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Swelling Behavior of Expansive Soil Deposit during Diffusion of Calcium Chloride Solution

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Abstract: *Expansive soil is truly assumed the notoriety of being the most difficult and problematic soil when this soil is used in field as a foundation material because of its low bearing capacity, high compressibility and high volumetric changes during dry wet seasons. Structures especially lightly loaded, founded on such soil deposit are severally damaged, because of the swell-shrink behavior with water content change, this necessitate 'In-situ' ground improvement. 'In-situ' expansive clay has certain water imbibing capacity of varying magnitude depending on its initial water content, by making the use of this property, one can modified soil behavior by using water soluble chemical. In the field chemical solution can be applied through bore hole or by ponding method. This paper presents laboratory investigations and analysis carried out for 'In-situ' ground improvement using calcium chloride solution by diffusion technique. In the present research work an attempt is made to study effect of calcium chloride solution on swelling behavior of soil of different degree of swellability with different initial physical states. Under the lab test condition the reduction in swelling 16% to 78% was observed due to diffusion of calcium chloride solution.*

Keywords: *Calcium chloride, Degree of swellability, Expansive soil deposit, Improvement by Diffusion technique, Swelling behavior*

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I. Introduction

Expansive soil is one of the major regional soil deposit in India, covering about 200,000 square miles and thus form about 20% of the total area of the country [1-3]. It is considered as the most problematic and treacherous as construction or foundation material because of its low bearing capacity, high compressibility and high volumetric changes during dry wet seasons [3-5]. The structures, especially lightly loaded, founded on such deposits exhibit various distresses, deformations and damages, sometimes even collapse of the structures also [3-5]. The severity of the problem can be gauged from the fact that the annual cost of damages to the civil engineering structures as reported in 1993 is to the extent of £150 million in the UK, $1000 million in the USA and many billion pounds worldwide [6,7]. In 2013 ITRC reported that soil movement in the UK has a financial impact of between £300-500 million per annum [8]. In India too, tens of millions of rupees are spent on repairs, maintenance and rehabilitation of damaged structures every year. Many researchers and investigators have developed various approaches and methods of improving the undesirable characteristics of expansive soil. The widely popular method of using of admixtures, like fly ash, lime, cement, chemicals, randomly distributed geosynthetic fibers and many waste materials etc. is found to be effective in this respect [4,5] [9-14]. However, in majority of the geotechnical construction problems one is faced with the construction on natural grounds in which case soil functions as a foundation material. Thus the improvement in expansive soil characteristics by any possible ground improvement technique is of utmost importance in civil engineering construction activities in expansive soil areas.

II. Broad perspective of the present work

Some of the probable methods for ensuring trouble-free performance of the structures on expansive soil are use of under reamed piles, provision of CNS layers or alternate cushion of other specified materials, granular anchor piles (GPA), use of stone columns, sand piles etc. [4,5] [12] [15-17]. Expansive soil being clayey soil, techniques like grouting etc. is not feasible for the purpose. Also though various admixtures like lime, cement, fly ash etc. are very effective in soil improvement their use in 'In-situ' ground improvement is practically impossible [4,5] [9-14]. However, the use of water soluble chemicals is considered feasible in this case [18-20]. Unfortunately, the review of literature on this aspect reveals that this aspect of 'In-situ' ground improvement of expansive soil by use of admixtures in the form of chemical solutions has remained almost inadequately investigated. The present work is meant for contributing to some extent in this inadequately investigated domain of 'In-situ' improvement of expansive clay sites by diffusion of chemical solutions.

III. Principle and Basic concepts

It is realized that the 'In-situ' expansive clay has certain water imbibing capacity of varying magnitude depending on its initial water content. Expansive clay with its electrochemical activity exhibits certain osmotic pressure and water suction characteristics. Water thus diffuses in to the soil mass in a definite zone surrounding the point of water supply source. It is thought that water soluble chemical may also enter in to the soil body if it is diffused in to it. The diffused chemical solution after entering in to the soil mass may interact with the electrochemically active clay particles of expansive soil thereby altering its characteristics with respect to strength, compressibility, stiffness and swell-shrink nature. The present study involves these considerations.

IV. Laboratory investigations

Laboratory investigations were carried out on reconstituted expansive soil samples (simulating the drying process of field soil) of four artificially prepared soils with different swelling characteristics to study the effect of diffusion of calcium chloride solution on swelling behavior of soil with different initial physical state. This scheme of the investigations was devised with the consideration that any In-situ' soil deposit at site may have different degree of swellability and also depending on the level below ground surface the soil may possess different initial water content condition in various seasons. Detail of the materials used, sample preparation and experimental procedure is explained below.

1. Materials used

Black Cotton Soil

In India the swelling soils which cover about 20% of the total area of the country are colloquially called as black cotton soils because of their black color and fertility to grow cotton crop in abundance. This black cotton soil was collected from the site in the neighborhood of Nagpur city of India by method of disturbed sampling after removing the top layer of soil upto1m depth. Collected soil transported in sacks to the laboratory.

Bentonite

Commercial grade Bentonite available in the local market was used for preparing soil mixes with higher swelling characteristic by mixing with native Black Cotton soil.

NSS

Non swelling soil (NSS) having least swellability characteristic was used to prepare soil mix of lowest swellability. In ancient India this soil was used for construction of Gadhi's or Haveli's of rich person. NS soil was collected from the Gadhi present over an area near Pawnar, Nagpur Road with due permission of local people and transported in sacks to the laboratory. In India this soil is named as Gadhi soil. Stated briefly, Gadhi soil is special type of artificially stabilized soil found in many villages of Maharashtra State of India [21].

Calcium chloride ($CaCl_2$)

Commercially available calcium chloride ($CaCl_2$) was selected for the study. It consisted of 72.79% calcium chloride ($CaCl_2$), <0.1% magnesium chloride ($MgCl_2$) and 27.21% water (H_2O). The values mention above is as per the test report shown in Table 1. Chemical analysis of calcium chloride was done in Anacon laboratories Pvt. Ltd.

2. Soil Mixes Used For Investigations

Natural soil with the finer active fraction (F) may also possess the swellability characteristics of different magnitude. Considering the varying degree of swellability of finer fraction (F) four mixes were prepared by adding different percentage of Bentonite and NS soil. These prepared soils are reported as Soil A, Soil B, Soil C and Soil D in the present paper. Finer fraction (F) material with 40% Bentonite and 60% of 2mm BC soil fraction is considered as fine active fraction with largest swellability, whereas finer fraction (F) containing 20% 2mm NS soil and 80% of 2mm BC soil fraction is considered have least swellable material. The constituents and physical properties of all four prepared soil is given in Table 1.

