Discussions

Free—Swell Index of Soils : A Need for Redefinition

by

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The authors have made out a case for redefining the free swell index which also entails making certain changes in the procedure stipulated in IS : 2720 (Part XL)—1977 for its determination.

Before discussing the merits or otherwise of the authors' definition and the test procedure proposed by them, the writers wish to review the origin of this test and its utility.

The free-swell index was defined by Holtz and Gibbs (1954) and was incorporated in the USBR test procedures. The test consists of sedimenting 10ml of loose dry soil passing No. 40 seive in a 100ml jar of water and observing the volume occupied. The free swell index is defined as the ratio of increase in volume to initial volume expressed as a percentage. The test was proposed merely to aid the identification of expansive soil and as early as 1956, Holtz and Gibbs in their reply to discussion by Dawson agreed with Dawson's comments (Dawson, 1956) that "the Atterberg limits are more reliable indicators of expansive characteristics than the free-swell test, and they wish to point out that the free-swell tests are considered applicable only for indicating general trends by a simple procedure".

A review of later literature (Chen, 1975) indicates that the test is crude and is of limited utility in identifying swelling soilds or predicting their swelling potential. As late as 1974, Gromko stated that the free-swell test could be used for predicting insitu heave but unfortunately no method for doing so was presented by him. Perhaps better yardsticks for identification of swelling soils would be X-ray diffraction, defferential thermal analysis, swelling potential test, Atterberg limits, linear shrinkage and colloidal content of the soil.

It should however be borne in mind that the latter feature (viz. colloid content) is important since it has been observed that presence of active clay minerals need not always result in a soil being expansive. Dudley (1970), Holtz (1059) and USBR (1974. vide Holtz and Kovacs, 1981) have observed that a colloid content of less than 15 per cent, renders the soil as one of low expansiveness. Bull (1964, vide Clemence and Finnbary, 1981) observed that maximum subsidence occurs when the clay amounts to about 12 per

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cent of the solids. Below 5 per cent there is little subsidence and above 30 per cent the clay swells. The type of the clay mineral does not, however, figure in Bull's observation.

It is perhaps not out of place to state here that what perturbs a practising engineer is the insitu heave feasible and not the free-swell index or the laboratory determination of swelling potential. However this simple test (free swell test) can have another application also.

The free-swell index as defined by Holtz and Gibbs (1954) and also defined by the IS : 2720 (Part XL)—1977 can logically result in negative values. Past workers have not paid much attention to this feature and its implications.

It has been reported by Lambe and Whitman (1969) that the same weight of soil particles can occupy different sediment volumes depending upon the electrolyte concentration, dielectric constant, type of cation and anion, valency and also temperature. Sediment volumes were predicted to increase with electrolyte concentratations, temperature, ion valency and decrease with pH and dielectric constant. The types of clay minerals present in the sediment were not considered, and for this reason it is not feasible to generalise their prediction.

Olson and Mesri (1970) reported that the equilibrium void ratio at a pressure of 100 psf (4.8 kPa) was more in air than in water for kaolinite and muscovite and the reverse was true in case of illite and smectite. The swelling index for all the clays is more in water than in air. Fluids like ethyl alcohol and carbon tetrachloride yielded values lying between those for water and air for both mineral groups.

The IS test procedure yields such a trend for kaolinite. The authors report a higher sediment value in kerosene (which is comparable with carbon terachloride) than in water. A negative free-swell index is obtained. If instead of the sediment volume in kerosene, the volume of kaolinite in air was taken as the datum a more negative value for the free-swell index should result. In other words, the other procedure (Holtz and Gibbs, 1954) should yield more negative values in case of kaolinite. In case of active clay minerals like smectite or montrimorillonite the free swell value from the Holtz and Gibbs method should be greater than those obtained using the IS procedure. The method proposed by the authors merely yield the volume occupied by sediment per gram of solids. While the values are thus rendered positive, there is no scope for further interpretation of test data.

For the above reasons, the writers opine that the free swell test as specified by Holtz and Gibbs (1954) be adopted and the test data be used for differentiating between collapsing and swelling soils. Collapsing soils are metastable soils which undergo compression under zero or little load when allowed to saturate. One test for whether a soil is metastable or whether its insitu void ratio is in excess of the void ratio corresponding to its liquid limit (Gibbs and Holland 1960, Gibbs and Bara 1967, Clemence and Finnbarr 1991, Knodel 1981, Hunt 1984).

