ACTIVE SOILS OF TRINIDAD: THEIR IDENTIFICATION AND CLASSIFICATION

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ABSTRACT

Soils which exhibit volume changes with variation in their moisture content are termed active soils. The differential movement resulting from drying and wetting around and under buildings and pavements is detrimental to the stability of these structures. Such soils occupy a significant area of the central and southern regions of Trinidad. Engineers and contractors, who have worked in these areas have faced problems with buildings and pavements cracking badly due to continual heaving and shrinking of these soils. There is, therefore, a need to identify and classify these soils and provide appropriate data for design and construction practices.

Behaviour of these active soils is a complex one since they are sensitive to local environment. Soil-water interaction in the prevailing enviroment is very important but is a difficult task to evaluate it. However, as a first step in this direction, correlations of activity of these soils with simple and common soil test results are presented to facilitate identification and preliminary classification of these active soils of Trinidad.

1.0 INTRODUCTION

Plastic clays which exhibit volume changes when subject to moisture changes due to seasonal climatic conditions or artificial causes are called active clays. By virtue of their capacity to volume change, they tend to cause enormous damage to structures raised on them, especially the light structures, such as single-storey residences, pavements, buried utilities, etc., which transfer small loads to supporting soils. The estimated damages attributed to these active clays, on a global basis is enormous (2). In the United States of America alone, the losses due to expansive soils exceed the losses due to earthquakes, floods, hurricanes and tornadoes all put together (3). That is the reason why the expansive soil problem is known as 'silent natural hazard'. Since it is not a dynamic phenonemon as other natural hazards, it does not produce an impact on people other than those who are directly affected by it.

This type of soils are found in abudance in the central and southern regions of Trinidad. Several buildings - single-storey residential buildings (Princes Town), two-storey school buildings (Pleasantville and Barrackpore) and sections of the highways (Solomon-Hochoy Highway), have suffered damage. The type of damages that have occurred are cracking of floors, slabs, walls, columns, beams, etc. of buildings, cracking of pavements resulting in roughness of pavement surfaces, lifting and breaking of sidewalks, watermains and so on. Further, these soils on slopes have contributed to extensive landsliding on account of soil creep. As such, these soils have become a problem to the nation's social and economic fronts.

The cause of failure of structures on expansive soils is partly due to the failure to recognise the existence of such soils and partly due either to lack of knowledge to cope with these soils or risking to avoid special measures of construction and hence, extra expense, especially by the small builders. The Government plans to embark on low-cost housing and school building projects, many of them , if not all, are likely to come up on expansive soil areas. Therefore, it is important to properly identify this problem at an early stage.

2.0 EXPANSIVE SOILS OF TRINIDAD

In Trinidad, expansive soils predominantly occurring in central and southern regions are of sedimentary origin. The parent material possessing high swelling montmorillonite clay mineral, in combination with other less active clay minerals like Illite and Kaolinite are predominantly clay shales, marls and clay alluvium. Depending on the type of the parent material, these soils are divided into calcareous and non-calcareous types. Calcareous types show less

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severity in swelling as the effect of lime content reduces the water-intake capacity and hence, plasticity. The montmorillonite content greatly influences the expansive nature of the soil. The basic soil types that are prone to swelling are :

Soil Series	Name	Parent Material	Formation
177	Talparo Clay	Clay Shale	Nariva
474/L	Princes Town Clay	Marl	Nariva
239	Debe Clay	Clay Shale	Upper Cipero
278/L	Tarouba Clay	Clay Shale	Nariva
77	Ecclesville Clay	Clay Shale	Upper Lengua

3.0 IDENTIFICATION AND CLASSIFICATION

In a design problem involving an expansive soil, it is an essential first step to identify in qualitative terms and if the need exists, to go further to classify it in a quantitative way estimating or measuring the potential swell of the soil. The potential swell may be defined as the volume change in the soil due to a change in its water content from in-situ water content to full saturation.

The identification process is thus a preliminary step to verify whether the problem of expansive soil exists. It consists of a visual observation carried out by a walk-over survey of the site and then confirming this observation by performing simple index tests on disturbed soil samples. At the next stage depending on the importance of the structure, investigations for a classification of the soil is made using empirical relations and/or laboratory test results and prediciting the potential swell. Depending on the potential swell, the soil is classified as low, medium, high and very high expansive type. Another way is to use the index properties of the soil and empirical relations or charts available to predict the potential swell and hence, the degree of expansion. The potential swell can be determined by performing oedometer swell tests on undisturbed soil samples. This however, involves expense and time. If the importance of the structure warrants a more rigorous and reliable analysis, then a comprehensive analysis must be done. This means a site investigation is necessary to determine:

i) the soil profile characteristics,
ii) the active depth, and
iii) swell parameters (percent swell and swell pressure) using undisturbed soil samples.

The sequential steps of identification and classification and their inter-relationships are illustrated in the flow chart of **Fig.1**.

3.1 Identification Tests

Expansive clay soils can be identified with the help of indirect and direct tests (Snethen, 1975). Some of the direct tests are :

i) soil classification tests such as Atterberg limits and other physical properties of soil,
ii) soil suction tests, and
iii) physico-chemical tests.

These test results, if correlated with swell test results or observed field heave values, can help to classify soils in terms of the degree of severity. Most of the identification and classification systems reported in literature employ index properties of soils as they are determined from simple and routine tests commonly performed in laboratories. The index properties, according to Snethen et al (1977) are the best indicators of the potential swell of a soil in its natural environment. Soil suction has emerged recently as a promising single parameter representing the expansive nature of a soil. However, it is not yet in place as a routine test. Although filter paper technique of measuring soil suction is simple in procedure, the precision with which the test is to be performed, the special requirement of a temperature controlled room and the time it takes, all make it difficult to be used as a routine test, especially in view of the small builders.