Table 1:- Constituents and physical properties of soil mixes

Physical Properties		***Soil Mix Category***			
		A (60% BCS+ 40% Bentonite)	B (80% BCS+ 20% Bentonite)	C (100% BCS)	D (80% BCS+ 20% NSS)
Liquid limit	w_L (%)	82.65	71.65	58.80	55.4
Plastic Limit	w_P (%)	44.29	40.75	33.16	31.8
Plasticity Index	I_P (%)	38.36	30.91	25.64	24.32
Shrinkage Limit	w_S (%)	9.90	11.03	12.29	13.81
Free Swell Ratio	FSR	4.314	3.89	2.522	1.423
Free Swell Index	FSI%	83	58	39	28
Specific gravity	G	2.6	2.68	2.71	2.53
pH value		7.79	7.38	7.06	7.57
Degree of Expansivity		Very High	Very High	High	Moderate
Soil Classification		CH	CH	CH	CH

It is clearly seen from Table 1 values of various property parameter that the soil A is of highest swellability among these soils and soil D is of lowest swellability. The continuous decrease in swellability is exhibited in the following order A→B→ C→ D. As per this sequence of soil type the values of w_L, I_p, FSI and FSR [25], show gradual decrease.

3. Swelling Behavior Study

Free swell test on series of reconstituted samples of different soil mixes with varying degree of swellability at different initial physical states were conducted. Procedure of sample preparation, experimental procedure of swelling behavior test is discussed as below

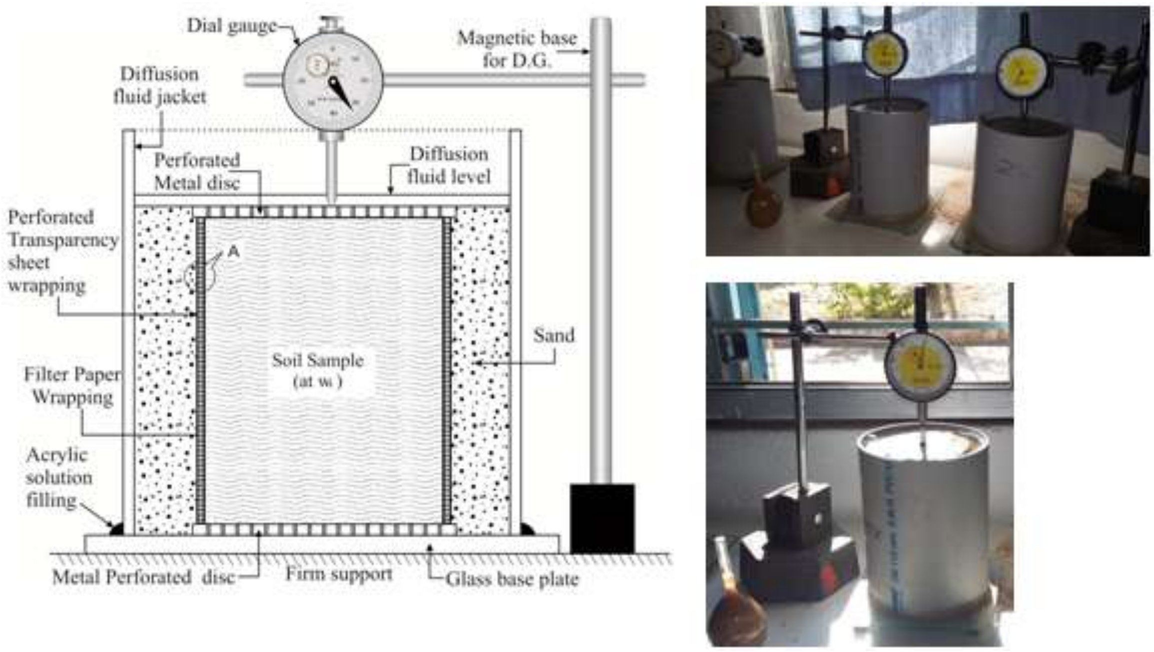
Sample Preparation

Initially air dried sample under warm atmospheric condition was mixed with water after its cooling to attain its water content at approximately midway between its plastic limit w_p and liquid limit w_L. The quantity of water for each soil mix was calculated from the liquid limit and plastic limit value as indicated in Table 1. Wet mass was kept in airtight plastic bag for minimum 10 hours for uniform distribution of water. For getting identical wet cylindrical soil samples PVC pipe of 8 cm diameter was cut in to number of pieces of 12 cm height and use for sample preparation. Grease was applied on inner side of each PVC pipe sampler tube so that wet soil mass easily extruded. Wet soil was then pressed into eighteen PVC open ended tubes. All the samples were air dried in shade, making them upside down frequently. Drying of initially fully saturated plastic soil sample caused its gradual shrinking (without development of cracks within) and consequent reduction in its water content and the degree of saturation. It was observed from few pilot tests of sample drying that 5 days air drying brought the water content of the sample to 74%, 35%, 29% while 10 days and 15 days drying lowered down the water content to 41%, 26%, 21% and 25%, 20%, 15% for soil mixes A(60%BCS+40%Bentonite), B(80%BCS+20%Bentonite), C(100% BCS) and D(80%BCS+20%NSS) respectively. These values of water content for the soil under investigation pertained to water content near-saturation state, near-OMC state and near-natural dry condition respectively of field soil deposit. Total eighteen wet samples were prepared for each soil mix; six samples of each soil mix (Series 1) were dried for 5 days. Remaining Twelve was dried for 10 days (Series 2) and 15 days (Series 3) respectively. This procedure formed the shrunken cylindrical samples. Out of the six samples in each series one was tested for determining its initial water content. The remaining five were kept for diffusion of fluids i.e. solutions of Calcium chloride of 0% (water), 1%, 1.5%, 2% and 3% concentration for 10 days in separate test assemblies as shown in Fig. 1(a,b) for further investigations. Concentration of Calcium chloride solution was selected on the basis of results obtain from series of pilot testing conducted on small scale sample of black cotton soil. In pilot testing concentration of calcium chloride solution were tried with increment of 0.5%; for the pilot testing 0.5%, 1%, 1.5%, 2%, 2.5% and 3% concentrations were used.

