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Investigation of Foundation Failure of a Residential Building – A Case Study

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ABSTRACT
Movement and distress in low rise building most commonly occur as a result of interaction between the footing system and the ground. This summarizes the study that is carried out to evaluate the possible causes of distress in the G+1 residential building founded on shallow foundation in Chennai, Tamilnadu, India by Detailed Investigation. Disturbed and Undisturbed samples are collected by drilling borehole up to significant depth by auger. Laboratory tests are carried out on disturbed and undisturbed soil samples obtained from the site of distressed building. The cause of failure of the structure are identified by considering the soil properties, intensity of loading, nature of foundation and pattern of cracks developed. Based on the degree of distress, the suitable measures are recommended.
***Keywords* –** cracks, distress, foundation, investigation, recommendations

I. INTRODUCTION

The investigation of a building where a failure has occurred is often necessary to establish the causes of the failure and to obtain the information required for the design of remedial measures. Observations and measurements of the feature of the structure to determine the mode of mechanism of failure are first needed, and these will often suggest the origin of the trouble, or at least indicate whether the ground conditions were partly or wholly responsible.

II. DETAILS OF THE DISTRESSED BUILDING

The G+1 Residential building founded on shallow foundation had undergone distress in Chennai, Tamilnadu. Hairline cracks were founded on exterior walls of the building. The building is surrounded by mango trees, azhadirachita indica (neem), coconut trees, and jack fruit trees about 20m height at a distance of 3.20m from the front exterior wall of the building. The distresses were found only on the front exterior wall of the building. The age of the building is about 35 years.

III. FOUNDATION DETAILS

The type of foundation is stepped continuous footing (wall footing). The depth of the foundation of the building is about 0.9m from the existing ground level. It is laid over 0.1m thickness of plain cement concrete and 0.3m thick sand cushion. At the time of soil exploration, a trench had been excavated near to the front wall of the building to identify the type and depth of foundation. The foundation details of the distressed building are shown in Fig.1.

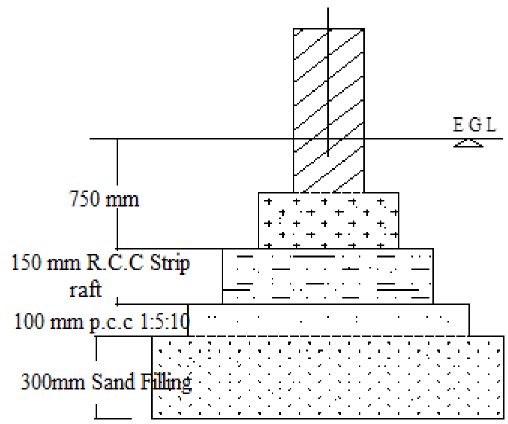

Fig.1 Foundation Details

IV. NATURE OF THE DISTRESS

The nature of the distress i.e. the typical crack patterns in the front wall of buildings that was observed are shown in Fig 2. The first crack was noticed during the year 2008 by the residents. There are a number of windows in the front wall

