INVESTIGATIONS ON THE EXPANSIVE SOILS OF ADDIS ABABA

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ABSTRACT

The significant engineering properties of the expansive soils of Addis Ababa have been studied in the laboratory. In addition, damages on structures due to heaving and shrinkage of the expansive soils have been assessed. A case study of 35 structures located within the expansive zone of the city was conducted. From the results of the investigations conclusions and observations that are of significant importance to Foundation Engineers have been drawn.

INTRODUCTION

A great deal of residential and office buildings are located in the eastern and southern part of Addis Ababa, where expansive soils are predominant. These soils are either black or grey in colour with thickness ranging from few centimeters to several meters.

It is a common occurance that structures which foundations are not adequately designed to withstand the stresses and strains caused by alternate heaving and shrinkage of the foundation soil crack. Cracks do not only affect the structural safety and aesthetics of the buildings but also bring about additional financial burden to owners for repair, if the structure is to be salvaged at all.

The object of this paper is to study the significant engineering properties of the expansive soils and assess the damages on structures as a result of heaving and shrinkage of the soil on which the foundations of the structures are erected. For this purpose samples were taken at six different locations and laboratory investigations carried out. A case study of 35 structures located within the area in question was also conducted.

SHORT BACKGROUND REVIEW

Occurance and Origion of Expansive Soils

Expansive soils are known to occur in many parts of the world. Some of these countries are: Argentina, Australia, Burma, Canada, Cuba, Ethiopia, Ghana, India, Iran, Israel, Mexico, Morocco, Poland, South Africa, Spain, Turkey, U.S.A., U.S.S.R., Venezuela and Zimbabwe [1].

The parent materials of expansive soils may be classified into two groups [1]. The first group comprises of basic igneous rocks. Here feldspar and pyroxene minerals of the parent rocks decompose to form montmorillonite — the predominant mineral of expansive soil — and other secondary minerals. The second group comprises of sedimentary rocks that contain montmorillonite. The expansive soils of Ethiopia are derived from both groups.

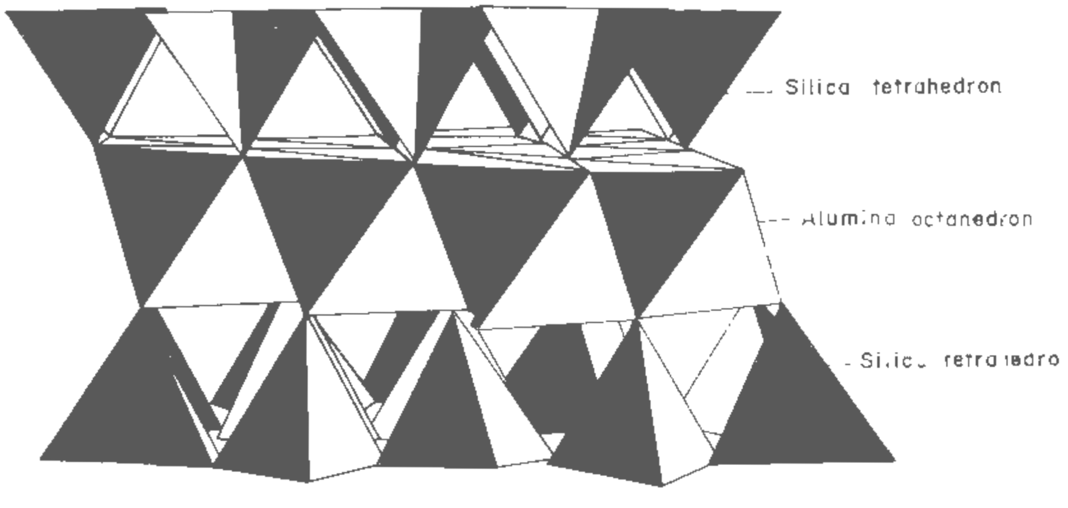

Fig. 1 Model of a Layer of Montmorillonite after Philip Low [4]

Mineralogical Composition and Characteristics of Expansive Soils

As stated above, the predominant mineral of expansive soils is montmorillonite. Basically, it is a three-layer mineral having a single octahedral alumina sheet sandwiched between two silica sheets [1]. The units are stacked one above the other like leaves of a book (Fig. 1). The bonds are comparatively weak and water can enter between the sheets causing them to expand readily. When water is removed from the boundary, the sheets contract. Thus soils containing substantial amount of montmorillonite will exhibit high shrinkage and swelling characteristics [2]. Experience shows that swelling problems arise when soils contain more than 20% montmorillonite [3].