Experimental Setup and Methodology for Swell Measurement

Experimental set up consist of a special mould prepared by a PVC pipe of 12 cm diameter, 14 cm height and enclosed with a glass plate. To make this assembly water tight a joint between pipe and glass plate fill with acrylic solution as shown in photographs of Fig. 1 b.

Prepared samples with required water content state were taken and each samples diameter, height and weight was measured. From this data engineering properties before diffusion were determined. One sample was kept in oven for initial water content determination and other five samples were wrapped with filter paper and perforated transparency sheet to prevent lateral budging. This samples then placed centrally in moulds with sand cushion of 1cm at bottom and top and samples were surrounded by fine sand passing through IS sieve 600µ. Sand was compacted well to ensure laterally confinement of soil sample at all stages and allow water/ calcium chloride solution to diffuse in it. On the top of sample a circular plate was kept to provide a level surface on which a tip of dial gauge was placed to measure the volumetric change during diffusion process. After assembling all the five samples in setup, water was filled in one assembly and calcium chloride solutions of concentration 1%, 1.5%, 2% and 3% were filled in four successive assemblies up to the top. Just after completion of filling diffusion fluid initial reading of dial gauge and corresponding time was noted for all five samples in test setup. For initial four days reading were noted at every 30 minutes interval and later on readings interval was increased when there is not much increment was observed in dial gauge reading. In such way samples was kept for 10 days diffusion. Finally increase in height of sample (Δh) with respect to its initial height (h) was observed from the dial gauge readings during 10 days of diffusion period. At the end of diffusion process samples were reached to near saturation state. Samples were then taken out and after removal of circumferential wrapping; they were tested for other physical state parameter such as final water content, dry unit weight and degree of saturation. The results of all three series of each soil mix (A, B, C and D) were tabulated and analyze.



(a) **(b)**

Fig. 1:- Swelling behavior of soil during diffusion of water

V. Analysis and Interpretation of the Results

This section presents the results of laboratory investigation carried out on clay collected from the site as well as artificially prepared soil mixes under investigation, with commercial-grade calcium chloride solution of different concentrations to understand the influence of calcium chloride ($CaCl_2$) on the swell and other physical state parameters of expansive soil deposits. The results of the above study are presented here under in the form of following aspects.

1) Swelling behavior of all four categories of soils with different initial water contents due to diffusion of water
2) Swelling behavior of all four categories of soils with different initial water contents due to diffusion of calcium chloride solution of different concentrations.
3) Comparative swelling behavior of all four categories of soils with different initial water contents due to diffusion of water and calcium chloride solutions

Cylindrical soil samples of different swelling characteristics attained different initial water contents after 5days, 10 days and 15 days drying as shown in Table 2.These laterally confined cylindrical soil specimens with different initial water content when immersed in water for 10 days causes diffusion laterally. During diffusion the increase in water content and vertical swell took place. For studying swelling behavior of soil during diffusion, swelling strain ($\Delta h/h_0\%$) on diffusion of water for each sample are calculated and plotted against time in Fig. 2. In order to plot $\Delta h/h_0\%$ vs. time graph, dial gauge readings were recorded during the free swell test. Δh is calculated for each reading by subtracting the value read at that time from the initial reading value and $\Delta h/h_0$ vs. time is plotted.

