Effect of salt solutions on compressibility of bentonite

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

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In

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CERTIFICATE

This is to certify that the project entitled *"Effect of salt solutions on compressibility of bentonite"* submitted by Mr. Haribabu. K (Roll No. 213CE1045) in partial fulfillment of the requirements for the award of Master of Technology Degree in Civil Engineering at NIT Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

Place: Rourkela   Prof. Ramakrishna Bag

Date: Department of Civil Engineering

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Abstract

The main intention of the thesis is to evaluate the effect of pore fluid composition and stress state on volume change behavior of bentonite. In this study compressibility behavior of several saturated bentonite specimens were studied. The initial water content chosen is greater than the liquid limit for the remoulded soils, referred to herein as the initially saturated soil. The bentonite specimens were inundated with distilled water, 0.5 M and 1.0 M NaCl solutions. Consolidation tests were conducted for the range of pressure varying between 10 kPa to 1250 kPa. The results show that with increase in concentration of NaCl salt solution change in void ratio is increasing. The compressibility behavior is increasing with salt solution concentration. The observed results similar to that has been reported by other researchers for compacted bentonite specimens subjected to NaCl salt solutions...

Acknowledgement

I am deeply indebted to **Dr. Ramakrishna Bag**, Professor of Geotechnical Engineering specialization, my supervisor, for the motivation, guidance and patience throughout the research work.

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Haribabu Kolamgiri

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INTRODUCTION

Introduction

1.1Background

Engineered barriers made up of compacted swelling clays are consider for isolating nuclear waste of high radioactivity at great depth. They are used to seal the galleries after placement of nuclear wastes is also considered. It is also suggested to use a mixture of highly plastic clay (bentonite) with sand to construct liner systems or other types of impervious buffer zones for waste disposal projects (Chapuis1990). Engineered clay barriers have different interesting properties related to waste isolation i.e. low hydraulic conductivity, low ion diffusivity, good self-sealing capacities, etc.

All these properties are provided by the swelling clay minerals known as smectites (also called "bentonites"). Growing attention has been intended for some time to the thermo-hydro-mechanical behaviour of smectites. The salt content in the ground-water is observed to increase considerably with depth at several possible depository sites. More recently, the importance of the influence of pore fluid composition on the macroscopic response of engineered barriers has been investigated in greater detail. A majority of researchers in this area has been focused on pure clays where as on bentonite it is very limited.

The choice to use bentonite instead of other clays is due to its properties:

- It exhibits low permeability to minimize the arrival of water (Westsik et al. 1982; Radhakrishna and Chan 1989).

- The high thermal conductivity to scatter heat produced from waste and from gas of the corrosion of the containers.

- The high swelling ability to seal the splits and cracks to keep the entrance to different boundaries (Komine 2004).

- The large specific surface to prevent radionuclide as to keep the water chemistry conservation

- The high plasticity for mechanical protection to ensure mechanical integrity of the capsule.

- It exhibits high suction capacity to sealing the repository.

1.2 Structure of montmorillonite

The term "bentonite", is used to describe a clay material whose majormineralogical component is formed by the smectite group and whosephysical properties are characterized by the smectite minerals (Grim andGuven 1978). Although the major constituent of bentonite ismontmorillonite, minor amount of feldspar, quartz, mica and gypsum maypresent in bentonite. Montmorillonite, which is a member of smectite clay mineral group, constitutes the major component of bentonite. Smectite clays are classified within the mica family of phyllosilicates, but they are different from truemicas due to their low layer charge and exchangeable interlayer charge.

In addition, one of the most distinguished features is that their interlamellarsurfaces and cations can be easily hydrated and dehydrated. All theseproperties led to smectite clays to be

classified as "swelling clays" (Fuenkajorn and Daemen 1996).Montmorillonite is composed of two basic types of sheets such asoctahedral and tetrahedral sheets. The octahedral sheet is sandwichedbetween two tetrahedral sheets leading the formation of 2:1 layer. Therefore; montmorillonite is called as 2:1 layer silicate. Layers may beseparated from one another by various interlayer cations such as Ca^{+2} andNa^+. The total assembly of a 2:1 layer plus interlayer cations is referred asthe unit structure of montmorillonite (Grim 1968; Bailey 1980). Crystalstructure of montmorillonite can be seen in the Figure given below.
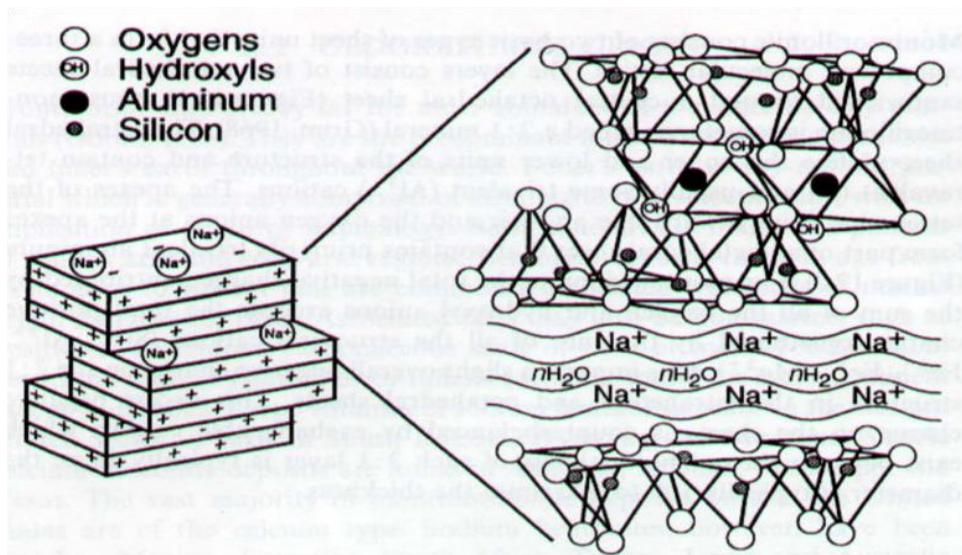
Figure 1.1. Crystal structure of montmorillonite bentonite indicating NaCations and interlayer water molecules (Fuenkajorn and Daemen, 1996).

Bentonites exist in nature either as sodium or calcium bentonite. They arecharacterized by the type of exchangeable cation (i.e., calcium or sodium) that is adsorbed onto the surface or between the interlayer positions of theclay particle. Na-bentonite has higher swelling capacity than Ca-bentonitesince the presence of Na increases the adsorption of water molecules tothe interlayer surfaces (Fuenkajorn and Daemen 1996).

Na-bentonite has some unique properties such as a large surface area, ionexchange capacity, high water absorption and expansion. Specific gravityof the Na-bentonite can range between 2.5 to 2.8. They have specificsurface area in the range of 700 and 800 m^2/g.

Na bentonite can adsorb atleast five times of its weight in water and expands when fully saturated withwater up to a volume 12-15 times its original dry size. Hydraulicconductivity values of Na-bentonite ranges from $1x10^{-7}$ to $1x10^{-9}$ cm/s(Fuenkajorn and Daemen, 1996).Therefore; permitting extremely low permeabilities, generating highswelling pressures and possessing sealing characteristics, Na-bentoniteshave been widely used as isolation material in underground waste disposalfacilities.

Chapter-2

LITERATURE REVIEW

Literature review

2.1 Introduction

The main intention of this chapter is to summarize and synthesize the arguments and ideas presented by previous researchers on the compressibility characteristics of swelling clays. To understand these engineering properties of soil, knowledge of the major factors affecting it are required. Accordingly, this literature review will have a significant focus on swelling clays.

