STABILIZATION OF EXPANSIVE SOIL USING POTASSIUM CHLORIDE

Rajesh Prasad Shukla[1], Niraj Singh Parihar[2] and Ashok Kumar Gupta[2]

1. *Department of Earthquake Engineering, IIT Roorkee, Roorkee, 24766, INDIA; shuklarajesh4687@gmail.com*
2. *Department of Civil Engineering, JUIT, Waknaghat-173234, INDIA; singhpariharniraj@gmail.com, ashok.gupta@juit.ac.in*

ABSTRACT

Expansive soils cover more than twenty-two percent of geographical area of India. These soils shrink and swell, respectively, with the decrease and the increase in water content of soil. In this study, experimental tests were conducted on an expansive soil to study the effect of mixing of potassium chloride on various soil properties. Liquid limit, swelling potential and plasticity index were found to be reduced significantly with mixing of potassium chloride. Initially, for potassium chloride of 6-8%, plastic limit has also been reduced but latter, it increased with the increase in quantity of potassium chloride. Mixing of potassium chloride increases and decreases, the maximum dry density and optimum moisture content, respectively. The mixing of potassium chloride increases the unconfined compressive strength and shrinkage limit of soil. Optimum amount of potassium chloride is found to be approximately 8-9% of dry soil weight. Potassium chloride altered the properties of expansive soil significantly, and most of the modifications are found to be favourable from civil engineers' point of view. Results of the present study are compared with previous study results too.

KEYWORDS

Atterberg limits, Expansive soil, Potassium chloride, Swell, Strength, Compaction

INTRODUCTION

Expansive soils cover a considerable part of several countries around the globe. In India, they are also known as black cotton soils due to their black colour and suitability for cotton crops. Expansive soils are most common soils in India and cover various states, such as Madhya Pradesh, Andhra Pradesh, Gujarat, Tamilnadu, Maharashtra, Karnataka and a few other parts as well. This type of soil covers approximately more than 20% of total geographical area of India.

Swelling and shrinkage are two main characteristics of expansive soils. These soils swell and shrink with the increase and decrease in water content of soil. This behaviour is mainly contributed to the presence of montmorillonite clay minerals [1]. In monsoon season, expansive clay minerals attract moistures from surroundings, and subsequently increase the volume of soil. However, in the summer season, the water evaporates form soil mass and reduces the volume. The expansion and contraction of expansive soils cause various problems to civil engineers at the time of construction and even after construction. Road network, railways, buried pipe lines and other lifeline facilities constructed on expansive soils are susceptible to damaging behaviour of soil. The behaviour of expansive soils depends on climate condition, physical characteristics and chemical properties of soil. Wong [2] found that diffusion of water can be a main cause of swelling.

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Sivapullaiah et al. [3] stated that the swelling consists of two stages, first stage is inter-crystalline swelling and the second stage is being double-layer repulsion.

There are many solutions available to reduce or avoid the losses due to hazardous behaviour of expansive soil. These solutions include removal of expansive soil up to a particular depth, maintaining water table well below the foundation level, reinforcing of soil, using under reamed foundation, including CNS layer or alteratingthe properties of expansive soil with some additives. After a certain depth, it is not feasible to remove the soil or to retain the water table well below foundation level. Therefore, most of the time, addition of additives proves to be a good option to alter the soil composition and improve the performance of soil. Mechanical stabilization, high strength geogrids and thermal stabilization have also been used in some studies to control the expansion and contraction of soil.

