Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Remedial Measures to Rectify the Distress in the Staff Quarters of CUTN, Thiruvarur, Tamil Nadu- Case Study

Muttharam. M[1] and Stalin.V.K[2]

[1,2]Anna University, Chennai, India

[1]muttharam@gmail.com

Abstract. The Central University of Tamil Nadu (CUTN), Thiruvarur had constructed 30 numbers of Staff Quarters with load bearing wall in 2013. During the end of 2016, considerable vertical, horizontal and diagonal cracks of 5mm to 10mm wide were noticed, in one building, on the exterior walls of living room and also caving-in of floor tiles and plinth protection slabs to a depth of 50 mm to 100 mm. The type of foundation was strip footing of 2m width placed at 2m depth (Footing pressure is 68.98 kN/m^2). Bore log data revealed that the top 4m soil below the footing is dominantly expansive clay of N-value 4 to 7 underlain by sandy layer of N-value 4 to 7. The consolidation settlement of 142mm and swell pressure of 410 kN/m^2 were computed for the soil below the footing. Hence, it was evident that excess settlement and swell pressure due to untreated expansive soil are the primary causes of distress in building. To remediate distress, it was recommended to stabilize the foundation soil by lime injection in the entire footing area of building. In the severely affected area, under reamed piles with single bulb was recommended up to a depth of 3.6m.

Keywords: Distress; expansive soil; remedial measures.

1 Introduction

The CPWD, Thiruvarur had constructed 30 no.s of Staff Quarters (duplex type) with load bearing wall at Nagakudi Campus in the year 2013. During the end of September 2016, diagonal cracks of 5mm wide have been noticed by the authorities of CPWD in one of the Staff quarters on the external wall of living room. The various crack patterns were observed. Apart from visual inspection, soil samples were also collected adjacent to the distressed building at a depth of 2.5m for laboratory testing.

This paper comprises of pattern of cracks, analysis of foundation suitability, possible causes of distress and recommendation over the remedial measures to be undertaken.

2 Site Location and History of Distress

The distressed building is located by a vacant land on the eastern side with trees, plants and shrubs, Staff Quarters to the northern side and western side. The southern side of building is located by vacant land with trees followed by main road connecting other university premises. The construction of 30 nos. of Staff Quarters seemed to have been started in the year 2012 and completed in 2013. Around the end of September 2016, considerable diagonal cracks of 5mm wide had been noticed in one of the Staff quarters by the Engineers of CPWD around the exterior and interior walls of living room that had propagated for the entire height of 6m. The cracks seemed to be active.

3 Observation made at the site during inspection

The following observations were made at the distressed building site during inspection:

1. Considerable vertical, horizontal and diagonal cracks of 5 to 10mm wide were noticed on the exterior walls of living room (southern side) that had extended to the entire height of 6m double storeyed wall. (fig.1 a, b)
2. Caving-in of the plinth protection slabs of the entire southern side of the building was noticed to a depth of 50mm to 100mm which had literally separated from the outer walls. (fig.1 c, d)
3. The platform and footsteps on the eastern portion of the building were completely damaged and were beyond repairable condition .
4. Cracks of 2mm to 5mm were even seen in the outer wall of bed room-1 on the eastern and northern side of the building and separation of plinth protection slab from the exterior wall. (fig.1 e)
5. Caving-in of the floor tiles to a depth of 50mm to 100mm were noticed at the interface of interior walls and vitrified tiled floors especially at the living area of southern side of the building. (fig.1 f)
6. The pattern of cracks whatsoever observed on the outer portion of load bearing walls were seen even in the inner portion of same wall and thus confirmed the complete separation of load bearing wall from its position.

The direction of propagation of diagonal, vertical and horizontal cracks indicated the likely foundation soil movement triggered by either excessive settlement or swell-shrink problems.