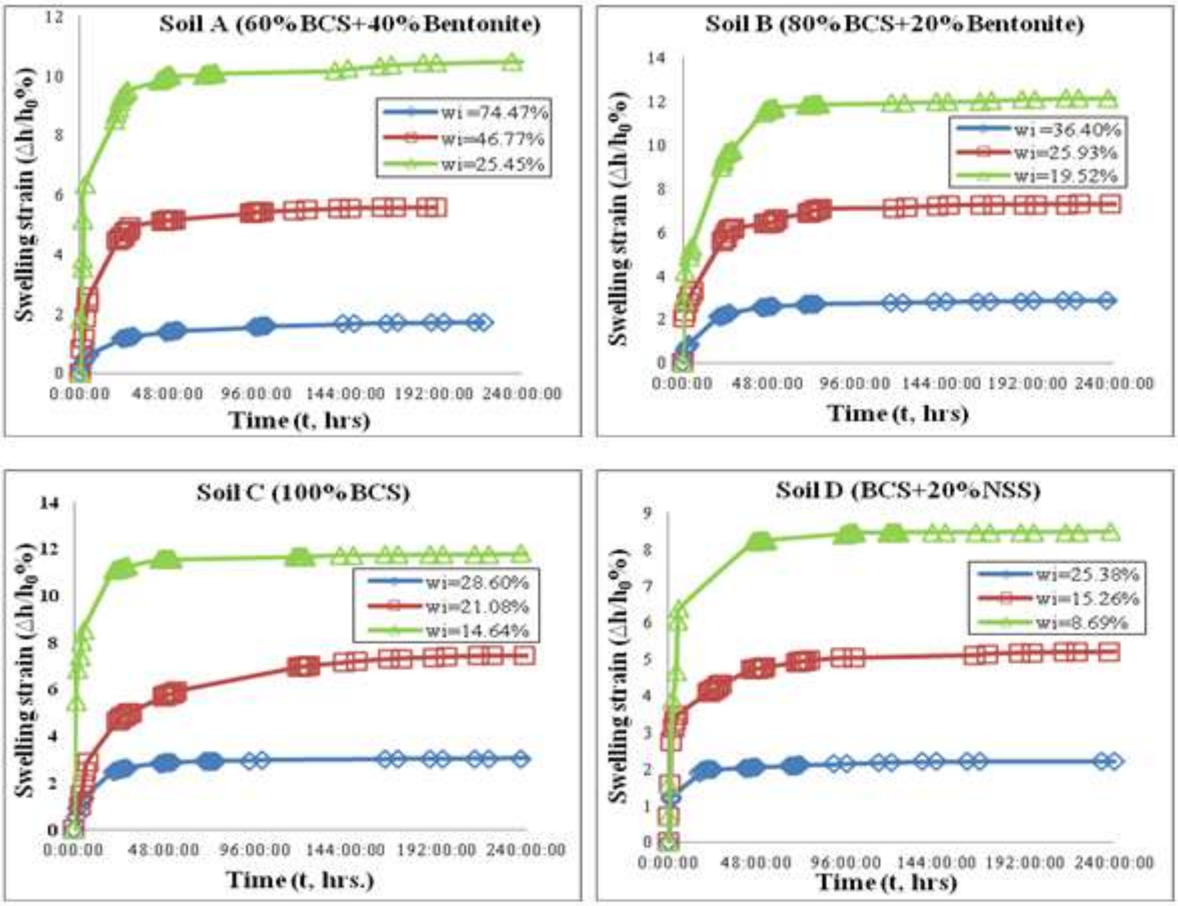


Fig. 2:- Swelling behavior of soil during diffusion of water

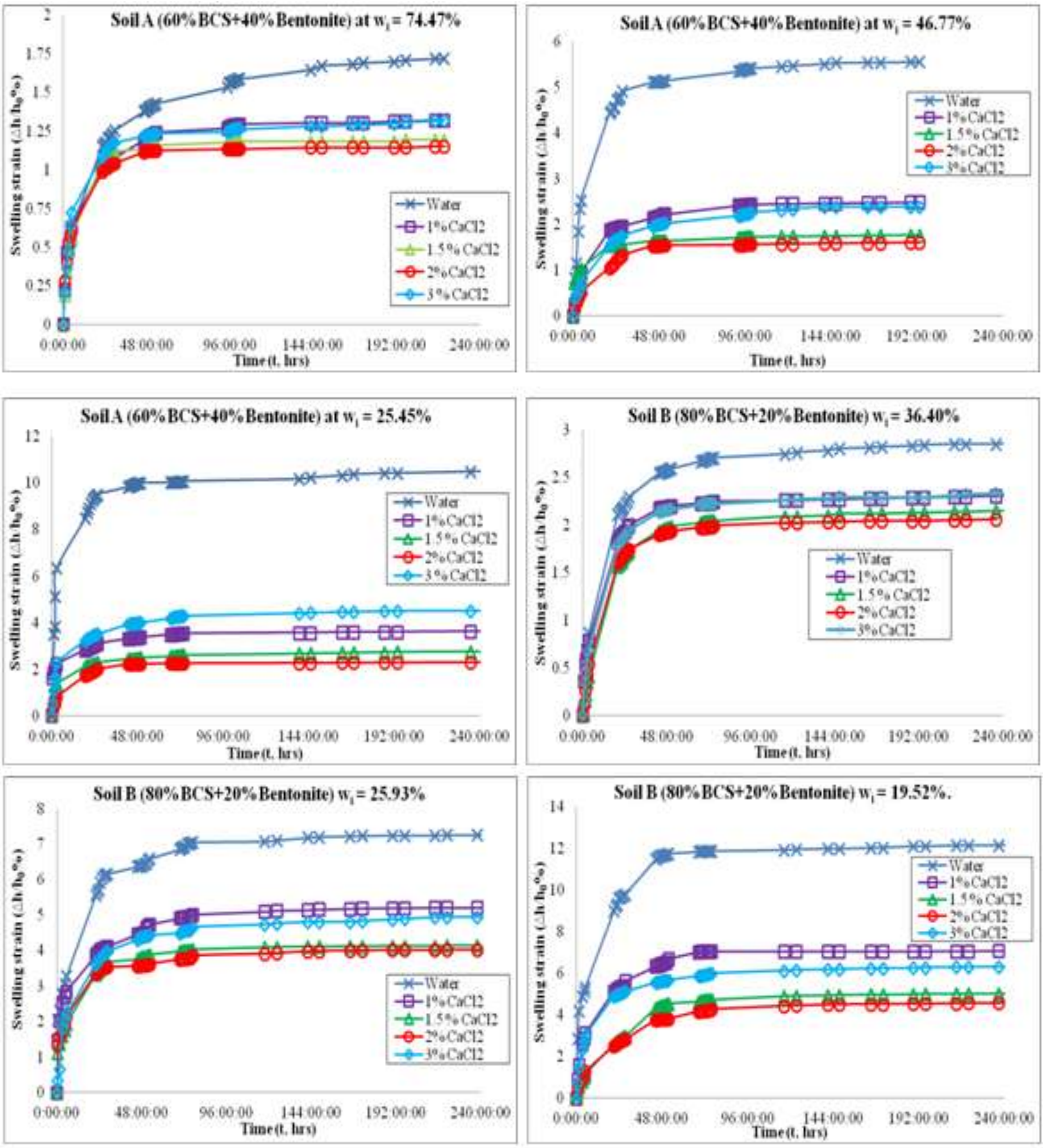
It is noted that during the imbibitions, swelling strain ($\Delta h/h_0\%$) for all soil specimen of different degree of swellability having different initial water contents is occurs in a similar way. The evolution of swelling strain ($\Delta h/h_0\%$) presents two phases: primary swelling where the evolution is very fast up to 48 hrs and a secondary swelling where the evolution is very slow up to 96 hrs and thereafter it becomes constant. This is in conformity with work reported by M.K. Gueddouda (2011).

Further it is observed from Fig. 2 the samples of each soil at low initial water content present a very important swelling strain ($\Delta h/h_0\%$) comparing to the soil with high water content. Significant reduction in swelling strain ($\Delta h/h_0\%$) with increase in the initial water content is also observed for all soil specimens from Table 2. This swelling behavior of soil with different initial water content is presented in Fig. 2. It can be noted from this Fig. 2 that as the initial water content of soil increases, the swelling decreases in all the cases. This observation is obvious because an expansive soil containing high initial water content has little scope for imbibing more water on submergence as all its mineral particles are already saturated and therefore very small swelling strain ($\Delta h/h_0\%$) is observed at high initial water content this is in conformity with work reported by Aparna et. al. (2014).

It is also observed that the percentage increase in swelling strain ($\Delta h/h_0\%$) of soil samples for 10 days and 15 days dried with reference to sample dried for 5 days is high for Soil A (60%BCS+40%Bentonite) with highest degree of swellability and low for Soil D (BCS+20%NSS) with lowest degree of swellability. For soil 'A' increase in swelling strain ($\Delta h/h_0\%$) is 2.24 and 5.10 for soil samples with w_i = 46.77% and 25.45%

respectively and for soil 'D' increase in swelling strain ($\Delta h/h_0\%$) is 1.35 and 2.82 for for soil samples with w_i = 15.26% and 8.69% respectively. Thus initial water content and degree of swellability affect greatly the swelling behavior of soil due to diffusion of water.

