Classification procedures for expansive soils

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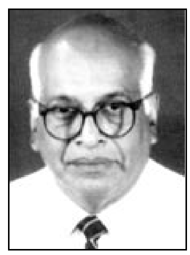

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Most of the national codes of practice do not give characterization and classification of expansive soils, in spite of expansive soils being distributed very widely over almost all geographical locations in the world, causing distress to the structures founded on them and discomfort to the users. A simple user-friendly approach based on the free swell ratio, defined as the ratio of the sediment volume of soil in distilled water to that in carbon tetrachloride or kerosene, is formulated considering the compatibility of the results with oedometer free swell tests and the soil clay mineralogy. Statistical illustrations are provided which clearly indicate that while the assessment of soil expansivity based on index properties is an overestimation, there is a consistency in the classifications based on oedometer test results and the proposed approach. It is recommended that simple approaches such as the one proposed here to classify the expansive nature of soils are entered into standard codes of practice.

Keywords: geotechnical engineering

Introduction

A soil classification is a systematic method of categorizing soils into various groups and subgroups according to their probable engineering behaviour but without detailed descriptions. Most of the earlier classification systems were based on grain size distribution (e.g. MIT classification) and soil texture (e.g. textural classification). However, with the introduction of Atterberg limits, new classification systems have come into existence.

2. It is possible to trace many soil classification systems such as the Casagrande unified soil classification system (USCS), the American Association of State Highway and Transportation Officials (AASHTO) system, the pedologic soil classification system, Federal Aviation Agency (FAA) system, US public roads administration (PRA) system, and the textural classification system. Currently, the USCS and the AASHTO system are in use in civil engineering practice.

3. The USCS was originally developed by Casagrande[1] and was later modified by the US Bureau of Reclamation (USBR) and the US Army Corps of Engineers, to enhance its applicability to many more fields. Many national standard codes of practice such as ASTM designation D2487-93,[2] BS 5930[3] and IS 1498[4] follow this modified version of the USCS as it stands or with slight modification.

4. Both systems, namely modified USCS and AASHTO, base their classification of soils for engineering purposes on particle size characteristics, liquid limit (w_L) and plasticity index (I_p) of soils. The subgrouping of coarse-grained soils is done with the help of parameters such as uniformity coefficient (C_u) and coefficient of curvature (C_c) to account for the gradation of soils. The subgrouping of fine-grained soils is entirely based on a plasticity chart (i.e. I_p plotted against w_L). In addition, some codes of practice give some useful criteria that need to be followed to obtain a rough estimation of soil characteristics such as angularity (of coarse-grained soils), moisture content, consistency, cementation, dry strength, plasticity, dilatancy, toughness, organic content (e.g. ASTM designation D2488-93,[5] IS 1498[4]). However, apart from IS 1498,[4] these systems do not have the criteria to assess the expansivity of the soil.

Soil expansivity

5. Expansive soils are found extensively in tropical areas. The presence of expansive soils greatly affects the construction activities in many parts of south-western United States, South America, Canada, Africa, Australia, Europe, India, China and the Middle East.[6] More and more expansive soil regions are being discovered each year with an increase in the amount of constructional activities, particularly in the underdeveloped nations. These soils are characterized by the presence of a large proportion of highly active clay minerals of the montmorillonite group which are responsible for the pronounced volume change capability of the soils. A number of soils such as volcanic ash soils[7] and diatomaceous earth[8] cannot be grouped by using the existing classification system only; however, their distribution is restricted to certain areas. Unlike these, the expansive soils are distributed geographically very widely, covering large areas. Hence, identification and classification of such soils is essential.

