West Indian Journal of Engineering Vol. 25, No. 2, (January 2003) Technical Paper (Venkataramana) 43 - 53

Building on Expansive Clays with Special Reference to Trinidad

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Expansive soils occur in abundance in the central and southern regions of Trinidad. Their expansive nature is facilitated by the seasonal changes that occur in the water content of these soils. They have been inflicting substantial damages to light buildings, pavements and utilty lines, therefore, an understanding of the behaviour of these soils and the local conditions in which they operate becomes essential so that the small builders, who are most often the victims, become aware of this phenomenon. With this objective, this paper is presented to explain in simple terms, the nature and causes of the deleterious behaviour of these soils in the local context.

1. Introduction

Expansive soil is a term generally applied to a soil which has a potential for shrinking or swelling due to changes in its moisture content. In the wet season, the soil will be able to absorb water and swell up and as a result, the whole ground level rises. This increase in ground level is usually called free-field heave. However, if a structure is raised on such a soil deposit, the foundations form an obstruction to the soil to freely move up and consequently, the soil applies an upward pressure on the foundation. This pressure that the soil applies on the foundation is called swell-pressure. If the footings transfer a downward stress which is smaller than the season, it shrinks and cracks and as a result the foundations sink. These upward and downward movements of foundations become cyclic seasonal movements during the entire life span of the structure. These cyclic movements tend to tear up the walls and eventually destabilise the whole structure. Light structures, such as single or double-storeyed residential buildings, pavements, etc. which generally transmit smaller stresses to the soil than the swell-pressure are those that suffer the damage most.

Once the structure develops cracks, it is hardly possible to rehabilitate it without significant expense. Building a house for most people is a lifetime venture and if it occurs on an expansive soil, the investment needs to be safeguarded. Therefore, there is need for the public to be aware of the implications of building on expansive soils in order to identify the problem at an early stage rather than regret later.

2. Is this Phenomenon Peculiar to Trinidad?

No. It is indeed a global phenomenon. Regions falling in the tropical zone where dry and wet seasons are in contrast are the most affected than others. The estimated damages due to the expansive soil phenomenon on a global basis is stupendous and runs into several billions of dollars on an annual basis. In the USA alone, the losses exceed those due to earthquakes, floods, hurricanes and tornadoes all put together [1]. This is the reason why the expansive soil phenomenon is known as a 'silent natural hazard'. This hazard is a passive phenomenon unlike others such as earthquakes, landslides, hurricanes, etc., which are dynamic in nature. It brings about damages to structures slowly with time and does not produce a sudden impact.

These types of soils are found all over the world but the intensity of their activity largely depends on their geological history and the prevailing climatic conditions. Although there are no proper records of losses due to these soils in Trinidad, they are believed to be substantial. Fortunately for Trinidad, because of

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Pertinent discussion will be published in July, 2003 West Indian Journal of Engineering if received by May, 2003.

high rainfall and relative humidity, seasonal ground moisture changes are not appreciable and hence soil volume changes are somewhat under restraint but this is no point for complacency because the problem is still there, more serious in the western region than in others as indicated elsewhere. Further, these soils on slopes have contributed enormously to land sliding especially along the secondary roads of the central region. As such, these soils are a real threat to the nation's socio-economic front.

3. What Mechanism Operates On These Soils?

A soil is a mixture of various sizes of particles like gravel, sand, silt and clay. Gravel and sand are the coarse fraction and they are considered inert materials because of their significant surface activity. In contrast, clays and silty clays are particles of ultra-fine size in the form of platelets. They carry an unbalanced negative electric charge on their surface. This electric charge and large specific surface they possess render them highly active. They can absorb water as well as the positively-charged ions from the salts in water to neutralise the electric charge they carry on their surface. The amount of water adsorbed depends on the type of clay mineral present in the soil. Three most common minerals present in clays are Kaolionite, Illite and Montmorillonite and their capacity to adsorb water increases in that order, therefore, the greater the percentage of Montmorillonite mineral present, the greater would be the expansive nature of the soil. A typical composition of Talparo Clay (Soil series 177) in Trinidad is 40% Montmorillonite, 20% Illite, 20% Kaolinite and the rest others. Composition of clay minerals can be estimated using X-Ray Diffraction Analysis or Thermal Differential Analysis. However, presence of Montmorillonite can be indirectly judged qualitatively using simple tests like Liquid Limit test. High liquid limit values are indicative of the presence of Montmorillonite. Besides, these intrinsic properties of soil, there are other environmental factors that influence the soil behaviour.