To study the effect of concentration of calcium chloride solution on swelling behavior of soft clay soil deposits A, B, C and D from higher to lower degree of swellability at different initial water contents, samples of each soil with different initial water contents were allowed to diffused in to calcium chloride solution of 0% (Water), 1%, 1.5%, 2% and 3% concentration. Variation of swelling strain ($\Delta h/h_0\%$) vs time for each sample during diffusion of calcium chloride solution of 0% (Water), 1%, 1.5%, 2% and 3% concentrations were plotted in Fig. 3. Similar trend of swelling strain ($\Delta h/h_0\%$) with respect to time is observed for all four soil deposit at three different initial water contents during diffusion of all concentrations of calcium chloride solution.



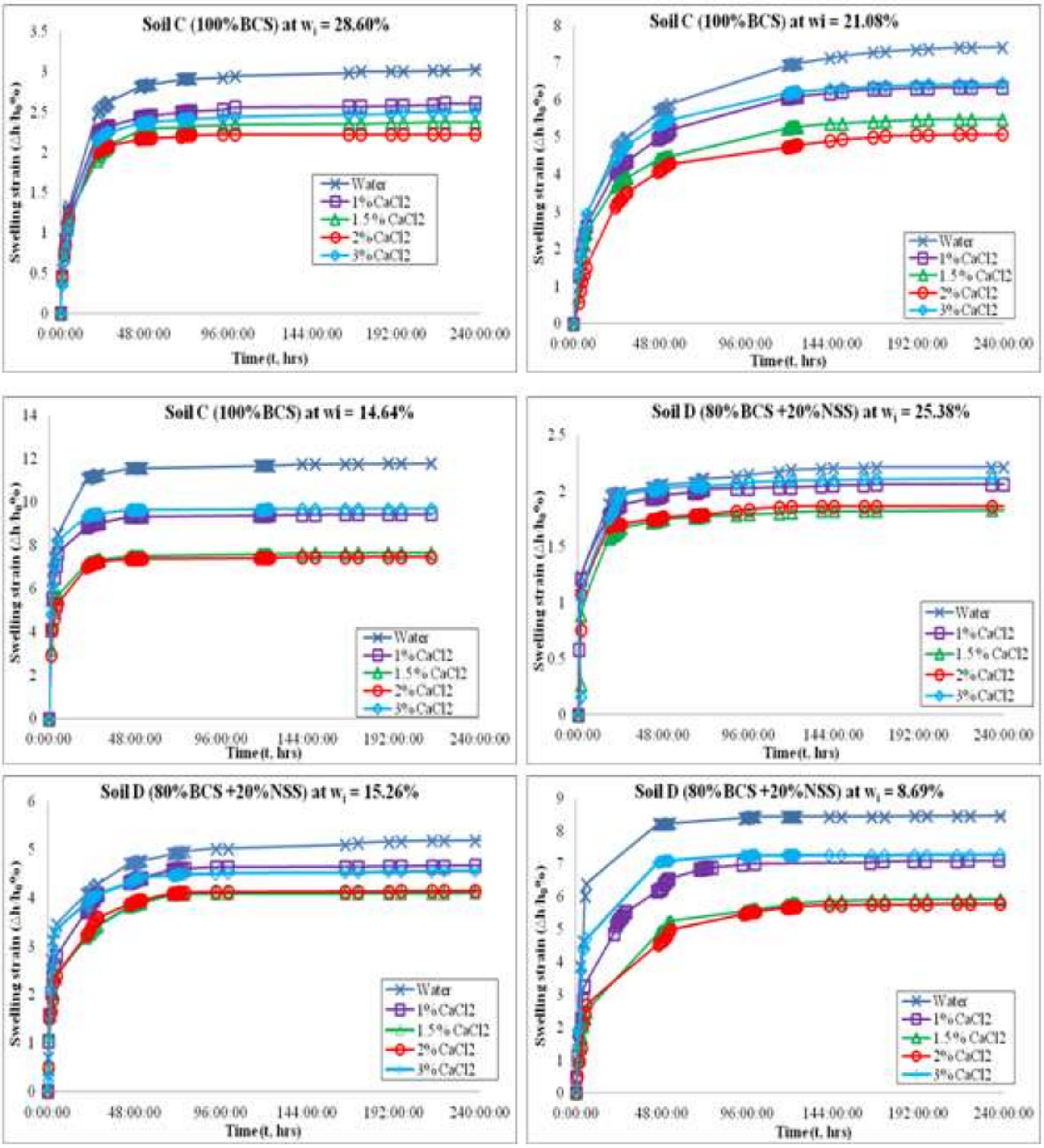


Fig. 3:- Swelling behavior during diffusion of calcium chloride solution of different concentrations

Examination of the curves of evolution of swelling strain ($\Delta h/h_0$%) as a function of time indicates that the reduction rate of swelling strain ($\Delta h/h_0$%) by calcium chloride solution is depends on the concentration of solution and it reduces with the increase in the concentration of calcium chloride up to 2%. For 3% concentration nominal decrease in swelling strain ($\Delta h/h_0$%) is observed for all soil. Soil with highest degree of swellability at low initial water content shows highest reduction in swelling strain ($\Delta h/h_0$%). Sharp decrement in swelling strain ($\Delta h/h_0$%) is observed for the soil A of highest degree of swellability at lowest water content of 25.45% as shown in Fig. 5.

To evaluate the efficacy of calcium chloride solution in reducing swelling of soft clay soil deposit, results of swelling test series of soil A, B, C and D are analyzed. The results reported in Table 2 presents that whatever may be the initial water content, soil attained finally almost the same water content to attain near saturation state when it immersed in water. Such as soil A (60%BCS+40%Bentonite) at initial water contents 74.47%, 46.77% and 25.45% attained approximately 85.15%, 84.42% and 83.91%. Soil B (80% BCS+20%Bentonite) at initial water contents 36.40%, 25.93% and 19.52% attained approximately 44.11%, 44.83% and 44.89%. Soil C (100% BCS) at initial water contents 28.60%, 21.08% and 14.64% attained approximately 34.72%, 34.56% and 34.45%. Soil D (80% BCS+20% NSS) at the initial water contents of 25.38%, 15.26% and 8.69% attained approximately 32.09%, 31.61% and 31.60% this is in conformity with reported work by Y. S. Golait (2012). After completion of diffusion process it is observed that the degree of saturation of all soil samples is within range of 95% to 100%. The resulting swelling strain as expressed by $\Delta h/h_0$ (%) for soil A , B, C and D are 1.72%, 5.57% and 10.49% ; 2.86%, 7.26% and 12.16% ; 3.04, 7.42 and 11.81; 2.22%, 5.211% and 8.47% respectively as shown in Fig. 4. As compared to this the diffusion of calcium chloride solutions of different concentration caused much smaller values of final water content (w_f) and swelling strain ($\Delta h/h_0$ %) as shown in Table 2.

