FAILURE OF A 4-STOREY RCC BUILDING AND ITS RETROFITTING WITH BI-LAYER FOOTING FOUNDATION UNDER EQ ZONE V – A CASE STUDY

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ABSTRACT: Substructure bears the significant value of sustainable development of any super structure, which is developed based on the properties of subsoil encountered in the proposed site. Hence, it draws importance in construction project. In regards to its importance, this paper brings a problem that happened during construction of 2nd floor height of a 4-storey RCC building. The efforts of solving the problem generate a suitable method of retrofitting the old foundation system. A technical new process is termed as Bi-layer footing foundation system with improved SBC is introduced herein. Such geotechnical problem may be a source for carrying out retrofitting work for old foundation.

INTRODUCTION

General
Substructure bears the significant value of sustainable development of any super structure. On the other hand, sustenance of such substructure wholly depends upon the subsurface sounding of the project site or soil properties comprising the subsoil which describes the project site. Thus studies of subsoil of any project site proclaim its importance in construction project. It is obvious that almost all construction projects in private sector/individual housing project, the owner neglects the importance of study of the subsoil of their proposed building project site beyond ground level and allowed their construction go ahead for which quite sometimes some of such owner become victims and lose their money and properties so invested, provided the subsoil conditions are found not to be perfectly sound. Looking to the above to element the drawbacks exist among common owner this paper has been prepared and exposed accordingly.

The Problem and the Efforts
In consistence to the above strategy, a problem that happened during construction of 2nd floor height of a proposed 4-storey RCC building came to me. Accordingly, the problem was investigated in the light of both geotechnical aspects and structural strength of the Columns, beams & slabs so constructed up to 2nd floor level. Design of the 4-storey building structure as well as a new foundation system were done and executed in the site for its future sound existence. The building is situated in the flange of Polocolony hillock at Naharlagun Township i.e. capital complex of Arunachal.

The problem is related to an individual, who came to me and entrusted the job for rectification/retrofitting. Consistently, my efforts to impart knowledge beyond planning, designing & guidance for proper execution, is to do a parallel job for owner of the proposed building, contractors, masons, etc. are all about the dissipation of knowledge pertaining to building bye-laws, its rules and regulation to achieve the best performance in reality such that victim should be reduced to zero during occurrence of Natural hazards.

The project ‘Design of 4-Storey RCC Building and … Retrofitting for its future existence’ (Ref.) was completed with the help of M/S Design-Tech. Pvt. Ltd., Naharlagun, which contains necessary detailing all about the design and reinforcement specifications of all RCC members including Bi-Layer footing foundation system (BL-FFS0 for achieving the following:

(i) Investigation of the problem and recommendation of suitable foundation system for such Old structures as retrofitting measures.
(ii) Retrofitting of all old members of the super structures built up to 2-storey level and then completion of the remaining construction.
(iii) Overall sustenance of the building under high earthquake shock pertaining to seismic Zone-V as it is situated in Hilly terrain with different level of Foundation (Fig.1). Hence, the building is proposed to be a 100% earthquake resistant building.

To meet the above demands, efforts have been made in accordance to the design guidance stipulated in different BIS: Code of practices, which are followed obediently. Hence, the proposed 4-Storey RCC building is designed to sustain during High Earthquake shocks of its life period which is expected undoubtedly if construction is found to be in order.

INVESTIGATIONS AT SITE

Geotechnical Investigation
There is limited scope for conducting detailed subsoil investigation to explore various geotechnical properties at site for achieving a thorough picture about the subsurface sounding of the building plot. The plot is found tight with its planning. The room height inside the building at ground floor is also low (2.9m). Hence, no field test could be carried out. On the other hand, there is no geotechnical information made available from the site before construction. Looking to the above situation 3-pit trenches
were advanced up to a depth between 1.5-2.0 m and disturbed and undisturbed soil

samples were collected to analyse the same in the laboratory. During investigation it was recognized that though there is no normally standing GWT as a high land in hilly terrain yet there are sufficient water seepages which generates water accumulation beneath foundation and saturated the subsoil underneath. With the collected soil samples routine tests were carried out in the laboratory except some special kinds of tests. The special tests are to evaluate and to fix the exact shear parameters and SBC perfectly. In this regard, the special tests conducted are
(i) Large Box Direct Shear test (LB-DST) under fully saturated drained condition & Small Box Direct Shear test (SB-DST) in saturated undrained condition.
(ii) A model PLT test in the LB-DS machine with water table at footing level.

Results of all the tests carried out in the laboratory were tabulated in tabular form and are given in Table 1. Further, for comprehensive understanding and to perceive the importance of conducting both kinds of direct shear tests with special attention, the results of the same were tabulated in tabular form and are given in Table 2.