INVESTIGATIONS

Within the framework of the present research, laboratory tests on samples taken at six different locations (Fig. 2) are conducted. At the same time case studies of 35 structures, all located within the region where samples were taken, are conducted.

Laboratory Investigations

To determine the engineering properties of the expansive soils, samples were taken from the following sites (Fig. 2):

(a) Old Air Port — Higher 24, Kebele 13.

(b) Bole Road (near Commercial School Alumnai Association) — Higher 18, Kebele 26.

(c) Near Civil Avaitation Radio Transmission Station — Higher 17, Kebele 23.

(d) Infront of Auto Manufacturing Company of Ethiopia (AMCE) — Higher 17, Kebele 24.

(e) In the compound of Yared Church (Nifas Silk) — Higher 19, Kebele 50.

(f) In the compound of Ethiopian Building Construction Authority (EBCA) — Higher 19, Kebele 47.

With the exception of site c, all other sites have two layers of soils. The first layer, with an average depth of one meter, is black in colour. The second layer is grey in colour and its depth may extend to several meters. The test pits are however limited to three meters.

Routine Laboratory Tests

Laboratory tests consisting of specific gravity, moisture content, total unit weight, dry unit weight, Atterberg Limits, free swell, swelling pressure and activity were carried out for the soil samples. The results are given in Table 1.

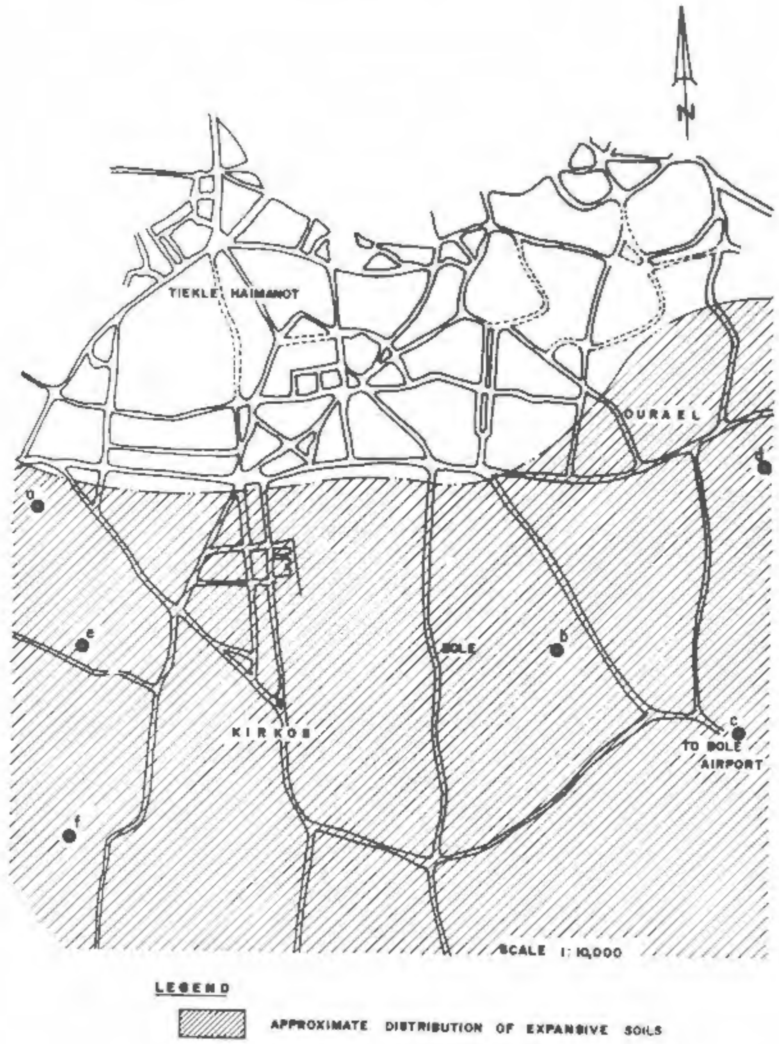

Fig. 2 Map of Addis Ababa [5]