Sridharan (1991) and Di Maio (1996) reported that salt solutions have a great impact on the behavior of clays, especially on swelling clays. The aftereffect of progress in burdens is relies on the pore liquid synthesis. Compressibility and swelling is likewise relies on upon the sort of replaceable cations. The diminishing of swelling and compressibility happens with expanding pore fluid ionic power, or with diminishing dielectric consistent.

Barbour and Fredlund (1989) demonstrated that pore liquid organization controls enormously the conduct of smectite earth. The adjustments in volume and shear quality are brought about by particle dissemination, under steady outer burdens.

Mesri and Olson, (1971) revealed that with increase in pore aqueous solution the compressibility of the smectite clay is decreasing , also with decreasing of dielectric constant of organic fluids the compressibility and coefficient of consolidation decreasing, whereas permeability increases.

Marcial et al. (2002) demonstrated the variety of e-log p bend of at first soaked bentonites to a weight of 30MPa. The variety can be recognized by two variables i.e. introductory weight territory and everywhere weights. It is watched that the change from an at first slant to a moderate incline at diverse weights relying on the kind of replaceable cations show in the bentonite. The compressibility conduct of the bentonites was happened because of two phenomena, for example, (i) the pressure of a gel structure at high void proportion (ii) the pressure of bury total voids. Past the move it is watched that the general game plan of dirt platelets is by all accounts parallel and essentially legitimate. The preassure-void proportion of the bentonite at this extent is generally influenced by the replaceable cations and the quantity of water particles contained in the hydration shells inside of the interlayer space.

Olson and Mesri (1970) studied the impact of mechanical and physiochemical on the compressibility conduct of bentonites. Physical properties like quality, surface erosion and adaptability of the earth minerals are controlling the short-run molecule collaboration of bentonite. The physicochemical impact on the compressibility of bentonite is controlled by the long-extend collaboration between the particles through the diffuse twofold layer. The compressibility for this sort of test is seen by both physical and physiochemical impact. The blend gets packed because of the twisting, sliding, moving and pounding of the dirt particles bringing about a higher estimation of Cc when a vertical solidification weight is connected.

Tripathy et al (2010) revealed that for the studied bentonite the reduction in water content and the void ratio is mainly because of increase in vertical pressure .It is observed that the volume change occurred due to an increase in vertical pressure. It accredited mainly because of mineralogy and the Physico-chemical interactions between the clay particles and the pore fluid. The study

revealed that reduction in the void ratio and water content is effective due to increase in vertical pressure.

2.2 **Factors effecting Compressibility of swelling clays**

- The influence of pore fluid composition
- vertical pressure

2.3 I**nfluence of pore fluid composition**

The influence of pore fluid composition on clay behaviour has important implications in geotechnical engineering. As a matter of fact, clay soils, whose natural state pore fluid is generally a compound solution, may also come in contact with different aqueous solutions or with organic fluids either deliberately or accidentally.

- Exposure to fresh water can cause heave of foundations on swelling clays.
- Exposure to concentrated leachates can produce a dramatic increase in permeability of clay liners and slurry walls.
- In the scientific literature, generally, the effects of ionic aqueous solutions and organic fluids on clay behaviour are investigated separately.
- In particular, results for materials prepared with aqueous ion solutions are analysed with reference to ion concentration, or to pH, whereas the effects of organic solvents are analysed with reference to their dielectric constant.

For the considered swelling clays, it has been shown that compressibility decreases with increasing of pore aqueous solution concentration (Barbour and Fredlund 1989; Di Maio 1996, 1998; Di Maioet al. 2004; Bolt 1956; Mesri and Olson 1971).

2.4 The vertical pressure

The primary variable which impacts the volume decrease and change in water substance is brought about by because of increment in vertical stress for highly saturated bentonites. The volume change conduct of saturated clays can be study by subjecting clays specimens to an increase in the vertical pressure. The vertical pressure-void ratio relationships are generally carried out by conducting oedometer test. On the other hand, the pressure-void ratio relationships are utilized to calculate settlement of saturated soils due to change in stress.

Destauration of soils will begin when the adsorbed water layers of two soil particles have overlapped. The repulsive pressure between the aggregates structures mainly due to the exchangeable cations present in the pore-fluid of the bigger voids. Similarly, the repulsion between clay platelets within the aggregates is mainly due to exchangeable cations present in the inter layers.

Also, the positively charged edge of the mineral crystals and the available anions in the clay leads to the edge to edge interaction between aggregates. Initially the compression of the bigger voids leads to the void ratio decrease due to an increase in vertical pressure (Marcial et al. 2002).

Objective of the study

A survey of past studies has uncovered that the greater part of past exploration here has concentrated on the behavior of sands or pure clays, while scrutinize on swelling clays has been exceptionally constrained. Keeping in this brain a progression of research facility tests are led to focus

- The effect of salt solutions on compressibility behavior of bentonite.

CHAPTER 3

MATERIAL AND METHODS

Material and methods

3.1 Material

This section depicts the procedure and materials used to accomplish the destinations. Bentonite was gathered from Bikaner, Rajasthan. System for test readiness, testing and testing methods utilized for portrayal of materials and additionally exploratory setup for examination are accounted for in the accompanying session.

3.2 Methods

Grain size distribution, specific gravity of the samples was determined according to IS: 2720- part 4 (1975), ASTMD-854-92, Na method (Chapman 1965), and ASTM D-2974-87, respectively. The test results are given below. Liquid, plastic, and shrinkage limits were determined as per IS: 2720-Part 5 and 6 (1985). The consistency limit tests were replicated more than two times, and the average values were presented here below.

3.2.1 Atterberg Limits

Atterberg limits were determined as per IS: 2720-Part 5 and 6 (1985) and the results are presented in the table.

Limits and Indices	Values
Liquid Limit	140 %
Plastic Limit	61 %
Shrinkage Limit	40 %
Plasticity Index	79 %

3.2.2 Specific Gravity

The specific gravity of bentonite were determined using pycnometer method as per IS: 2720-Part 3 (1980) and it is found to be **2.67**.