The swelling of all four artificially prepared soils for diffusion of calcium chloride solutions of different concentrations is compared with swelling affected by water to study the effect on swelling behavior of soils having different degree of swellability at different initial physical state. The results of reduction in swelling strain (RSS %) caused due to diffusion of calcium chloride solution are presented in Fig. 5 and Fig. 6. Fig. 5 indicates that Soil A of higher degree of swellability at lower initial water content shows maximum percent reduction in swelling strain approximately 78%. The reduction in swelling strain (RSS %) is found to be depends not only on concentration of calcium chloride solution but also on the initial water content as well as degree of swellability of soil as shown in Fig. 5.

The variation of reduction in swelling strain (RSS %) is plotted with concentration of calcium chloride solution in Fig. 6 It is observed that the reduction in swelling strain (RSS %) increases with increase in concentration up to 2% for soil A , B, C and D, beyond 2% there is a nominal reduction in the swelling strain.

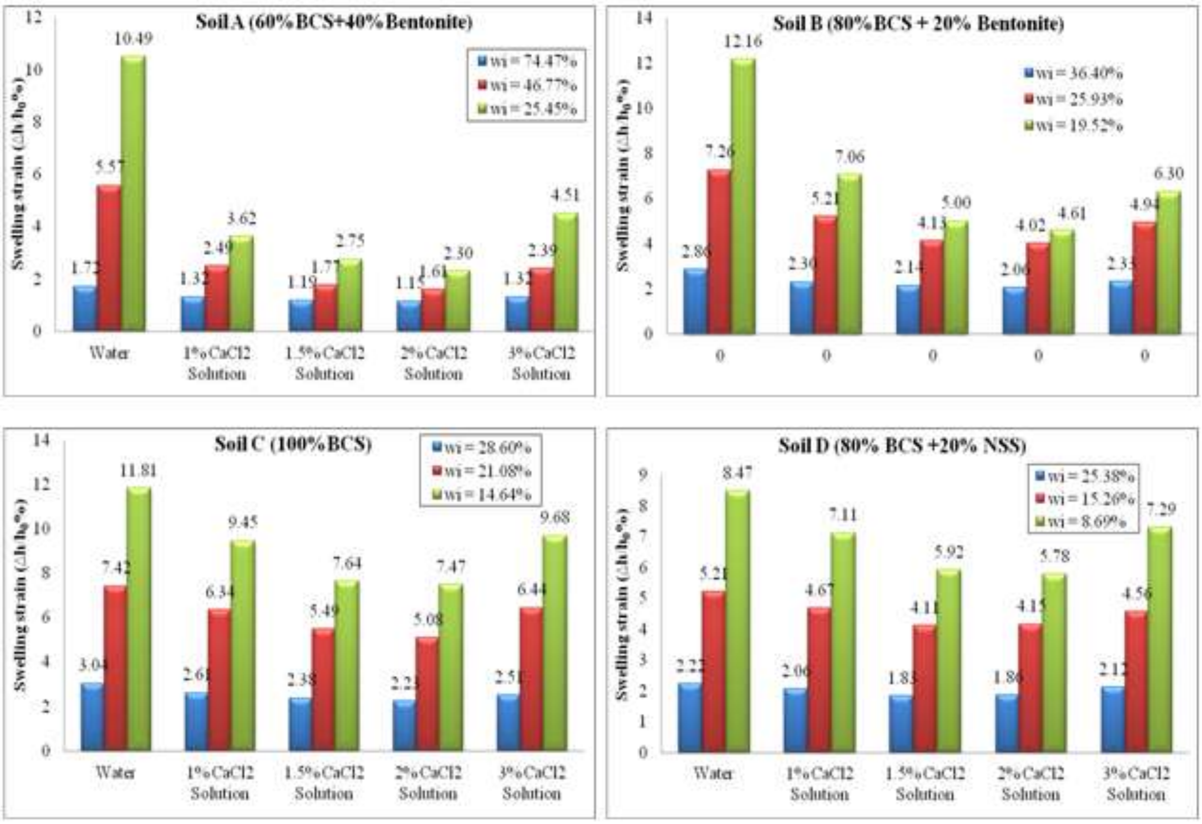


Fig. 4:- Swelling strain ($\Delta h/h_0$ %) exhibited by all four soils at different w_i during diffusion of water and $CaCl_2$ solutions of different concentrations