Moreover, assessment of the complex expansive soil behaviour based on a single parameter is not advisable in view of the limitations and reliability of performance of these tests. Therefore, the soil suction results may have to be used in conjuction with index or other soil properties. However, use of soil suction to categorise expansive soils is likely to enhance confidence in the results.

The important physico-chemical properties that indicate the expansive behaviour of soils are (i) ionic environment and (ii) the cation exchange capacity of the clay minerals. Ions absorbed on the clay minerals and ionic concentration in the pore water greatly influence the expansive nature of the soil. Montmorillonite and vermiculite clay minerals present render the soil highly expansive because of their high cation exchange capacity which denotes the amount of exchangeable cations the expansive clay can absorb. Greater the exchange capacity, greater the expansive property. The degree of expansion of a soil

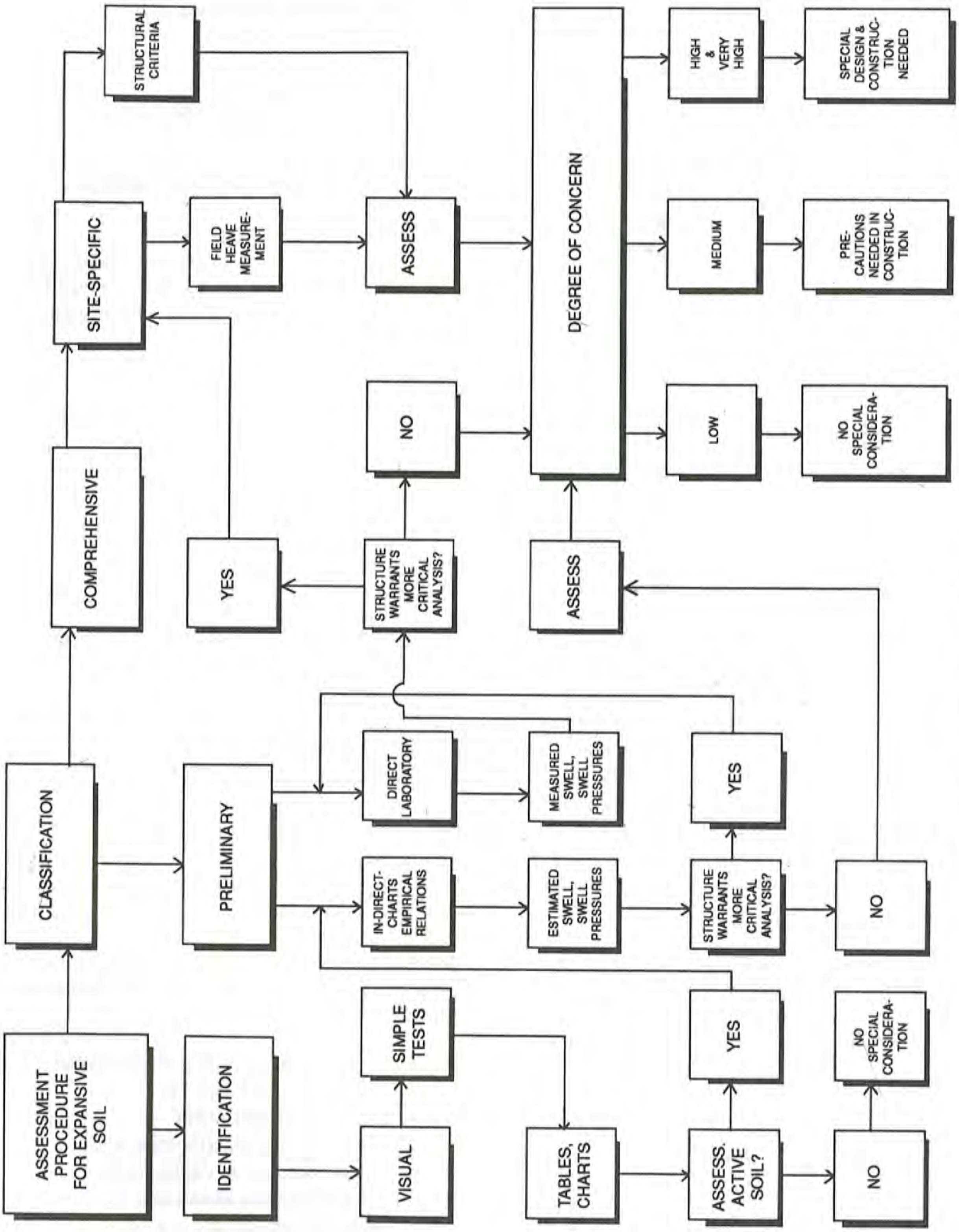

Figure 1: Flow Chart showing the Sequential Steps of Identification and Classification

is also influenced by the type of cation absorbed. For instance, sodium-montmorillonite exhibits greater volume changes than calcium-montmorillonite. Although the physico-chemical tests are good indicators of the expansive quality of a soil, they are difficult tests to perform from the point of view of a small builder. However, Atterberg limits are believed to reflect the physico-chemical properties indirectly and hence, are more popularly used in identifying expansive soils.

Direct tests are those which quantitatively assess the expansive quality of soils. The potential swell and the swell pressure are the two parameters that express the volume change characteristics of a soil. These parameters are obtained by conducting swell test in the oedometer, the procedure of which is dealt with under 'swell test' in Section 4.1. The measured swell parameters using oedometer swell tests are found to give conservative values because the in-situ soil would hardly have enough quantity of water to completely saturate the soil down to the active depths as the laboratory sample would have. Further lack of standard test procedure variations in the measured values may be significant. Correlation of direct and indirect test results are commonly used to develop quantitative estiamation of the degree of expanison.