In order that the test be more effective, the writers suggest that water be slowy added to 10 ml of loose dry soil passing. No. 40 sieve taking care to reduce disturbance of the particles. After allowing 24 h, the volume of the soil can be read. This procedure will largely eliminate the effect of fabric changes which are likely to occur if the particles were to sediment through water. The original fabric of loose dry soil (which is analogous to sedimenting in air medium) is now subjected to the effects of saturation. The ratio of the change in volume to the original volume in air, expressed as a percentage, yields a free-swell index. Whose negative or positive nature will identify whether the soil in question belongs to the collapsing or swelling type. As a check, the void ratio obtaining in the loose dry soil specimen can be compared with its liquid limit void ratio.

References

CHEN, F.H. (1975): "*Foundation of Expansive Soils*" Elsevier Scientific Publishing Company.

CLEMENCE, S.P., AND FINBARR, A.O. (1981): "Design Considerations for Collapsible Soils" *Jl. of Geotechnical Engg. Div.*, ASCE, 107: GT3: 305-317.
DAWSON, R.F. (1956): Discussion of "Engineering Properties of Expansive Clays" by W.G. Holtz, and H.G. Glbbs, *Transactions*, ASCE, 121: 664-667.

DUDLEY, J.H. (1970): "Review of Collapsing Soils", *Jl. Soil Mech. and Found. Div.*, ASCE. 96, SM3, 925-947.

GIBBS, H.J., AND HOLLAND, W.Y. (1960): "Petrographic and Engineering Properties of Loess", *Bureau of Recl. Engg. Monograph* No. 28, U.S. Dept. of Int., Denver.

GIBBS, H.J., AND BARA, J.P. (1967): "Stability Problems of Collapsing Soils". *Jl. of Soil Mech. and Found. Div.*, ASCE, 93: SM4: 577-594.

GROMKO, G.J. (1974): "Review of Expansive Soils". *Jl of Geotechnical Engg. Div.*, ASCE 100; GT6: 667 687.

HOLTZ, R.D., AND KOVACS, W.D. (1981): "*An Introduction to Geotechnical Engineering*". Prentice Hall, Inc., Englewats Cliffs, New Jersey.

HOLTZ, W.G., AND GIBBS, H.J. (1954): "Engineering Properties of Expansive Clays". *Proceedings*, ASCE, Sep. No. 516.

HOLTZ, W.G., AND GIBBS, H.J. (1956): "Engineering Properties of Expansive Clays". *Transactions*, ASCE, 121: 641 677.

HOLTZ, W.G. (1959): "Expansive Clays—Properties and Problems". *Quarterly J. of the Colorado School of Mines*, 54: 4; 89 125.

HUNT, R.E. (1984): "*Geotechnical Engineering Investigation Manual*". McGraw Hill Book Company.

KNODEL, P.C. (1981): "Construction of Large Canal on Collapsing Soils". *Jl. of Geotechnical Eng. Div.*, ASCE, 107; GT1: 79-94.

LAMBE, T.W., AND WHITMAN, R.V. (1969): "*Soil Mechanics*". John Wiley & Sons, Inc., New York.

OLSON, R.E., AND MESRI, G. (1970): "Mechanisms Controlling Compressibility of Clays". *Jl. of the Soil Mech. and Found.* Div., ASCE, 96; SM6; 1863-1878.

U.S. BUREAU OF RECLAMATION (1974): *Earth Manual*, 2nd Ed., Denver.

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Numerical data presented by authors certainly indicates the limitation of existing definition of free-swell index. However proposed definition is based only upon Kaolinitic and montmorillonitic soils. To what extent will the proposed definition be reliable while using this as a general equation (even for other soils containing comparatively less expansive minerals, Illite, Mixed—layer, el, M-I etc. and in various compositions)?

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The authors have brought out an interesting comunication. Holtz and Gibbs (1954) have for the first time defined the term "Free Swell" as the ratio of the volume change of 10 cc of dry soil passing through 40 number sieve to that of initial volume (10 c.c.) and expressed as a percentage. Further, it has been also indicated that soils having a free swell values as low as 100 per cent may exhibit considerable volume changes and soils having free swell values below 50 per cent very seldom exhibit appreciable volume changes even under light loadings.

The authors have used almost a similar definition (used by Holtz and Gibbs, 1954) in redefining the term "Free Swell Index" and considered 10 gm of dry soil instead of 10 cc of dry soil.