Alteration of soil characteristic by adding chemicals admixture in the soil is a very popular technique for stabilization of expansive soil. Chemical stabilization causes a reduction in swelling and shrinkage characteristic of soil along with reduction in soil plasticity [4]. As compared to gravitational forces, electrical forces predominantly affect the behaviour of clay. Electrical forces mostly depend on the concentration, strength and other characteristics of existing ions in the pore water, and therefore, within the last two decades, a number of electrolytes have been used as stabilizing agent. It was observed in the number of various studies that the electrolytes are very efficient in reducing the swelling and shrinkage characteristic of soil. Electrolytes, such as potassium chloride, ferric chloride, sea water or calcium chloride can be efficiently used in place of the popular and frequently used lime, as these chemicals are having more dissolvability in water than the later [5-6]. The main problem involved in the use of electrolyte is non-uniform mixing of the chemicals, and it may lead to erratic and undesirable outcomes.

Katti and Brave [7] used various additives such as potassium chloride, sodium chloride, magnesium chloride, barium chloride and calcium chloride to stabilize expansive soil, and found that potassium chloride (KCl) is relatively more effective as compared to other additives. Frydman et al. [6] used KCl (0-9% by weight) to stabilize expansive soil, and found that the activity of soil has reduced significantly. Al-Omari et al. [8] mixed more than 99% pure potassium chloride in expansive soil. It was found that KCl reduced the optimum moisture content, liquid limit and plasticity index of the soil. KCl increased the dry density and plastic limit of expansive soil. However, the strength and expansive characteristics were not studied in the study.

From literature study, it is found that only a few studies have been conducted on potassium chloride mixed highly plastic expansive soil, and most of studies considered some selected parameters. The studies on medium plastic expansive soil are missing in the literature. In this study, KCl has been used as an additive to stabilise the medium plastic expansive soil, as it is easily available in market at a reasonable cost. The effect of KCl on various soil properties has been discussed in detail.

Materials and apparatus used in the study

Soil samples were collected from Shimla district, Himanchal Pradesh, India. A number of samples were collected from four different places. The soil is found to be expansive, and consists of fine content more than 60%. The Laboratory test results are shown in Table 1.

Tab. 1 - Description of soil used in the study

Soil Properties	Description	Soil Properties	Description
Liquid limit	43-45%	Specific gravity	2.45
Plastic limit	22-25%	Optimum Moisture content	18-20%
Plasticity index	19-22%	Maximum Dry Density	15.60-15.80 kN/m^3
Shrinkage limit	12.7-12.8%	Soil Classification	CI

KCl used in the powder form with purity more than 99%, and its appearance is white crystalline. The relative density of used KCl is approximately 1.988 and melting point is 771^{0}C.

Apparatus used in this study are Casagrande liquid limit apparatus, consolidation apparatus, Indian standard compaction mould and unconfined compressive test apparatus.

Method used in the study

Grain size distribution of soil was determined as per guidelines and procedure given in Indian standard IS: 2720, Part IV: 1975 [9]. Different percentages of KCl (ranging from 3 to 15% by weight of soil) were thoroughly mixed with the soil. The plastic limit (PL) and liquid limit (LL) of virgin soil as well as KCl mixed soil were determined as per Indian standard IS: 2720 (Part-V)-1985 [10]. The plastic limit and liquid limit of soil samples were obtained using the thread rolling method and mechanical method (Casagrande percussion method) respectively. Shrinkage limit was determined as per IS: 2720 (Part-VI)-1972 [11] using the mercury device method.

Optimum moisture content (OMC) and maximum dry density (MDD) of the expansive soil were determined as per guidelines and procedure given in Indian standard IS: 2720, Part-VII, 1983 [12]. For KCl mixed soil, optimum moisture content and maximum dry density relationship were determined as per IS: 4332, Part III: 1967 [13]. KCl was first mixed thoroughly with soil then placed in Indian standard compaction mould. Soil samples were compacted in three layers using an automatic tamping rod. A rammer having weight of 2.6 kg was dropped from a height of 310 mm. This automatic tampering rod has an advantage over manual tampering rod as it transfers same amount of compaction energy in each blow to the soil. After completion of compaction, the soil sample was detached from mould. Soil samples were collected from the bottom and top of the specimen to determine the water content of soil. This entire process was repeated for soil samples with different amount of potassium chloride. After determination of water content, the dry density was calculated, and graph was plotted between the water content and the dry density for soil with different quantity of added potassium chloride.

