Evaluating the Influence of Montmorillonite Content on Swelling Behaviour in Relation to Its Plasticity

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1 Introduction

It is forced to utilize the available land irrespective of its type due to the rapid growth of cities since a decade. Expansive soils are one among them, which pose a severe threat to the infrastructure constructed over it with their swell/shrink behaviour during changes of seasons. In India, approximately 20% of the available land is covered with expansive soils. It reflects that most of the constructible areas may encounter this kind of soil, especially near water bodies. Expansive soils comprise clay content as a major portion. It comprises different minerals, among which montmorillonite is the prime triggering factor behind the plasticity and swelling behaviour. Free swell index (FSI) is an easy method to identify the swelling behaviour of expansive soils [1]. Employing it, Sivapullaiah et al. [2] introduced a modified free swell index for determining swelling behaviour. Further, Prakash and Sridharan [3] investigated the swelling behaviour of expansive soils using FSI. On the other hand, Holtz and Kovacs [4], Mitchell [5], and Skempton [6] predicted swelling behaviour indirectly from plasticity and other parameters of clay soils. Studies also reported that the consolidation apparatus can be employed for the estimation of swell potential in expansive soils [7–10]. However, it is a time-consuming process and not possible to judge the dominant mineral behind the swelling behaviour.

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It is evident from the literature that understanding the clay minerals is essential to evaluate the swelling behaviour of expansive soils. In this context, Mitchell and Soga [11] also stated that mineral type plays a vital role in the swelling behaviour and it can be determined by subjecting the soil sample to X-ray diffraction (XRD) analysis. Tahasildar et al. [12] measured the MMC and swelling behaviour from consolidation and reported a linear relationship between these two parameters. In a similar line, Reddy et al. [13] experimented with several expansive soils and measured MMC in clay content and swelling potential from FSI. The results revealed a linear relationship between these parameters. Most of the studies available in the past literature are confined to the establishment of a relationship randomly between MMC (i.e. in clay content/whole soil) and swelling potential (i.e. from FSI/Consolidation). But, very minimal attempts were made to study MMC of expansive soil and swelling behaviour from FSI, in relation to the plastic behaviour. In order to address the same, the current study intends to study the influence of montmorillonite content alone on the swelling behaviour from FSI in relation to the plasticity of expansive soils. In order to avoid problems due to volume change behaviour, it is essential to investigate the mineral behind it. It will give an idea for the selection of materials to arrest or reduce the heaving of soil under different environmental conditions.

2 Materials and Methods

Expansive soils of approximately 36 numbers have been collected from different locations across India (Bhopal, Guntur, Kendrapara, Warangal, Vijayawada, Kakinada, Mysore, Raipur, and Nagpur), which is at a depth of 1 m from the ground level by following the guidelines of ASTM A1452 [14]. The soil samples and their corresponding designations used in the study are listed in Table 1. The topsoil has been discarded to avoid foreign materials in the test samples. Soil samples were dried, pulverized, and downsized to the specific requirement of different tests adopted. Further, the physical properties of all the soil samples were determined, and their corresponding values can be found in Rao et al. [7]. The swelling behaviour of the soil samples was determined by employing the free swell index (FSI) in line with the guidelines of IS 2720 (Part-40) [1], and the values can be found in the work carried by Reddy et al. [7]. The mineralogical contents of expansive soils were determined by subjecting the dry powdered samples to X-ray diffraction followed by quantification of minerals using the software TOPAS 4.2. The detailed procedure related to the quantification and their corresponding values can be found in Rao et al. [9].

Table 1 Region and designations of soil samples used in the current study

Region	Sample ID	Region	Sample ID	Region	Sample ID
Bhopal	B1	Vijayawada	V1	Nagpur	N1
	B2		V5		N2
	B3		V6		N3
	B4		V7		N4
Guntur	G1	Kendrapa	KP1		N5
	G2		KP2		N6
	G4		KP3		N7
	G6		KP4		N8
	G7		KP5	Raipur	R1
Kakinada	K1		KP6		R2
	K2	Warangal	W1		R3
	K3		W2		
Mysore	M1		W3		

3 Results and Discussion

From the obtained test results, a plasticity chart indicating the relationship between liquid limit (LL) and plasticity index (PI) to classify the expansive soils used in the current study as depicted in Fig. 1. From the figure, it can be observed that almost all the soils possess an LL value of > 50% except very few. It indicates that most of the soils possess high compressibility, which is an indirect indication of the presence of swelling minerals, i.e. MMC. Certifying it, many researchers attributed higher plasticity values to the presence of MMC only [4, 9, 12, 13, 15].