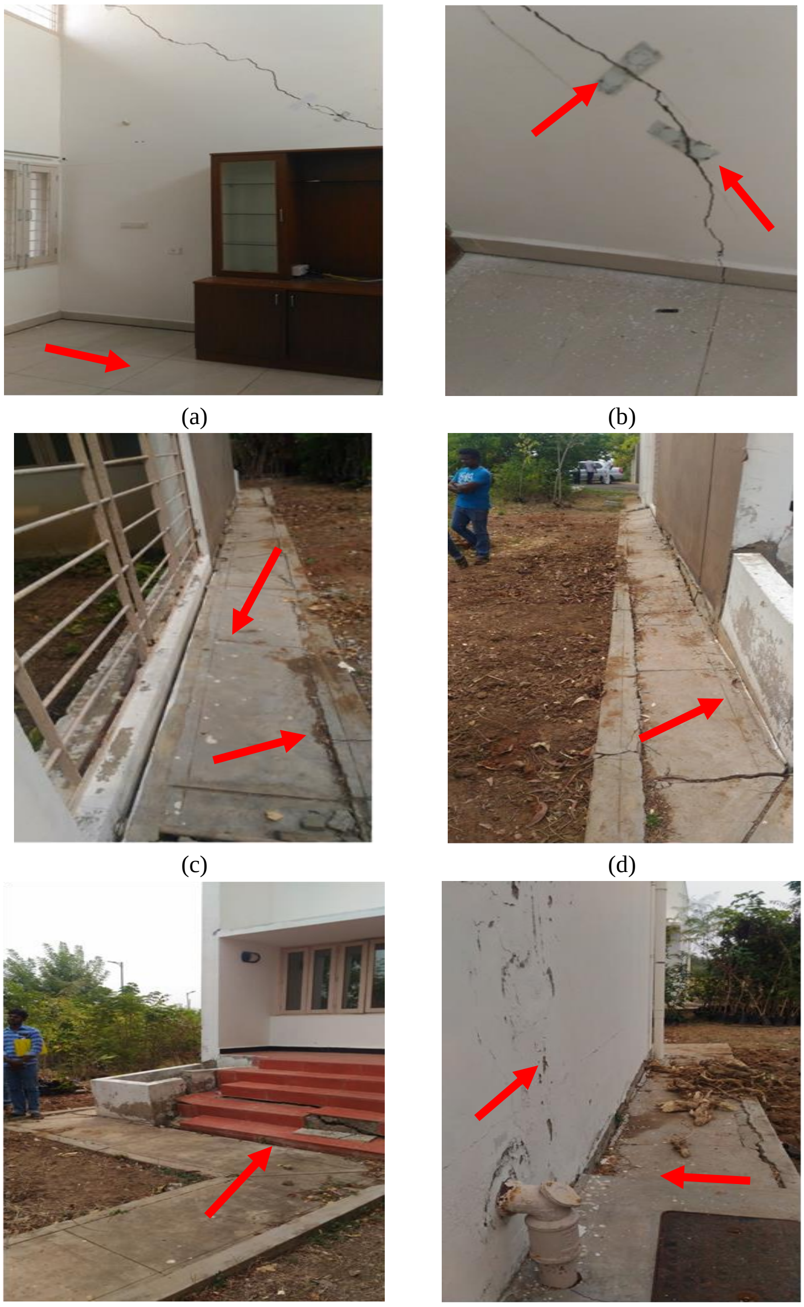

Fig.1 (a) View of caving-in of vitrified tiles and (b) diagonal wall cracks in the inner portion living room area; (c),(d) Caving-in of the plinth protection slab southern side (e) Damages of platform and footstep of eastern portion of the building (f) Views of wall crack and caving-in of plinth protection slab on northern side

4 Variation of Foundation Soil Profile

The following inferences were made from the soil investigation report: (prior to the start of construction)

1. The variation of soil profile in all the six boreholes were more or less uniform upto the termination depth of 22.5m.
2. The original ground water table was located at a depth of 4.0m from the existing ground level. Ground water level was assumed at ground surface for the design of foundations to consider the worst condition.
3. In all the boreholes, the top 4m was dominantly grayish clay of ‘N’ value 4 - 7 only underlain by a sandy layer of ‘N’ value 4 - 7.
4. The top 4m clay layer is high compressible and high swelling in nature. The clay layer present at 2 - 3m depth may induce some amount of swell pressure to the foundation system.
5. At 6m and 7m depth brown silty clay was found with ‘N’ values of 15 – 20 underlain by brown sand upto 10.5 m depth with ‘N’ value of 16 – 48
6. Beyond 12m upto 16.5m, grayish and brown silty clay of ‘N’ value of 30 – 54 underlain by a brown clayey sand of ‘N’ values of 51 – 56 were present.

