TILTING PREVENTION OF A FOUR FLOOR RESIDENTIAL BUILDING WITH THE ASSISTANCE OF MICRO-PILES BENEATH THE FOUNDATION

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Abstract: The following presents the successful prevention of dangerous large deformations of a residential building caused by its inclination. The building has concrete panels in its construction, and was built 50 years ago. It possesses four floors and two entrances. Foundations are strips in depth of 2.50m each. The reason for the uneven subsidence is swelling silt thicker than 6m below the building. The first cracks appeared more than ten years ago and reinforced concrete elements have gradually showed cracks 5 to 10 cm of separation. Prior to the restoration of the upper structure, the ground was stabilized and foundations were reinforced by a system of inclined, vertical micro-piles to mitigate swelling of clay and stop further deformation of the building. These were micro-piles injections, installed using the pressure of the grout. The plan for their deployment is done according to the measured subsidence and tilting of foundations. The injection was performed in two phases to achieve higher injection pressure. Lengths of the piles were 4 m each.

Control measurements were performed one year after repairs and showed no new subsidence. The restoration of the roof structure is also completed.

1. Introduction

Many residential buildings were erected by the technology of large-sized precast armored concrete panels in the cities of Bulgaria between 1964 and 1990. The industrial approach to their construction required high degree of projects' and constructions' unification. For a period of 25 years, a few generations of standards for prefabricated panel structures were developed that only needed to be customized according to the conditions of the foundation. The first constructions of the above type, built in Sofia in 1964 had some defects, which were improved with the newer projects. Of course, national norms for design and construction also experienced amendments with regard to wider use of prefabricated panel buildings.

The report is presenting our experience with strengthening of one such building in Sofia due to systematic design deficiency and incomplete consideration of ground characteristics.

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2. Portrait of the Building

The building depicted is a true rectangle, sized 10.20 m x 35.40 m. In the transverse direction, frame axles are11, located in 3.60 m from each other. Axes in the longitudinal direction are 3 with 5.10 m for each (Fig.1).