Table 1. Laboratory Test Results

LOCATION	Depth	Colour	Specific Gravity G_s	Natural Moisture ω	Total Unit Weight γ_t	Dry Unit Weight γ_d	Liquid Limit ω_L	Plastic Limit ω_P	Plasticity Index I_P	Shrinkage Limit ω_s	Free swell	Swelling Pressure	Clay Fraction	Activity
	m	–	–	%	KN/m³	KN/m³	%	%	%	%	%	KN/m²	%	
AMCE	1.20	Black	2.63	38.6	18.4	13.3	102	24	78	12	130	125	50	1.6
	2.00	Grey	2.60	32.6	18.5	13.9	123	30	93	9	120	125	70	1.3
Bole Road	1.00	Black	2.65	32.4	17.9	13.5	110	35	75	12	150	188	60	1.3
	2.00	Grey	2.64	34.8	18.3	13.6	108	22	76	13	140	220	55	1.4
Civil Aviation	1.20	Black	2.66	36.7	18.2	13.3	94	22	72	10	130	157	45	1.6
EBCA	1.00	Black	2.69	30.2	18.2	14.0	101	26	75	9	140	251	50	1.5
	3.00	Grey	2.48	34.8	18.0	13.4	87	15	72	10	90	94	40	1.8
Old Air Port	1.00	Black	2.78	39.3	18.2	13.1	98	30	68	14	140	235	50	1.4
Yared Church	1.00	Black	2.69	40.0	17.6	12.6	114	25	89	11	125	94	60	1.5
	2.00	Grey	2.56	32.9	17.7	12.6	107	25	82	8	170	188	47	1.8

Mineralogical Identification

For mineralogical identification X-Ray Diffraction technique was used.

In general clay minerals may consist of kaolinite, illite, chlorite, montmorillonite, vermiculite and undifferentiated mixed layer clays. The variation of the minerals in a given sample could be seen from an X-Ray intensity curve. To quantify these variations, a method of semi-quantitative clay mineral estimation is used [4]. This semi-quantitative estimate is based on the comparison of the heights of appropriate diffraction peaks above the X-Ray diffractogram background (Fig. 3). This method has been used as most peaks are sharp and rather symmetrial indicating well-crystalized minerals.

As the samples used for the X-Ray diffraction tests were not treated with chemicals, existing standard value of mineral interplanar spacing as given by Beavers and Jones [5] were used for identifying the various minerals. The interplanar spacing values are given in Table 2.

Table 2. Interplanar spacing for untreated clay sample according to Beavers and Jones [5]

MINERAL	INTERPLANAR SPACING Å
Kaolinite	7
Illite	10
Chlorite	14
Montmorillonite	12–15
Vermiculite	14
Undifferentiated mixed layer	29

Procedure for calculating the percentage of all the minerals present in clay samples is given elsewhere [4]. Within the framework of this paper emphasis is laid on montmorillonite and the percentage of montmorillonite present in the samples is determined (Table 3).