Swell potential of soil samples were determined using fixed ring consolidation test apparatus. An air dried porous stone and filter paper was placed on oedometer. After placing the filter paper, the soil sample was placed within the oedometer, and testing was performed under an initial seating pressure of 7 kPa. The swelling was directly noted down from the vertical dial gauge reading. The final reading, which remains constant for a sizeable time was considered to determine the swell potential of soil as the percentage increase in thickness of the sample with respect to the initial level. Procedure to evaluate the swell potential was adopted from Seed et al. [14]

Unconfined compressive strength (UCS) of KCl added expansive soil samples were determined as per procedure specified in IS 2720, Part X: 1991 [15]. An adequate amount of water was gradually added to KCl mixed soil up to the optimum moisture content (OMC) of the concerned mix proportion to allow smooth mixing and maximum compaction of soil. A metallic mould was used to prepare the soil samples for unconfined compressive strength test. This mould has inner diameter of 38 mm and length of 76 mm. Soil samples for testing were prepared at a water content equal to the optimum moisture content of soil. To achieve uniform density, soil sample was compacted from both ends. Soil sample was detached from the mould with the help of a hydraulic jack and then placed on the pedestal of unconfined compressive strength testing machine. A strain rate of 1.2 mm/min was applied during the testing.

RESULTS AND DISCUSSION

All tests were conducted on expansive soil with and without addition of potassium chloride. The results of present study are compared with the results of Al-Omari et al. [8]. The influence of KCl on various properties of expansive soil is discussed separately on sections namely; Atterberg limits, compaction parameters, strength of soil and expansivity of soil.

Atterberg limits

Figure 1 shows the results of Casagrande test. It shows the relationship between the water content and the number blow. KCl contents were varied from 3% to 15% with an increment of 3%. The Figure 1 shows that the relationship between the water content and the number of blow improves significantly up to KCl content of 6% and mixing of additional KCl does not have any significant influence.

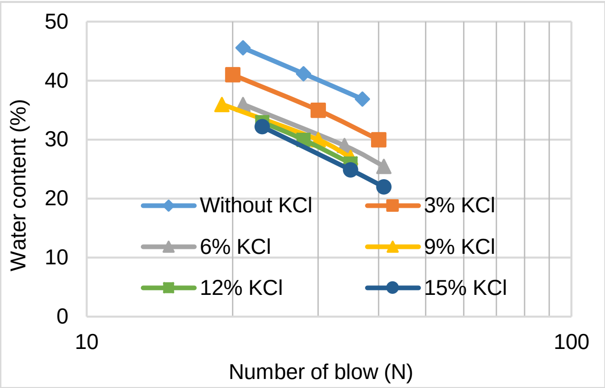

Fig. 1 - Casagrande test result for various amount of KCl

The change in Atterberg limits of soil samples for various proportions of added KCl are given in Figure 2. Figure 2(a) shows that the addition of KCl decreases the liquid limit of soil by a substantial magnitude. The effect of KCl on liquid limit is more prominent up to 6-7%, and any additional mixing does not affect this property. Liquid limit is an indicator of soil compressibility. The reduction in liquid limit indicates the reduction in soil compressibility. Though, the LL decreases in both cases (present study as well Al-Omari et al.[8]), the efficiency of KCl seems to be higher in case of Al-Omari [8].

The variations in plastic limit are shown in Figure 2(b). Plastic limit initially remains almost constant up to a KCl content of 3%, but later, it increased with the increases in quantity of KCl up to 9% of soil weight. Plastic limit does not change significantly with addition of KCl, which is quite different from the results of Al-Omari [8], where a significant increase in the plastic limit of expansive soil was observed. This may have been attributed to the lower plasticity of soil used in the study as compared to latter one. The addition of KCl helped the soil to maintain its semisolid state even at higher water content.