3.1 Water Content

Initial water content of soil is an important factor that controls the expansive capability of a soil. A soil initially in a dry state can absorb a large quantity of water, swell up significantly compared to when its initial water content is close to saturation. The initial water content of foundation soil at the time of construction, therefore, plays an important role. This condition is largely controlled by the climatic conditions. However, variation in soil moisture content can also be brought about by artificial means, such as, leaking water mains, watering of lawn and plants on one side of a building, storm water drain discharging at one corner of a building and so on. Localised water supply to the soil is extremely dangerous because it leads to differential heaving of the foundation soil. Maintenance of a constant soil moisture condition around the structure is important for its stability.

3.2 Topography

Drainage pattern of a site is another consideration. Ditches and depressions allow standing water, which activates the expansive soil in a localised manner leading to differential heaving of soil in the site. The direction of flow of surface runoff or storm water drain discharge should be away from the building. The quicker the water can flow out, the better it is. Expansive soils on a slope tend to move down the slope due to soil creep especially when the soil is wet. Soil creep is a very slow movement down the slope, which is not perceptible. However, over time it can be significant and can damage the foundations as shown in **Figure 1**. The steeper the slope, the greater is this effect. Furthermore, on slopes, these soils can cause landslide problems. Slopes steeper than about 14° (a residual friction angle of soil) have the tendency to slide, if conditions are favourable.

3.3 Vegetation

Trees close to buildings in expansive soil sites have a deleterious effect on foundations. They absorb water from the nearby foundation soil through their root system and cause shrinkage of soil especially during the dry season when moisture available for roots to suck is the least. This is the reason why big trees should not be located within a distance of 1 to 1 1/2 times their mature height from the structure. If big trees are felled just before construction, transpiration loss of moisture through leaves is discontinued and the soil moisture accumulates and allows the soil to swell. Therefore, trees have to be cut down far in advance of construction so that soil moisture condition reaches an equilibrium condition. If trees are retained, moisture barriers should be put in place as shown in **Figure 2**. A typical barrier may be a Geomembrane Curtain Wall