Soil samples were also collected at 2.5m depth adjacent to the southern side of the existing distressed building at the time of site investigation. The soil samples thus collected were tested for grain size distribution, liquid and plastic limit, free swell index and swell pressure test as per Indian standards SP 36 Part-1, 1987. The test results are presented in Table 1.

Table 1 Index and swell properties of foundation soil

Description	Gray Blackish clay
Grain size %	
Gravel	3
Sand	24
Silt	18
Clay	55
Liquid limit (%)	64
Plastic limit (%)	23
Plasticity index (%)	41
Shrinkage limit (%)	7.75
Free Swell Index (%)	125
Swell pressure* (kg/cm^2)	4.1

*Swell pressure test was conducted by expanding volume method at a surcharge pressure of 0.05 kg / cm^2 at a density of 1.65 gm / cc and 5% IMC.

As per IS classification, the soil is classified as ‘CH’ category (clay of high compressibility or high plasticity). According to FSI value, the soil is classified as ‘high expansive clay'. The swell pressure value of 4.1 kg / cm^2 corresponds to the description of soil swelling as 'severe' (Chen 1988, Varghese 2005).

In general, expansive soil undergoes severe volume change, both swelling and shrinkage, during extreme environmental changes. Normally, expansive clays should be treated prior to the construction, with stabilization methods such as lime column, lime injection or CNS (clay of non swelling layer) to control the swell-shrink behaviour.

Alternatively, suitable foundation system such as under reamed pile, T-beam strip foundation, Virendel frame with brick infill, waffle slab (rigid mat) etc. may also be provided.

The top expansive clay of 4m thick was having 'N' value of 4 - 7 only, which corresponds to the classification of medium consistency. Upon swelling, because of the volume expansion, the strength of the expansive clay may get reduced and in turn the foundation is at risk in terms of effective load transfer onto the underlying soil.

5 Computation of Total Load of Building Acting on Foundation System

A. Bed Room Area:

The estimated load acting on the bedroom area was 6.5 kN/m^2 and the load on the wall per metre run was 38.83 kN. The recommended width of the footing was 0.55m.

B. Living Room Area:

The estimated load acting on the living room area is 6.5 kN/m^2 and the load on the wall per metre run was 51.74 kN. The recommended width of the footing was 0.75m.

6 Computation of Settlement of Foundation Soil below 2m Depth

The founding depth of strip footing was 2m. In order to check the adequacy of settlement criteria of the foundation, a typical worst soil profile is considered for the computation of consolidation settlement of foundation soil of 4m thick as shown in figure 2.

The liquid limit of 4m clay layer is 62% and initial void ratio (e_0) is 0.85. The compression index of soil is computed using equation Cc = 0.009 (LL - 10) [Skempton, 1944 -for undisturbed clays] and surcharge pressure at foundation level (P) is 49.2 kN / m^2. For the total load of 51.74 kN / m in living room area, the additional pressure (Δ P) is computed as 18.81 kN / m^2 at the mid of 4m clay layer.

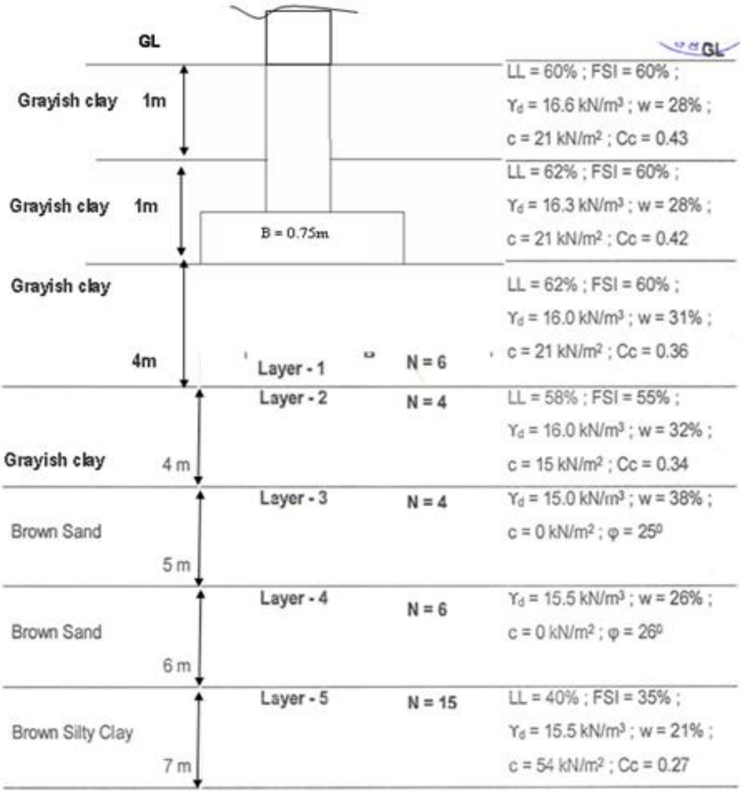

Fig.2 Soil profile below foundation (worst soil profile from BH1 to BH7)