4.0 SAMPLING AND TESTING OF LOCAL EXPANSIVE SOILS

In order to cover most types of expansive soils of Trinidad, 17 locations were chosen for soil sampling and testing. Disturbed and undisturbed soil samples obtained from a depth of 1m below ground surface were chosen as a representative depth of foundations for light structures. Sampling was done using Shelby tubes and the samples were properly sealed and stored in a temperature controlled room before testing.

Samples were tested for consistency limits, grain size distribution, natural moisture content and density etc. Undisturbed samples were used for performing swell tests in consolidometer to measure potential swell. The test procedure is described as follows.

4.1 Swell Test

The swell test procedure recommended by the U.S Army Corps of Engineers (1968) is adopted. The soil sample is first loaded to its in-situ overburden pressure. When compression of sample is complete (Point B of **Fig.2a**), then the sample is unloaded to a seating load (Point C) before saturating the sample with distilled water. The sample is allowed to expand until equilibrium condition is reached (Point D). At this point, the sample is loaded to consolidate it, as shown in the figure.

Potential swell is then calculated using the relation,

$$s(\%) = \frac{\Delta H}{H} x100 = \frac{\Delta H}{(H_o - \Delta H_i)} x100 \quad \text{.....................(1)}$$

Fig 2a illustrates the terms used in this relation.

4.2 Swell Test Results

Using this test procedure, potential swell values of all soils investigated are measured and shown in **Fig 2b**. The curve fitted is represented by the equation,

$$s(\%) = 0.20e^{0.06(ll-w)} \quad \text{.....................................(2)}$$

where s = percent potential swell
ll = liquid limit, (%)
w= natural moisture content, %

4.3 Rating of Potential Swell Values

Based on failures and performance of buildings at different locations, such as two-storey school buildings at Pleasantville and Barrackpore and residential buildings in Princes Town etc., the measured potential swell values of soil are classified as follows:

Potential Swell (%)	Degree of Expansiveness
<1	Low
1 - 2	Medium
2 - 5	High
>5	Very High

In this classification the limits for potential swell values set by Vander Merwe (1964) for buildings in South Africa were also considered.

5.0 AVAILABLE METHODS AND THEIR THEIR APPLICATION TO LOCAL ENVIRONMENT

Several identification and classification systems for expansive soils are reported in the literature. In these systems, soil parameters identified to indicate expansive behaviour of soil are combined to form different classification systems. Commonly used correlation parameters include Attenberg limits,