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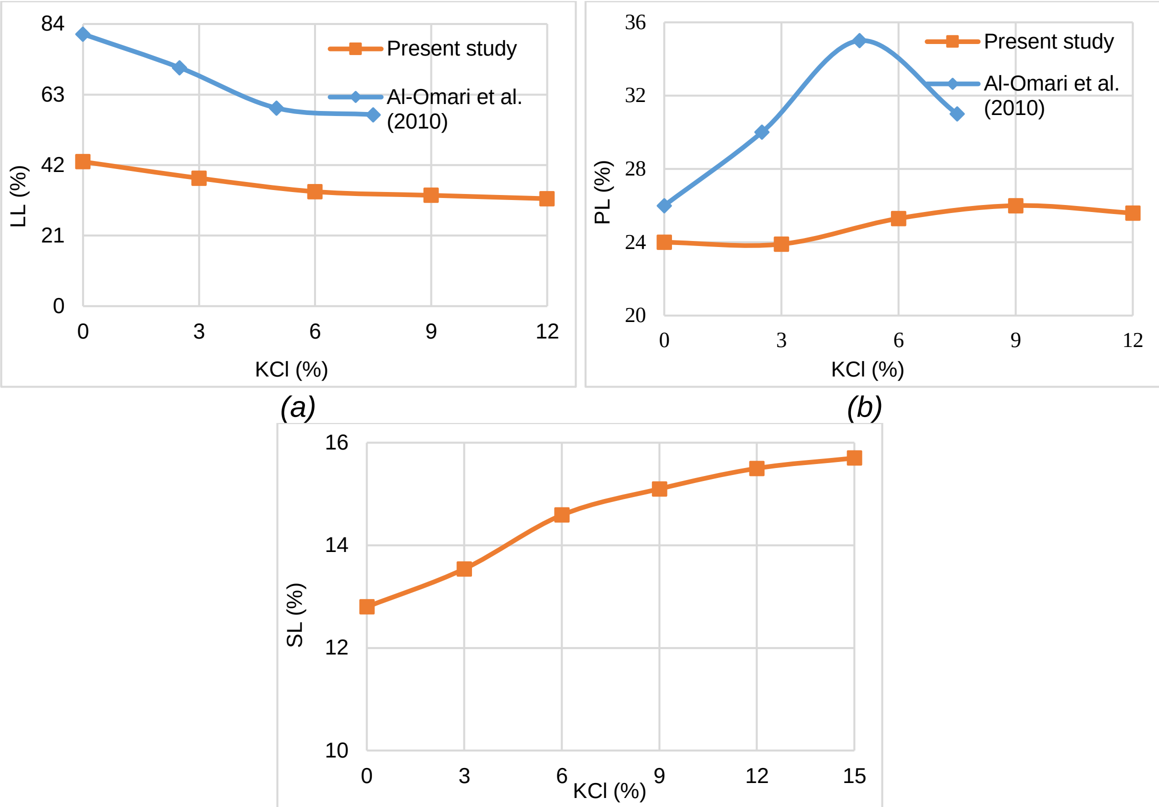