6. Many criteria are available to identify and characterize expansive soils, such as liquid limit (Table 1), plasticity index (Table 2), shrinkage limit (Table 3), shrinkage index

Table 1. Soil expansivity prediction by liquid limit

Degree of expansion	w_L: %	
	Chen[6]	IS 1498[4]
Low	< 30	20–35
Medium	30–40	35–50
High	40–60	50–70
Very high	> 60	70–90

Table 2. Soil expansivity predicted by plasticity index

Degree of expansion	I_p: %		
	Holtz and Gibbs[10]	Chen[6]	IS 1498[4]
Low	< 20	0–15	< 12
Medium	12–34	10–35	12–23
High	23–45	20–55	23–32
Very high	> 32	> 35	> 32

(Table 3), free swell index (FSI) (Table 3), activity and per cent free swell.[4,9–14]

7. Chen[6] observed that there was no conclusive evidence of the correlation between swelling potential and shrinkage limit. Sridharan and Prakash[15] have also shown that the shrinkage limit can not be satisfactorily used to predict the swell potential of a soil and that the mechanisms governing the shrinkage and swelling are entirely different.

8. Holtz and Gibbs[10] proposed the per cent free swell test. It consists of pouring slowly 10 cm^3 of oven dried soil (passing a 425 μm sieve) into a 100 cm^3 measuring jar filled with distilled water and noting the volume of the soil after it comes to rest at the bottom of the jar. The free swell is then reported as the increase in the volume of the soil expressed as a percentage of the initial volume. The major drawback of this method, which is crude,[6] is that measuring 10 cm^3 of soil is not that easy and the procedure therefore introduces personal judgement as one more factor. It is normal to quantify 10 cm^3 as the volume occupied by 10 g of soil. This does not account for variations of density.

9. IS 1498[4] gives a criterion to predict the expansivity of soils, based on the free swell index.[16]

$$\mathrm{FSI} = \frac{(V_d - V_k)}{V_k} \times 100 \tag{1}$$

where V_d is the sediment volume of 10 g of oven dried soil passing a 425 μm sieve placed in a 100 ml graduated measuring jar containing distilled water, and V_k is the sediment volume of 10 g of oven dried soil passing a 425 μm sieve placed in a 100 ml graduated measuring jar containing kerosene.

10. However, this method gives negative free swell indices for kaolinite-rich soils and may underestimate the expansivity of montmorillonitic soils, if the soils contain a significant amount of kaolinite clay material. To eliminate this difficulty, Sridharan *et al.*[17] have defined the modified free swell index (MFSI) as the ratio of equilibrium sediment volume (V_d) after 10 g of oven dried soil is mixed thoroughly with the distilled water to form a soil–water suspension of 100 ml initial volume in a 100 ml measuring jar and allowed to settle, to the dry weight of the soil. Thus

$$\mathrm{MFSI} = \frac{V_d}{10} \tag{2}$$

11. Sridharan *et al.*[18] have observed that the sediment volume occupied by unit weight of dry soil in distilled water together with that in carbon tetrachloride provides useful information about the soil expansivity and nature of the soil type—expansive/non-expansive/combination of both (Table 4).

12. The predictive capability of the MFSI is evident from the following statistical illustrations. About 32 soils from various parts of India, 16 of them kaolinitic ($25\% \leqslant w_L \leqslant 100\%$) and the remaining 16 montmorillonitic ($47\% \leqslant w_L \leqslant 124\%$), were considered for the analysis (data from Sridharan *et al.*[19,20]). These soils are placed on the plasticity chart as shown in Fig. 1. It can be noted that both the kaolinitic

Table 3. Soil expansivity predicted by other measures

Degree of expansion	Colloid content[10]: % minus 0·001 mm	Shrinkage limit[10]: %	Shrinkage index[4]: %	Free swell index[4]: %	Per cent expansion in oedometer* as per Holtz and Gibbs[10]	Per cent expansion in oedometer† as per Seed *et al.*[12]
Low	< 17	> 13	< 15	< 50	< 10	0–1·5
Medium	12–27	8–18	15–30	50–100	10–20	1·5–5·0
High	18–37	6–12	30–60	100–200	20–30	5–25
Very high	> 27	< 10	> 60	> 200	> 30	> 25

* From dry to saturated condition under a surchare of 7 kPa.
† From compacted, saturated condition under a surcharge of 7 kPa.
Note: Shrinkage index = (plastic limit − shrinkage limit).