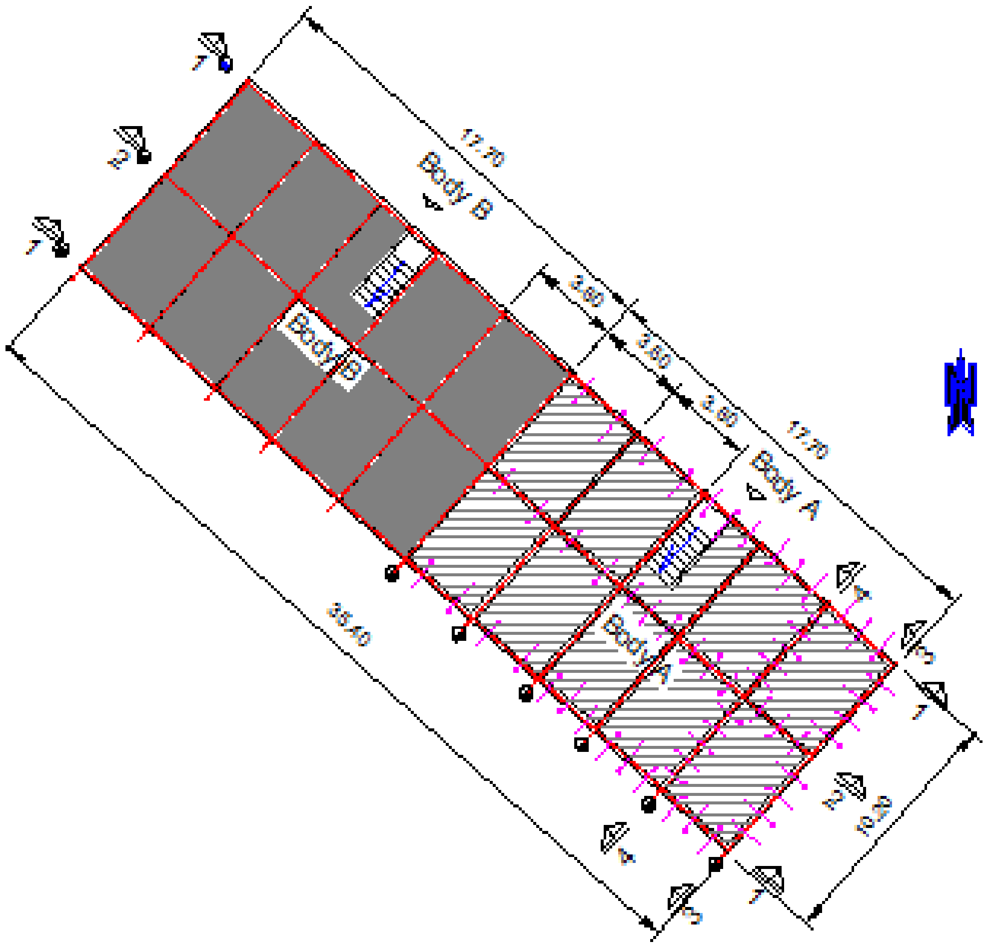


Fig. 1: Plan of the Building

The building has two entrances and does not have a deformation joint between its two sections. Each entrance has three apartments on a floor. There are four floors, each 2.7 m high. The building has a basement with a height of 2.20 m. The roof is flat.

The framing consists of load-bearing transverse walls, including the end axel. The median longitudinal wall is flat load bearing wall. The scheme is similar to the form of a herringbone. The interior walls are 18-cm thick. Façade panels have curtain functions. Their weight is taken by the floor panels that also take the load of staircase landings, and interior panels.

The basement is of solid concrete with wall thickness of 24 cm. Foundations are of strip concrete, and their width is the following:

- 70 cm for the median foundation;
- 74 cm for transverse foundations (excl. end ones);

- 45 cm for the end foundations;
- 45 cm for foundations beneath the facade.

The depth of the foundation is up to 1.70 m below ground level. Under the foundation slab, we found a 20 cm concrete base; in other words, the foundation trench was made up to 1.90 m beneath ground level. The ground surface is flat more or less, with a slight inclination to north-west and north-east.

3. Failure Description

The inspection of the building found damage that occurred during its life with joints opening between panels, concrete cracks, collapse of the eastern part of the building, broken sidewalk pavement around the building and other defects.

We noticed open vertical joints between the façade panels. Joint width was ranging from 7 mm at the first floor level to 40 mm at the roof level and the latter was apparent from the north-east and south-west view of the façade. Joints appeared also in the compounds of internal longitudinal panels at axis No. 8

There are open and horizontal joints in the framing between staircase landings and interior panels, as well as between the panels at the floor levels. The measured widths of these gaps started from14 mm at the 2nd floor level to 29 mm at the 4th floor level. The increase in the longitudinal joint width with the height of the building was almost proportionally linear. In Section B of the building, there were cracks similar to those of section A, but their width was within the tolerance for this type of prefabricated buildings.

There was a drop in the south-eastern part of the housing block, and the largest drop (about 35 mm) was at the outer wall. The depth of subsidence also varied proportionally. The drop in axis No. 9 is about 10 mm, while in axis No. 8 is not visible at all, or equal to ZERO. There were apparent sidewalk collapses, with the biggest ones in the pavements outside and around Section A.

Concrete strength was identified through a non-destructive method to compliment the determination of gaps values in the panel compounds. The measured average values of concrete strength in various components ranged from 17.7 MPa to 27.8 MPa. Results showed that concrete strength was equivalent to the strength required by the design and acceptable by construction norms.

4. Stress Analysis

The geotechnical report, prepared for the building showed that the foundation, located at a depth of 1.90 m is laid on the second of three geological layers under the building – the one of the silty sandy clay. The average bearing capacity of this layer was estimated at 250 kPa.

Calculations showed that stresses in the ground beneath strip foundations of the building are the following:

- 163 kPa for foundations along the medium longitudinal wall
- 217 kPa for foundations beneath the transverse walls

- 254 kPa for foundations beneath the end transverse walls

The basement wall was not located centrally at the foundation, so the edge pressure was as high as 507 kPa (for foundations beneath the facade walls the secondary stress should be 178 kPa and the edge stress should be 356 kPa).

It was evident that stress over the ground under the strip foundations along the contour of the building exceeded the average load-bearing capacity of the ground (250 kPa).

Most clearly, it was observed that by the eccentric overload pressure in the end transverse walls (507 kPa), where the load of the centric stress is about the same as the bearing capacity of the ground itself (254 kPa). The situation beneath the longitudinal walls at the façade contour of the building (the eccentric stress was 356 kPa) was similar, though to a lesser degree.