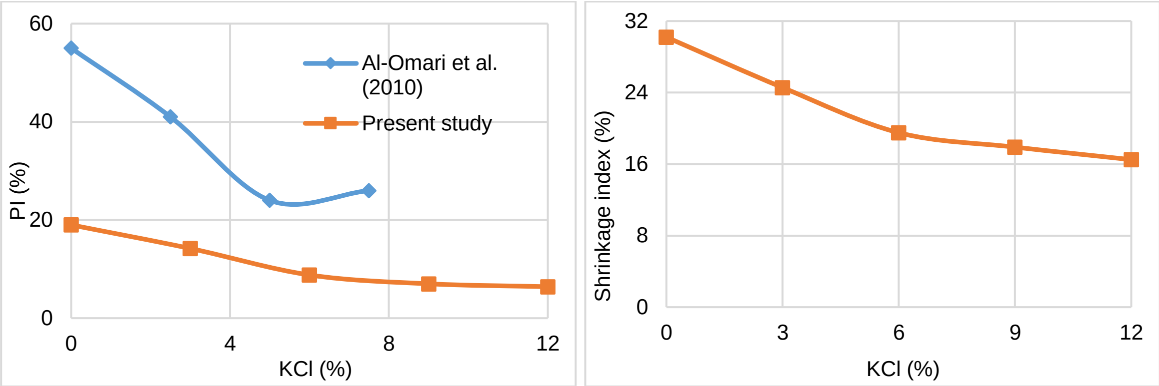
(c)

Fig. 2 - Variation of Atterberg limits with KCl content: (a) Liquid limit, (b) Plastic Limit, and (c) Shrinkage limit

Shrinkage limit is a very valuable index property for the soils which undergo large volume changes with the change in water content. The Shrinkage limit can be used to assess the swell potential, crack development potential, and shrinkage potential of earthwork involving cohesive soils [16]. Figure 2(c) shows that shrinkage limit is increasing significantly up to KCl content of 9%, but for higher KCl content, the effect is negligible. The increase in shrinkage limit after addition of KCL indicates that soil can maintain its physical state even at higher at water content without increasing the soil volume. For untreated soil, it is essential to maintain the soil water content equal to or less than 12.8% to avoid any change in soil volume. However, for KCl treated soils, the water content can be varied between 0 to 15.70% without any change in the soil volume.

The effect of KCl on plasticity index (PI), and shrinkage index is shown in Figure 3. Plasticity index and shrinkage index are reducing drastically up to 7% of potassium chloride. However, for higher quantity of KCl, it reduces with a low rate. Figure 3 also shows that the rate of decrease in PI is relatively higher in case of Al-Omari et al. [8] than the present study. It may have been attributed to the difference in plasticity of soil used in both the studies. The decrease in shrinkage index with addition of KCl is relatively significant in comparison to the decrease in plasticity index of soil.

Plasticity index of soil indicates a range of water content, over which the soil can uphold its plastic state. After addition of potassium chloride, soil can remain in the plastic state for a narrower range of water content than untreated soil. Frydman et al. [6] and Al-Omari et al. [8] found that the increase in concentration of electrolyte or chemicals has caused the reduction in the thickness of the double layer, which increases the shearing resistance between soil particles. The increase in the shearing resistance between soil particles caused the decrease in the plasticity index and liquid limit [17]. Addition of KCl has changed the classification of soil. As per Unified Soil Classification System and Indian classification system, the untreated soil is classified as clay of intermediate plasticity (CI) and treated soil is classified as clay of low plasticity (CL).



(a) *(b)*

Fig. 3 - Effect of KCl on (a) Plasticity index, (b) Shrinkage index

Compaction parameters

The effect of KCl on dry density and moisture content relationship is shown in Figure 4. Mixing of KCl increases dry density and decreases moisture content of soil. The change is more prominent on the dry side of the optimum than the wet side. This increase in the density and decrease in the water content is observed due to reduction in the thickness of diffuse double layer of water. A similar observation has also been made by Lambe and Whitman [18] and Al-Omari [8].

