Estimation of existing tall buildings pile foundations bearing capacity under seismic and wind loads

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ABSTRACT

In the paper two ways of justification of building's height increasing possibility are discussed - strengthening of foundations in order to improve their bearing capacity and numerical investigations of existing structure in order to identify its reserve of capacity. Results of structural analyses of a high-rise residential building are presented, performed in order to increase its height from 16 to 21 with minimized intervention level to the originally designed structure. At the period of investigations 11 floors of the building have been erected. The positive results of analyses allowed to reject proposed by designers method of strengthening of existing pile foundation and sub-grade soils using bore-injection piles.

Introduction

Increase of the buildings' height all over the world becomes a real factor in spite of all design and construction complexities. Especially, it's important for large cities in conditions of expensive and limited construction areas.

Typically investors encourage investigations related to optimal use of the capacity reserve of structures since this allows to increase the number of floors and therefore to increase effectiveness of investments. And usually the idea of structural optimization comes when foundations and part of the structure are already completed. This creates additional difficulties providing minimal necessary reinforcement of upper structure when existing foundation already has some limit of bearing capacity and its reinforcement requires more serious investments and intervention to the foundation sometimes causes large technical and financial problems. Therefore, modifications to the structure in order to improve effectiveness of investment are often limited by the bearing capacity of existing originally designed foundations.

Preliminary the owner of the building ordered design of 16-story multi-story residential structure. Therefore, when the frame was erected up to 11 stories, according to the project of Tbilisi Mayor’s Office “New Life of Old Tbilisi” it was recommended to increase the building's height with 5 additional stories. New design project considered strengthening of existing structures – columns and inclusion of additional diaphragms of stiffness. But the question of the reinforced concrete piles strengthening remained undecided. Some technical proposals regarding reinforcement of the original foundation structure have been not applicable technically and required not acceptable additional investments.
Proposed methods to solve the problem

Reinforcement of Foundations. The main problem related with the pile foundations is consisted in the method of strengthening, recommended by designers. Briefly, these recommendations include the following steps:

1. To drill boreholes at the depths 10.5 - 22.7m in the places of those indicated in the project (Fig.1. Foundation slab and location of existing piles); fastening of piles in bedrock at the depth not less than 1.0m is necessary.
2. At drilling works of foundation slab not to damage reinforcing bars of the slab.
3. In the drilled borehole to be installed d=127mm steel perforated pipe with a length of 3000 mm, which will remain into the body of pile after concreting. Then, reinforcing bars Ø32 A-III will be installed in the borehole preliminarily painted with two layers of anticorrosion paint. The mixture supply to the bore hole to be done under the pressure 10 atmosphere. Total length of 694 bore-injection piles – 12151m.

4. From the point of view of the technology the concreting of the cementation bore -injection piles is performed from the bottom level to the top.
5. Required amount of materials for the injection works: concrete volume - 162m³; steel pipes - 25.3t and steel bars - 76t.

Implementation of these works required unjustified charges and more than 2.0 million dollars. Technically this method was unrealizable as well. Unrealizable because of height of the first floor-car park H=2.12-2.44 m. No drilling facilities can work in this space area and drill about 12.0 km bore-holes. Ineffective, since the cementation process is uncontrolled and the results of strengthening are not predictable. In addition, drilling process of the bottom concrete slab by oneself caused many damaged of reinforcement of existing slab. Thus, due to technical and financial reasons this method of improvement of the foundation capacity has been rejected.
**Structural Analyses.** Alternatively, the numerical analyses of the building capacity have been proposed with adjusted input data. First of all, the existing engineering-geology investigation report (“Autodesignroad” Ltd, dated 2005) has been analyzed. The results of this investigation showed that the soil bearing capacity value (1.70MPa for bedrock) could be adjusted. Characteristics of the base rock with alternation of the inter thin layers of argillites and loamy sandstones seemed inadequate and it was decided to perform the new engineering-geology investigations. This job was implemented by Georgian Institute for Regional and Urban Planning “AKHALI SAKKALAKMSHENPROEKTI” LTD (Report #11-18/45, 12/10/2011).