Finally geotechnical investigation report recommends the value of unrestrained SBC of the subsoil, is 13.5 t/m² (i.e. Field condition) and the type of foundation for accommodating the retrofitting provision of the old foundations is a unique form of foundation system introduced first time in India as Bi-layer combined footing foundation. Table 1 gives the details about the geotechnical properties of the building site.

**Structural Investigation**

In absence of any drawing, there is difficulty to study the overall plan and specification of the built-up structure upto 2nd floor level. Hence, detailed measurement survey was carried out. After measurement the different dimensions of the building room, columns, beam and slab were found out and are given in a drawing form which is shown in Fig. 2.

It was observed during the time of investigation in February 2011 that the sizes of all columns, beams and slabs are inadequate. Span of the beams are regular in X-direction and almost irregular in Y-direction (Fig. 2). Maximum size of column having 6.0m span is 290x355 mm. and minimum size is 250x300mm. On the other hand, maximum size of beam in section found for 5.0m & 6.0 m span is 320x 450mm.

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**Table 1 Result of various engineering properties of the subsoil derived from laboratory tests**

<table>
<thead>
<tr>
<th>Location of samples</th>
<th>Depth of undisturbed soil samples 'D' in metre</th>
<th>Field Bulk density 'γ' in gm/cc</th>
<th>Field moisture content 'W' in %</th>
<th>Sieve analysis (p. c. passing) size in mm</th>
<th>Type of soil</th>
<th>Compresssion index Cc</th>
<th>Shear parameters from SBC of Sub-soil</th>
<th>SB-DST*</th>
<th>LB-DST*</th>
<th>C=0.50</th>
<th>φ=61</th>
<th>C=0.10</th>
<th>φ=39</th>
<th>C=0.55</th>
<th>φ=26.5</th>
<th>From model PLT, 13.7 t/m² &amp; From Analysis, 16.1 t/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Road-side</td>
<td>1.5</td>
<td>1.95</td>
<td>17.6</td>
<td>99.1 93.4 81.9 69.9 57.9 30.9 CL 0.981</td>
<td>0.075</td>
<td>0.075 IS:8=75 micron</td>
<td>SB-DST*</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
</tr>
<tr>
<td>East Road-side</td>
<td>1.3</td>
<td>1.85</td>
<td>12.5</td>
<td>97.6 88.9 68.5 57.4 46.4 27.7 SM quick</td>
<td>0.815</td>
<td>0.815 IS:8=75 micron</td>
<td>LB-DST*</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
<td>88.126</td>
</tr>
</tbody>
</table>
Table 2 Result of LB-DST and SB-DST tests giving the variations

(a) Evaluation of different parameter of the LB-DST Test :

<table>
<thead>
<tr>
<th>Initial-Normal Pressure at failure in kg/cm²</th>
<th>Vertical settlement in mm</th>
<th>Corrected properties after test</th>
<th>Shear Stress in kg/cm²</th>
<th>Result of the Test as stated</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>918.090</td>
<td>17627.3</td>
<td>1.85</td>
</tr>
<tr>
<td>0.304</td>
<td>4.25</td>
<td>905.213</td>
<td>17484.1</td>
<td>1.86</td>
</tr>
<tr>
<td>0.764</td>
<td>4.75</td>
<td>890.820</td>
<td>17245.4</td>
<td>1.89</td>
</tr>
<tr>
<td>1.224</td>
<td>5.25</td>
<td>874.913</td>
<td>17054.4</td>
<td>1.91</td>
</tr>
<tr>
<td>1.833</td>
<td>5.75</td>
<td>857.490</td>
<td>16863.5</td>
<td>1.93</td>
</tr>
<tr>
<td>2.202</td>
<td>6.25</td>
<td>838.553</td>
<td>16736.8</td>
<td>1.95</td>
</tr>
</tbody>
</table>

* Moistures: (i) during remoulding 19.58 % & (ii) after test is the saturation moisture tabulated as above

(b) Evaluation of different parameter of the SB-DST Test :

<table>
<thead>
<tr>
<th>Initial-Normal Pressure at failure in kg/cm²</th>
<th>Vertical settlement in mm</th>
<th>Corrected properties after test</th>
<th>Shear Stress in kg/cm²</th>
<th>Result of the Test as stated</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>35.76</td>
<td>90.5</td>
<td>1.85</td>
</tr>
<tr>
<td>0.300</td>
<td>4.00</td>
<td>33.37</td>
<td>89.2</td>
<td>1.87</td>
</tr>
<tr>
<td>0.500</td>
<td>4.00</td>
<td>33.37</td>
<td>88.1</td>
<td>1.90</td>
</tr>
<tr>
<td>1.000</td>
<td>5.00</td>
<td>32.77</td>
<td>86.7</td>
<td>1.93</td>
</tr>
</tbody>
</table>

Substructure constructed is of Isolated footing foundation placed at different foundation level even for Ground floor also. The footings are poorly connected by tie beams in X-direction. Along Y-direction there is no tie beam for 6.0 m span bay (Fig. 4). Maximum size of the isolated footing foundation found is 1.5 m x 1.5 m. These footings are placed at various levels from 1.5 m upto 2.8 m.