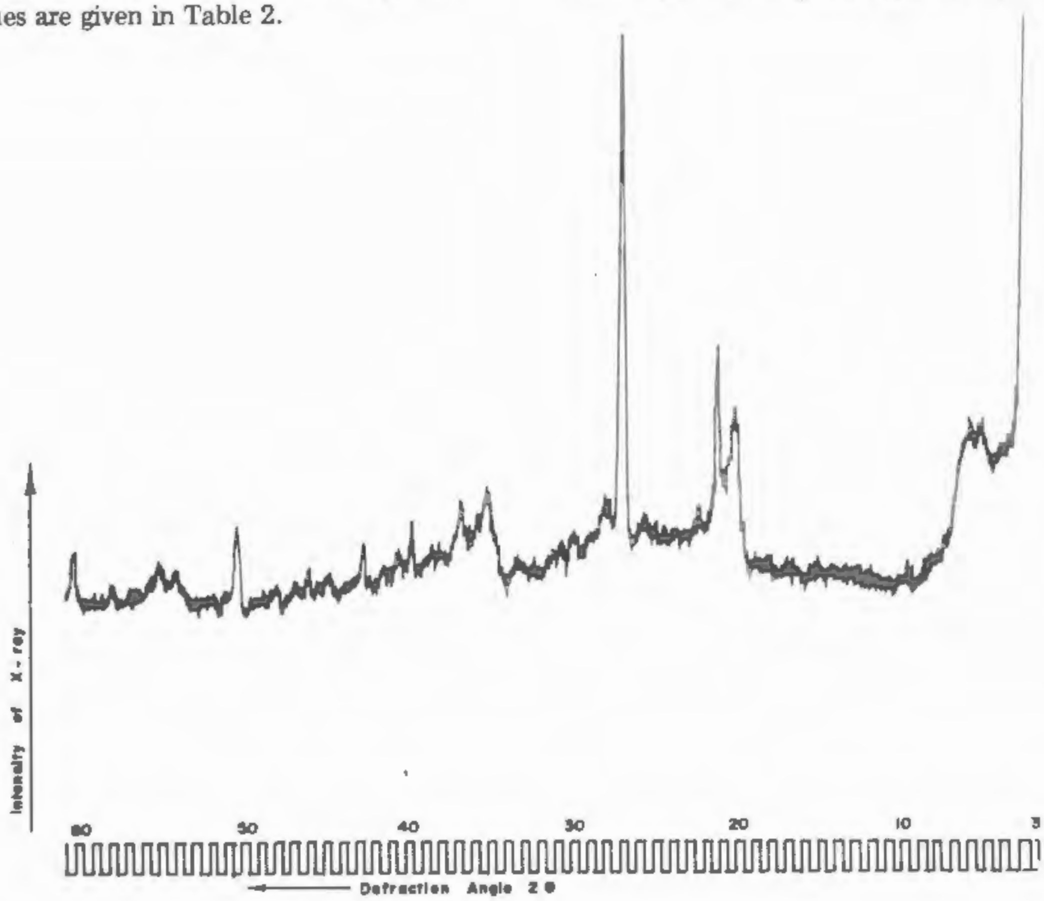

Fig. 3 Typical Result of X-Ray Diffraction Analysis (Sample from Civil Avation Radio Station at 1.20m Depth)

Table 3. Percentage of montmorillonite present in the soil samples tested

Location	Depth	Colour	Amount of montmorillonite
	m	—	%
AMCE	1.20	Black	50
	2.00	Grey	45
Bole Road	1.00	Black	46
	2.00	Grey	78
Civil Aviation	1.20	Black	75
EBCA	1.00	Black	49
	3.00	Grey	60
Old Airport	1.00	Black	50
Yared Church	1.00	Black	87
	2.00	Grey	50

Discussion of Test Results

The laboratory test results are plotted in the Plasticity and Activity Charts (Fig. 4 and Fig. 5). From the Figures one observes that:

(a) all samples are inorganic clays of high plasticity

(b) all samples are located between the Activity 1 and 2

(c) there is not clear distinction between the black and grey soils with regard to plasticity and activity.

It is useful to note here that most of the non-expansive red and brown clays have activity less than 0.5.

Swelling Potential. The swelling potential of the samples are calculated according to the empirical formula of Anderson [7].

$$S = 0.23\, I_p - 3.12$$

where

S = Swelling potential

I_p = Plasticity index.

Anderson has correlated the swelling potential with the degree of expansion as given in Table 4.

Table 4. Relationship between swelling potential and degree of expansion according to Anderson [7]

Degree of Expansion	Plasticity Index I_p	Swelling Potential S
Low	20	1.5
Medium	20 — 31	1.5 — 4.0
High	31 — 39	4.0 — 6.0
Very high	> 39	> 6.0

The swelling potential and the degree of expansion of the soil samples are given in Table 5.

As may be seen from Table 5, all samples manifest very high degree of expansion.

Swelling Pressure. Swelling potential is manifested by swelling pressure. Since swelling pressure is the actual pressure required to keep the volume of swelling soil constant, its magnitude indicates the danger that is to be anticipated. The test results of Table 1 indicate that both the grey and black soils show high swelling pressures.