Table 4. Soil expansivity classification based on MFSI[18]

MFSI: cm^3/g	Sediment volume in carbon tetrachloride: cm^3/g	Clay type	Soil expansivity
<1·5	1·10–3·00	Non-swelling	Negligible
1·5–2·0	>1·1 and <MFSI	Mixture of swelling and non-swelling	Low
1·5–2·0	⩽1·1	Swelling	Moderate
2·0–4·0	⩽1·1	Swelling	High
>4·0	⩽1·1	Swelling	Very High

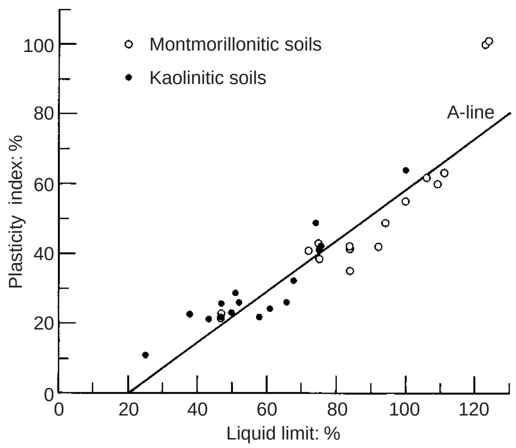

Fig. 1. Position of the soils analysed on the plasticity chart

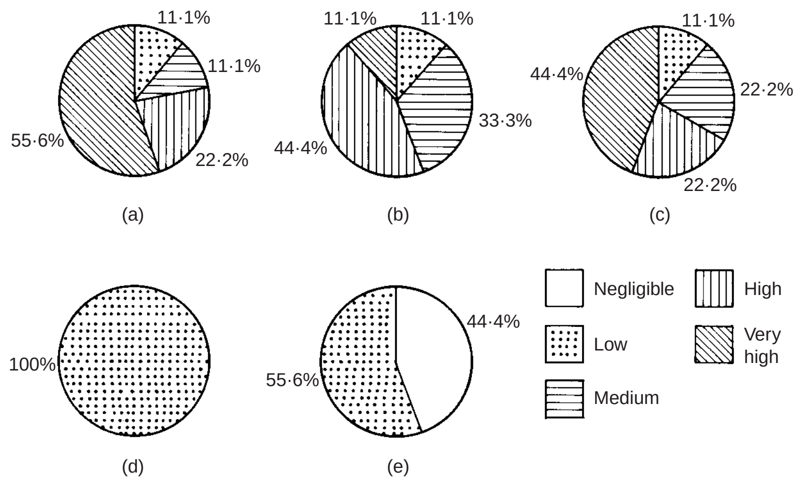

Fig. 2. Prediction of soil expansivity of kaolinitic soils by: (a) liquid limit; (b) plasticity index; (c) activity; (d) oedometer test; and (e) MFSI

and montmorillonitic soils lie above and below the A-line. Hence, nothing can be inferred regarding their expansive nature just by their position on the plasticity chart.

Analysis—phase 1

13. In the first phase of analysis, 18 soils[19] (nine kaolinitic and nine montmorillonitic) are considered. The degree of expansivity of these soils has been assessed based on their liquid limit,[6] plasticity index, activity,[14] percentage swell in the oedometer test[10] and MFSI according to Table 4. Winterkorn and Fang[21] and Chen[6] suggest that the most useful and reliable assessment of swelling capabilities for expansive soils can be obtained from conventional oedometer tests. According to USBR,[10] the criterion for expansiveness of a soil is the total volume change of a soil from air dry to a saturated condition under a surcharge of 7 kPa, in an oedometer. Hence, the results obtained from oedometer swell tests conducted on air dry soils assessed as per Table 3 are taken as a reference point.