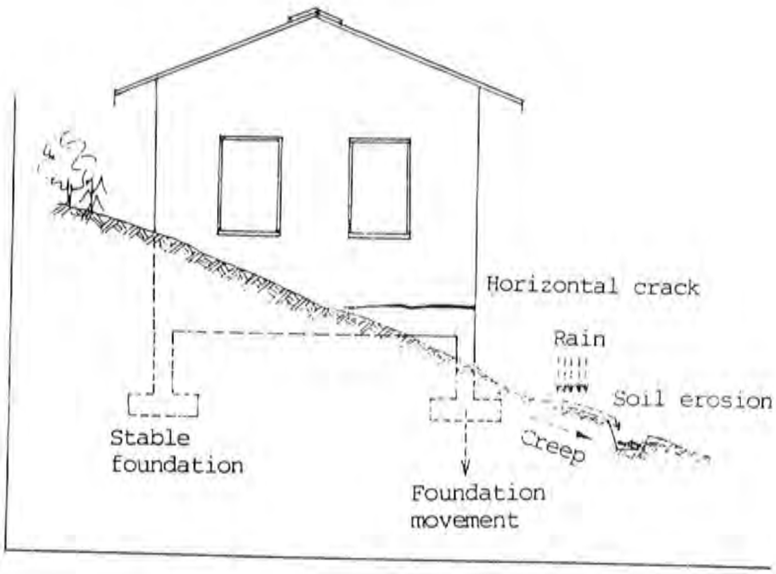


FIGURE 1: *Structural Damage due to Soil Creep*

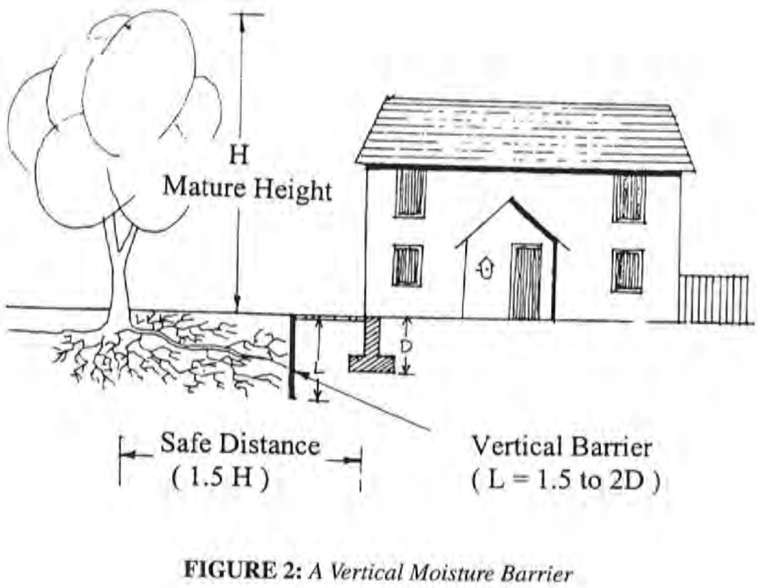


FIGURE 2: *A Vertical Moisture Barrier*

manufactured under different commercial names, such as, GSE Curtain Wall and GSE Gundwall. These products are more economical and also facilitate easy installation. Reinforced Concrete Curtain wall, east in-situ can also form an alternative.

3.4 Climate

The climatic factors that influence the soil potential for volume change are:

(i) Amount of rainfall,

(ii) Relative humidity,

(iii) Temperature and duration of dry spell periods

Soil moisture condition is actually controlled by the hydrologic cycle, or in other words, the amount of rainfall and evapo-transpiration losses. The difference between these two components indicates the moisture excess or deficiency in the soil. This condition is usually expressed by the Thornthwaite Moisture Index which is defined as the difference between the mean annual rainfall in inches and the amount of water that is returned to the atmosphere by evaporation from the ground surface and transpiration from vegetation also in inches. Locations falling in the range of TMI values of -20 to +20 are prone to significant soil volume changes.

Figure 3 shows the humidity map of Trinidad. In the areas marked as continuously moist, there is substantial moisture retained in the soil throughout the year. Hence, the activity of expansive soil is restrained. However, areas marked 3 & 4 are troublesome because the state of soil moisture condition is variable.

Furthermore, the thickness of expansive soil layer below the ground surface and the depth to which the seasonal moisture varies, called the 'Active depth', greatly influence the amount of heave the ground would undergo. **Figure 4** shows the seasonal moisture variation and the active depth. Below the active depth, the soil water content is considered to remain constant, therefore, foundations situated within the active depth, which is typically 3 to 5m, are subject to distress from soil volume changes.

4. What Soils of Trinidad are Expansive?

Soils predominantly occurring in central and southern regions are found to possess expansive nature. These soils are typically clay shales, marls and clay alluvium. The basic soil types are silty clays belonging to the following categories:

TABLE 1: *Soil Series and Parent Material*

No.	Name of Soil	Soil Series	Parent Material	Formation
1	Talparo Clay	177	Clay shale	Nariva
2	Princes Town Clay	474/L	Marl	Nariva
3	Debe Clay	239	Clay shale	Upper Cipero
4	Tarouba Clay	278/L	Clay shale	Nariva

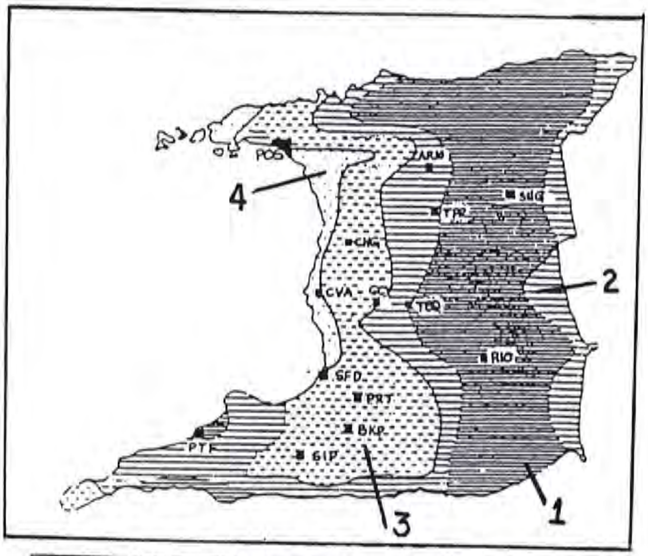
Talparo Clay is the most extensive and Ecclesville Clay is the least extensive in their areal distribution. A typical Talparo clay shows a Liquid Limit = 85%, Plasticity Index = 56% and Clay mineral content of Montmorillonite = 40%, Illite = 20% and Kaolinite = 20% and the rest others.