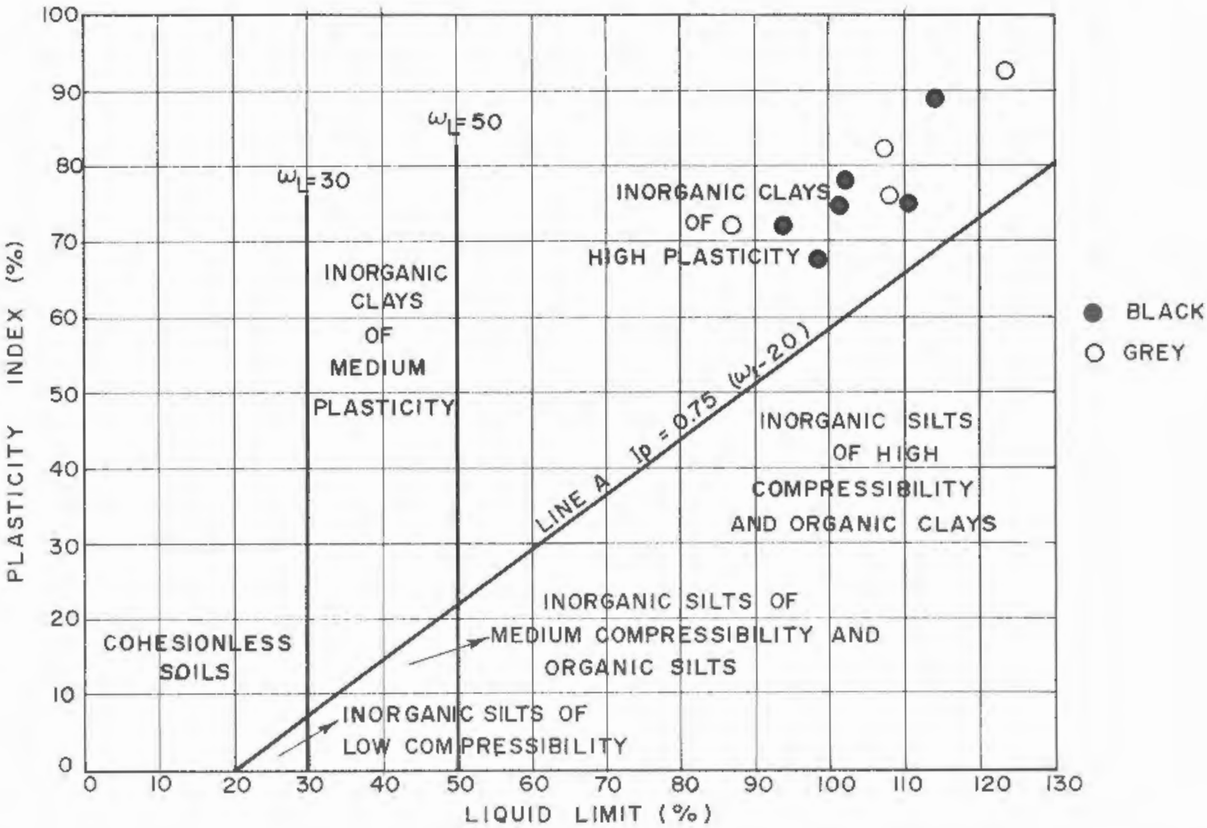

Fig. 4 Plasticity Chart

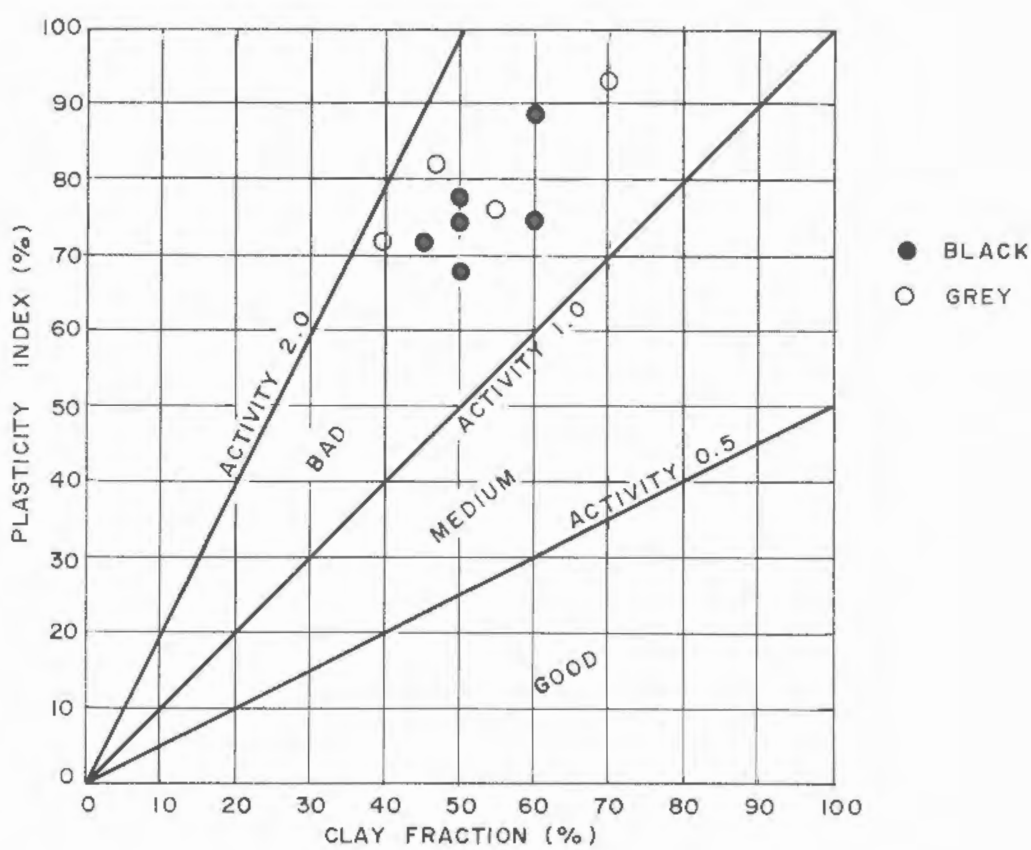

Fig. 5 Activity Chart

Table 5. Swelling potential and degree of expansion of the tested samples

LOCATION	Depth in metres	Colour	Plasticity Index I_p	Swelling Potential S	Degree of Expansion
AMCE	1.20	Black	78	14.9	Very high
	2.00	Grey	93	18.3	Very high
Bole Road	1.00	Black	75	14.1	Very high
	2.00	Grey	76	14.4	Very high
Civil Aviation	1.20	Black	72	13.4	Very high
EBCA	1.00	Black	75	14.1	Very high
	3.00	Grey	72	13.4	Very high
Old Air Port	1.00	Black	68	12.5	Very high
Yared Church	1.00	Black	89	17.5	Very high
	2.00	Grey	82	15.9	Very high

Table 6. Summary of type of structure, foundation and observed damage

Item	Type of Structure	Type of Foundation	Number of Structures Inspected		Intensity of Damage	Remarks
			Damaged	Not damaged		
1	Single story load bearing "Chika" or hollow cement block walls	Stone masonary	13	1	Severe wall cracks	–
2	Single story re-inforced concrete framed structure	Footing	3	–	Severe wall and column cracks	–
3	Single story load bearing bricks or hollow cement block walls or reinforced concrete framed structure	Mat	–	3	–	–
4	Single or two story reinforced concrete structure	Ordinary or under reamed pile	14	–	Moderate to severe cracks	Piles were located within the active zone of the expansive soil

Case Studies

Case studies of 35 structures all located within the regions of expansive soils (Fig. 2) were conducted. Typical damages that are observed are given in the pictures attached.

