Analysis of Building Failures at Chowdawaram & Srikakulam, Andhra Pradesh

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This paper embodies the investigation of failure of 24-hrs Primary Health Centre for women at chowdawaram near Anakapalli, front office and main building had more than 3-inch wide cracks in the roof slabs, noticed round subsidence, Severe cracks in the compound wall, main building damaged beyond repair because of presence of an expansive sub-soi and aggravation of cracks took place due to presence of large trees and many buildings at Srikakulam, North coastal area of Andhra Pradesh, establishing the reasons for failures and suggested remedial measures. Extensive damages occurred to well-engineered framed structures leading to collapse, severe cracking or abandoning of some load bearing structures within two to five years after construction. It was reported that these buildings were constructed on sandy stratum. Soil investigation report and bore-log data were not available. Trial pit data, done up to foundation level, was showing the above reported Sandy stratum. Structural designs are once again checked and found inline. Hence the failures could not be attributed to either structural designs or to the sub-structure failure due to Geo-technical aspects. Thereby, the reasons of failure became a mystery in that region.

On observation of the extensive cracking developed and cracking pattern, the presence of expansive soils was suspected, but could not be found at foundation levels. To establish reasons for building failures, extensive soil investigation was carried out up to a depth of 20 m below EGL. ER-Survey was also conducted to supplement the data up to 50m depth to have correlation of soil layers with physical observations. Interestingly, it is observed that most of theses buildings are founded in river alluvium within 1.5 to 1.8 m depth and underlain by expansive clay. GWT fluctuates between 0.5 to 8.0 m due to the proximity of river Nagavli, thus causing cyclic swelling /shrinkage in these soils. Tests like XRD and SEM were also carried out to identify the clay mineral. To mitigate the damages, different types of foundations are explored for adoption to counteract swelling and some innovative, foundations proposed.

Introduction

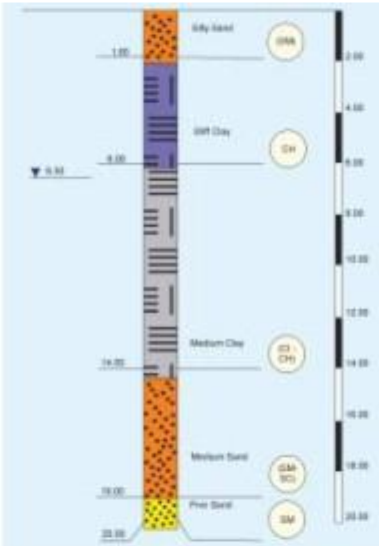

Figure 1: Typical Borelog

Table 1: ERS Data Interpretation		
Layer	Thickness (m)	Interpreted Lithology
1	0.0 - 8.0	Silty Sand / Silty Clay
2	8.0 - 20.0	Clayey with sand lenses
3	20.0 - 30.0	Weathered / fractured rock
4	30 - 50	Hard rock

Several buildings were damaged, and became un–inhabitable, though they are engineered both structurally and geotechnically. This has raised the curiosity among engineers and thus a team of engineers tried to investigate and find reasons for the failures of these engineered structures. On enquiry, it was reported that soil investigation was conducted and the trial pit data shows the soils up to and just below the founding level as well, as river alluvial deposits and constructed on sandy stratum. Soil investigation report does not have bore-log data. It is decided to check structural designs once again and also to conduct elaborate geotechnical field investigation.

However, the structural designs are found ok. Hence the failures could not be attributed to structural designs and since the underlain soils are reported as sandy (non– swelling) soil, the failures could not be attributed to shrinkage/ swelling failures. Thus it is concluded to crack the mystery only by thorough field investigations. It is also seen that in some of the Government offices, severe cracking and extensive damages occurred leading to collapse of some load bearing structures in this area within five years after construction. One of the buildings collapsed completely. Some were abandoned because of severe cracking and became un-inhabitable. Some buildings like District Civil Supplies Office, SETSRI, A.P. Irrigation D e v e l o p m e n t Corporation., are in severe distressed condition and District Industries Centre had collapsed. This dreadful problem necessitated an in depth study. The District authorities requested investigations to identify the cause of failure of the existing buildings and to suggest solutions to remediation.

Investigations

On summarizing the information, the available data collected from the site indicated sandy strata at and below the foundation level. The structures built were well engineered framed light structures. But the buildings experienced severe cracking. The cracking pattern indicates doming type heaving of the soils. GWT is located at 6.0m below EGL at the time of investigations. Fluctuations in GWT due to seasonal changes can be from 0.5m to 8.0m below GL, as the site is hardly 500 m away from river.