5. How Do These Soils Cause Structural Damage?

When a building is constructed on an expansive ground surface evaporation and temperature variations are retarded below it. As a result, patterns of soil movement under the building are identified on the basis of (a) short-term effects and (b) long-term effects.

In the short-term, i.e., just after the construction is complete, below the centre of the building, moisture variation remains small while at the edges, seasonal moisture changes continue to occur. If the building is constructed during the dry season, in the wet season that follows, soil around the building absorbs rainwater and swells pushing up the peripherfoundations. This effect is called the edge heave. The dry season that follows causes the soil at the edges to shrink and the foundations settle. This is called the edge-shrink effect.

However, in the long-term, moisture starts continuously accumulating under the centre of the building being drawn up from the ground water at depth by capillary action until an equilibrium moisture condition is attained. This means that the soil under the building continuously swells with time and finally attains a mound shape while at the edges, the seasonal effects continue to occur. This is termed the centre-heave condition. As a consequence of this, the



Region	Soil Humidity	Dry period (months)
1	Continuously moist	-
2	Weak dry season	1
3	Marked dry season	2 – 3
4	Strong dry season	4 - 5

FIGURE 3: *Soil Humidity Map of Trinidad*

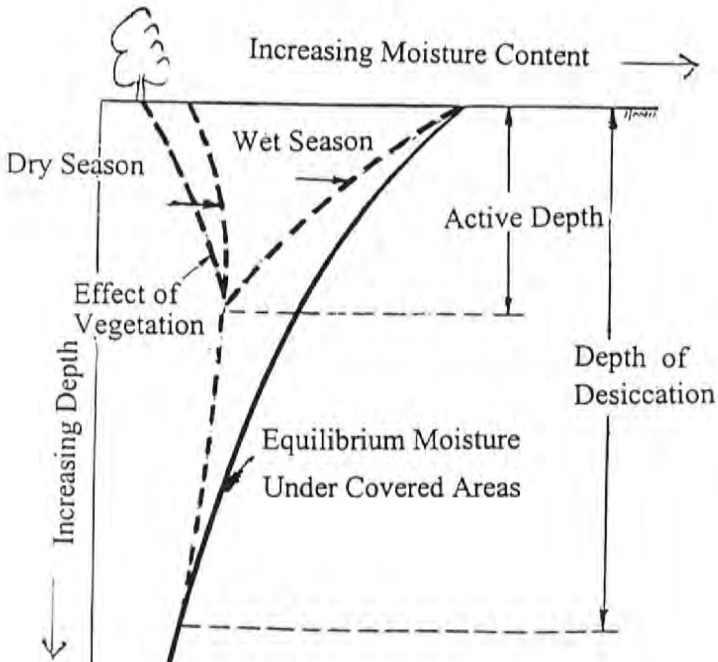


FIGURE 4: *Seasonal Moisture Variation*

foundation gets only a partial support from the soil at the centre as shown in **Figure 5**. The height of the mound formation depends on the area of soil covered by the building and also the active depth. Cracking of walls start in the upper region and traverse downward.

In the edge-shrink condition shown in **Figure 6**, cracks propagate diagonally across from top to bottom being wider at top and narrower towards the bottom of the structure. However, in the edge-lift case, the cracks develop from the lower region and traverse diagonally upwards being wider at bottom and narrower at top as illustrated in **Figure 7**.

Damage caused by a tree is similar to the edge-shrink condition because the soil at the periphery of the building is depleted of water by the tree roots (**Figure 8**).

6. How to identify if this Problem exists at the Site

Identifying the existence of an expansive soil at the site is an essential first step in the foundation design process. The procedure is simple and consists of (a) a desk study and (b) a site visit.

A desk study involves going through soil investigation reports of structures already constructed in the neighbourhood, expansive soil hazard maps for the area, if available, soil maps of the area, etc. A hazard map of expansive soil for Trinidad is shown in **Figure 9**.