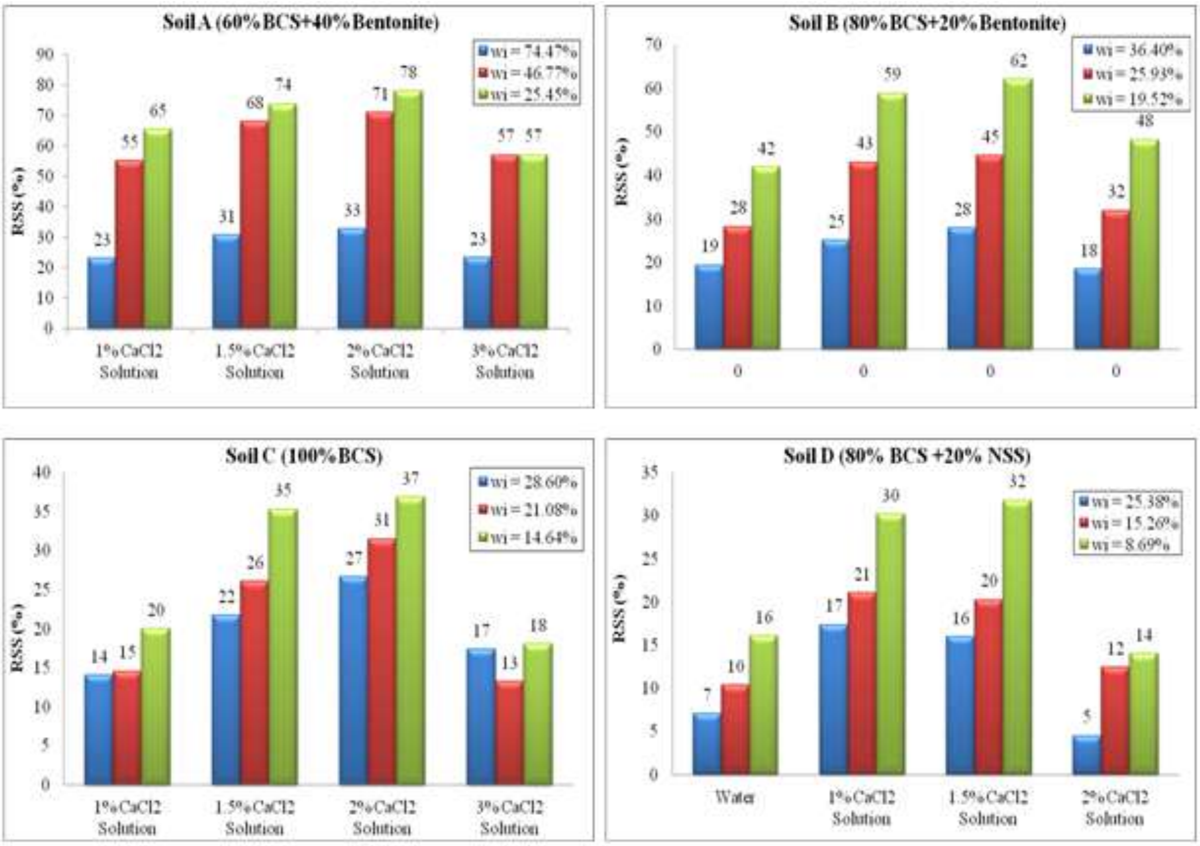


Fig. 5:- Reduction in swelling strain caused due to diffusion of $CaCl_2$ solutions of different concentrations

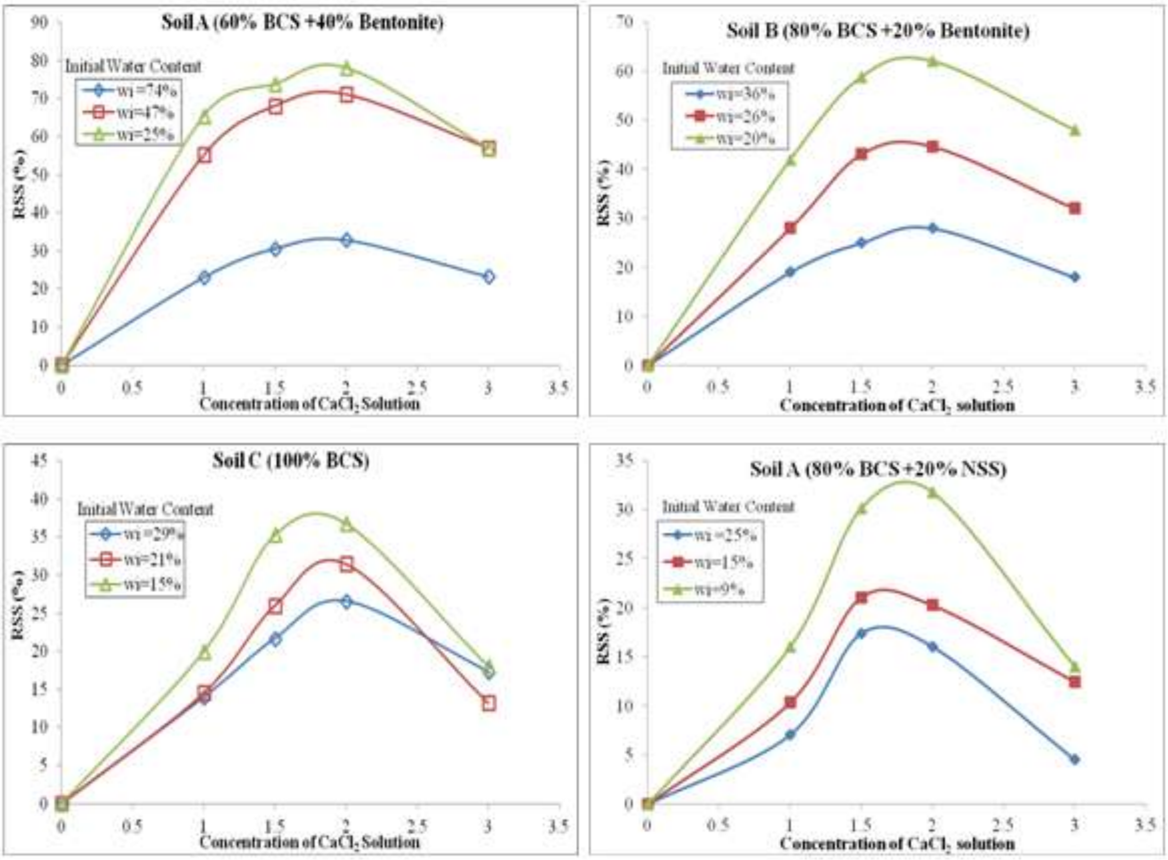


Fig. 6:-Variation of percentage reduction in swelling strain with concentrations of $CaCl_2$ solution

Table 2:- Results of swelling strain ($\Delta h/h_0$ %) of soil during diffusion

Soil A (60%BCS+40%Bentonite)

Diffusing fluid	w_i (%)	w_f (%)	Δw (%)	γd_i gm/cm^3	γd_f gm/cm^3	$\Delta h/h_0$ (%)	RSS (%)
Water	74.47	85.15	10.7	0.84	0.78	1.72	0
1 % $CaCl_2$		82.39	7.9	0.85	0.80	1.32	23
1.5 % $CaCl_2$		80.72	6.2	0.85	0.81	1.19	31
2 % $CaCl_2$		79.06	4.6	0.85	0.82	1.15	33
3 % $CaCl_2$		83.03	8.6	0.85	0.80	1.32	23
Water	46.77	84.42	37.6	1.11	0.80	5.57	0
1 % $CaCl_2$		66.21	19.4	1.12	0.95	2.49	55
1.5 % $CaCl_2$		60.00	13.2	1.12	0.99	1.77	68
2 % $CaCl_2$		57.00	10.2	1.12	1.03	1.61	71
3 % $CaCl_2$		63.67	16.9	1.11	0.97	2.39	57
Water	25.45	83.91	58.5	1.47	0.79	10.49	0
1 % $CaCl_2$		59.60	34.1	1.47	1.01	3.62	65
1.5 % $CaCl_2$		55.84	30.4	1.47	1.06	2.75	74
2 % $CaCl_2$		54.22	28.8	1.47	1.08	2.30	78
3 % $CaCl_2$		60.34	34.9	1.47	0.99	4.51	57