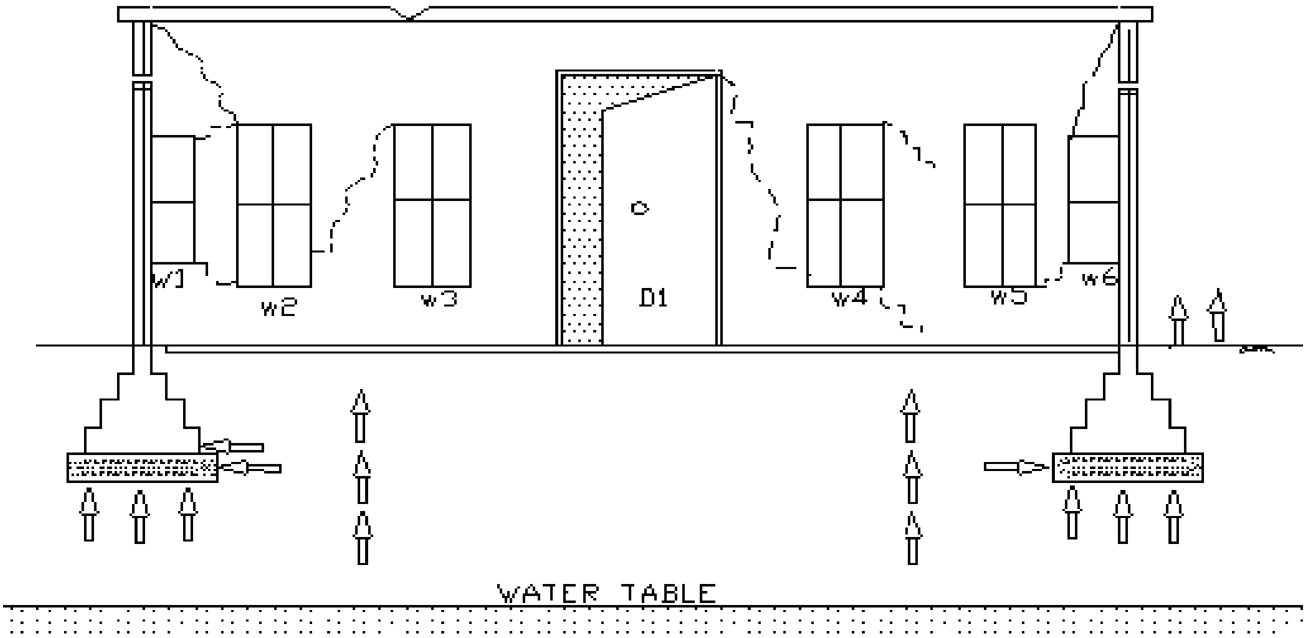

Fig.2 Sketch Depicting Cracks in Exterior Wall

of the building and are marked as W1, W2 and etc. The Cracks were propagated from window to window and window to door. The width of the footing was about 3mm to 5mm. As per AS 2870-1996, the Residential slab and footing code, damage due to foundation movement, this building is classified under the category 3.

V. SOIL EXPLORATION

Two auger- borings were drilled adjacent to the distressed building up to the depth of the water table. Disturbed samples were collected at every one feet of bore hole. Undisturbed samples were collected from borehole 1 at 1.5m and 2.4m depth. From borehole 2, undisturbed samples were also collected at a depth of 1.2m and 2.1m. The water table was at a depth of 3.2m from the ground level during the exploration which was done during September 2012.

VI. LABORATORY TEST RESULTS

The routine laboratory tests such as grain size distribution, Atterberg's limits, UCC, and Differential free swell were conducted on the disturbed and the undisturbed samples collected from the two bore holes. All the tests were done as per relevant I.S. Codes.

6.1 Natural Moisture Content

The natural moisture content is obtained from the disturbed samples collected from the every feet of the two boreholes. In the borehole 1, there is general increase in moisture content with depth, from 16.46 % in 1.2m to 29.39 % at 2.7 m. In borehole 2, also there is an increase in moisture content with depth from 17.26 % at 1.2m to 33.34 % at 2.7 m.

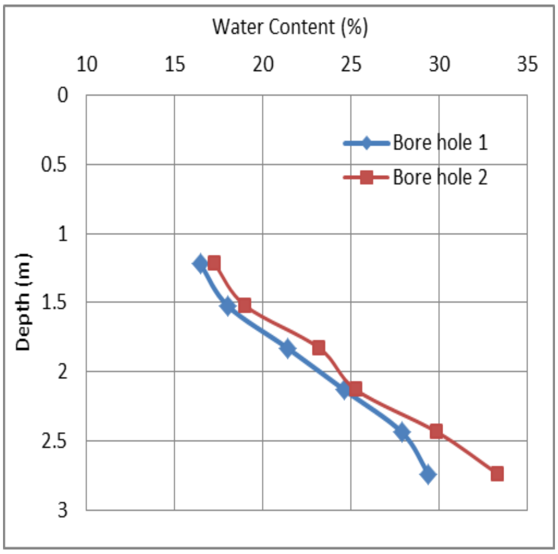

Fig.3 Variation of natural moisture content with respect to depth

All the laboratory test results obtained on the disturbed and the undisturbed samples are consolidated and presented in the Table 1 and Table 2 respectively