14. Figure 2 shows the comparison of such an assessment for kaolinitic soils. While the oedometer tests assign a low degree of expansivity for those soils true to their mineralogy (note that kaolinite is a non-expansive clay mineral), the criteria based on liquid limit, plasticity index and activity show a large percentage of the non-expansive soils to have a low to very high degree of expansivity. Plasticity index, activity and liquid limit predict a high to very high degree of expansivity in about 55·5, 66·6 and 77·8% of cases respectively. However, the evaluations based on the MFSI given in Table 4 are in better agreement with those from the oedometer tests.

15. Figure 3 illustrates the comparison of the evaluation of the degree of expansivity of montmorillonitic soils by the different criteria. It can be noted that liquid limit, plasticity index and activity greatly overestimate the soil expansivity in comparison with those observed in oedometer tests. As Chen[6] quotes, while it may be true that a high-swelling soil will manifest a high index property, the converse need not be true. On the other hand, the

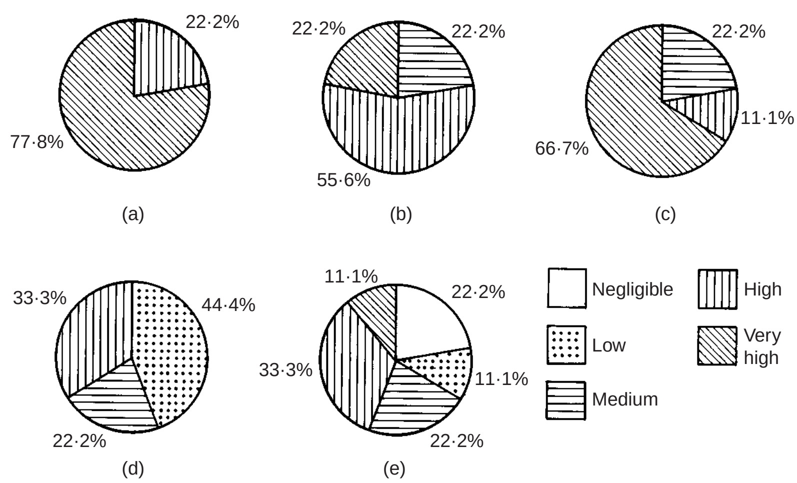

Fig. 3. Prediction of soil expansivity of montmorillonitic soils by: (a) liquid limit; (b) plasticity index; (c) activity; (d) oedometer test; and (e) MFSI

Table 5. Proposed expansive soil classification

Oedometer per cent expansion*	Free swell ratio	Clay type	Soil expansivity
<1	⩽1·0	Non-swelling	Negligible
1–5	1·0–1·5	Mixture of swelling and non-swelling	Low
5–15	1·5–2·0	Swelling	Moderate
15–25	2·0–4·0	Swelling	High
>25	>4·0	Swelling	Very high

*From air dry to saturated condition under a surcharge of 7 kPA.

predictions of soil expansivity based on the proposed MFSI are again quite satisfactory.

16. It is not untimely to mention that the mechanisms controlling the liquid limit of kaolinitic and montmorillonitic soils are entirely different from each other. While the liquid limit of a kaolinitic soil is controlled by the particle arrangement and the interparticle attractive forces, that of a montmorillonitic soil is controlled by the double layer thickness.[20,22] Hence, higher liquid limits do not necessarily mean expansive montmorillonitic soils. This is the reason why the liquid limit and the related index properties, without any consideration of clay mineralogy, cannot satisfactorily indicate the soil expansivity. Instead, they may give an altogether different and wrong picture.

17. It has been observed by the authors that there are instances wherein the values of sediment volumes, obtained from free swell tests, in water and carbon tetrachloride do not fall into any of the categories listed in Table 5, thus resulting in ambiguity. This limitation can be avoided by the use of the ratio of equilibrium sediment volume of 10 g oven dried soil passing a 425 μm sieve in distilled water to that in carbon tetrachloride, which is defined herein as 'free swell ratio'. It is the authors' experience that while dealing with the Indian black cotton soils, the expansion predictions by the oedometer test proposed by Holtz and Gibbs[10] are slightly underestimated. With this experience, considering the clay mineralogy of the soils, the authors propose a criterion for classifying the soils based on their expansive nature as shown in Table 5.