Next step is to visit the site to verify information gathered from the desk study. The visual inspection of the site should include inspection of soil condition, topography and condition of neighbouring structures.

If the site inspection notes reveal the following, then there is evidence of soil being the expansive type:

(i) In dry season, the ground is extensively cracked up bearing a turtle-back appearance, the likeness of which may be seen on the front cover page. It is hard to crush a clod of dry soil between fingers.

(ii) In the wet season, soil is sticky and it sticks to shoes and car tyres. When a pat of wet soil is rolled between palms into a thread, approximately 3mm in diameter and a few centimetres long, it stands on its own weight when held down at one end.

(iii) Neighbouring buildings bear cracks on walls, doors are jammed, sidewalks are heaved up and so on.

If these observations show an evidence of an expansive soil being present, then the next step should be to collect disturbed soil samples for qualitative analysis in order to confirm the observations made during the site visit.

7. What is Qualitative Analysis?

Qualitative analysis is a procedure of identifying the degree of expansivity of soil using simple soil tests and existing correlations in literature. The soil tests commonly used for this identification are liquid limit, plastic limit, activity of soil, etc. These test results are applied to the charts available in literature to get the soil swell potential in terms of low, medium, high and very high degrees of expansivity.

Depending upon this classification, a suitable foundation type is chosen. This method is suitable only for small and unimportant structures. A note of caution is appropriate in the use of charts available in the literature. These charts are developed with reference to climatic and geological conditions obtaining in the application. Sometimes conclusions drawn based on these charts might prove disastrous. The correct approach would be to first test these systems with local geological and climatic conditions and measured data before adopting them.

For instance, Vander Merwe [2] developed a chart for South African soils and is popularly being used. This chart is shown in **Figure 10**. Clay fraction and plasticity indices of clays from 17 locations in South and Central Trinidad are shown plotted in the figure. Potential swell values measured of soils at these locations are not reflected by the chart. Therefore, the chart had to be modified suitably and the modified version is shown in **Figure 11**. A modified plasticity chart prepared for local use is also presented in **Figure 12**. It should be pointed out here that though this approach does not involve much expense, its reliability is low.