**Description of the Building**

Multi-storey apartment house #34a, Al. Kazbegi ave., in the central part of Tbilisi is characterized by overall dimensions in plan - 24.4x60.0m. Structural system of the building - monolithic reinforced concrete frame with RC diaphragms and pumice concrete blocks for infill external walls and partitions. The total height of the building including car park is 65m. The building is not regular, the column mesh is different - 6.6x6.6m; 6.0x6.6; 6.6x4.4 and 6.0x4.4m. Location of diaphragms is shown below:

![Design numerical model, location of RC diaphragms](image)

The soil conditions on the site area and the basic soil lithologic sections are presented by four engineering geology elements (EGE):

- **EGE - 1.** Filled soil with thickness up to 1.4m;
- **EGE - 2.** Sandy loam with inter layers of sand and loam, small degree of water saturation and layers of the average degree of water saturation, solid, unsetttled, depth from 1.4 to 18.5m;
- **EGE - 3.** Crushed material of base rock with loam filling, unsettled, depth from 18.5 to 22.0m;
- **EGE - 4.** Base rock with alternation of inter thin layers of argillite and loamy sandstones, slightly weathered, unsettled with depth from 22.0 to 25.0m.

The established level of underground water for the period of investigations (03.10.2011) was fixed in sandy loams at the depth of 1.4-1.6m from the surface. The end-bearing piles with d=1.2m are fixed into this type of soil.
Input Data for Numerical Analyses

For numerical analyses of the building the following important adjustments and modifications have been done:
- Adjustments to the existing design model (originally developed by “KONEX” Ltd) related to geometry, physical-mechanical parameters of materials have been implemented.
- Soil reaction parameters were adjusted based on last geological investigations.
- Wind load cases with pulse component added.
- Time history seismic load cases added. Several accelerograms have been applied- records of the Tbilisi 25 April 2002 epicentral earthquake, artificial accelerograms calculated for the construction area soil conditions. All records were scaled for 0.2g. One of artificial accelerograms is presented in Fig. 3.
Fig. 3. Artificial accelerogram #2, velocity, displacement functions, response spectra
- Dead and imposed loads were adjusted as well.
- Considering that the building is not regular in plan and rotational effects could take place, the diagonal directions of seismic excitation have been analyzed as well.
All numerical analyses have been performed using structural software LIRA-Window (developed in NIIASS- Kiev, Ukraine).

**Main Results of Analyses**

Results of numerical analyses contain full information on stress-strain state of the building's elements, their reinforcement, dynamic parameters of the building, vibration modes, horizontal displacements at design load combinations and other data.

Maximum horizontal displacements in all directions under wind and seismic excitation are within code limits (Fig. 4, 5):

![Fig. 4. Maximum horizontal seismic displacements don't exceed 36cm (H/200)](image-url)
Fig. 5. Maximum horizontal wind displacements don't exceed 13cm (including 6.1cm from pulse component) i.e. H/500

Calculated bearing capacity of piles [2] is defined as

\[ F_d = \gamma_c \cdot R_A = 1 \times 2166 \times 1.131 = 2450t, \]

where

\[ R = \frac{R_{as}}{\gamma_s} \left( \frac{l_a}{d_f} + 1.5 \right) = \frac{1300/1.4 \times (1/1.2 + 1.5)}{2166 \text{ t/m}^2} \]

1982 < 2450t with 20% reserve.

Where 1982 t- maximum normal force in the element at the bottom level of the most loaded pile at design load combinations. 1300 t/m\(^2\)- soil bearing capacity based on the engineering-geology investigations.

**Conclusions and Recommendations**

Based on analyses of results the main conclusions and recommendations have been developed:

1. The calculated bearing capacity of piles at design load combinations is sufficient for 21-story building with additional reserve of 20%. Minimal reserve of the load bearing capacity is 20 %. Reinforcement of piles 24Ø32=192cm\(^2\) exceeds required reinforcement - 165cm\(^2\) for A500 steel. No strengthening works of the pile foundation is required.

2. Horizontal displacements of the building due to seismic and wind loads are in the range of the construction rules and regulations requirements: seismic displacement is H/200 (H – height of the building); wind displacement including pulse component is H/500 (13cm).

3. External infill walls and partitions to be erected with pumice blocks, that was taken into account in the project and in structural calculations.

**References**