18. Figure 4 indicates the statistical predictions of soil expansivity of 18 soils, considered in the first phase of the analysis, by the proposed classification based on expansion from oedometer tests and free swell ratio. It can be observed that the predictions based on the two methods proposed match very well and also that the predictions based on the proposed free swell ratio (i.e. Fig. 4) are in line with those from the consideration of Table 4 (i.e. Figs 2 and 3).

Analysis—phase 2

19. Seed *et al.*[12] have also proposed an expansivity classification based on per cent swelling potential observed by compacted soils at maximum dry density and optimum moisture content conditions, under a surcharge of 7 kPa (Table 3). In order to prove the enhanced capability of the proposed free swell ratio in classifying the soils, the second phase of analysis is done as follows.

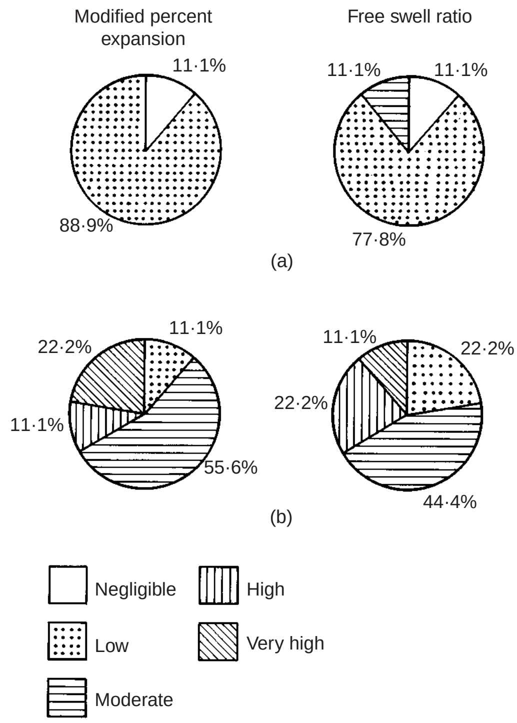

Fig. 4. Prediction of soil expansivity by proposed oedometer per cent expansion and free swell ratio criteria for: (a) kaolinitic soils; and (b) montmorillonitic soils

20. Fourteen soils,[23] seven kaolinitic and seven montmorillonitic, compacted at standard Proctor's maximum dry density and optimum moisture conditions, were allowed to swell under a surcharge of 7 kPa. Using the criteria of Seed *et al.*[12] and that based on the proposed free swell ratio, the 14 soils are classified with respect to their expansive nature; the results are shown in Fig. 5. A very good correlation is observed between the predictions from two entirely different testing procedures which indicates the acceptability of the free swell ratio for predicting the soil expansivity.

21. The determination of sediment volume of highly expansive soils in distilled water can be problematic, as such soils take a prohibitively long time to settle. This difficulty can be

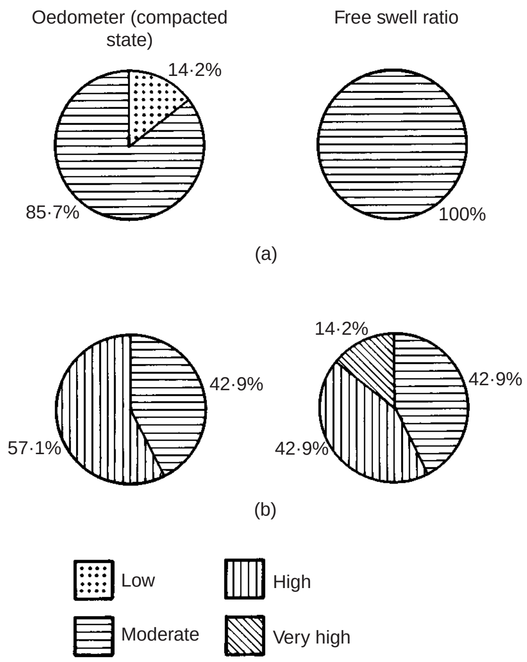

Fig. 5. Prediction of soil expansivity of soils from the data of soils compacted at optimum conditions and from free swell ratio for: (a) kaolinitic soils; and (b) montmorillonitic soils