3.2.3 Particle Size Distribution

Particle size distribution of bentonite was determined using hydrometer method in accordance with IS: 2720- part 4 (1975)..
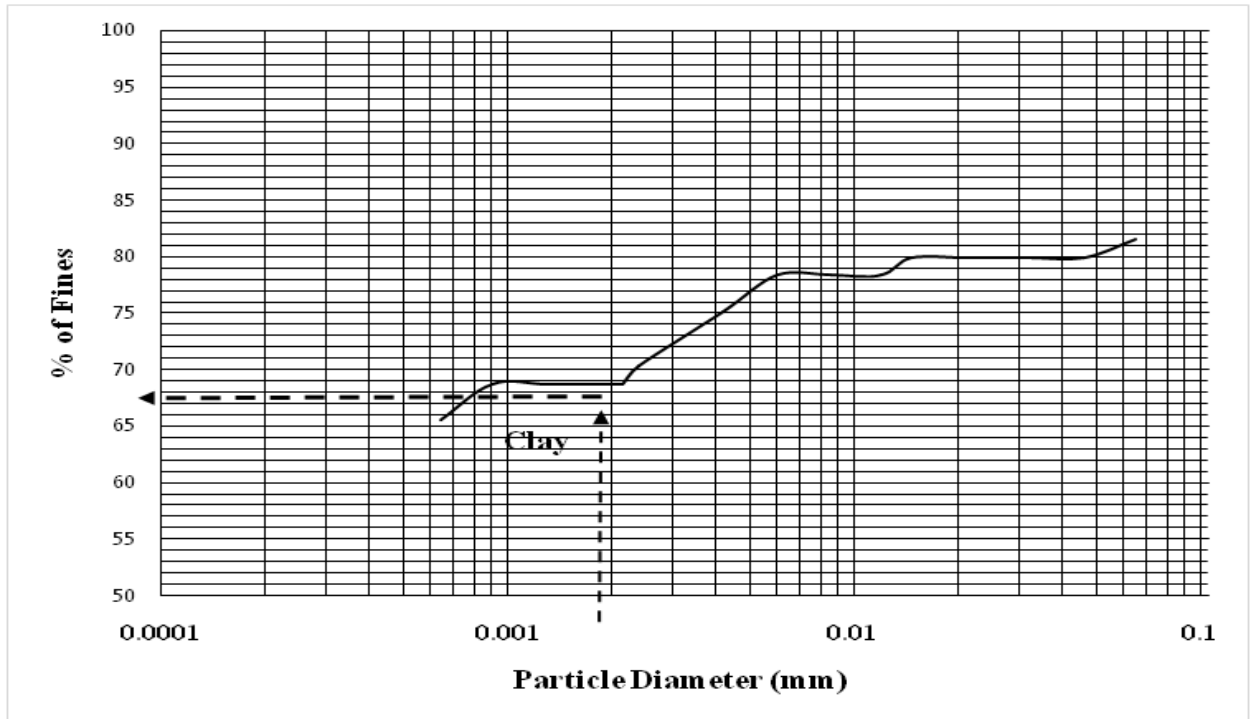

Figure 3.1. Particle size distribution of bentonite.

The coefficient of uniformity i.e. $Cu = D_{60}/D_{10}$ and coefficient of curvature i.e. $Cc = D_{30}^{2}/ (D_{10}* D_{60})$ are calculated and representative values are 8.34 and 2.08 respectively.

3.2.4 XRD ANALYSIS

The mineral structure of bentonite was controlled by X-ray diffraction system. As per Bragg's law, the XRD distinguishes the minerals in view of the relationship between the point of frequency of the X-beams, θ, to the c-pivot separating, d. A Philips computerized powder diffractometer was utilized for XRD examination as a part of this study.

Fine grained bentonite force of 1.5 g was kept in stove drying for 2 hours and permitted to cool in room temperature. At that point, test is filled in the specimen holder of diffractometer and the XRD example is gotten by looking over edge scope of 20° to 100°, 2θ at 0.25°/min.In the stride mode, a 0.05° - 2θ stage for 2 s is given. Results are examined utilizing Xpert High Score programming and mineral structure has been found. Quartz, Montmorillonite, Muscovite and Calcite are the minerals found. Result is indicated in fig3.2
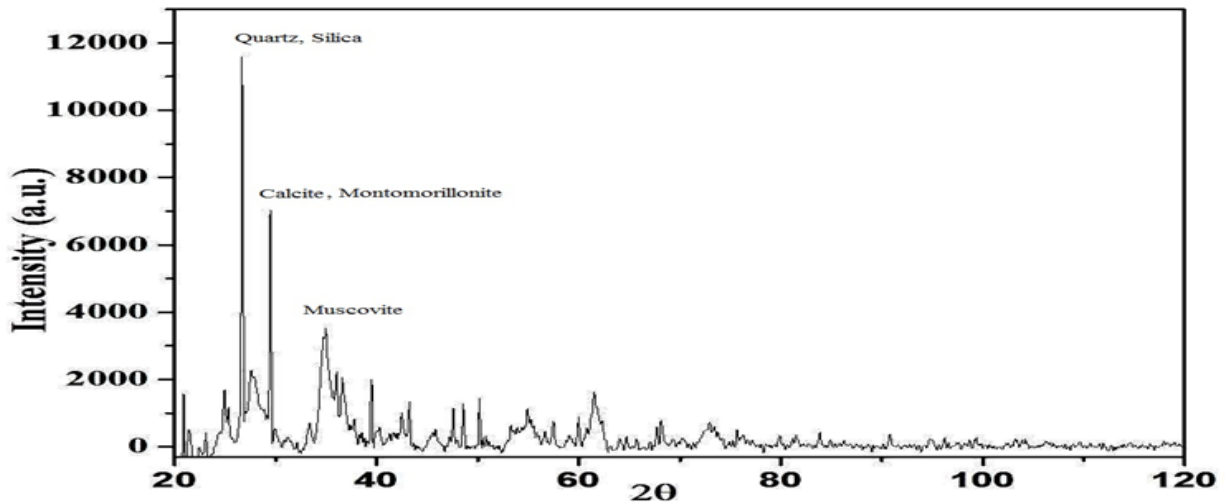

Figure 3.2. XRD analysis showing mineralogical composition.

3.2.5 BET Analysis

Specific surface area being the significant physical parameter has a great impact on the quality and utility of solid phase samples. Gas adsorption investigation is the broadly utilized strategy for estimation of particular surface zone. This system includes presentation of gas to the strong specimen under different natural conditions accordingly measuring volume of test. The Brunauer, Emmett and Teller (BET) procedure is normally utilized device to focus the surface territory of powder test. Here, nitrogen gas is utilized as test that is uncovered on the strong material under standard conditions. Hence, surface region of the specimen can be measured from the monolayer adsorbed utilizing the earlier learning of cross sectional range of test being utilized. Enactment of test must be done to guarantee that no air or gas has been adsorbed on the strong molecule before assessment which may influence the specimen quality. Enactment should be possible by warming the example under vacuum conditions. Particular Surface Area has been controlled by BET analyzer and quality is found to be 79.23 m²/g

3.2.6 Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) is defined as the amount of exchangeable ions that a soil can hold at a given pH value. The Cation Exchange Capacity (CEC) of the soil sample and soil lime mixture was found as per ASTM D7503 – 10 method. The Nitrogen concentration was determined by spectrophotometer as per modified Parsons et al. (1984). The nitrogen concentration was determined by the graph obtained by the absorbance of the standard solution of known concentration. After Nitrogen Concentration is known, the CEC of the sample is calculated by the equation

$$CEC\left(\frac{cmol}{kg}\right) = \frac{N \times 1 \times 0.25}{140 \times mass\,of\,soil\,taken} \times 1000$$

Where N = nitrogen concentration in mg/L.And the CEC value of bentonite is calculated as

54.71 meq/100 g.

3.3 Oedometer test

3.3.1 Sample preparation

To set up the oedometer test examples, bentonite was blended completely by including distilled water in a few stags utilizing a spry and blending with a spoon until it reaches to a water content of 140%. At that point the soils were blended deliberately by hands until coming to a uniform blend. The blends were set in plastic sacks and fixed to evade loss of water and permitted to cure in desiccator at room temperature for 24 h. Within the ring was spread with a meager layer of silicone oil to dodge the grating between the ring and the dirt example. Filter paper was set at the top and base of the sample. A top with permeable stone was put over the soil specimen. The whole setup was Placed in the consolidation cell and positioned in the loading frame. The consolidation ring was immersed in the DI water, and the entire consolidation cell was covered with a plastic bag to reduce evaporation. The consolidation cells were then allowed to equilibrate for 24 h prior to commencing the tests. All the samples were at first stacked with a weight of 10kPa and expanded continuously by an addition proportion of 1 to a most extreme weight of 1,280kPa.For every weight augment, the adjustment in the thickness of the specimen was measured, and the adjustment in the void proportion comparing to an overburden solidification weight was computed Compression index (Cc) for the samples was calculated as the slope of the straight line portion of virgin e–log p curve.