Although researchers employed consistency limits as indirect indicators and prediction of swelling behaviour, direct determination offers better accuracy as they are of two different techniques. FSI is an easy and direct technique, which is used to measure the swelling behaviour of expansive soils. The typical photograph of FSI during the test can be seen in Fig. 2. In this context, a relationship is established between MMC and FSI in relation to the plasticity behaviour and depicted in Figs. 3 and 4. From Fig. 3, it can be observed that the swelling increased linearly with MMC up to 85%, irrespective of soil location for CH. The maximum FSI value of 105% is observed with an MMC of 54.58%. In a similar line, Reddy et al. [13] also reported an increment in FSI with the increment of montmorillonite content in clay content. This is due to the fact that the availability of MMC enhances the thickness of the diffuse double layer, in turn, which reflects as swelling. In addition, the pertinent data are collected from the literature and superimposed over the present study. Interestingly, the plotted relationship is in good agreement with the past literature data revealing its authenticity. Supporting this, observations made in the current study are in line with Tahasildar et al. [12] who investigated the influence of MMC on swelling behaviour.

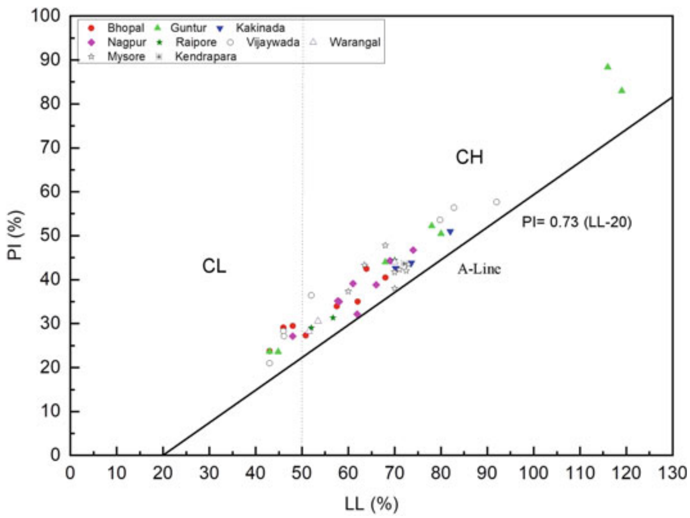

Fig. 1 Plasticity chart classifying the expansive soils used in the study

Fig. 2 Free swell index of different soil samples

In the case of Fig. 4, i.e. CL soils, mimicking the behaviour of CH, the trend increased linearly with MMC. The maximum FSI value of 84% is observed with an MMC of 56.34%. However, significant scatter can be observed. It is due to the marginal variation of MMC with respect to other soil samples. It conveys a fact that