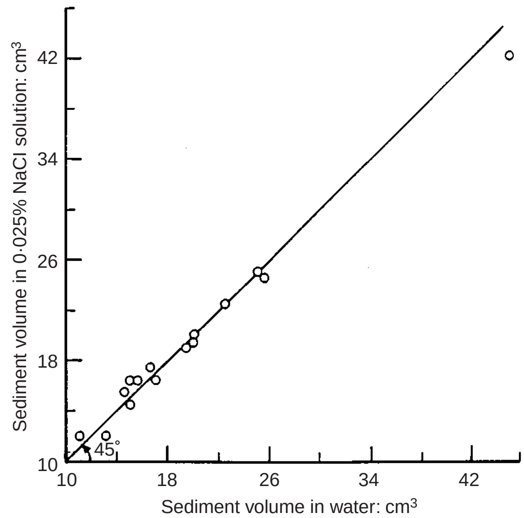

Fig. 6. Comparison of equilibrium sediment volumes in 0·025% NaCl solution with those in distilled water[23]

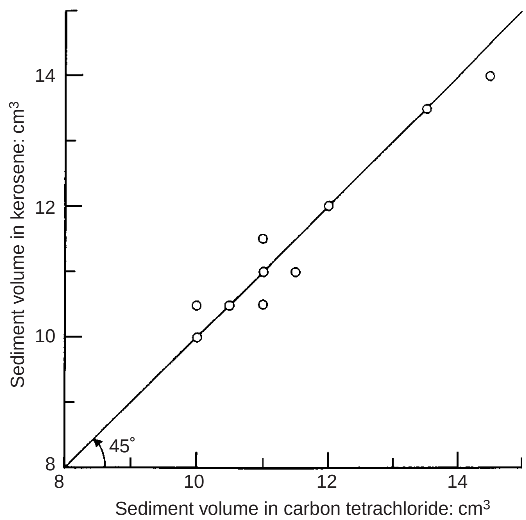

Fig. 7. Comparison of equilibrium sediment volumes in kerosene with those in carbon tetrachloride[23]

overcome by using 0·025% NaCl solution instead of distilled water, which reduces the settling time markedly without affecting the final equilibrium sediment volume (Fig. 6). It has been observed[23] that the soils have taken about 24–216 h to reach equilibrium in water depending upon the type of soil. However, the same soils took about 4–24 h to reach the equilibrium in 0·025% NaCl solution. Likewise, kerosene is a more easily available, cheaper non-polar liquid which is relatively less volatile than carbon tetrachloride. The equilibrium sediment volumes obtained in these two liquids are almost the same (Fig. 7), with a maximum error of $\pm 5\%$. Hence, use of kerosene instead of carbon tetrachloride is suggested, owing to its greater accessibility.

Conclusions

22. The previously described analysis has clearly indicated that the index properties such as liquid limit, plasticity index and related parameters cannot satisfactorily predict the soil expansivity, as they do not consider the effect of clay mineralogy. The free swell ratio approach, in addition to predicting the soil expansivity more realistically and satisfactorily, gives additional information about the nature of the clay mineralogy of soils.

23. The free swell index test discussed in this paper involves a very simple, user-friendly testing procedure, requiring negligible instrumental sophistication. The test results in the form of free swell ratio proposed can be used to obtain quite reliable information about the degree of soil expansivity and about the soil type (Table 5). As the sediment volumes in the non-polar liquids carbon tetrachloride and kerosene are almost equal, the applicability of the test can be further enhanced by using commonly available kerosene in place of carbon tetrachloride. The authors feel that the inclusion of such a simple test to evaluate the expansive nature of the soils in standard codes of practice of various national organizations would be useful.