The consolidation settlement computed is 142 mm which is much higher than the recommended allowable settlement of 50mm.

7 Possible Causes of Distress in the Staff Quarters

The stability of any structure resting on soil is primarily governed by two factors. One is the stability of foundation system and the other is stability of super structure. Distress of building / structure would normally emanate whenever there is structural inadequacy such as inadequate structural member, inadequate of stiffeners (tie beam), inadequate reinforcement, poor construction, etc.,

Apart from structural inadequacy, distress of building structures would also occur due to poor foundation system which include inadequate foundation system (not considering the bearing capacity and settlement criteria) and foundations made to rest on problematic soils such as expansive clays, soft clays, collapsible soils, dispersive soils, etc. wherein soil would excessively settle or swell or shrink depends on site specific conditions.

On carefully reviewing the structural design drawing and soil investigation report, crack patterns, calculations on settlement and swell pressure of foundation soil, the following reasons are concluded for the possible distress of the Staff Quarters building.

Foundation Problem:

1. The design drawing recommended by CPWD has assumed SBC of 10 t / m^2 and width of strip footing as 0.75m at 2.0m depth. But, the soil investigation report recommended only 70 kN / m^2 (7 t / m^2) as SBC at a foundation depth of 2.5m. Further, to avoid differential settlement expected out of expansive clays, combined footing or raft foundation was recommended. However, strip footing was adopted. Further, provision of sand cushion was recommended in the report to minimize the differential settlement, which does not seem to have been executed.
   Because, the foundation is allowed to rest of 4m expansive soil, there was every possibility for foundation soil to undergo excess settlement and also exert swelling pressure onto footing under complete inundation.
2. Consolidation settlement computations revealed that the excess settlement of 142 mm of foundation soil could be one of the major causes for the distress of the buildings.
3. Adding further, the swelling pressure of the foundation soil is 4.1 kg/cm^2 ($\cong$410 kN/m^2). The footing pressure exerted on foundation at bed room area is 51.77 kN/m^2 and the footing pressure exerted on foundation at living room area is 68.98 kN/m^2. Thus, the swell pressure exerted by the foundation clay is more than the footing pressure and consequences of which there could have been upward thrust of the expansive clay on to the footing especially during complete inundation of foundation soil in rainy seasons. This could have induced movement of foundation in turn distress to the building.

Structural Problem:

1. While all the footings were interconnected, as per the design drawing given by CPWD, the living room area was not interconnected at ground level to the adjoining area such as bed room, toilet-I and staircases, even though the living room area is double storeyed height, (interconnection would have distributed the load uniformly and the severity of the distress could have been averted).
2. The crack propagated in the load bearing wall of the living room area to a height of 6m possibly because of non-availability of intermediate beam or stiffener, otherwise crack would have stopped at 3m itself from the ground level.

Considering the above facts, it is thus concluded that excessive settlement of foundation soil and excess swell pressure exerted by untreated expansive clays of 4m depth below the footing are the primary causes for the distress of the Staff quarters especially in the double storeyed height living area.

8 Recommendations of Remedial Measures

The following remedial measures are recommended to upkeep the building from further distress:

1. In order to mitigate the high compressive and swelling clay of 4m thick below the footing, the foundation soil may be stabilized with lime injection method at regular intervals and this will arrest the swell-shrink behaviour of expansive soil during extreme environmental condition as shown in fig.3. In the process of attempting to control the swell-shrink behaviour of expansive clay by lime injection, the soil would become less compressible in nature and the soil would not settle further more, once if it is stabilized with lime injection. Soil samples may be collected and tested, after minimum curing period, after the lime injection treatment to ensure the improvement upon treatment of ground.