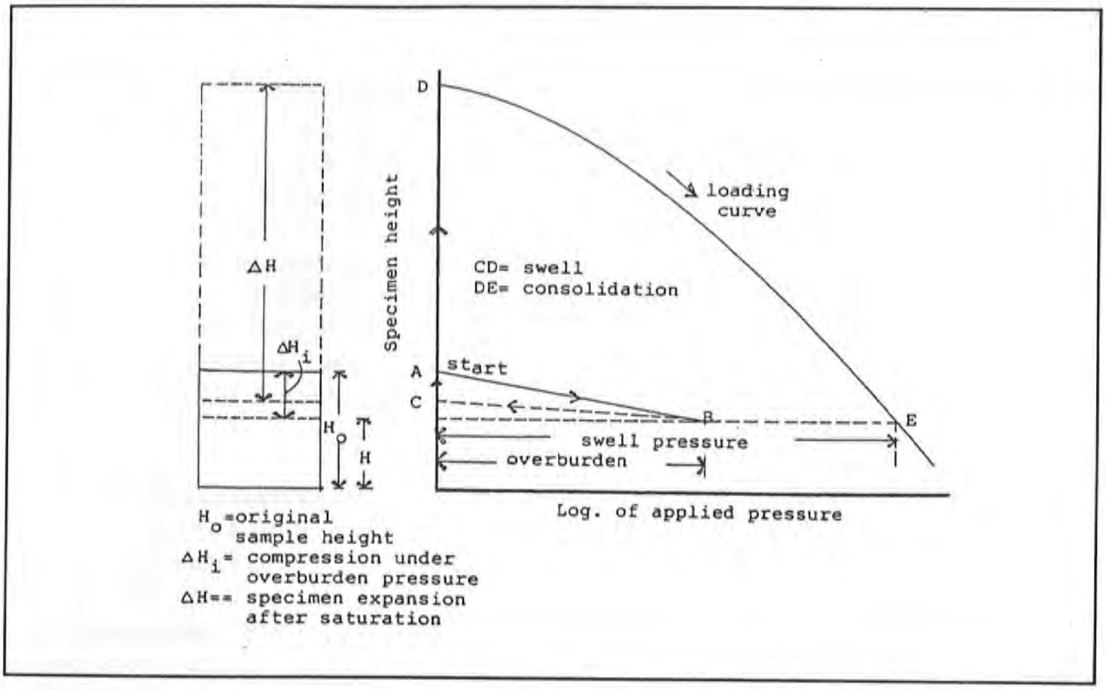

Figure 2(a): **Swell Test Procedure**

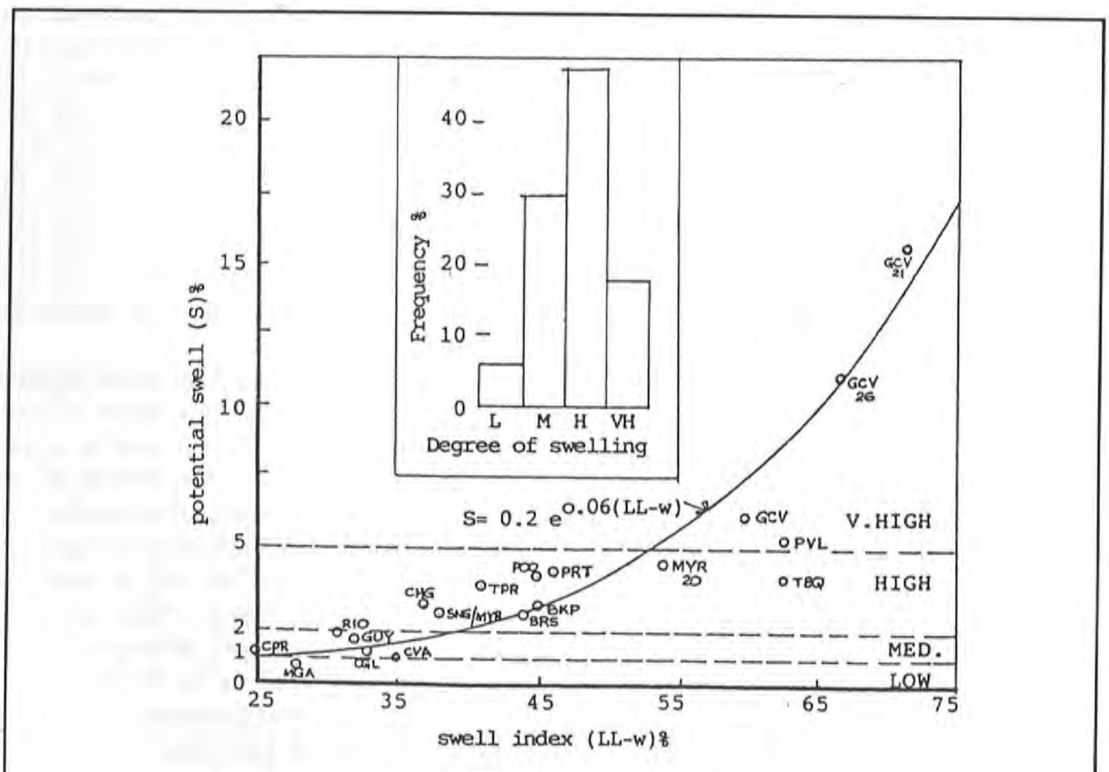

Figure 2(b): **Measured Potential Swell Values of Local Soils** collodial clay content, activity and swell parameters measured in oedometer swell tests with various loading conditions (Snethen, 1975). Generally, these systems specify a range of values of the parameters used to categorise the soil into degrees of expansion such as low, medium high and very high. They are, however, developed with reference to a particular climatic and geological conditions and also probably with a specific type of foundation in view.

As such, it would be difficult to expect them to have a universial application. It is likely that design engineers or builders would proceed with the actual design process on the basis of simple laboratory test results on hand and drawing guidelines from such available classification systems as described. Therefore, there is need to review some of the important existing systems in order to verify their validity for application to local conditions. To achieve this, correlation of the actual swell parameters measured for local soils with the chosen systems of classification has to be studied. If this correlation leads to a good agreement, then it suggets that the chose systems are applicable to local environment. If not, they have to be modified using local data. With this objective, two classification systems namely USBR Classification System and Vander Merwe Chart, which are widely used are chosen for application to local situation. The predicted degree of expansivity using these methods is compared to the rating of potential swell of local soils (Section 4.3) in form of histograms.

Colloid Content (<0.0001mm) %	Plasticity Index %	Shrinkage Limit %	Probable Expansion (% Total Volume Change)	Degree of Expansion
>28	>35	<11	>30	Very high
20 - 31	25 - 41	7 - 12	20 - 20	High
13 - 23	15 - 28	10 - 16	10 - 20	Medium
<15	<18	>15	<10	Low

Table 1: **USBR Classification Data from Index Tests**

5.1 USBR Classification

Extensive work of Holtz and Gibbs (1959) on undisturbed natural soil samples revealed that collodial clay content, plasticity index and shrinkage limit were good indicators of the expansive nature of soil. U.S Bureau of Reclamation (USBR) classification is based on this work. The degree of expansion and the range of values of correlated properties are shown in **Table 1.**

5.2 Vander Merwe Chart

This chart devised by Vander Merwe (1964) is presented in **Fig. 4**. It shows the empirical relationship between the degree of expansion and soil properties viz, clay content, plasticity index and activity. In this classification, the degree of expansion is related to potential expansion (PE) of the ground expressed in inches/feet. These PE values adopted are based on oedometer swell tests and field observations. This chart developed for South African soils is popularly used.

5.3 Applicability to Local Soils

USBR Classification and Vander Merwe charts applied to local soils to verify their validity for local use. The soil data of local soils necessary to apply to these two systems is presented in **Table 2.**

Applying the soil data to these systems, degree of expansitivity of local soils is obtained and compared to that developed locally in **Fig. 3** and **Fig. 5.** From the results of these figures, it may be observed that both the systems do not adequately represent the local situation. Therefore, in order that these systems can be adapted to local conditions, there is a need to modify them to account for the different climatic and geological conditions.

5.4 Modified Version for Local Applications

Certain modifications were introduced into the USBR Classification System so that it could be applied to the local conditions. The modified form of the system is shown in **Table 3.** Collodial clay content is replaced by clay content, shrinkage limit by liquid limit and total volume change (air dry to saturation) by probable maximum volume change from minimum water content to saturation. Minimum water content of soils is estimated using McDowell's (1956) expression, w_{min} = 0.2 (liquid limit) + 9%. The probable maximum swell that the soil is likely to experience is obtained using the equation (2).