References

1. Casagrande A. Classification and identification of soils. *Transactions of ASCE*, 1948, **113**, 901–992.
2. American Society for Testing and Materials. *Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System).* ASTM Designation D2487-93. Annual Book of ASTM standards, 1995, West Conshohocken, **4.08**.
3. British Standards Institution. *British Code of*

Practice for Site Investigations. BSI, London, 1981, BS 5930.
4. Bureau of Indian Standards. *Indian Standard Classification and Identification of Soils for General Engineering Purposes*. BIS, New Delhi, 1970, (Reaffirmed 1987), IS 1498.
5. American Society for Testing and Materials. *Standard Practice for Description and Identification of Soils (Visual–Manual Procedure)*. ASTM Designation D 2488-93. Annual Book of ASTM standards, 1995, West Conshohocken, **4.08**.
6. Chen F. H. *Foundations on Expansive Soils*. Elsevier, Amsterdam, 1975.
7. Suzulki A. and Kitazono Y. Engineering classification of volcanic cohesive soils. In *Report on Volcanic Ash Soils in Japan: Properties and Practical Use*. 1998, pp. 39–43.
8. Nagaraj T. S., Onitsuka K., Tateishi Y. and Hong Z. Is diatom earth a collapsible material? *Proceedings of the International Symposium on Problematic Soils*, Sendai, Japan, 1998, vol. 1, 257–260.
9. Altmeyer W. T. Discussion on engineering properties of expansive soils. *Transactions of ASCE*, 1956, **121**, 666–669.
10. Holtz W. G. and Gibbs H. J. Engineering properties of expansive clays. *Transactions of ASCE*, 1956, **121**, 641–663.
11. Head K. H. *Manual of Soil Laboratory Testing, Vol. 1: Soil Classification and Compaction Tests*. Pentech Press, London, 1992.
12. Seed H. B., Woodward R. J. and Lundgren R. Prediction of swelling potential for compacted clays. *Journal of the Soil Mechanics and Foundations Division, ASCE*, 1962, **88**, No. SM3, 53–87.
13. United States Bureau of Reclamation. *Earth Manual*. USBR, Federal center, Denver, 1973.
14. Van Der Merve D. H. The prediction of heave from plasticity index and the percentage clay fraction of the soils. *The Civil Engineer, South African Institution of Civil Engineers*, 1984, **6**, 103–107.
15. Sridharan A. and Prakash K. Mechanism controlling the shrinkage limit of soils. *Geotechnical Testing Journal, ASTM*, 1998, **21**, No. 3, 240–250.
16. Bureau of Indian Standards. *Indian Standards Method of Test for Soils*. BIS, New Delhi, 1977, IS 2720: Part 40.
17. Sridharan A., Rao S. M. and Murthy N. S. Free swell index of soils: A need for redefinition. *Indian Geotechnical Journal*, 1985, **15**, 94–99.
18. Sridharan A., Rao S. M. and Murthy N. S. A rapid method to identify clay type in soils by the free-swell technique. *Geotechnical Testing Journal, ASTM*, 1986, **9**, No. 4, 193–203.
19. Sridharan A. and Rao S. M. A scientific basis for the use of index tests in identification of expansive soils. *Geotechnical Testing Journal, ASTM*, 1988, **11**, No. 3, 208–212.
20. Sridharan A., Rao S. M. and Murthy N. S. Liquid limit of montmorillonite soils. *Geotechnical Testing Journal, ASTM*, 1986, **9**, No. 3, 156–159.
21. Winterkorn H. F and Fang H. Y. Soil technology and engineering properties of soils. In *Foundation Engineering Hand Book*. Galgotia Book Source, New Delhi, 1986.
22. Sridharan A., Rao S. M. and Murthy N. S. Liquid limit of kaolinitic soils. *Géotechnique*, 1988, **38**, No. 2, 191–198.
23. Sridharan A., Rao S. M. and Joshi S. Classification of expansive soils by sediment volume method. *Geotechnical Testing Journal, ASTM*, 1990, **13**, No. 4, 375–380.

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