3.3.2 Test procedure

Compressibility characteristics of the samples were determined using one-dimensional consolidation test apparatus according to ASTM D 2435-96 (ASTM, 1999). The soil specimens are placed in a stainless steel ring whose diameter is 60 mm and height is 20 mm. a dialguage is attached to the loading frame to calculate the settlement. Initially a seating load of 10kPa load applied and it is remained until the deformation ceased. When the swell deformation ceased, incremental loading of 10, 20, 40, 80, 160, 320, 640, 1280kPa were applied. Each load is maintained until the deformation is minimum. All specimens were tested at their liquid limit to eliminate the effect of initial water content on results.. A load increment ratio of unity was adopted, and soil specimens were restrained laterally and loaded axially with total stress increments. The coefficient of compression index has find out from the e-log p curve shown in figures below.

CHAPTER4
RESULTS AND DISCUSSIONS

Results and Discussions

4.1 Introduction

The tests are conducted on the bentonite specimens to understand the effect of pore fluid composition on the volume change behaviour. Initially the specimens are inundated with distilled water and observed the effect on compressibility behaviour. Also the specimens are tested by changing the inundation fluid from distilled water to salt solutions. The specimens are allowed to test with 0.5M NaCl and 1.0M NaCl solutions. The observations made during each stage of loading and unloading. Thevarious graphs are plotted from the observed data such as e vs log p, Time vs Settlement and Time vs void ratio.

4.2 Consolidation test with distilled water as saturating fluid

Consolidation test conducted with distilled water and results are shown for each increment of loading in table 4.1.from the results it is observed that the void ratio was decreasing with increase in load. Initially the void ratio of the specimen is 3.47 and after the test it is observed to be 1.45. Initially the height of the specimen is 20 mm and after completion of test it is observed that 10.82mm. The amount of decrease in void ratio is found to be 58%.the amount of volume change of the specimen is found to be 45.90%.

Table 4.1Calculation of change in void ratio for loading path of consolidation test conducted using distilled water as inundating fluid.

Load (kg/cm^2)	Initial thickness, H (mm)	Change in thickness, ΔH (mm)	Final thickness, H- ΔH (mm)	Initial void ratio, e	Change in void ratio, Δe	Final void ratio, (e – Δe)
0	20	0	20	3.47	0	3.47
0.1	20	0.93	19.07	3.47	0.2	3.27
0.2	19.07	0.77	18.3	3.27	0.17	3.1
0.4	18.3	1	17.3	3.1	0.22	2.88
0.8	17.3	1.35	15.95	2.88	0.3	2.58
1.6	15.95	1.4	14.55	2.58	0.31	2.27
3.2	14.55	1.38	13.17	2.27	0.3	1.97
6.4	13.17	1.25	11.92	1.97	0.28	1.69
12.8	11.92	1.1	10.82	1.69	0.24	1.45

Table 4.2Calculation of change in void ratio for unloading path of consolidation test conducted using distilled water as inundating fluid.

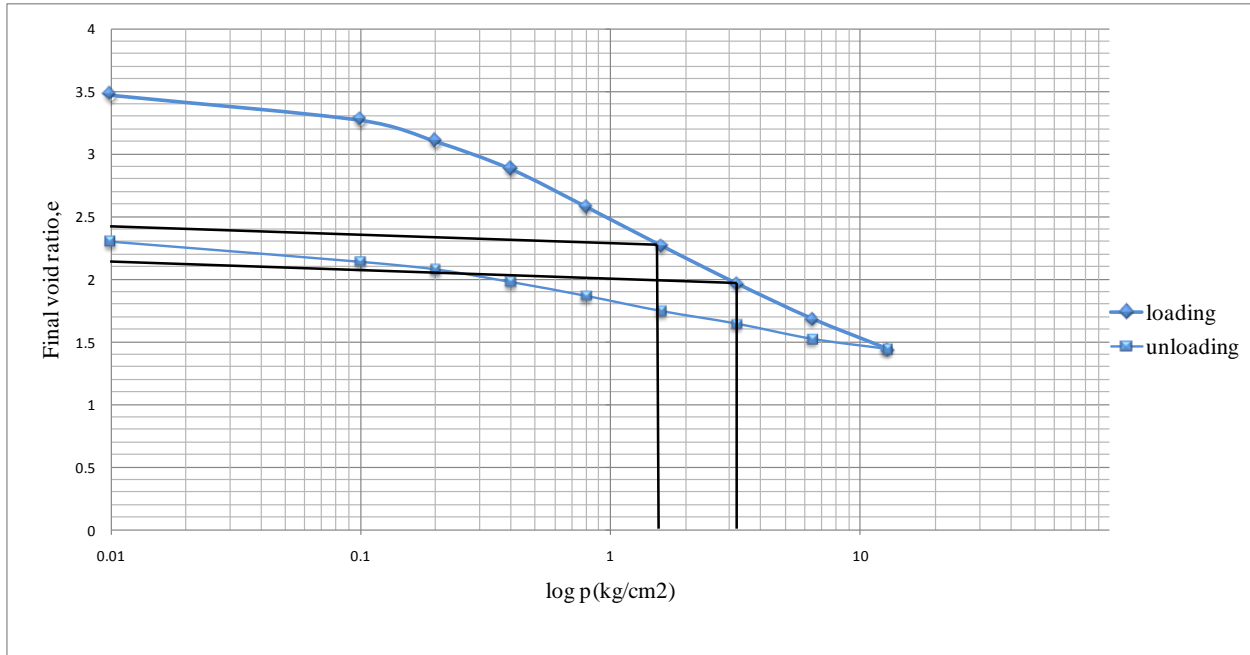| Load (kg/cm^2)	Initial thickness, H (mm)	Change in thickness, ΔH (mm)	Final thickness, H- ΔH	Initial void ratio, e	Change in void ratio, Δe	Final void ratio, (e – Δe)
12.8	11.92	1.1	10.82	1.69	0.24	1.45
6.4	10.82	0.38	11.2	1.45	0.08	1.53
3.2	11.2	0.54	11.74	1.53	0.12	1.65
1.6	11.74	0.46	12.2	1.65	0.1	1.75
0.8	12.2	0.55	12.75	1.75	0.12	1.87
0.4	12.75	0.49	13.24	1.87	0.11	1.98
0.2	13.24	0.45	13.69	1.98	0.1	2.08
0.1	13.69	0.31	14	2.08	0.06	2.14
0	14	0.71	14.71	2.14	0.16	2.3