It was informed that the age of the construction is about 1 year and all members were constructed with M15 concrete grade and steel grade Fe 500. In such condition, structural investigation reveals that all the beams having 6.0 m span execute vertical shear cracks at three different locations. They are at centre of the beam i.e. at about 3.0 m from the column support and almost ¼ of the beam span length at both ends. Such cracks also executing by the 6.0 m beam at 2nd floor level also.

Consequent to both of geotechnical and structural investigations proclaims that the cracks so developed in the 6.0 m beam may be due to differential settlement occurred at Isolated footing foundations which are not connected by tie beam or due to inadequate width of the footing foundation as the SBC and compression index of the site are very poor (Table 1).

ANALYSIS AND DESIGN OF STRUCTURES

Analysis of Building Structure
To find out the shear force and moments to be acted upon the foundation, there need to evaluate the above. To get these, lot of exercises starting from load counting up to static and seismic analysis, are needed to be carried out within the fixed dimensions of frame-work of proposed building which is normally done. For carry out the seismic analysis, seismic coefficient considered is maximum which is stipulated in BIS:1893-1975. For instance, the result of the seismic analysis carried out for moment resistant frame portal SP-2 is shown in Fig. 1. In this regard, it will be worth mentioning that, the building has two major foundation level (Fig. 1) located below ground floor and also below first floor level. It was done by the owner without having knowledge about the effects of earthquake horizontal force over structures. Fortunately it was analysed for the building for such situation and the moments are evaluated accordingly.

Analysis and Design of Substructures

Analysis
After finding the vertical load and moments subjected to the base of column the foundation connecting the columns are to be analysed properly. Looking to the available situation of the columns some of them are in one line is combined and analysed accordingly. For instance the bending
moments and shear forces for a group of such combined footing to be placed as the top layer of the Bi-Layer footing foundation system is shown in the Fig. 3.

**Fig. 3** Design of combined footing for 5-columns to be placed as 2\textsuperscript{nd} layer of the Bi-layer Footing foundation system

**Design of Bi-layer footing foundation**

Conception of Bi-layer footing foundation is derived from this problem to suit the situation of retrofitting an old building foundation i.e. foundation has already been constructed years back. In general, the design and construction of Bi-layer footing foundation (The term footing implies here for having columns bases both at Isolated footing level and at surface footing level), the details of which is not possible to described due to page limitations, yet trying to write a few lines, because for India, it is a fresh subject. There is no published knowledge that is constructed. However, with some laboratory experience with 20 years of field experiences drawn through geotechnical engineering and structural design, it is developed to overcome the present problem in hand.

**Conception and Definition of Bi-layer Footing Foundation**

The conception is as: a Bi-layer footing foundation has two footing level under a single column base. The design is carried out by considering that 1/3 load of the column is to be carried out by the 1\textsuperscript{st} footing placed at lowest level with field SBC (i.e. unrestrained SBC) and the remaining 2/3 load of the column will be carried out by 2\textsuperscript{nd} footing placed at shallowest depth or at surface ground floor level with higher or improved SBC or restrained SBC. All combined footings were designed with improved SBC found as 18 t/m\textsuperscript{2}. The method of improving the SBC from 13.5 t/m\textsuperscript{2} (unrestrained) to 18 t/m\textsuperscript{2} is done at site by adopting replacement of in-situ silty-clay layer with sandy-gravel soil through mechanical compaction by hand ramming. Fig. 4 represents the progress of such retrofitting work under the parts of building failure.

**DISCUSSION**

It is seen from the result of geotechnical investigation that the soil properties within the small size building plot (19.5mx 20.5m trapezoidal shape) varies extensively. Hence, there is a great scope of occurring differential settlement in the superstructure with isolated footing foundation of improper sizes and poor existence of tie beam. On the other hand, inadequate sizes of the columns and beams rest on two-different foundation level in hilly terrain gives a lot of scope for occurring failure of not only beam but also the whole structure of the building in the worst situation.

After completion of retrofitting work, the building will have a Bi-layer footing foundation at every level, which is more suitable for high earthquake prone area like Naharlagun, Arunachal Pradesh, which is marked in the BIS:1893-1975 under Seismic zone-V.

**CONCLUSIONS**

From the above study following may be concluded as:

1) Without carry any geotechnical investigations suitable SBC and settlement criteria never reveals, hence sound foundation can not be procured in reality, which offer threatening nature for occurrence of failure hazard.

2) Without proper analysis and design no building should be constructed more particularly in earthquake prone areas.

3) A general construction habit may be grown for new proposed Building with Bi-layer footing foundation system especially in earthquake prone region.

**ACKNOWLEDGEMENT**

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