Since clay content is difficult to determine accurately because of flocculation problems in

No.	Location	Short	Clay Content		LL%	PI%	SL	Natural Moisture Content	Activity (PI/Clay %)
			<2mic.	<1mic.					
1	Barrackpore	BKP	82	65	84	56	24	39	0.69
2	Brasso-Venado	BRS	52	42	79	46	18	34	0.88
3	Caparo	CPR	40	35	55	32	21	25	0.79
4	Caigual	CGL	35	30	56	33	13	23	0.94
5	Chaguanas	CHG	35	35	51	23	14	14	0.67
6	Couva	CVA	36	30	60	33	19	25	0.91
7	Gran Couva	GCV	69	55	93	65	21	33	0.94
8	Guayaguayare	GUY	39	32	47	23	20	16	0.59
9	Mayaro	MYR	70	60	74	48	12	36	0.69
10	Moruga	MGA	35	30	43	26	25	15	0.73
11	Pleasantville	PVL	50	45	94	71	16	31	1.43
12	Poole	POO	57	50	81	48	19	37	0.83
13	Princes Town	PRT	72	60	83	58	14	37	0.79
14	Rio Claro	RIO	22	17	70	44	24	39	1.99
15	Sangre Grande	SNG	49	45	76	44	13	38	0.89
16	Tabaquite	TBQ	62	50	106	67	19	43	1.08
17	Talparo	TPR	60	52	73	48	16	32	0.80

Table 2: Soil Properties

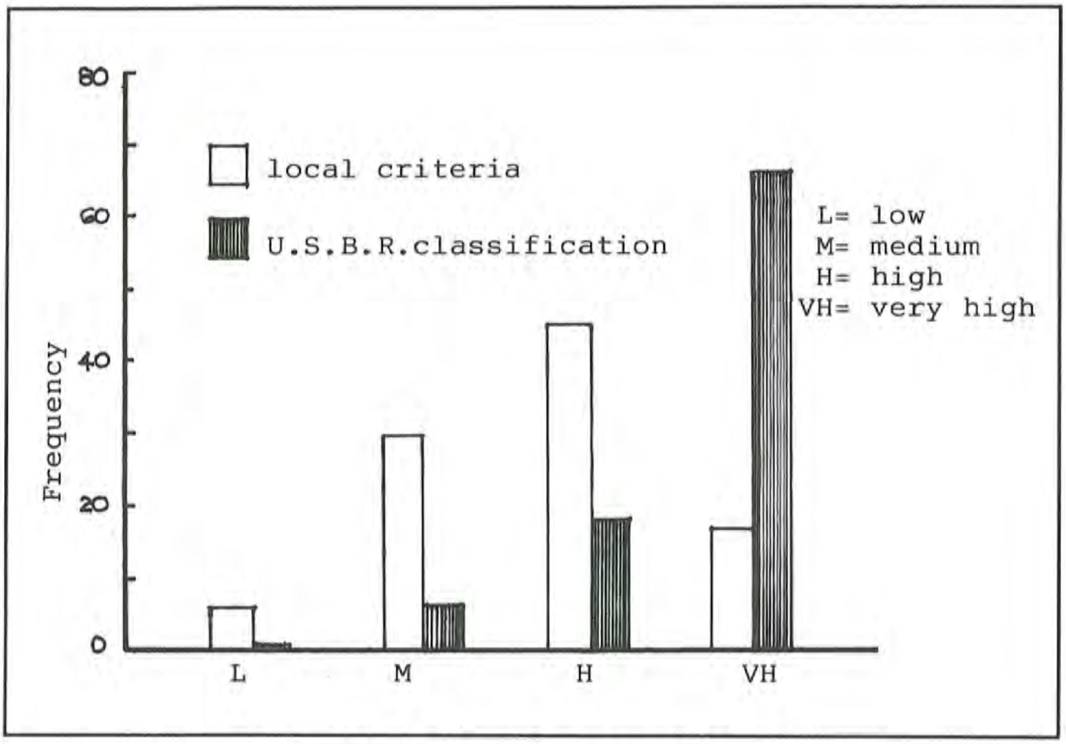

Figure 3: **Histogram comparing Degree of Expansion of Local Soils with USBR classification**