Table 6 gives the summary of the results of the investigation. The types of foundations are catagorized and the observed damages are recorded.

PLATE 1:

DIAGONAL CRACK FROM DOOR CORNER TO CIELING HIGHER 18, KEBELE 26, HOUSE NUMBER 114

PLATE 2:

CRACKS DEVELOPED AFTER THE ERECTION OF ADJOINING STRUCTURES HIGHER 17, KEBELE 20, HOUSE NUMBER 1139

PLATE 3:

DIAGONAL CRACKS FROM FLOOR LEVEL TO DOOR CORNER HIGHER 17, KEBELE 23, HOUSE NUMBER 1025

CONCLUSION

From the results of the investigation the following conclusions and observation may be drawn:

(i) The black and grey soils found in the eastern and southern part of Addis Ababa are highly expansive.

(ii) The percentage of montmorillonite present in the black and grey soils ranges from 45 to 87 percent.

(iii) There is not any distinction between the heaving characteristics of the grey and black soils.

(iv) Structures founded on conventional masonary wall foundations resting on an expansive soil are liable to crack.

(v) Structures founded on footings or piles that are located within the active zone of the expansive soil are liable to crack.

(vi) Structures which did not manifest any sign of cracks in their recorded history, have cracked severely when an adjoining structure is constructed.

(vii) Framed structures are found to be highly susceptible to damages due to heaving than other forms of construction.

(viii) The provision of proper drainage system plays an important role in reducing damage due to heaving.

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