Field Testing

To investigate the reasons for failure of buildings, soil investigations were carried out by drilling two 150/100 mm diameter bore holes, using rotary rigs up to 20 m depth, below EGL for collecting disturbed and un-disturbed soil samples, and conducting SPT at regular intervals.

Generalized soil profile (Figure 1 & Table 1) indicates the following sub-soils:

a. The first layer from 0 to 1.8 m below G.L is filled up earth consists of medium dense silty sand and is classified as (SM) according to I.S. classification.
b. The Second layer from 1.8 to 6.0 m comprises of stiff expansive clays of CH group with FSI ranging from 40 to 50.
c. The third layer from 6.0 to 14.0 m comprises of soft to medium expansive clays with sand of CI and CH groups.
d. The fourth layer comprises of medium dense sand from 14 to 19 m depth.
e. The fifth layer is fine sand from 19m till the termination depth of 20 m.

Sub soil profile interpretation & comparison using ERS Survey

Bore hole investigations were supplemented with "Electrical Resistivity Survey" to map the ground up to a depth of 50 m below GL. ERS sounding was conducted using Schlumberger configuration. Results of interpretation about expected litho*logy was presented in Table-1 Based on this survey results, the analysis suggests the site to be a flood plain with river alluvium as top-soil. Granitic-gneiss out crops were seen in the river bed around 1.0 km from the site. The same type of rock can be expected at the site.

Laboratory Testing

A detailed Laboratory testing was conducted on all the disturbed & undisturbed samples collected. Results for a typical UD–sample are presented in Table 2A, below.

The summary of the Lab Tests conducted is given hereunder in Table below Table 2.

X–Ray Diffraction & SEM Studies

Lab Tests Conducted	Results
Liquid Limit (in %)	49 - 62
Plastic Limit (in %)	19 - 25
Plasticity Index	30 - 43
Shrinkage Limit (in %)	18 - 11
Plasticity Index (in %)	33 - 41
Differential free swell Index FSI (in %)	35 - 60
Swell Pressure (kPa)	20 – 80

Table 2: Summary of Lab Test Results

	Test Pit No.	BH-I	
	Depth in m. :	S_1 = 1.0	S_2 = 2.1
S. No	Description of Test		
1	Grain Size:		
	a) Gravel	02	03
	b) Sand	80	20
	c) Silt & Clay	18	77
2	Atterberg's Limits		
	a) Liquid Limit	20	52
	c) Shrinkage Limit	NA	09
	d) Plasticity Index	0	31
3	I.S Classification	SM	CH
4	γ_b in kN/m^3	18.14	19.03
5	NMC (w)	09	28
6	γ_d in kN/m^3	16.58	14.81
7	Specific Gravity of soil solids (G)	2.64	2.66
8	Triaxial Shear Test a) UU-Test (Q-Test) i) Cohesion (c) (kN/m^2) ii) Angle of Shearing Resistance (ϕ)	14.71 28°	29.43 4°
9	Consolidation Test a) Compression Index b) Initial Voids Ratio c) c_v cm^2 / Sec	NA	0.216 0.8 3.84 x 10[illegible]
10	Differential free swell Index FSI in %	NA	33
11	Swell Pressure Tests (kPa) Odometer Test (C.V Method)	NA	80
12	Swell Potential (%)	NA	19

X-ray diffraction analysis was carried out to investigate the mineralogical properties and their effect on theengineering behavior. The studies were performed using Philip x-ray diffraction (PW 3020) for the 20 range 15 to 760. XRD pattern for clays shows the presence of montmorrilonite. It is to be noted that montmorrilonite phase corresponding to card numbers (12-231) form the major fraction of the clay. Apart from this, it also matches the peaks of montmorrilonite family (card nos: 13– 259, 13 – 135, 29 – 149 and 29 – 1499) which appears to be the mixer fraction of the clay. It is to be noted that preheated and ethylene glycol saturated samples also resemble similar features of the XRD pattern except some minor changes in the d-spacings. This can be attributed to diffusion of some elements due to heating. SEM was carried out in ACMS at IIT-Kanpur.

