. The plasticity index of soil decreases and shrinkage limit increases.

2. The optimum moisture content increases and maximum dry density of soil decreases with increasing concentration of alkali content in the fluid.

3. The swell pressure and the compressibility of soil decrease.

4. The shear strength of soil decreases essentially due to decrease in the cohesion of the soil particles.

5. The hydraulic conductivity of the soil increases with higher concentrations of alkali solution.

6. The changes in geotechnical properties of soil which are not consistent with changes in index properties are explained based on structural changes in soil particles due to mineralogical alterations.

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