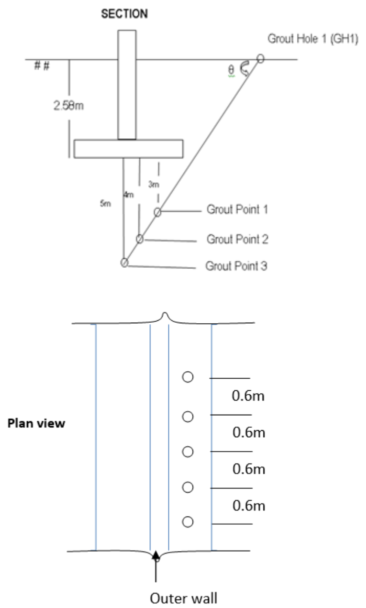

Fig.3 Schematic view of pressure grouting to be executed at the distressed site

2. In the severely affected places, where the cracks are considerable, especially the living area with double storeyed height, under-reamed piles with single bulb may be provided on either side of the wall with interconnected beams such that the load intensity of the load bearing wall be shared on to the pile as shown in figures 4 and 5. In the span of 5.46 m wide living room, a minimum of two sets of under-reamed pile may be provided as shown in figure 5.

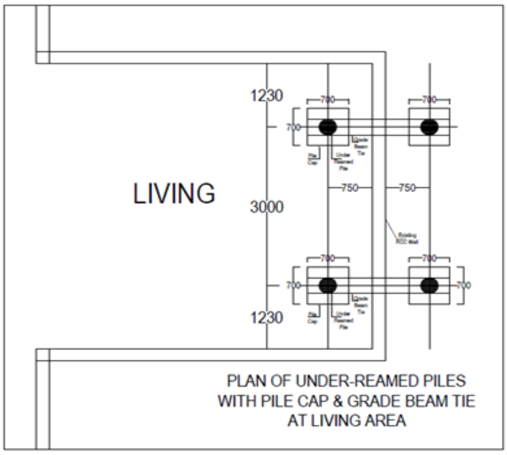

Fig.4 Plan of Under- Reamed piles with pile cap and grade beam tie at living area

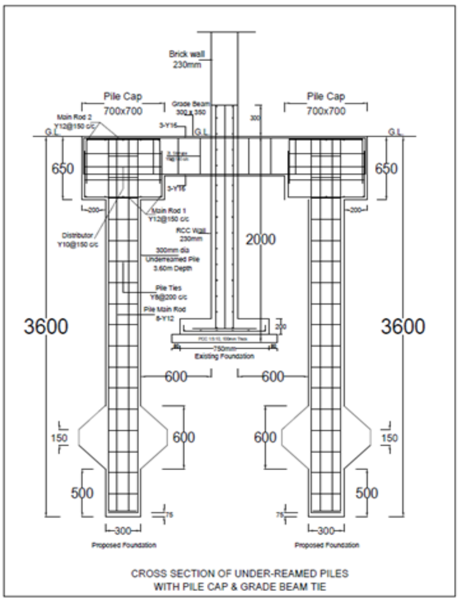

Fig.5 Cross section of Under-Reamed piles with pile cap and grade beam tie

3. At ground level, a tie beam may be provided interconnecting living area with bed room-1 and dining area.
4. In the living room area (double storeyed) of 6 m height, an intermediate beam at 3m from the ground level may be provided.
5. The cracks on the brick wall may be patch plastered by routine procedure.

6. In the entire plinth protection slabs of the building, soil may be replaced to a depth of 60 cm with good quality of soil such as red soil / moorum and slab may be relaid.

Acknowledgement

The authors are thankful to the authorities of CPWD, CUTN, Nagakudi campus for all their cooperation that have been extended during the soil investigation process and recommendation of remedial measures.

References

[1] SP 36 Part I: 1987, "Laboratory Testing on Soil for Civil Engineering Purpose", Compendium on Indian Standards on Soil Engineering, Bureau of Indian Standards.

[2] IS 2911, Part 1 (2010),"Code of Practice for Design and Construction of Pile Foundations", Bureau of Indian Standards.

[3] Varghese P.C. (2005), Foundation Engineering, Prentice – Hall of India Private Limited, New Delhi

[4] Chen, F.H., Foundations on Expansive soils, Elsevier Science, New York, 1988.

[5] Building drawing of CPWD submitted by the Executive Engineer, CPWD, TRPD-II, CPWD, Thiruvarur.