5. Engineering - Geological Conditions

Ground beneath the building consists of expensive silt clay with thickness of about 7 to 8 m. Below, there is a layer of permeable sand with silt of 1m to 2m, but the level of the ground water was deeper than this. There are about 2m organic soil and embankment onto the base layer.

The physical and mechanical characteristics of the 2nd carrier layer (brown silty clay) are the following:

- Bulk Density ρ_n = 1.87 g/cm^3
- Dry Bulk Density ρ_d = 1.53 g/cm^3
- Void ratio e = 0.756
- Degree of water saturation S_r = 0.78
- Natural Water Content w_n = 21.94 %
- Plasticity index I_p = 30.80 %
- Consistence Index I_c = 1.04
- Angel of Internal Friction ϕ = 23,8°
- Cohesion c = 40 kPa
- Deformation Modulus E_0 = 17,5 MPa

The average swelling stress was measured by laboratory test at 60 kPa.

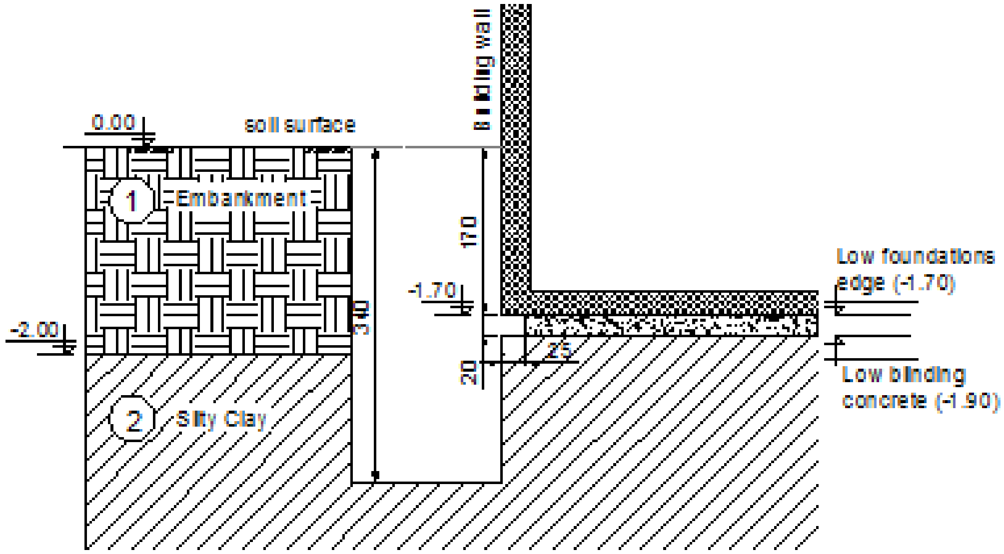


Fig. 2: Profile of the investigating trench at the base of the building

The thickness of the lowest 3rd layer varies from 1 to 2m (small damp medium compact sand). Please look at its physical and mechanical characteristics as well:

- Bulk Density ρ_n = 2.00 g/cm^3
- Deformation Modulus M = 16 MPa
- Poison's ratio v = 0.31
- Angel of internal Fraction ϕ = 36,6°

6. Triggers and Causes of Accident

High stress is a prerequisite for the deformation of the building, but it was not enough to cause it by itself, because the load was one and the same for the entire building and only the south-eastern part was deformed. Therefore, we assumed that there should have been other reasons influence, which were different for the different parts of the building and casing the deformation.

According to residents' interviews, the first cracks and discontinuities occurred in the joints between the precast panels around 1994, when there was a breakdown in the water supply tubes along the street and there was extreme water flow to the building. Water itself was collected around the south-eastern part of the building and retained there for a long period of time. Part of the water has evaporated, but the larger portion permeates into the soil. Values of deformation modules decreased additionally due to the extreme soil moisture. Stress concentrated beneath the short walls of the building rectangular contour and stayed there for a very long time.