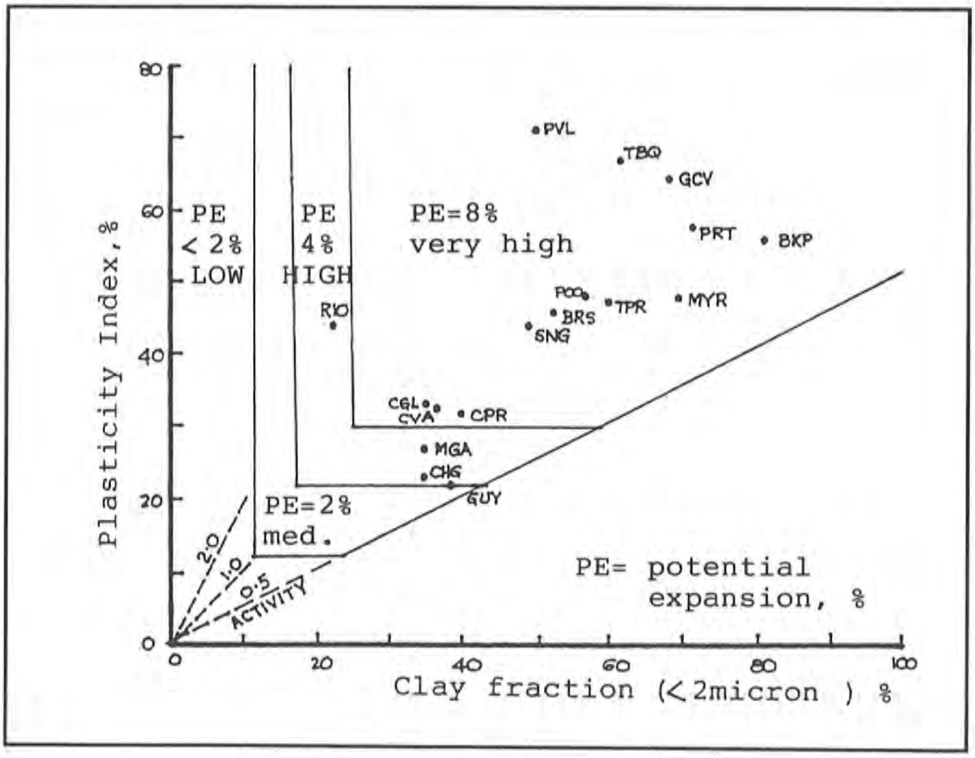

Figure 4: **Vander Merwe Chart**

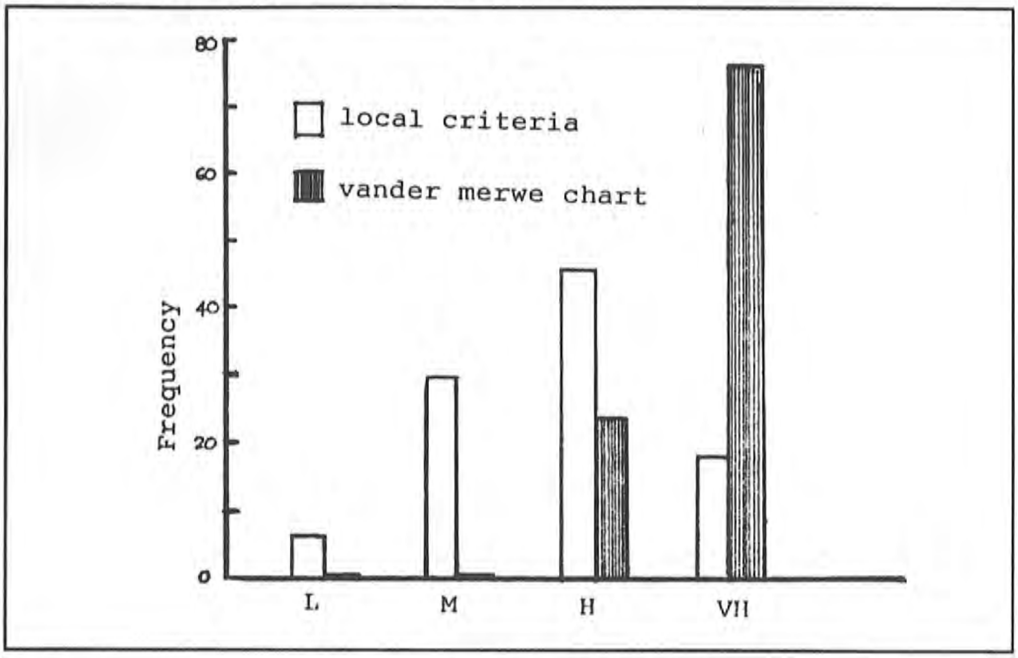

Figure 5: **Histogram comparing Degree of Expansion of Local Soils with Vander Merwe Chart**

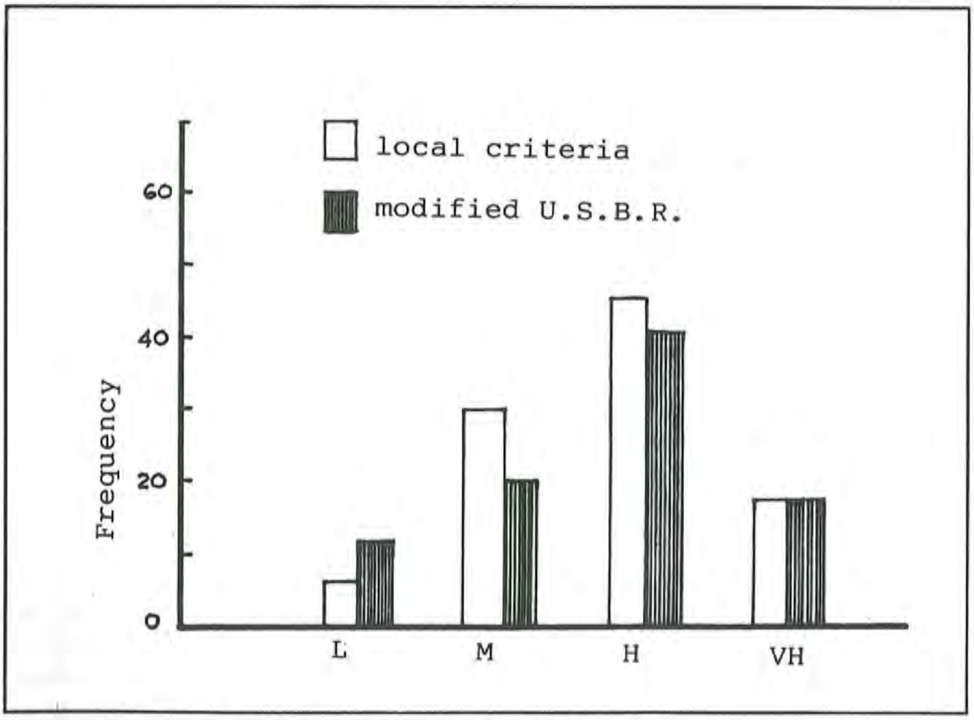

Figure 6: **Histogram comparing Degree of Expansion of Local Soils with Modified USBR**