Figure 4.1(a) *e*-**log** *p* **curvefor the consolidation test conducted using distilled water as inundating fluid.**
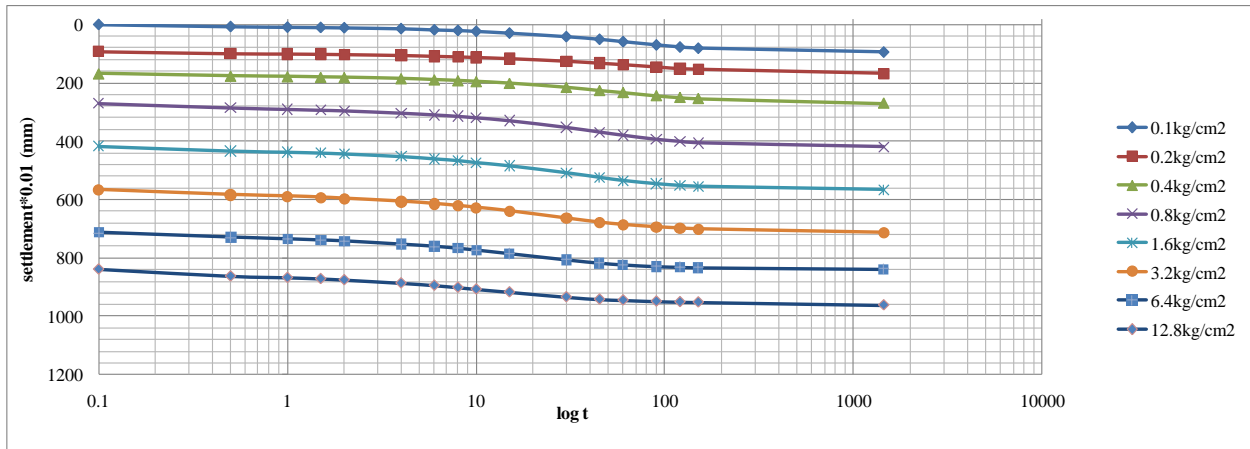

Figure 4.2(a). Settlement with time for the consolidation test with distilled water.
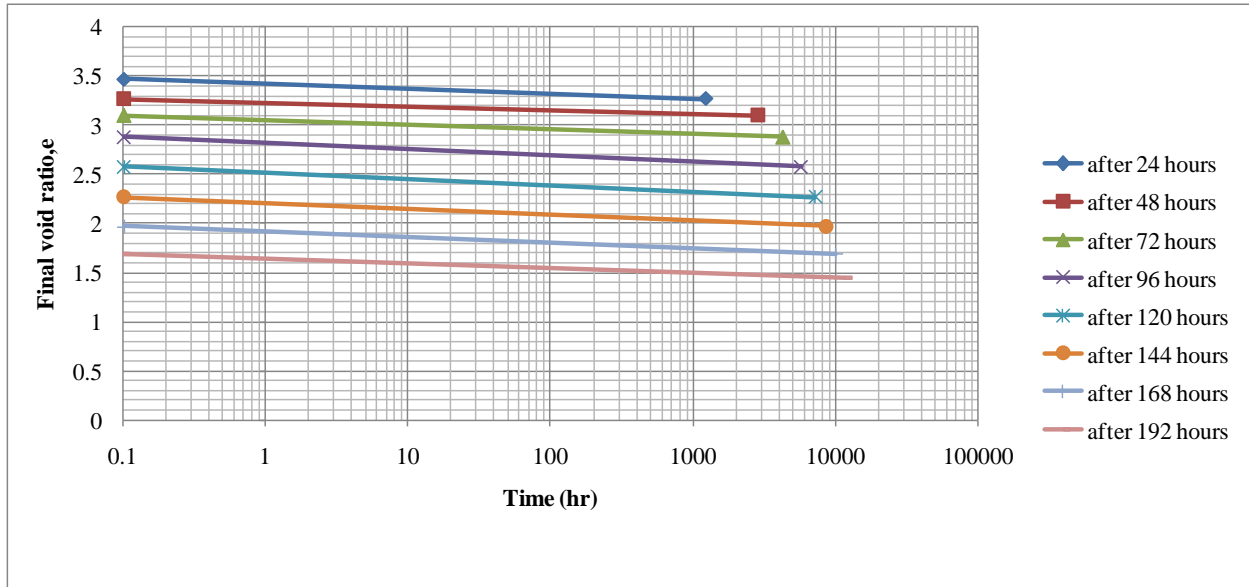
Figure 4.3(a). Change in void ratiowith time for the consolidation test with distilled water.

4.3 Consolidation test with 0.5M NaClsolution

The test conducted by changing the inundation fluid from distilled water to 0.5M NaCl solution.The observed results are shown in table 4.3.from the results it is observed that void ratio is decreasing same as like with distilled water, but the effect of salt solution is causing the specimen to compress more. The void ratio is decreased by 62.46%. The salt solution is also affected on volume change behavior. The amount of volume change is observed to be 49.15%.

Table 4.3Calculation of change in void ratio for loading path of consolidation test conducted using 0.5 M NaCl solution as inundating fluid.

Load (kg/cm^2)	Initial thickness, H (mm)	Change in thickness, ΔH (mm)	Final thickness, H- ΔH (mm)	Initial void ratio, e	Change in void ratio, Δe	Final void ratio, (e – Δe)
0	20	0	20	3.57	0	3.57
0.1	20	1	19	3.57	0.22	3.35
0.2	19	0.85	18.15	3.35	0.19	3.16
0.4	18.15	1.25	16.9	3.16	0.28	2.88
0.8	16.9	1.45	15.45	2.88	0.33	2.55
1.6	15.45	1.4	14.05	2.55	0.32	2.23
3.2	14.05	1.38	12.67	2.23	0.31	1.92
6.4	12.67	1.3	11.37	1.92	0.3	1.62
12.8	11.37	1.2	10.17	1.62	0.28	1.34

Table 4.4Calculation of change in void ratio for unloading path of consolidation test conducted using 0.5 M NaCl solution as inundating fluid.