Table. 1 Soil Profile of Borehole 1

Soil profile		Depth (m)	Grain size distribution: Gravel (%)	Sand(%)	Silt (%)	Clay (%)	Atterberg Limits: w_L(%)	w_P (%)	w_S(%)	Ip (%)	BIS Classification	nmc (%)	Unconfined compressive strength (kN/m²)	Cu (kN/m²)	Differential free swell %
	0														
Top layer		1.2	-	-	-	-	49	20	13	29	CI	16.4	-	-	40
Dark Brown Stiff Clay		1.5	-	14	36	50	56	21	12	34	CH	18.0	169.6	84.8	-
		1.8	-	-	-	-	62	26	9	37	CH	21.3	-	-	70
		2.1	-	-	-	-	69	28	10	41	CH	23.6	-	-	-
Brownish Red, Medium stiff Clay		2.4	-	54	8	38	38	14	14	24	SC	27.8	96.4	48.2	-
	W.T	2.7	-	-	-	-	-	-	-	-	-	29.3	-	-	-

Table. 2 Soil Profile of Borehole 2

Soil profile		Depth (m)	Grain size distribution: Gravel (%)	Sand(%)	Silt (%)	Clay (%)	Atterberg Limits: w_L(%)	w_P (%)	w_S(%)	Ip (%)	BIS Classification	nmc (%)	Unconfined compressive strength (kN/m²)	Cu (kN/m²)	Differential free swell %
	0.0														
Top layer		0.9	-	54	16	30	36	18	12	18	SC	16.3	-	-	-
		1.2	-	-	-	-	47	21	13	26	CI	17.2	-	-	40
Dark Brown Stiff Clay		1.5	-	12	40	48	56	23	12	33	CH	19.0	104.8	52.4	-
		1.8	-	-	-	-	63	27	9	36	CH	23.19	-	-	-
		2.1	-	-	-	-	72	24	10	48	CH	25.3	89.4	44.7	70
Brownish Red, Medium Clay		2.4	-	50	10	40	36	16	14	20	SC	29.88	-	-	-
	W.T	2.7	-	-	-	-	-	-	-	-	-	33.34	-	-	-

6.2 Unconfined Compression Tests

Undisturbed samples were collected from borehole 1 at 1.5m and 2.4 m depth and also collected from borehole 2 at a depth of 1.2 and 2.1m. In Borehole 1, the undrained cohesion obtained from the UCC tests are 84.8kN/m^2 and 48.2kN/m^2 at a depth of 1.5m and 2.4m respectively. The Stress-Strain Curve for UDS of Borehole1are presented in the Figure 4 and Figure 4.

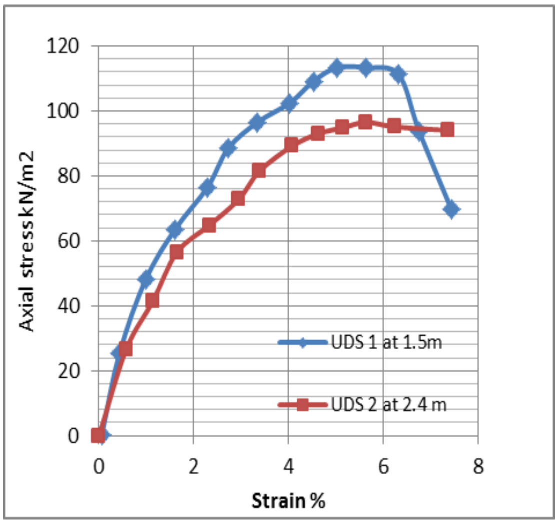

Fig. 4 Stress-Strain Curve for UDS of Borehole1

In Borehole 2, the undrained cohesion obtained from the UCC tests are 52.4kN/m^2 and 44.7 kN/m^2 at a depth of 1.2m and 2.1m respectively. The Stress-Strain Curve for UDS of Borehole1are presented in the Figure 4 and Figure 5.

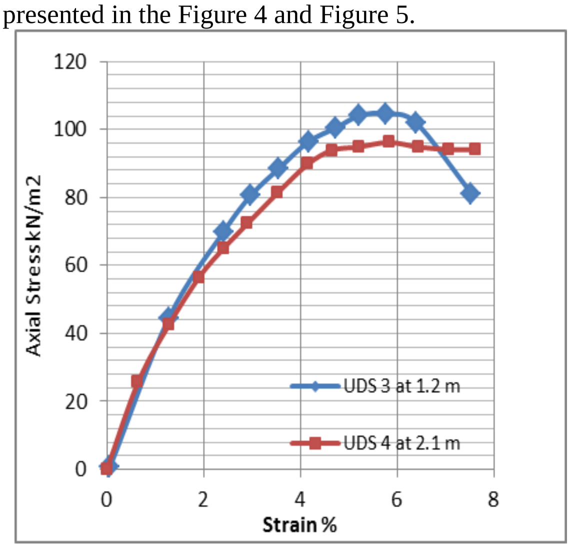

Fig. 5 Stress-Strain Curve for UDS of Borehole2

6.3 Swell Test

For situations where it is necessary to investigate expansive soils, it is necessary to estimate the magnitude of swell, i.e., surface heave, and the corresponding swelling pressures that may occur if the soil becomes wetted. The swelling pressure represents the magnitude of pressure that would be necessary to resist the tendency of the soil to swell. A one-dimensional swell potential test was performed in an odeometer on remolded samples according to ASTM D 4546.