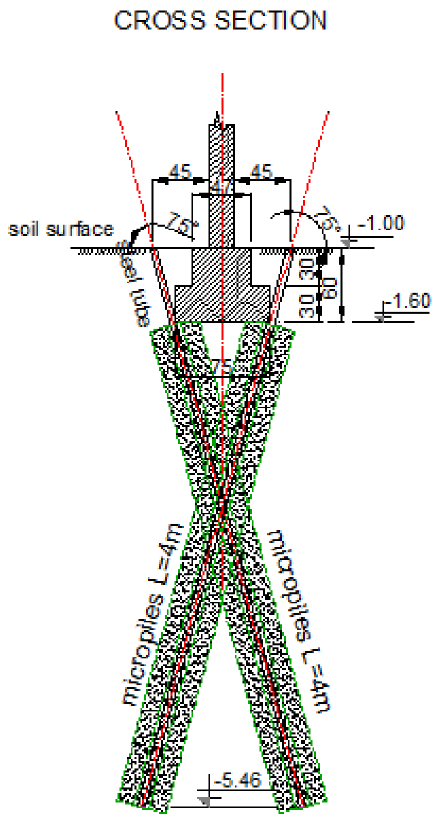
Therefore, these foundations dropped more than those in the middle of the long walls of the building

7. Design Protection Scheme

The first phase of rehabilitation, proved also by the analysis of deformation causes was to strengthen the basement walls and further eliminate the effects of shrinkage and swelling of the soil. This was necessary to also prevent a further deformation of the structure. Only after completing the above foundation repairs, we were able to continue with reconnecting panels, flooring and plastering.

The building was in active and continuous use by its inhabitants and it wasn't possible to do large and long construction rehabilitation.

Reviewing the above, we considered to repair the foundations with the micro-pile injections. Micro-piles were drilled deep under the strip foundation, coating and anchoring the soil by injecting grout under high pressure to displace moisture from the pores and improve deformation properties of the soil (Fig. 3).



. Fig. 3: Micro-piles under the foundations – Cross section

8. Technological Peculiarities of the protection works

Micro-pile technology is known in Bulgaria, but practiced by a few specialized companies. Foundation may even be raised by controlled synchronized pressure injection depending on specific geological conditions and the load of the structure foundation.

There were 57 piles, each 4m long to be placed at different distances, 83-90 to 180 cm from each other (Fig. 4). The injections were inclined at 75 ° to the horizontal line, and alternately from either side of the walls. They formed an X - shaped reinforced earth base in transverse profile, which is less affected by humidity, and has better deformation properties.

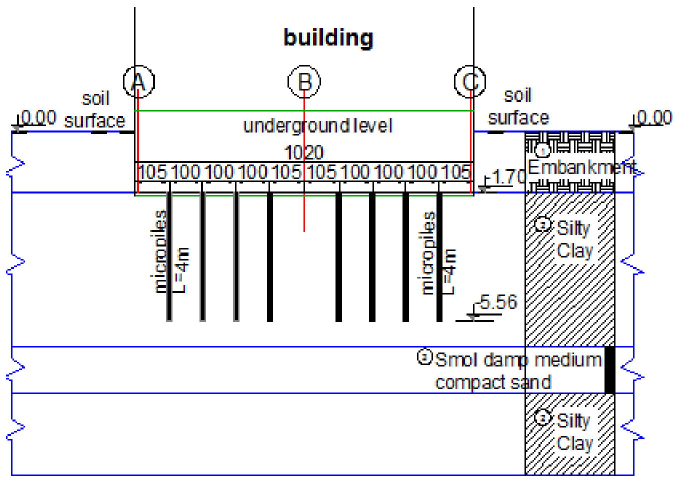


Fig.4: Micro-piles under the foundations – longitudinal section

Injection of micro-piles were performed in five profiles - three piles longitudinal to the building (along axes A, B and C) and two piles transverse to the building (along axes 5 and 6). The exact location of the micro-piles and their density is higher along profiles 5 and 6, and lesser along axis No. 1 (Fig. 5). Micro-piles were placed on the outside and inside of the basement, along with axes A, C and 6, while micro-piles along with axes C and 5 were done only in the basement.