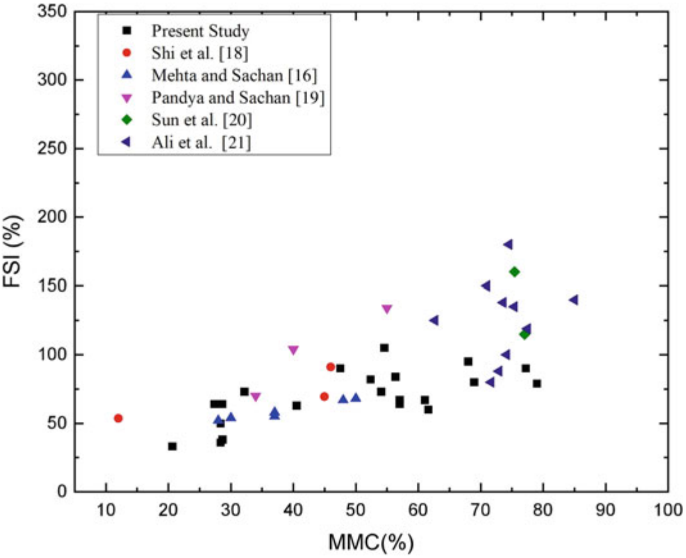

Fig. 3 Variation of FSI with MMC of CH soils

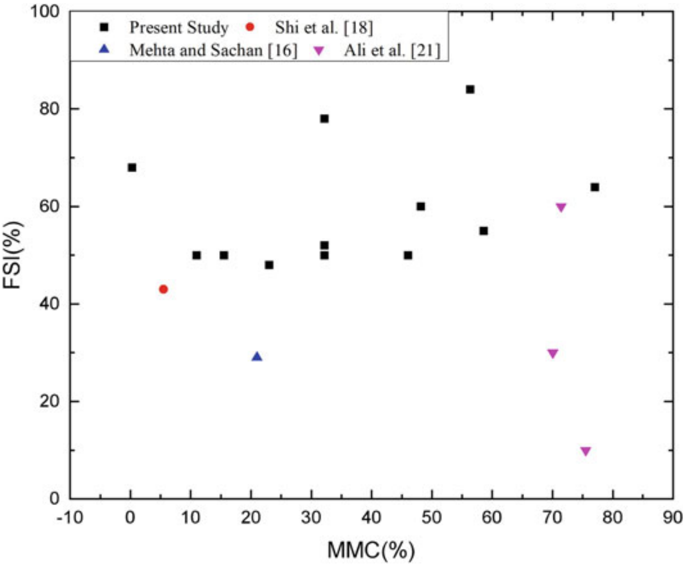

Fig. 4 Variation of FSI with MMC of CL soils used in the study

may not remain the same with the locations of soil samples, and so does the variation, which indicates its priority. Interestingly in both Figs. 3 and 4, two different swelling values can be observed with similar MMC. This is due to the fact that soil does comprise another mineral either may be alone or in a mixed form that can have a significant impact on the swelling behaviour. In this context, Tahasildar et al. [12] and Mehta and Sachan [16] reported that montmorillonite-based mixed minerals can influence the swelling behaviour of expansive soils. The close observation of corresponding MMC of maximum FSI values, later one is greater, but less swelling of 84% only. This is attributed to the presence and influence of the non-swelling mineral kaolinite. It is in confirmation with the studies of Sridharan et al. [17] who reported negative swelling with the presence of kaolinite mineral.

Overall, it can be inferred from the above that the MMC may not remain the same location and have a direct impact on the swelling behaviour of expansive soils. In order to have a safe construction over expansive soils, consideration of mineralogy in addition to swelling behaviour offers better accuracy.

4 Future Scope and Limitations

It is evident from the current study and past literature that the swelling behaviour of expansive soils is controlled by the constituent minerals. Interestingly, two different values of FSI can be observed with the same MMC, which indicates that there is an interference of other minerals, i.e. mixed minerals. Along with individual minerals, soils do comprise montmorillonite-based mixed minerals that can have a significant impact on the swelling behaviour. Identification of these mixed minerals can offer better accuracy in swelling determination. However, their determination is a little tedious task due to the availability of the necessary facilities.

5 Conclusions

In the current study, the influence of MMC on swelling behaviour measured from FSI in relation to the plasticity of expansive soils is evaluated. For achieving the same, expansive soils are collected from different parts of India and are subjected to extensive experimental investigation. From the results obtained, the following conclusions are derived.

(1) The expansive soils used in the current study are falling in the category of CH and CL, which comprise MMC in the range of 0–79%. The MMC contents varied with the location, and so does the swelling behaviour.

(2) The maximum FSI value of 105 and 84% is obtained for MMC of 54.58 and 56.34% for CH and CL soils, respectively. The general trend revealed that the FSI increased linearly with an MMC of up to 85% in the case of CH. Similar trends have been followed in the case of CL also but with significant scatter.
(3) Although with similar MMC, two different FSI values are measured both in CH and CL soils, which is due to the presence of montmorillonite-based mixed minerals.

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