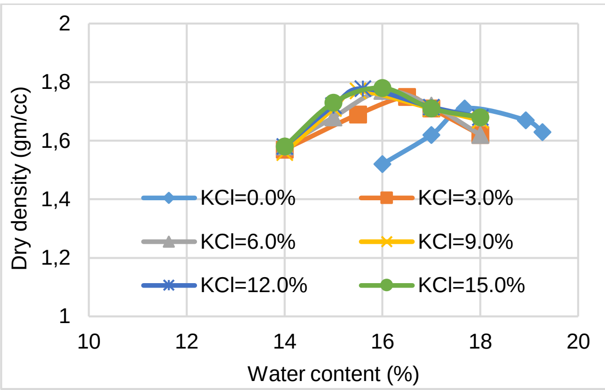


Fig. 4 - Relationship between dry density and water content for various amount of potassium chloride

On the wet side of optimum, there is a very less change in dry density of the soil, this might have attributed to the presence of large amount of water into the soil. Water surplus to the optimum moisture content have probably diluted the ion exchange and agglomeration capacity of KCl leading to increased thickness of double layer of water with subsequent volume expansion and decreased density of the mix.

The variation in maximum dry density and optimum moisture content are shown separately in Figures 5 (a) and (b) respectively. The maximum dry density is increasing up to KCl of 9%, but it started reducing for a higher amount due to absorption of water by surplus KCl added into

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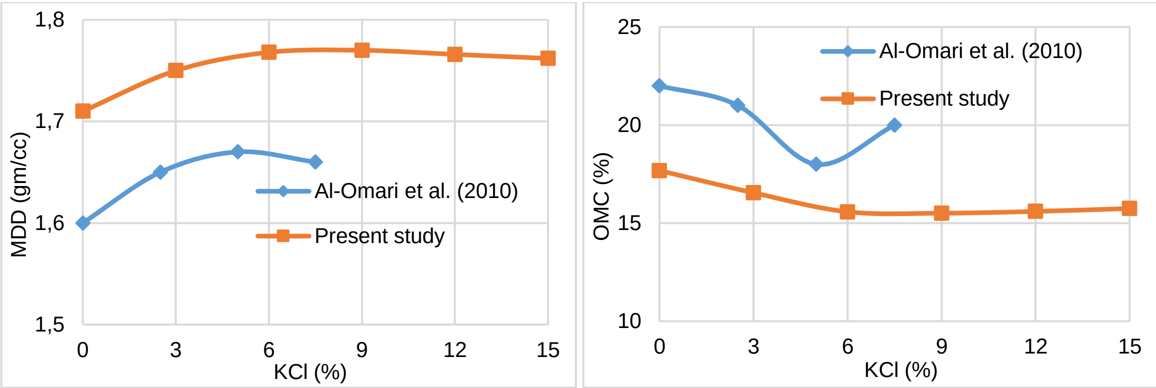
expansive soil. The optimum moisture content is decreasing with the increase in amount of KCl up to 9%. However, further additional of KCl increasing the optimum moisture content of soil by a small amount.



(a) (b)

Fig. 5 - Effect of KCl on compaction parameters of KCl mixed expansive soil (a) Maximum dry density, (b) Optimum moisture content

Unconfined compressive strength

Figure 6 shows that the unconfined compressive strength of expansive soil increasing with the increase in KCl content. But, the effect of KCl reduces, when the amount of added KCl is more than 6%. The addition of KCl more than the optimum amount can develop a repulsive force between soil particles, which leads to loose packing of soil grains [19]. The addition of large amount of KCl also increases the cations in the soil mix, and the additional cations can be responsible for the reverse action, which reduces the maximum dry density and increases the optimum moisture content. Strength of fine-grained soil, especially clay, is significantly dependent on water content. The absorption of moisture by surplus quantity of potassium chloride (more than 6%) could have been contributed to the reduction in the unconfined compressive strength of soil [6].