Clay Content (< 0.0002 mm) %	Plasticity Index, %	Shrinkage* Index, %	Liquid Limit	Probable Maximum Swell, %	Degree of Expansion
< 30	< 25	< 30	< 50	< 2	Low
30 - 50	25 - 45	30 - 40	50 - 70	2 - 5	Medium
50 - 65	45 - 65	40 - 50	70 - 90	5 - 10	High
> 65	> 65	> 50	> 90	> 10	Very High

At least three of the four parameters should agree on the degree of expansion.
* Shrinkage Index = (liquid limit - shrinkage limit).

Table 3: Modified Version of USBR Classification

sedimentation tests, for a quick assessment in qualitative terms, a modified plasticity chart (**Fig. 7**) is also presented, which involves determination of only liquid limit and plasticity index. This chart is expected to have a promising application in the local context. The modified form of Vander Merwe's chart is presented in **Fig. 8**. The histograms resulting from the application of the modified versions of the two classification systems chosen, show a good agreement with the local classification (**Fig. 6** and **Fig. 9**).

6.0 CONCLUSION

From the foregoing analysis, the following conclusions are drawn:

1. The classification systems reported in literature are applicable to regions of a particular climatic condition and geological environment. Perhaps they are also pertinent to a particular structure in view. As was revealed in this analysis, these systems if applied to other regions of different climatic and geological conditions, the results may be erratic and deceptive. Therefore, there is need to develop rational systems of classification of expansive soils based on the regional basis taking into account the composition of soils, especially the type of clay mineral, hydrological conditions and soil profile development.

2. A selected system of classification from the literature can be adapted in the local context provided its validity is tested with the local data as is done in the case of USBR and Vander Merwe charts.

3. A modified plasticity chart is presented as a simple and useful tool for local expansive soils.

4. Since swell measurements in laboratories are not guided by a common standard procedure, variations in the test procedure and criteria used may bring in several uncertainties. In view of this, the laboratory swell measurements correlated with index and other properties should be interpreted only as mere guidelines or indices of potential expansiveness. Hence, they are useful only as preliminary assessment procedures.

5. Systems that predict potential expansiveness are based on soil volume changes from in-situ moisture content to saturated conditions. As in-situ moisture content is likely to vary from time to time, such systems can underestimate or overestimate expansiveness depending on the initial moisture content. A more rational approach would be to assess on the basis of a maximum swell that the soil would experience starting at the minimum value of the in-situ moisture content to saturated conditions.

6. For less important structures such as residential buildings, wherein a small builder cannot resort to a comprehensive analysis, a quantitative method, based on index properties and consolidometer swell tests may be quite useful. However, the design of a structure should still be deemed only as semi-empirical, because these test results do not