| Load (kg/cm^2)	Initial thickness, H (mm)	Change in thickness, ΔH (mm)	Final thickness, H- ΔH (mm)	Initial void ratio, e	Change in void ratio, Δe	Final void ratio, (e – Δe)
12.8	11.37	1.2	10.17	1.62	0.28	1.34
6.4	10.17	0.24	10.41	1.34	0.05	1.39
3.2	10.41	0.36	10.77	1.39	0.08	1.47
1.6	10.77	0.35	11.12	1.47	0.08	1.55
0.8	11.12	0.42	11.54	1.55	0.09	1.64
0.4	11.54	0.37	11.91	1.64	0.08	1.72
0.2	11.91	0.31	12.22	1.72	0.07	1.79
0.1	12.22	0.26	12.48	1.79	0.06	1.85
0	12.48	0.19	12.67	1.85	0.04	1.89
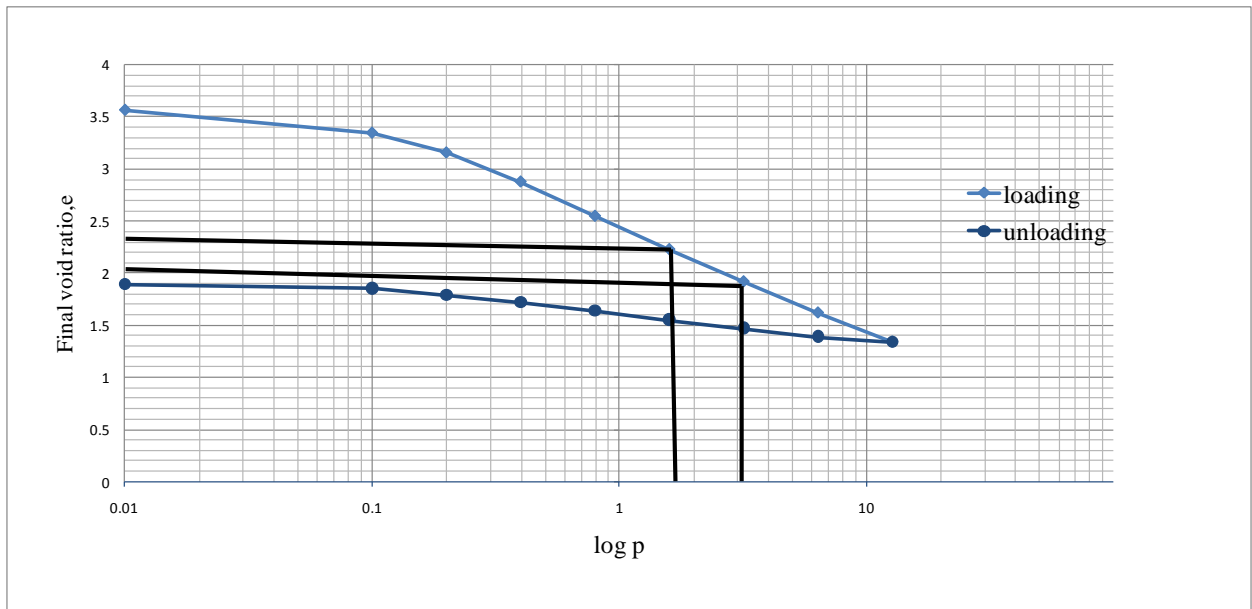
Figure 4.4(a). *e*-log*p* curve for the consolidation test conducted using 0.5 M NaCl solution as inundating fluid.
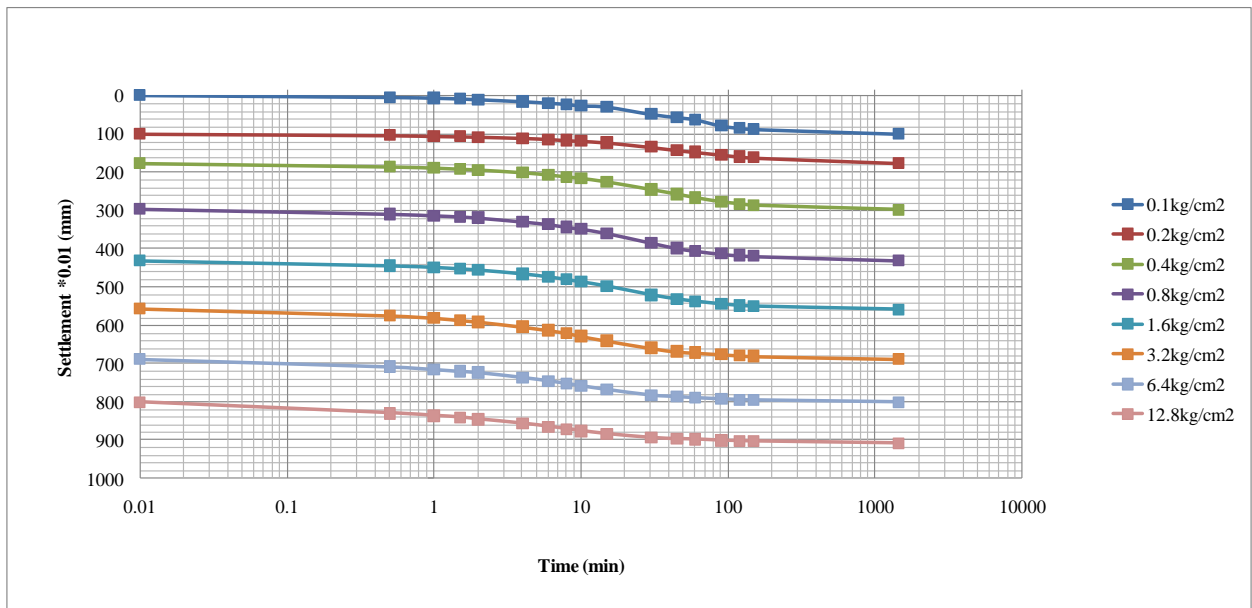

Figure 4.5(a).Settlement with time for the consolidation test with 0.5 M NaCl.
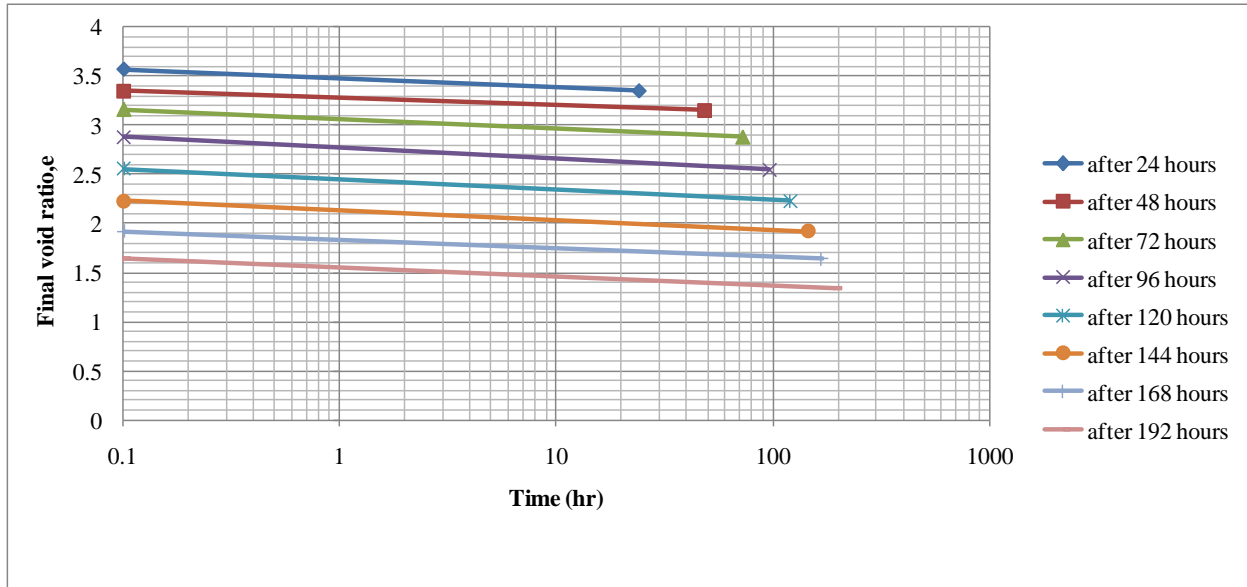
Figure 4.6(a). Change in void ratio with time for the consolidation test with 0.5 M NaCl solution.

4.4 Consolidation test with 1.0 M NaClsolution

The test has conducted again with 1.0M NaCl solution to find the effect on volume change behavior and compared the results with distilled water and 0.5M NaCl solutions. It is observed that the void ratio is keep decreasing with increase in concentration. Compared with distilled water the effect of 1.0M NaCl on volume change behavior is more significance.the amount of void ratio decreased is found to be 66.10%.the amount of volume change of the specimen is also observed as 52%.

Table 4.5Calculation of change in void ratio for loading path of consolidation test conducted using 1.0 M NaCl solution as inundating fluid.

Load (kg/cm²)	Initial thickness, H (mm)	Change in thickness, ΔH (mm)	Final thickness, H- ΔH (mm)	Initial void ratio, e	Change in void ratio, Δe	Final void ratio, (e – Δe)
0	20	0	20	3.57	0	3.57
0.1	20	1.41	18.59	3.57	0.32	3.25
0.2	18.59	0.92	17.67	3.25	0.2	3.05
0.4	17.67	1.36	16.31	3.05	0.31	2.74
0.8	16.31	1.57	14.74	2.74	0.36	2.38
1.6	14.74	1.44	13.3	2.38	0.33	2.05
3.2	13.3	1.41	11.89	2.05	0.32	1.73
6.4	11.89	1.24	10.65	1.73	0.28	1.45
12.8	10.65	1.04	9.61	1.45	0.24	1.21

Table 4.6Calculation of change in void ratio for unloading path of consolidation test conducted using 1.0 M NaCl solution as inundating fluid.