Seed et al. (1962) defined the swelling potential as the percentage of sweel of a laterally confined soil sample on soaking under 1 psi surcharge after being compacted to the maximum dry density at optimum water content in the standard AASHO compaction test. Did the authors use the term swelling potential in the same way ? If so, what is the basis for the classification of swelling potential suggested by the authors in terms of Free swell index?

A more logical and scientific classification for swelling potential (Seed, et al 1962) has been given by Ranganathan and Satyanarayana, (1965) in terms of shrinkage index (Liquid limit—Shrinkage limit) of the soil. The writer suggests that the authors may concentrate on developing superior methods rather than titerating the existing ones.

References

HOLTZ, W.G. AND GIBBS, H.J. (1954): "Engineering properties of expansive soils" *Proc.* ASCE, Vol. 80, p. 516.

SEED, H.B., WOODWORD, JR., AND LUNDGREN (1962): "Prediction of swelling potential for compacted expansive clays", *Proc.* ASCE, SM Division, Part I.

RANGANATHAN, B.V. AND SATYANARAYANA, B. (1965): "A rational method of predicting swelling potential for compacted expansive clays", *Proc. 6th Int. Cong.* on SMFE, Vol. I Montreal, Canada.

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Authors' Reply

The authors appreciate the interest shown towards their paper.

Allam and Bhanuprasad make a case that the free-sweel test could be better utilized to distinguish betwen collapsing and swelling soils, than as an indicator of soil expansivity. It needs to be emphasized here that collapsible soils are metastable soils which are susceptible to large decrease in bulk volume under zero or little load when allowed to saturate. These metastable soils are characterized by loose structures of bulky shaped grains, often in the silt to sand range. It is because of such a farbric that the soil is reasonably strong and incompressible when dry (Mitchell, 1976). When saturated and on application of loads, the fabric is disrupted, the soils loose their stability and undergo settlement. Pulverization of the soil sample into a fraction passing 425 μ IS sieve, as required by the free-swell test would disrupt the fabric of the metastable soil. Consequently settlement of the soil on water saturation in the free-swell test would be negligible. Hence, the utility of free-swell procedure for identifying collapsible soils is questionable.

It is to be stated here that kaolinite and GTRE campus soils gave a negative free-swell index using the earlier definition (IS Code, 1977), because of the physico-chemical forces involved in the non-polar solvent (Rao and Sridharan, 1985) and not due to the collapsible nature of the soil. The latter point was verified by the negligible decrease in void ratio of the undisturbed GTRE soil on saturation and application of small load (0.0625 kg/cm^2) as determined in the one dimensional consolidation test.

Jha has raised a valid point on the applicability of the proposed definition to soils containing less expansive clays such as illite or mixed layered montmorillonite-illite minerals. The definition of free-sweel index has been developed on the observed sediment volumes in water of kaolinitic and montmorillonitic soils, which represent the two extreme conditions in soil expansivity. As, illite and mixed layered montmorillonite—illite minerals have expansivity in between kaolinitic and montmorillonitic soils, any difficulty in estimating their free-swelling potential is not foreseen; their swelling potentials is anticipated to lie intermediate between the kaolinite montorillonite values.

Satyanarayana has observed that the authors have used a definition similar to that of Holtz and Gibbs (1956). It needs to be pointed out that the re-defined term is an improvement over that of Holtz and Gibbs in the following aspects.

Holtz and Gibbs (1956) have recommended the use of 10 cm^3 of dry soil passing the No. 40 sieve, in the determination of free-swell value, in percentage. This could introduce inaccuracies in the results, as slight variations in the pouring technique could lead to different weights of soil for 10 cm^3 volume, and hence cannot be relied upon. The above difficulty is overcome by measuring the free-sweel volume of 10 g of dry soil as recommended in the paper.

Satyanayana has further quoted Holtz and Gibbs, stating that, soils having a free-swell value below 50 per cent very seldom exhibit appreciable volume change even under light loadings. As early as in 1956, Dawson in his discussion (1956) on Holtz and Gibbs paper had pointed out that several Texas clays with free-swell values in the range of 50 per cent have caused considerable damages through expansion.

The swelling potential term used in the paper does not correspond to that defined by Seed et al. (1962).

The basis of classification of the degree of expansion are the experimentally observed free-swell values.