Review & Analysis

The GWT table which was at 6.0 m depth, during investigation time fluctuates significantly rising to about 1.0 m from EGL. Extensive cracks were observed. It is reported that crack widths are also changing with change in seasons. Crack pattern studies indicate the presence of expansive clay below GL. Only the top 2.0 m is covered with medium dense sand (SM) below which the expansive clay is present. As the existing structures are light structures with only ground floor or ground + first floor, there is not much downward thrust exerted by the buildings to counter the uplift forces from soil expansion. As previous soil exploration was not conducted up to deeper depths, the presence of expansive clays was not identified, leading to the failures & problems in structures. On analysis of bore log data and laboratory test results, barring the top soil layer of 1 to 2 m, the stratification mainly consists of clayey sub-soil of CI-CH group with high expansive behavior. FSI ranges between 35 and 50. The value of cohesion is 30 kN/m2 and the friction angle only 40. The swell test on the soil by the constant volume method indicates that the swell pressures to be in the range from 20 to 80 kpa. The swell potential was also estimated with a newly deviced equipment, which

provides quick saturation around the soil specimen, than a regular laboratory testing equipment. The test results indicated reasonably high swell potential. The probable cause for the structural failure could be the swell pressure exerted by the sub-soil. The structures were pushed up because of the swelling of soils leading to structural failure of buildings as shown in photographs 1 to 4.

Photograph 1: First floor slab collapsed on ground floor roof slab (District Industries Centre)

Photograph 2: Setsri Building (CMEY) at Srikakulam (Severe Cracking and building abandoned)

Photograph 3: APSIDC Building at Srikakulam (Severe Wall Cracks were Observed in the entire buildings)

Photograph 4: Working Women's Hostel's at Srikakulam (Sevre Wall Cracks were Observed in the building)

The challenge with designing building foundations on moderate to highly expansive soils is the potentially detrimental effects of differential movements of the foundation structural elements due to volumetric changes of the underlying and surrounding soils. In simple terms, expansive soils swell and can cause heave with increasing soil moisture, or can dry out and cause subsidence with decreasing soil moisture. Differential movements between various parts of the building often lead to high internal stresses in building components resulting as distress in the form of cracks, splitting, bending, buckling and in some cases failure of the structure itself. Hence, selection of type and design of foundation should be so as to economically mitigate the detrimental effects of foundation movement. This can be done either by isolating the elements of the foundation system from potential soil movements or by utilizing design methods and details that help to control the effects of the movement of the soil. The foundation systems are subdivided into two groups:

(i) Deep support systems and

(ii) Shallow support systems. Each of these systems has an associated level of risk of damage that can occur to the building superstructure and architectural components due to differential foundation movements as well as an associated relative cost of construction. When comparing the various foundation systems, the level of risk is generally found to be inversely proportional to the level of cost. Higher risks are often accepted due to economic considerations. For example, shallow support systems typically have a relatively higher level of risk than deep support systems, but are often selected due to economics and affordability.

Many alternatives are available to deal with this type of expansive soils which are generally adopted.

(I) Deep Support Systems

Photograph 5: 3-Inch Wide Cracks on the roofs top of PHC building at Chowdawaram

Photograph 6: Rebars were exposed on the roof slab rendered the PHC-building, useless & abandoned

Deep support systems are defined as foundations having deep components such as drilled piers or piles that extend well below the moisture active zone of the soils. They function to limit the vertical movements of the building by providing vertical support in a soil stratum that is not susceptible to downward movements caused by moisture fluctuations. Foundations must be placed much below the depth where in constant Volume zone is met with usually it is more than three meters below GL. CBRI investigated with instrumentation that at a depth of 5.0m below EGL, almost ground movements were observed to be negligible.

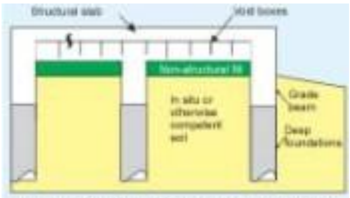

Figure 2: Structural Slab with Void Space and Deep foundation

Table 3: Under-Reamed Pile Capacities (IS 2911-Part III)

Pile stem dia (D) in Cm.	Under Reamed Bulb Dia (Du) in Cm.	Capacity of Pile in Tonnes. Length of pile from tip to cut-off level = 6 M		
		Vertical Capacity (T)	Uplift Capacity (T)	Horizontal Capacity (T)
30	75	20	12	2.4
45	112.5	38	22	4.8

This foundation system consists typically of a reinforced concrete slab with cardboard carton forms to create a void space that separates the slab from the surface soils. The depth of the void forms ranges from four to eight inches and depends on the expansiveness of the soils. The more expansive the soil (i.e. the higher the plasticity index), the deeper the cardboard carton forms needed. The slab is called a “structural slab” because it spans between reinforced concrete grade beams that are supported entirely by deep foundations.