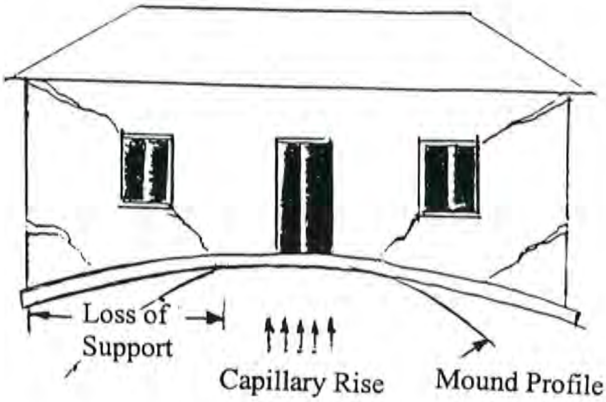


FIGURE 5: *Centre Heave Condition*

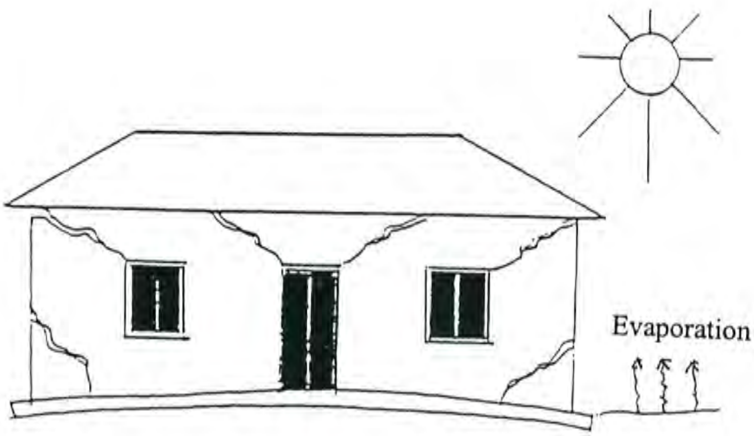


FIGURE 6: *Edge Shrink Condition*

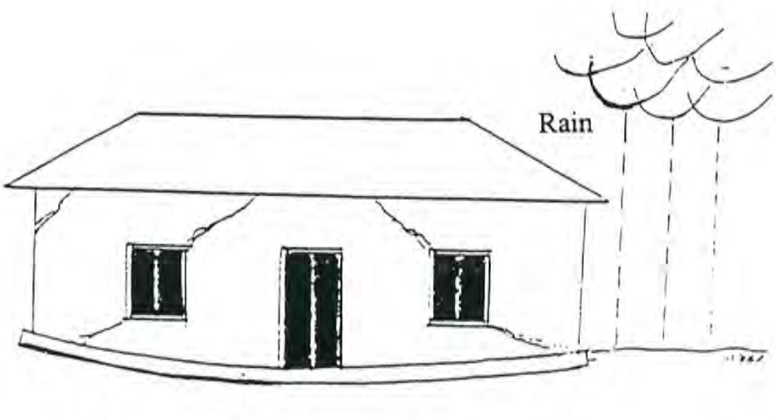


FIGURE 7: *Edge Heave Condition*

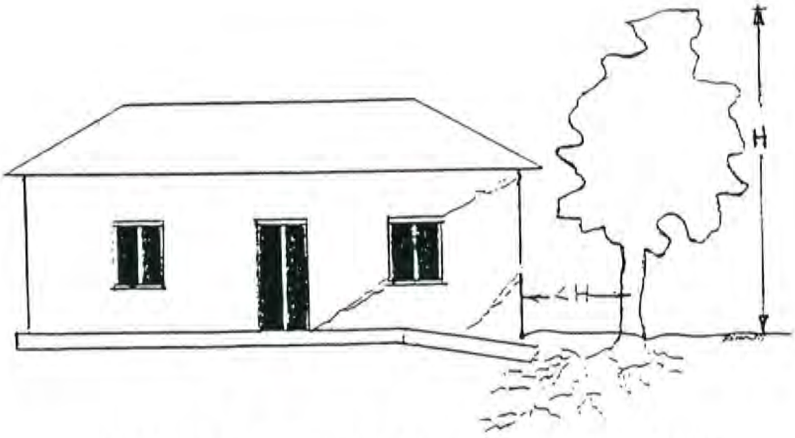


FIGURE 8: *Down Warping of Foundation due to Trees Closeby*

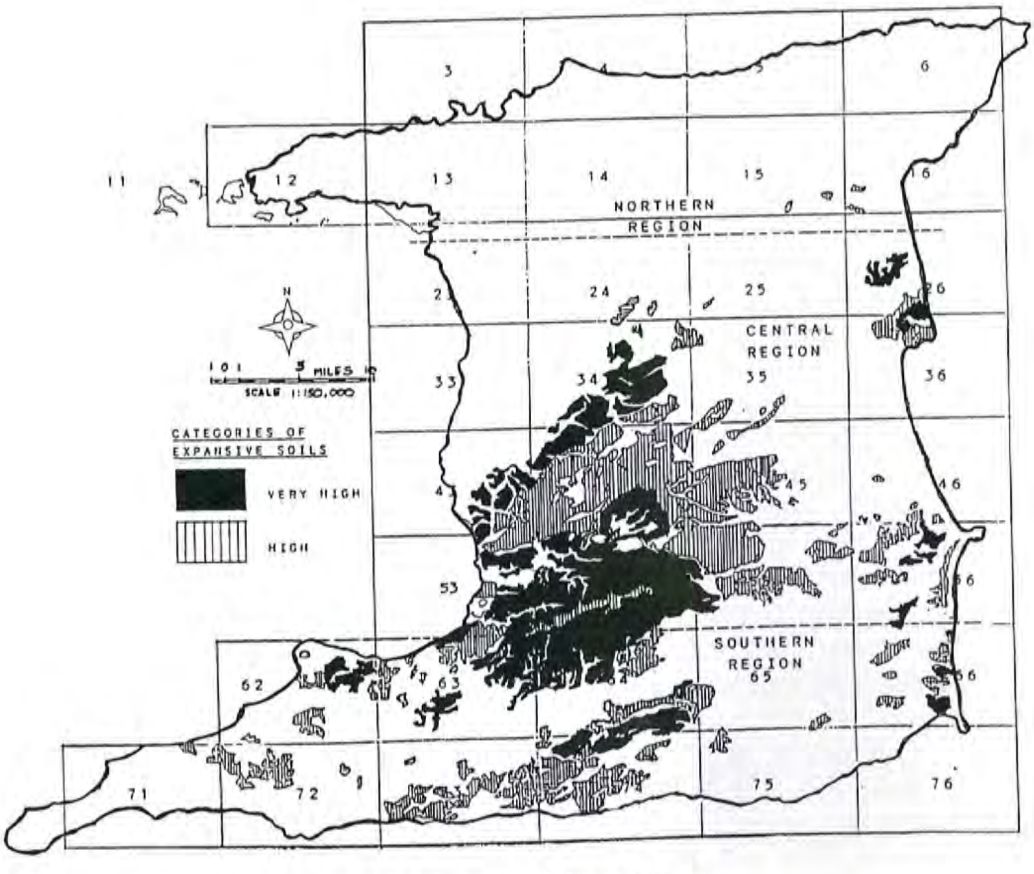


FIGURE 9: *A Hazard Map of Trinidad*

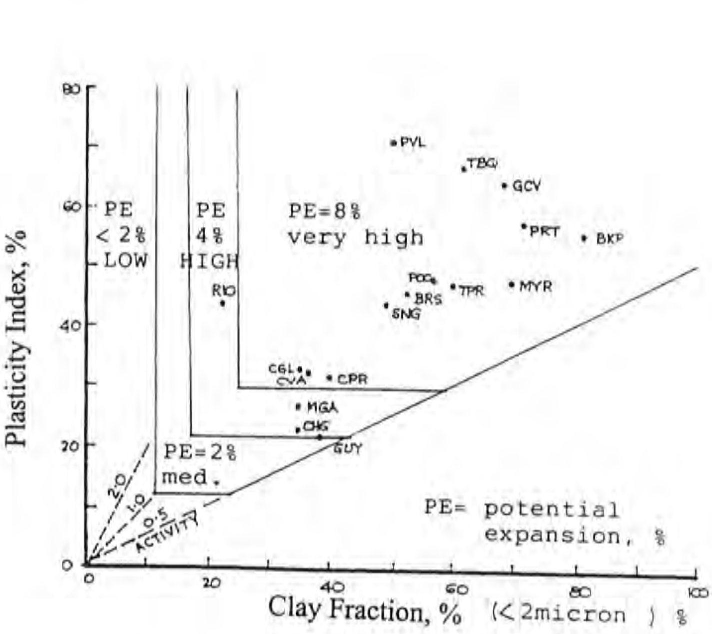


FIGURE 10: *Vander Merwe Chart*

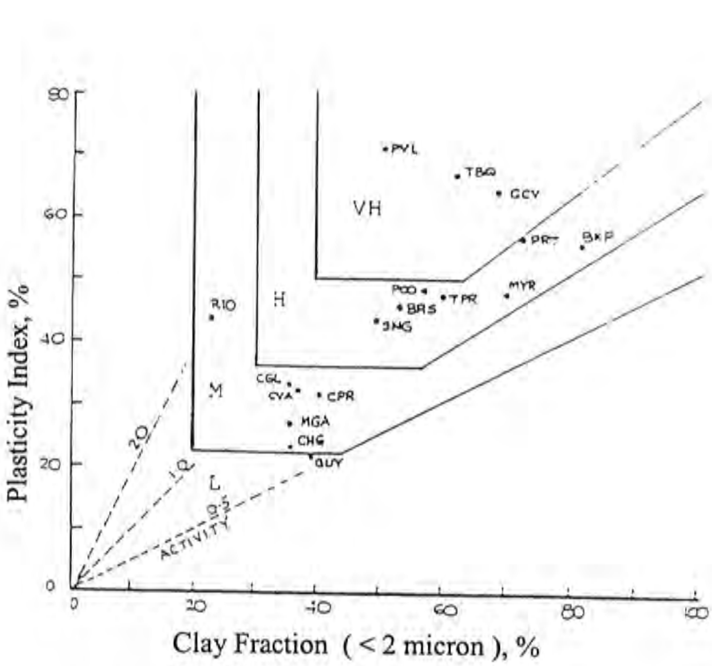


FIGURE 11: *Modified Vander Merwe Chart*

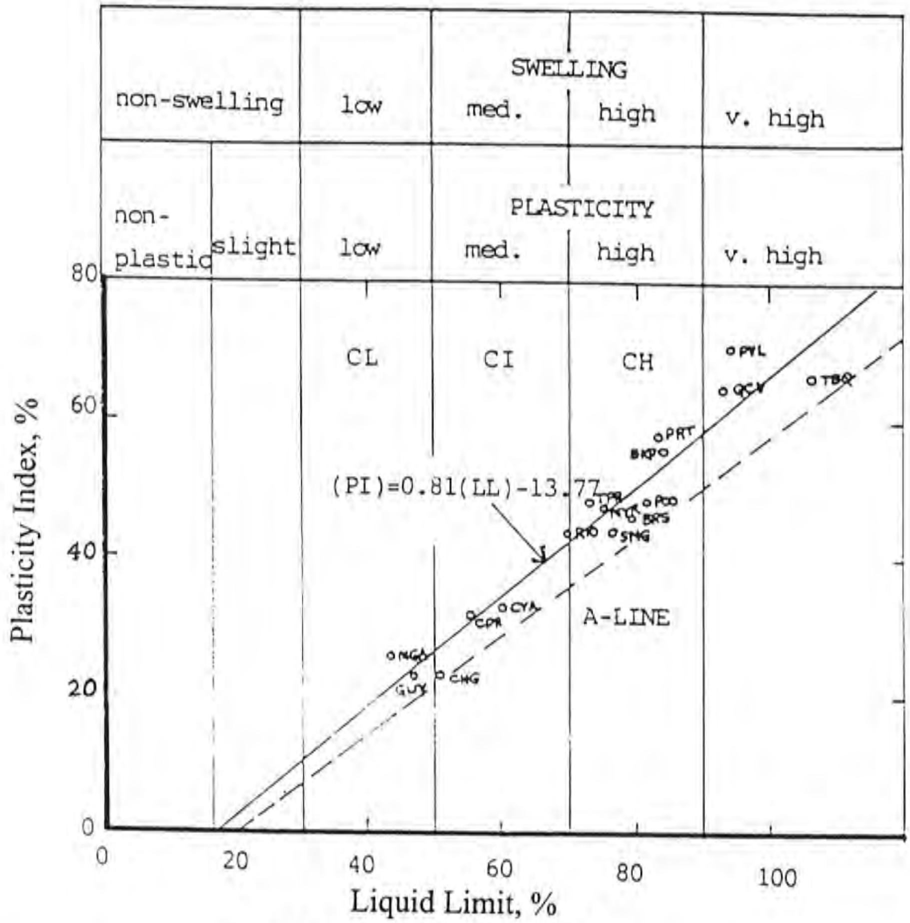


FIGURE 12: *Modified Plasticity Chart*

8. Is there a Method more reliable than the Qualitative Analysis?

Yes. Quantitative Analysis. The objective of this analysis is to predict a realistic value of the ground heave, which forms the basis for choice of foundation type