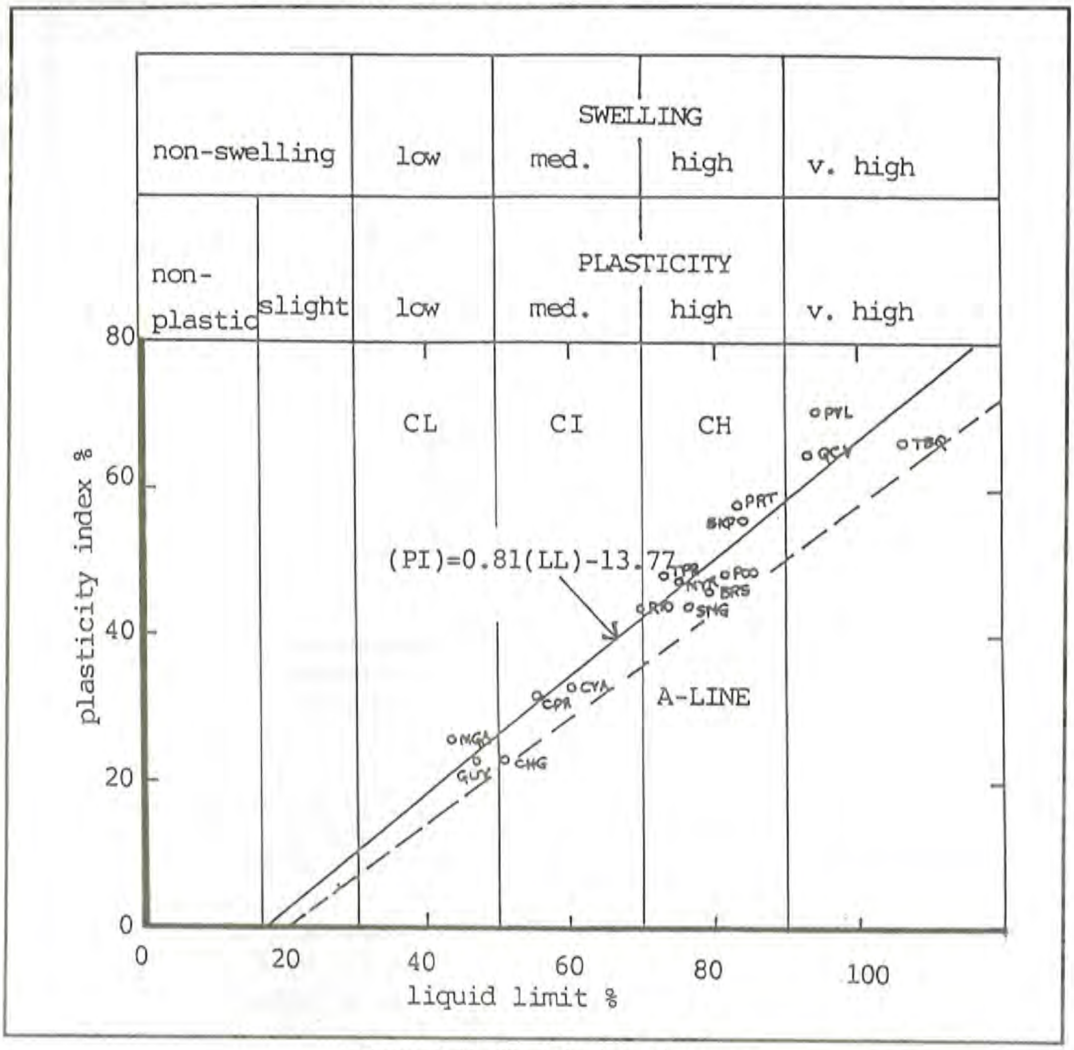

Figure 7: Modified Plasticity Chart

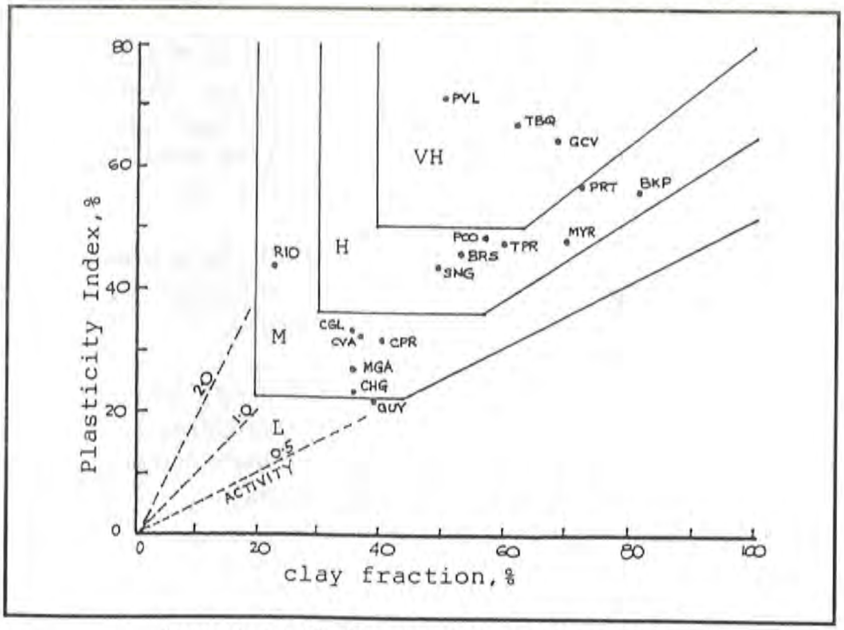

Figure 8: Modified Version of Vander Merwe Chart

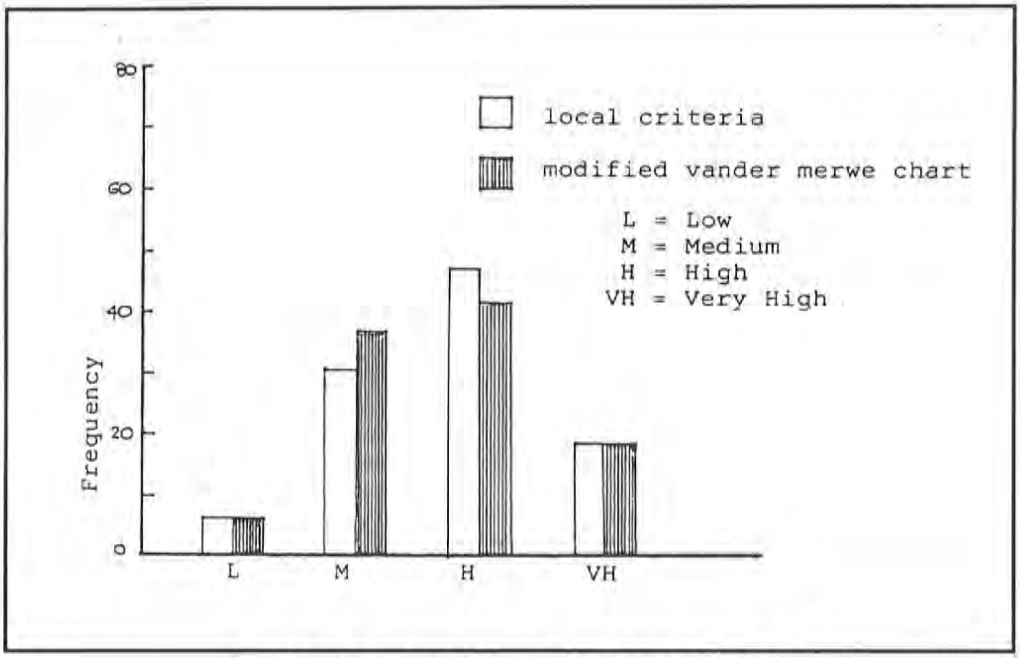

Figure 9: Histogram comparing Degree of Expansion of Local Soils with Modified Vander Merwe Chart

relate to the actual active depth, soil profile, etc. If the structure is of importance, a comprehensive evaluation is required for a more reliable design procedure. This approach essentially involves evaluation of site specific data and structural characteristics as indicated in the flow chart of **Figure 1**.

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