Satyanarayana has further referred to the classification of swelling potential given by Ranganathan and Satyanarayana (1965). The degree of expansion as evaluated from their method for some of the soils is listed below.

Soil No	Soil	Principal Clay mineral	Shrinkage index	Degree of expansion
1	Kaolinite	Kaolinite	22.0	medium
2	Mangalore Marine	Kaolinite, montmorillonite	57.1	high
3	I.I.Sc.	Kaolinite, montmorillonite	54.9	high
4	Domalur	Kaolinite, montmorillonite	60.5	high to very high

The shrinkage index predicts medium expansivity for soil 1, a high degree of expansivity for soils 2 and 3 and a high to very high expansion for soil 4.

The clay mineralogical composition of the soils are as follows. Soil 1 refers to the non-expanding kaolinite clay. Soil 2 refers to a highly acidic (pH of 1:2 suspension by weight = 3.2) soils from Mangalore coast. Acidic soils contain the polyvalent aluminium as the exchangeable cations with a consequent low swelling capacity (Yong and Warkentin, 1966). Soils 3 and 4 refer to the commonly termed Red Earth soils whose clay fractions are dominated by non-swelling kaolinite with pressure of small amounts of montmorillonite.

It can be readily seen from the clay mineralogical composition of the soils that the shrinkage index does not give a realistic picture of the soil's swelling ability, for soils cantaining kaolinite or mixtures of kaolinite and montmorillonite. In particular, classification of soils 1,3 and 4 as moderately, highly and high to very high swelling, though their clay fractions are constituted/dominated by the non-swelling kaolinite is indeed questionable. Similarly the acidic soil 2, which has a low swelling capacity due to the presence of polyvalent aluminium ions, is categorized as highly swelling.

The shrinkage index could serve as an indicator of a soil's swelling ability for soils containing montmorillonite alone, however, its usefulness in predicting expansivity of soils containing kaolinite or a mixture of kaolinite and montmorillonite is perhaps restricted since the mechanisms controlling the Atterberg limits and swelling of kaolinitic soils may not be the same (Sridharan and Venkatappa Rao 1973, 1975, 1979, Olson and Mesri 1970, Matichelle 1976, Sudhakar Rao and Sridharan 1985).

References

DAWSON, R.F. (1956): Discussion, "Engineering Properties of Expansive Clays," *Transactions of the American Society of Civil Engrs.* 121; 664-666.

HOLTZ, W.G. AND GIBBS, H.J. (1956): "Engineering Properties of Expansive clays" *Transctions of the American Society of Civil Engrs.* 121: 641-663.

INDIAN STANDARD CODE (1977): I.S. 2720 (Part XL).

MITCHELL, J.K. (1976) "*Fundamentals of Soil Behaviour*" John Wiley, New York, 422p.

OLSON, R.E. AND MESRI, G. (1970): "Mechanisms Controlling Compressibility of Clays". ASCE *J. Soil Mech. Found.* Div. 96: 1863-1878.

RANGANATHAN, B.V. AND SATYANARYANA, B. (1965); "A Rational Method of Predicting Swelling Potential for Compacted Expansive Clays," *Proc. 6th Int. Conf.* SMFE, Vol. I, Montreal, Canada.

SEED, H.B., WOODWORD, J.R. AND LUNDGREN, R. (1962); Prediction of Sewelling Potential for Compacted Expansive Clays," *Proc.* ASCE, SM3; 53-87.

SRIDHARAN, A. AND RAO, G.V. (1973): "Mechanisms Controlling Volume Change of Saturated Clays and the Role of Effective Stress Concept," *Geotechnique*, 23; 359-382.

SRIDHARAN, A. AND RAO, G.V. (1975): "Mechanisms Controlling the Liquid Limit of Clays", *Proc. Instanbul Conf. on* SMFE Vol. I, 75-84.

SRIDHARAN, A. AND RAO, G.V. (1979): "Shear Strength Behavior of Saturated Clays and the Role of Effective Stress Concept," *Geotechnique*, 29; 177-193.

SUDHAKAR, M. RAO AND SRIDHARAN, A. (1985) "Mechanisms Controlling Volume Change Behavior of Kaolinite, *Clays and Clay Minerals*:" 33; 323-328.

YONG, R.H. AND WARKENTIN, B.P. (1966) "*Introduction to Soil Behavior,*" Mac Milan, New York, 451 p.