and its design. The ground heave computations are carried out on the basis of swell tests performed on undisturbed soil samples. These soil samples are extracted from bore holes at suitable intervals reaching below the active depth. On account of the work involved and expertise required, this method may prove more expensive and time-consuming but is more reliable.

9. After the Quantitative Analysis - What next?

After the ground heave is computed using Oedometer swell test data, a suitable foundation system is chosen from Table 2 for detailed design.

However, it is worthwhile considering an alternative of excavating and replacing the expansive soil by a non-swelling clay soil, even for less than a metre from

TABLE 2: *Predicted Heave and Choice of Foundation Type*

Predicted Heave (mm)	Suitable Foundation Type
< 13	No precaution
13 - 50	Pad footings Strip footings
50 - 100	Stiffened mat Short piers
> 100	Pier foundations straight shaft belled piers

the surface. This under-cutting would greatly reduce the magnitude of heave allowing a simpler and less expensive foundation to be used.

Irrespective of the choice of a foundation system, it is essential that certain precautionary measures are put in place to safeguard against such effects as:

(i) Moisture penetration into foundation soil

(ii) Avoiding floors and beams directly resting on expansive soil and

(iii) Avoiding non-uniform watering of garden, etc. Other related aspects of construction are beyond the scope of this paper.

Acknowledgement

Funding from NIHERST and support facilities extended by The University of the West Indies and the Department of Civil Engineering in particular, for carrying out this research project are acknowledged.

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