Because of the relatively small void space that is used with this system, the bottom portion of the grade beams are normally cast directly on the soil, even though they are designed to span between the deep foundations. The slabs typically range in thickness from four to eight inches. The reinforcement can consist of a single or double mat of rebar. The structural slab is designed in accordance with the IS 456.

Void forms serve as formwork for the placement of concrete by acting as a temporary platform that supports the weight of the wet concrete. Void forms typically are made of corrugated paper arranged in an open cell configuration. The raft footing.

In the event of swelling, because of the anchorage developed by the anchor bars, pressure on the surrounding soil of granular anchor pile increases. There by the pore- pressure in the soil underneath the foundation increases, but dissipates into adjacent granular soil, thus relieving pore/swell pressures. Especially for the bulk / medium housing colonies this method is cost effective.

Anchored Geo Grid

Anchored Geogrid is one of the promising methods, which is useful in expansive soils. In this method, a Geo Synthetic / geogrid is spread at the bottom of the foundation. The geogrid is anchored by means of anchor pins into the soil.

Where these pins are provided, it is preferable that the soil underneath them is treated with chemicals in order to minimise the swelling nature. Since the anchors do not move, when there is a swelling in the adjacent soil, the grid tries to counteract the swell pressure., thus restricting the transfer of swell exterior surface may be wax impregnated to temporarily resist moisture. The forms are specifically designed to gradually absorb ground moisture, lose strength, disintegrate over time, and leave a void between the expansive soils and the concrete slab. If the soil below the concrete heaves, it can expand into the space created by the void form without lifting the foundation

By the Usage of Under-reamed Piles5

UR-pile foundations are one of the best possible solutions for providing foundations in swelling soils. But investigations revealed that the main reasons of failures are due to improper workmanship, poor quality, lack of expertise, due to absence of gap between the plinth beam and the soil surface etc. In the above case study UR-Pile foundations are recommended due to the availability of expertise and the pile capacities were estimated in accordance with IS-2911 (part-III) (Table -3).

Granular Anchor Piles

Other important alternate type of foundation is by providing Granular Anchor piles. GAP is an innovative Solution Sreerama Rao .A,. et al3 Since a mere granular pile gets sheared off when swelling occurs as it cannot resist uplift forces.

To counteract the heave, granular anchor piles are used. Usually a bore is drilled similar to under-reamed pile bore, with expansion bulbs in the pile stem. The bore is filled with granular material/ Sand.

Based on the uplift expected, two or three rods are lowered prior to filling of granular material and they are anchored at the bottom of pile as shown in the Figure 3, either by geo-grid or by embedding the rods into PCC. The rods are tied and anchored into the foundation pressures to the foundation. On the top of the geo-grid, a layer of granular soil is laid for the dissipation of pore pressure caused by swelling,

One of the combination methods i.e use of geogrids with micropiles technique is expected to give better results and the configuration is as shown in Figure 4 (a) & (b).

Helical Piers4

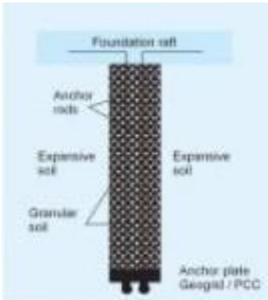

Figure 3: Granular Pile Anchor

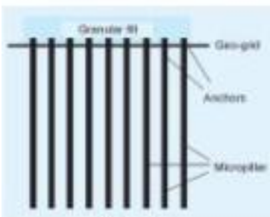

Figure 4a

Steel helical piers, also known as screw anchors or screw-in piles, have been used since the early 1950s as tie back anchors for retaining walls and as foundations for lighthouses, substations, towers, heavy equipment, and other similar applications. They are now gaining popularity for use in supporting foundations for residential, other low-rise buildings anchoring of floating & other important marine structures. etc,

The anchor consists of a plate or series of steel plates formed into the shape of a helix to create one pitch of a screw thread. The shape of the plate permits easy installation, which is accomplished by applying torque to the shaft of the anchor and screwing it into the ground using rotary motors. The anchors can be used to resist a tensile or compressive load, which is accomplished by means of bearing pressure resistance on the area of each helix, and not by skin friction along the shaft. The plate helices of helical pier foundations are attached to a central high strength steel shaft that can be segmented to facilitate construction and to allow various combinations of the number and diameter of helices used. The pier is screwed into the soils until the applied torque readings indicate that the necessary load capacity has been achieved or until the desired depth below the moisture active zone of the expansive soils is obtained. In new constructions, the pier shafts are typically anchored to the grade beams by using fabricated brackets that are tied to the grade beam reinforcement before placing the concrete, and bolted to the top of the pier shafts.