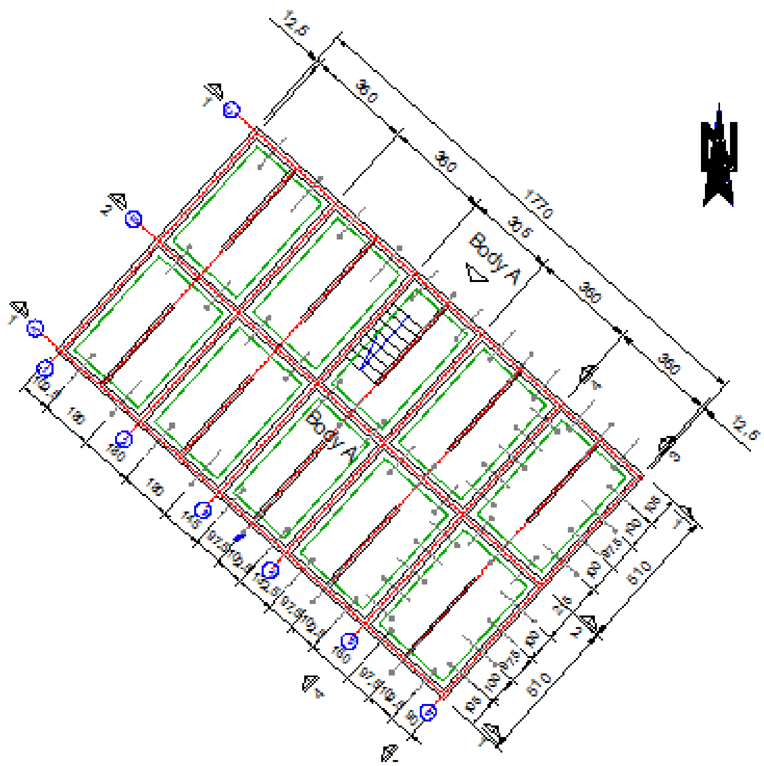


Fig.-5: Plan of the foundations and micropiles

Micro-piles in the basement were injected with a small portable drill 50 to 70mm in diameter. A thick, closed-ended steel tube with similar diameter, fitted with a nozzle and packer, was inserted in the apparatus mouthing. The grout was fed through the packer and thereafter, the team monitored pressure and possible deformation of the structure. As a result of the injection, a “collar" of grout was formed around the borehole and it entered the ground in a radius of about 40 - 45cm.

Injection ceased when the "collar" of grout have reached the main plane of the strip foundation. The steel tube can remain concreted in the pile and become an additional reinforcement. There is no need to dismantle the flooring for portable drill’s removal. It is enough to use light drilling for the purpose.

Micro-piles, used for outside injections in the field were placed with the same small drill or with a more powerful one, because there were no restrictions on the entry of the mast in space.

Specific characteristics of the technology suggested some small changes in parameters and profile due to the specific conditions on the basis structure and some reactions during the injection works.

We refined location parameters and the final number of piles within the injecting phase. For the perfect execution and effect we ensured and used precise geodetic equipment to monitor deformations.

Finally, the total length of the micro-piles was 228m, and the total length of steel tube was 279.60 m.

Design and implementation of maintenance, panel assembly, coating, flooring and plastering remained for the next phase of rehabilitation.

9. Results and Final Recovery

After the successful ground stabilization and completion of the injection works, the team proceeded with strengthening and recovery of the top construction of the superstructure. Panels were embedded (Fig. 6) with steel bars and bolts, joints and cracks were restrained and facades were plastered and painted.

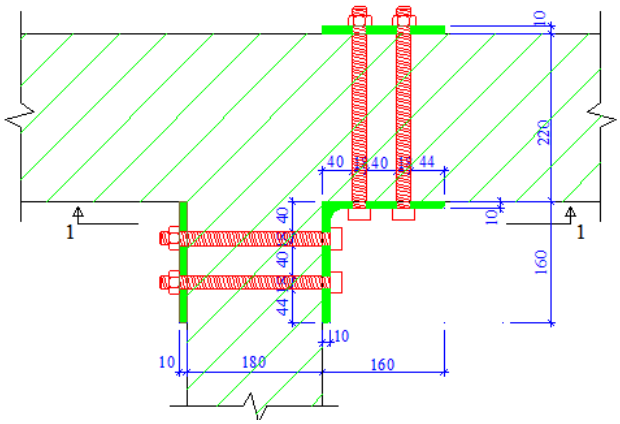


Fig. 6: Embedded panels with steel bars and bolts

The above best practice of restoration was presented to the new municipality administration and community for recovery of similar buildings in the area.

10. Conclusions

Micro-piling technology is very effective and efficient in repairing buildings damaged by-swelling soils. Injection eliminates the effects of swelling and increased dramatically the load-bearing capacity of the ground.

Fine stress control while injection works are done can strengthen the ground without causing additional pressure and deformations to the top sections of buildings. Micro-pile injection can be applied to pre- wound swelling soils, and before construction of any kind of buildings and premises.

11. References

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[2]. Kolev Ch. (2011), Foundations Ltd. – Technical design

[3]. Bojadjiev H. (2011), University of Transport – Sofia – Expert's report