The swelling potential and swelling pressure tests were conducted on soil specimens compacted to moisture content in the range of 12% to 28%. At shrinkage water content, the percent swell is 2.8%. For 26% water content, the swell was 1.2 %. The differential free swell is about 40 % in 1.2 m and increased to 70% in 1.8m.

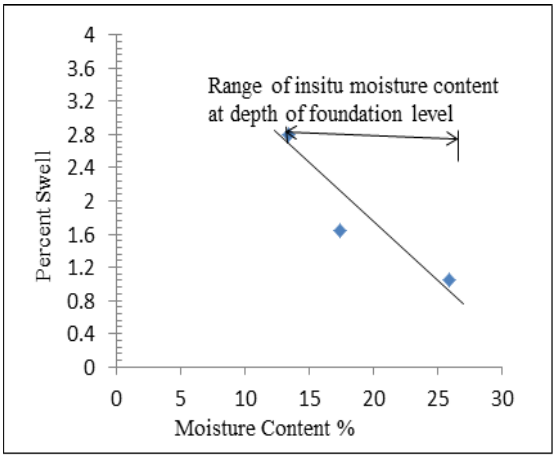

Fig. 6 Moisture Content Versus Percent Swell

VII. INTERPRETATION OF THE RECONNAISSANCE SURVEY

The type of foundation is strip raft and is locate at a depth of 0.9m from the existing ground level. Apparently the stiffness of the building had been reduced due to the provision of doors and windows.

During the reconnaissance survey, it was gathered that cracks were initially developed in the front wall of the building during a dry period of year 2008. The building is surrounded by jack fruit tree about 20m height at a distance of 3.20m from the front exterior wall of the building. The water table is located at a depth of 3.2m during the investigation.

VIII. INTERPRETAION OF THE RESULTS

Bore log table reveals that the foundation of residential building was laid over CH type of clay with considerable volume - change characteristics As it could be perused, the soil up to 2.80m depth are CH type of clay with possible volume – change characteristics in which the top layer up to 1.10m has higher shear strength than the bottom layer.

Besides, the plastic limit and the natural water content are almost same. The consistency of the clay is medium stiff to stiff. Based on Driscoll (1983), the natural moisture content is close to the range of 0.5 time's liquid limit which shows that the clay layer has undergone significant desiccation.

IX. REASONS FOR DISTRESS IN THE BUILDING

The reasons attributed for the distress of a building selected in the present investigation are detailed below.

i. Moisture differences between the interior and exterior portion of the building caused by the environmental factors such as vegetation growth, evapo-transpiration and climatic variations. The trees are located very close to the building i.e., the distance between tree and building is lesser than height of the tree.
ii. The severe distress in the front wall when compared to other distressed portion was due to the large openings provided in the form of doors windows especially in the corner
iii. From the soil profile and foundation data, it is expected that the distress may be due to the presence of CH type of clay layer beneath the footing where has undergone significant desiccation.
iv. The factor of safety of bearing capacity is five and is based on the actual load on the footing and shear strength of underlying clay. Hence it is concluded that the presence of desiccation of CH type clay layer beneath the footing is the cause of the distress.

X. REMEDIAL MEASURES

The methods proposed to ensure moisture - balance consists of following steps:

- Drilling the bore holes up to active zone or up to the water table around the building perimeter.
- Filling the bore holes with brick jelly with lime. The percentage of lime is to be added based on lime reaction with soil (4% to 6%)
- Saturating the lime brick jelly with water, so it will reach the sides of the bore hole and reduce the degree of desiccation. During rainy season, the rainwater can be diverted into the boreholes.
- Prevent the cycle of heave and shrinkage by protecting the foundation of the building from water content changes, it was recommended that, all the trees located at a distance ranging from 1 to 1.5m from the front wall were removed, if the distress are very severe in future.

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