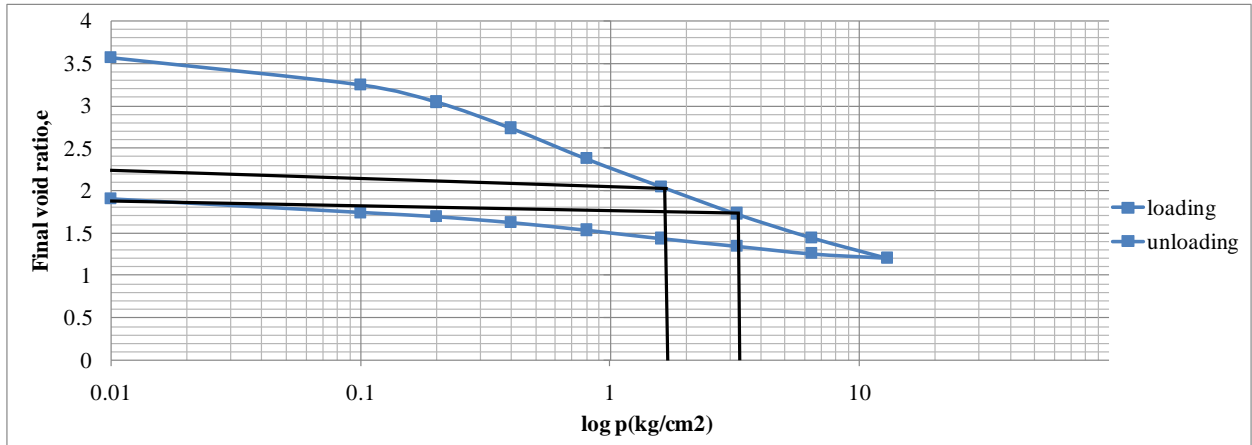| Load (kg/cm²)	Initial thickness, H (mm)	Change in thickness, ΔH (mm)	Final thickness, H- ΔH (mm)	Initial void ratio, e	Change in void ratio, Δe	Final void ratio, (e – Δe)
12.8	10.65	1.04	9.61	1.45	0.24	1.21
6.4	9.61	0.25	9.86	1.21	0.05	1.26
3.2	9.86	0.4	10.26	1.26	0.09	1.35
1.6	10.26	0.42	10.68	1.35	0.09	1.44
0.8	10.68	0.45	11.13	1.44	0.1	1.54
0.4	11.13	0.42	11.55	1.54	0.09	1.63
0.2	11.55	0.33	11.88	1.63	0.07	1.7
0.1	11.88	0.25	12.13	1.7	0.05	1.75
0	12.13	0.72	12.85	1.75	0.16	1.91

Figure 4.7(a). *e*-log*p* curve for the consolidation test conducted using 1.0 M NaCl solution as inundating fluid.
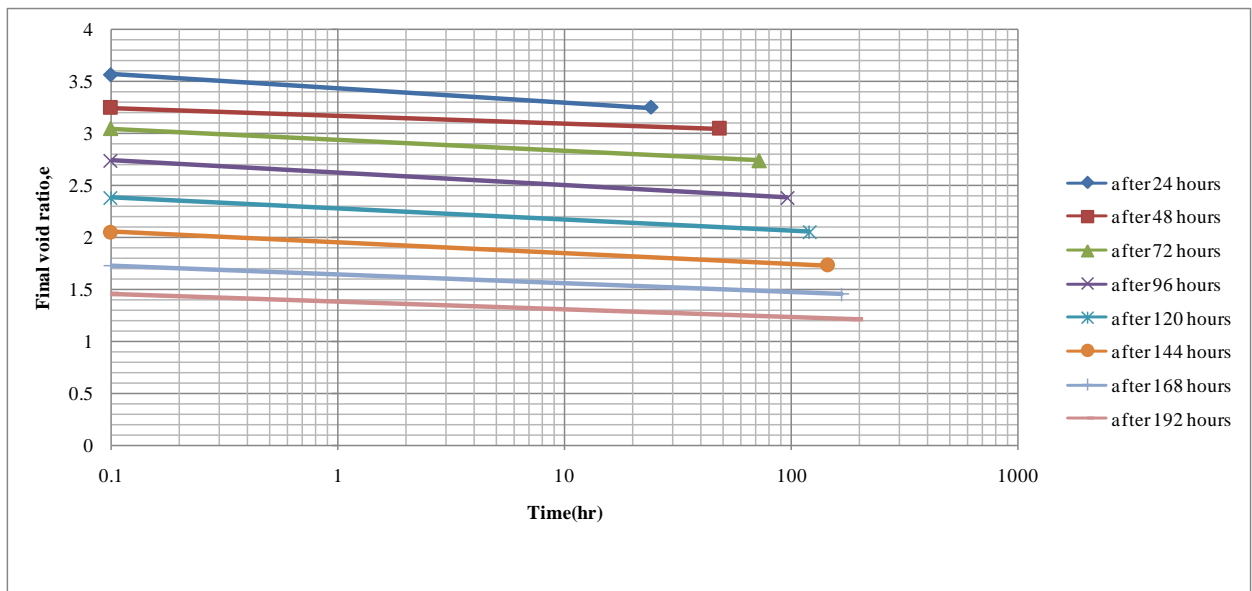

Figure 4.8(a). Change in void ratio with time for the consolidation test with 1.0M NaCl solution.
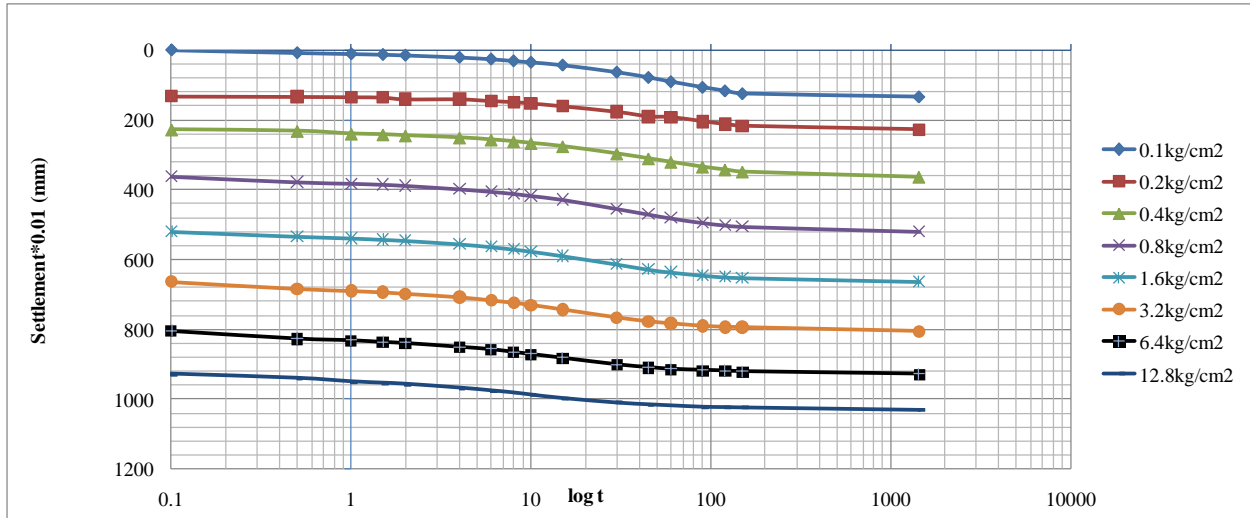
Figure 4.9(a). Settlement with time for the consolidation test with 1.0M NaCl.