(ii) Shallow Support Systems

This foundation system is similar to that discussed in Section (i) A above, except that the slab is placed, without a void, over the expansive soils and new fill and the grade beams are supported directly by the underlying soils instead of spanning to deep foundations. The key advantage of this system is that the grade beams need only to penetrate a minimum of six inches into the competent natural soils.

By Providing CNS Layer Cushion1,2,6

By Providing CNS Layer cushion, Katti.R.K1, along with solid waste materials like rice husk ash, fly ash etc. The efficiency of this method depends on the thickness of cushion as well as the density to which it is compacted. However, the performance is observed to be decreasing with repetition of swelling-shrinking cycles of the expansive soils. To improve the efficiency of [CNS(NS)] soils, they can be again stabilized by lime (3-5%) or cement2 before using them.

By Chemically Stabilizing the Ground7

This is a cost-effective solution and chemical injections with chemicals like CaO / $CaCl_2$ / $Ca(OH)_2$ / KCl / $FeCl_3$ etc. are used to stabilize the soils. These chemicals can be injected or grouted into the ground. However, due to fluctuating water table, these chemicals get washed away.

Miscellaneous Methods

These may consist of raft on three point support system, piled-raft foundations, steel helical piers, known as screw anchors or screw in piles, moisture control systems etc.,

To Adopt Combination of the Above Methods

Combinations of the above methods were tried on an experimental basis and they were found to yield good results. Especially when the granular piles are used along with chemical stabilization, the soil has shown very minimal swelling. This appears to be one of the suitable methods, where the chemical injection facilities are also available and the structures to be built are of important nature.

Conclusion

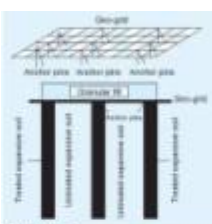

Figure 4b

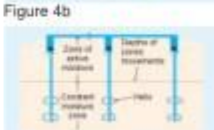

Figure 5: Helical Piers

Soil Investigation to the recommended depths must be made mandatory prior to the construction of any important Structure. The above paper describes the implications of not performing the soil exploration properly and not assessing the soil properties and its behavior. This reflects how disastrous that could be, which finally lead to even collapse of structures itself, loosing the primary cause of construction. Finally, after thorough exploration, it is observed that most of theses buildings are founded in river alluvium within 1.5 to 1.8 m depth and underlain by expansive clay. GWT fluctuates between 0.5 to 8.0 m due to the proximity of river Nagavli, thus causing cyclic swelling/shrinkage in these soils.

The probable cause for the structural failure could be the swell pressure exerted by the expansive sub-soil as already discussed in the previous paragraphs. The structureswere pushed up because of the swelling of soils leading to structural failure of buildings.

It has been once again proved that Conventional Foundation are not suitable for expansive sub-soils.

Hence, it is once again emphasize us, how important the soil exploration is and not only the extent but also to the required depth etc.. At this juncture, the authors feel that the stipulations for rightful exploration shall be made mandatory as per IS guide lines, before taking up any construction. The authors have also explored the different foundations types which can resist the swell pressures and discussed. For the present case, it was recommended to adopt combination method Grade- Supported Stiffened Structural Slab, which is described in the para “E” above along with the chemical treatment of sub soils with $CaCl_2$, prior to construction of foundation. For existing buildings with lesser cracks, it was recommended to immediately adopt Lime slurry stabilization around the building by excavating trenches, which had yielded good results and found that further propagation of cracks were reduced.

Granular anchor piles with surrounding chemically stabilized ground shows 20–25% increase in the up-lift capacities it is hoped to have a promising future in the application of these techniques. Some more investigations are in progress. Various methods which can be used in such type of swelling soils are summarized and also other innovative methods which tackle such type of soils are listed to address the problems due to swelling of soils. Experiments and research are in progress, especially to assess the functioning of the GA Piles and also the anchored geogrid type foundations, which seems to yield promising. These methods if popularized, building failures can be avoided.

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