Soil B **(80%BCS+20%Bentonite)**

Diffusing fluid	w_i (%)	w_f (%)	Δw (%)	γd_i gm/cm^3	γd_f gm/cm^3	$\Delta h/h_0$ (%)	RSS (%)
Water	36.40	44.11	7.71	1.30	1.22	2.86	0
1 % $CaCl_2$		41.44	5.04	1.32	1.26	2.30	19
1.5 % $CaCl_2$		40.00	3.60	1.30	1.27	2.14	25
2 % $CaCl_2$		39.60	3.20	1.30	1.27	2.06	28
3 % $CaCl_2$		40.45	4.05	1.30	1.25	2.33	18
Water	25.93	44.83	18.90	1.51	1.20	7.26	0
1 % $CaCl_2$		39.55	13.63	1.49	1.30	5.21	28
1.5 % $CaCl_2$		36.50	10.57	1.50	1.34	4.13	43
2 % $CaCl_2$		35.56	9.63	1.50	1.36	4.02	45
3 % $CaCl_2$		38.08	12.16	1.50	1.32	4.94	32
Water	19.52	44.89	25.37	1.68	1.19	12.16	0
1 % $CaCl_2$		36.55	17.03	1.68	1.35	7.06	42
1.5 % $CaCl_2$		33.59	14.07	1.68	1.41	5.00	59
2 % $CaCl_2$		31.86	12.34	1.67	1.45	4.61	62
3 % $CaCl_2$		35.53	16.01	1.67	1.35	6.30	48

Soil C (100%BCS)

Diffusing fluid	w_i (%)	w_f (%)	Δw (%)	γd_i gm/cm^3	γd_f gm/cm^3	$\Delta h/h_0$ (%)	RSS (%)
Water	28.60	34.72	6.12	1.48	1.42	3.04	0
1 % $CaCl_2$		33.21	4.61	1.48	1.44	2.61	14
1.5 % $CaCl_2$		32.04	3.44	1.48	1.45	2.38	22
2 % $CaCl_2$		31.20	2.61	1.48	1.42	2.23	27
3 % $CaCl_2$		32.73	4.13	1.48	1.40	2.51	17
Water	21.08	34.56	13.48	1.65	1.48	7.42	0
1 % $CaCl_2$		30.87	9.79	1.65	1.50	6.34	15
1.5 % $CaCl_2$		29.23	8.15	1.65	1.52	5.49	26

2 % $CaCl_2$		28.15	7.07	1.65	1.46	5.08	31
3 % $CaCl_2$		31.25	10.17	1.65	1.40	6.44	13
Water	14.64	34.45	19.81	1.77	1.49	11.81	0
1 % $CaCl_2$		29.94	15.29	1.77	1.55	9.45	20
1.5 % $CaCl_2$		26.16	11.52	1.77	1.56	7.64	35
2 % $CaCl_2$		25.74	11.09	1.77	1.48	7.47	37
3 % $CaCl_2$		29.89	15.25	1.77	1.42	9.68	18

Soil D (80%BCS+20%NSS)

Diffusing fluid	w_i (%)	w_f (%)	Δw (%)	γd_i gm/cm^3	γd_f gm/cm^3	$\Delta h/h_0$ (%)	RSS (%)
Water	25.38	32.09	6.71	1.45	1.38	2.22	0
1 % $CaCl_2$		30.74	5.37	1.46	1.39	2.06	7
1.5 % $CaCl_2$		30.14	4.76	1.46	1.40	1.83	17
2 % $CaCl_2$		30.20	4.83	1.46	1.40	1.86	16
3 % $CaCl_2$		30.58	5.21	1.46	1.40	2.12	5
Water	15.26	31.61	16.35	1.62	1.39	5.21	0
1 % $CaCl_2$		28.70	13.44	1.62	1.43	4.67	10
1.5 % $CaCl_2$		27.34	12.08	1.62	1.46	4.11	21
2 % $CaCl_2$		27.27	12.01	1.62	1.47	4.15	20
3 % $CaCl_2$		27.76	12.50	1.62	1.45	4.56	12
Water	8.69	31.60	22.91	1.75	1.39	8.47	0
1 % $CaCl_2$		28.30	19.61	1.75	1.46	7.11	16
1.5 % $CaCl_2$		25.46	16.77	1.76	1.51	5.92	30
2 % $CaCl_2$		24.63	15.94	1.75	1.52	5.78	32
3 % $CaCl_2$		26.42	17.73	1.75	1.48	7.29	14

VI. Conclusion

1. It is observed that the diffusion of calcium chloride solution in expansive soil develops the positive effects in respect of reducing the swelling and improving the strength characteristics of expansive soils. Out of the five concentrations (1%, 1.5%, 2% and 3%) of calcium chloride solutions, solution of 2% concentration gives the better effectiveness of calcium chloride in improving the expansive soil properties.
2. The initial water content and degree of swellability significantly governs the maximum water content change and the corresponding swelling during diffusion of water. For each soil, sample with low initial water content shows maximum swelling.
3. Calcium chloride solutions of 1%, 1.5%, 2% and 3% concentration have different effects on the values of change in water content (Δw) and swelling strain ($\Delta h/h_0$). However, the rate of change in swelling strain with change in water content is almost same for all the diffusing fluids for a particular swelling soil.
4. The percentage reduction in swelling strain caused by diffusion of calcium chloride solutions depends significantly on the initial water content state of soil and degree of swellability of soil.

It is observed that soil of very high swellability (Soil A) treated by solution of 2% concentration exhibits RSS of 78% for initial water content of the soil nearer to its very dry physical state (w_i approximately 25%), where as RSS of 33% only is exhibited for its initial water content nearer to saturated wet condition (w_i approximately 74%).
As compare to this the soil of very low swellability (Soil D) exhibited the corresponding values of RSS of 32% for dry soil (with w_i approximately 9%) and 16 % for very wet soil (w_i approximately 25%).

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