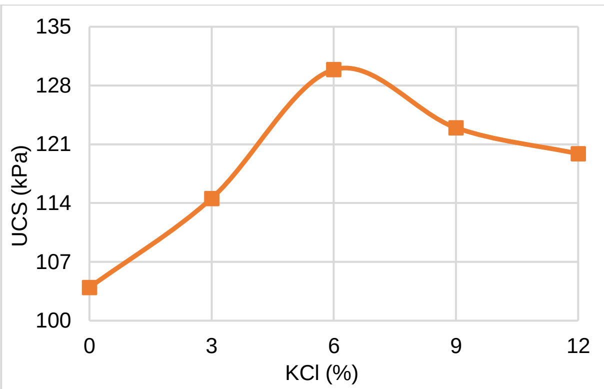


Fig. 6 - Effect of KCl on unconfined compressive strength of expansive soil

Soil expansivity

Figure 7 shows the variation in the swell potential of soil with potassium chloride contents. The swell potential is reducing significantly with the increase in KCL content up to 9% and any

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further addition of the same showed negligible influence. Untreated soil has swelling potential 8.1%, which indicates that the soil have medium swell potential [21]. Addition of KCl reduces the swelling potential of soil from medium (8.1%) to low (2.6%).

Soil expansivity can be predicted based on various empirical relations developed by number of researchers. Soil has liquid limit of 43%, and as per IS 1498, it has high or medium degree of expansion. Based classification of Chen 1975, soil can also be classified as soil with high degree of expansion. Based on plasticity index (PI=19%), soil possess medium degree of expansion. As per classification of Holtz and Gibbs [16] and IS 1498-1970 [20], for evaluated shrinkage limit and shrinkage index, the soil has high degree of expansion. So, the empirical formulae also predict the soil expansivity from medium to high.

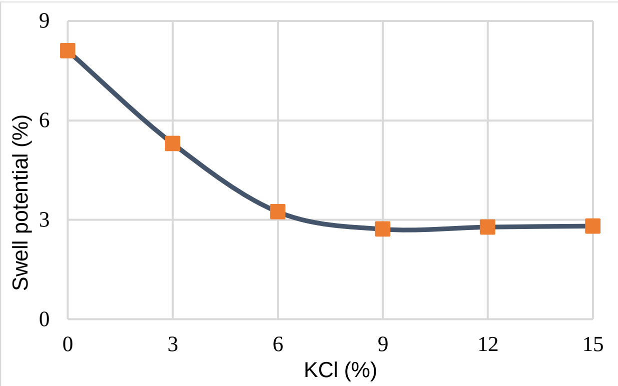

Fig. 7 - Effect of KCl on swell potential of soil

Frydman et al. [6], Al-Ashou and Al-Khashab [19] and Al-Omari et al.[8] found optimum content of KCl to be 5.5%, 6% and 5% respectively. From the Figures 2-8 and discussion on the results, the optimum content of KCl is found to be approximately 6-8%, which is significantly higher than the earlier studies. This difference might be observed due to the differences in soil characteristics used in the present study and the earlier studies. The difference in optimum content of KCl with the previous studies shows that the optimum quantity of KCl increases with the decrease in the plasticity of soil which is most probably a result of mineralogical change in the soil. The results of present study also indicates that the soil-KCl skeleton had formed well in case of earlier studies of Frydman et al.[6], Al-Ashou and Al-Khashab [19], Al-Omari et al. [8], where the soils of high plasticity were used.

CONCLUSIONS

Potassium chloride altered the soil property significantly and most of changes in the soil properties are favourable. Though, the liquid limit, plasticity index, shrinkage index, optimum moisture content and swelling potential are reducing with mixing KCl into the soil. However, the reduction is very significant in swell potential and shrinkage index of expansive soil. Plastic limit, shrinkage limit, unconfined compressive strength and maximum dry density improved with addition of KCl. KCl is more competent in improving the swelling characteristic of soil than the strength characteristics of soil. KCl mixed expansive soil can maintain its strength and volume constant even at higher water content. Optimum amount of potassium chloride depends upon the properties of soil, and the present study found it to varying between 6 to 8%, which is higher than the values suggested in earlier studies. The efficiency of KCl depends on the plasticity of soil. KCl is relatively more effective for highly plastic soil. The optimum amount of KCl increases with the decrease in the plasticity of soil.

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