4.5 Comparison of test results

The results are compared with distilled water and NaCl solutions. As the concentration increases the void ratio is decreasing more and it leads to more compression. In case of distilled water the void ratios is 1.47 and whereas with 0.5 M NaCl it is 1.34 and with further increase in concentration to 1.0 M NaCl it is reached maximum void ratio of 1.21. The variation of e-log p curves has shown in Fig. 4.10. The variation of void ratio with time also plotted and it has shown in Fig. 4.11. From the plot we can observe that the void ratio with time and with varying concentration. It is observed that void ratio is decreasing with time and with increase in concentration. Finally it is observed that the NaCl solution has a great impact on the volume change behavior of swelling clays compared to distilled water.
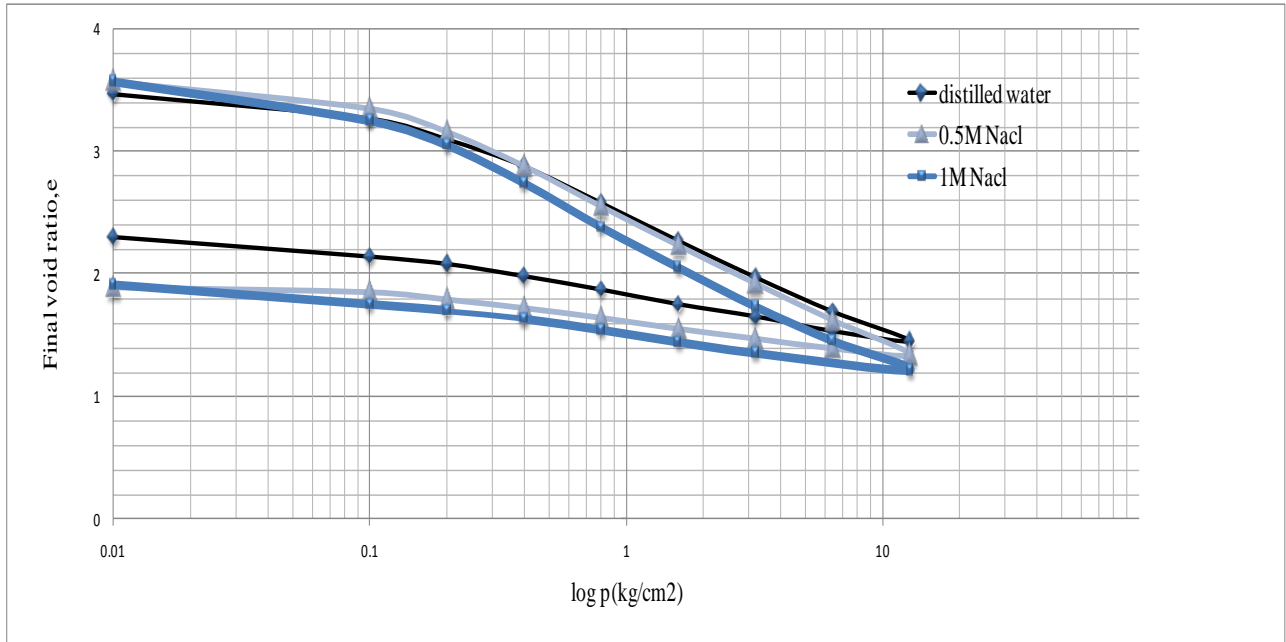
Figure 4.10. Comparison of *e*-log *p*curves for the consolidation tests conducted with distilled water, 0.5 M and 1.0 M NaCl solutions.
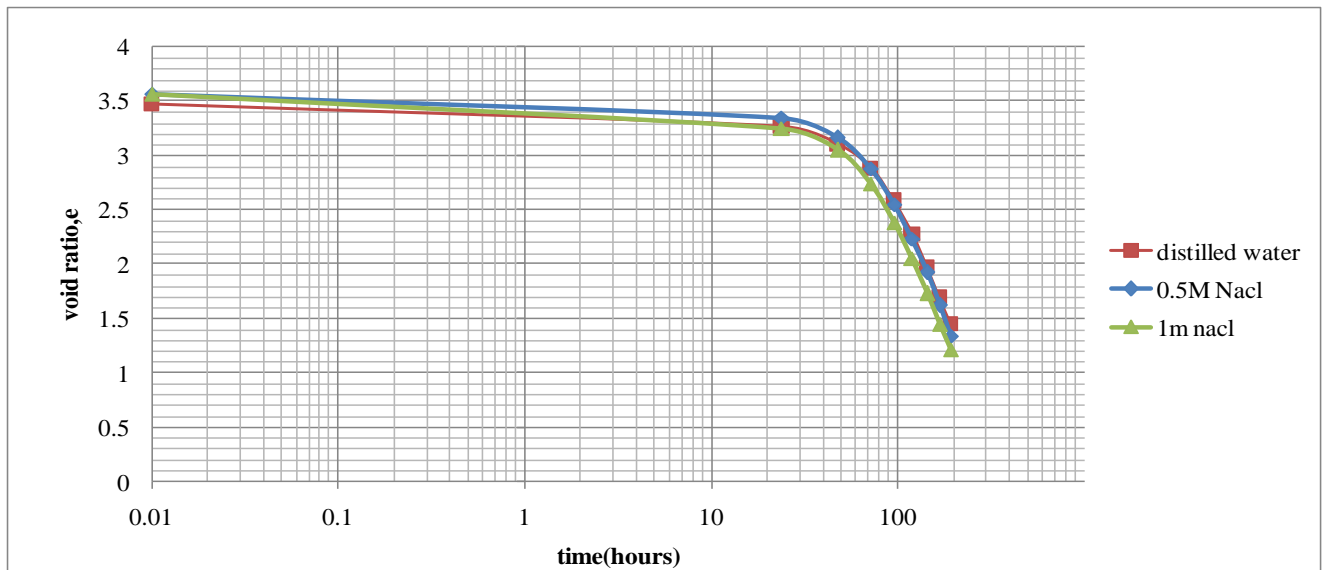
Figure 4.11.Comparison of change in void ratio with timefor the consolidation tests conducted with distilled water, 0.5 M and 1.0 M NaCl solutions.

Table 4.7 Comparison various parameter found during consolidation test

Test	C_C	C_S	$m_v(cm^2/kg)$	% change in ht
Distilled water	1.0	0.33	64.75×10^{-3}	45.90
0.5 M NaCl solution	1.03	0.30	67.56×10^{-3}	49.15
1.0 M NaCl solution	1.06	0.26	84.09×10^{-3}	52.00

CHAPTER 5

CONCLUSIONS

<div align="right">Chapter 5</div>

Conclusions

Based on the results of laboratory testing program on bentonite specimens inundated with liquids of distilled water and NaClat various concentrations, the following conclusions can be drawn.

- ✓ Liquids with various NaCl concentrations reduce the swelling capacity and increase the compressibility characterstics.

- ✓ Compared to distilled water the volume compressibility increases with increasing NaCl concentration.

- ✓ The effect of 0.5M NaCl is very less compared to 1.0M NaCl solution.

- ✓ The significance of NaCl in changing void ratio is very high compared to distilled water

Future scope

- Tests can be continued for higher stress range.

- Instead of using salt solution as inundating fluid, salt solutions can be mixed with bentonite.

- Theoretical work can be carried out using diffuse double layer and Stern layer theory to compare with experimental results.

- Results can be compared by testing other soil specimens or other bentonites.

- Test also can be conducted at elevated temperature.

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