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Case Study on the Foundation and Site Geotechnical Evaluation for the Rehabilitation of an Emergency Hospital Building

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CASE STUDY ON THE FOUNDATION AND SITE GEOTECHNICAL EVALUATION FOR THE REHABILITATION OF AN EMERGENCY HOSPITAL BUILDING

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ABSTRACT

This case study is about the foundation and the site geotechnical potential evaluation for the rehabilitation of an emergency hospital building, placed in Bucharest. This building was strongly damaged by the main earthquakes that occurred in Romania, within the last 30 years (March 4th, 1977, August 30th, 1986 and May 30th, 1990). The building had, from the beginning, an unfavorable structural concept, in what concerns its shape in plane. The paper presents the methods used for the rehabilitation of the existing building foundation, together with the integration of a new foundation for a new building, that appeared necessary to be built, as a single solution for the strengthening of the old one. Important additional loads were considered for the proposed solution and thus an extensive study on the foundation and geotechnical aspects of the project were carried out, including a site geotechnical study, evaluation of bearing capacity and settlement, evaluation of safety factors on bearing capacity, before and after the strengthening. The paper also presents some considerations on the peculiarities of the seismic events that occur in Romania.

INTRODUCTION

Earthquakes in Romania have been known since Roman times, when Traian's legionnaires began the colonization of the rich plains stretching from the Carpathian Mountains to the Danube River. The seismic activity of Romania is considerable, with approximately 10 distinct seismic zones, closely related to their geomorphologic features, the most important among them being Vrancea, Fagaras, Banat and Dobrogea. Since recordings from seismographic stations have become available, it has been established that the most frequent in largest earthquakes are from subcrustal Vrancea sources, located in the bent of Carpathian Mountains.

Vrancea is by far the most seismically active zone of Romania, which affects more than 2/3 of the territory. The largest magnitude event during last century (M = 7.4, where "M" is the Gutenberg - Richter magnitude) occurred on November 10th, 1940 at 133 km depth. The largest instrumentally recorded event (M = 7.2) occurred on March 4th, 1977, at 93 km depth, and, with this occasion, the first and the most important free-field strong ground motion Romanian record was obtained (0.2g peak ground acceleration and 1.6s long predominant period of soil vibration).

Some other three seismic events occurred in Romania after 1977 (August 31st, 1986, May 30th, respectively May 31st, 1990). The frequent occurrence of strong earthquakes in Romania led to a situation in which an important part of the building stock was damaged several times and, in the absence of appropriate rehabilitation works, has become more vulnerable than initially.

CITY OF BUCHAREST AND EARTHQUAKES

"*Nowhere else in the world is a center of population so exposed to earthquakes originating repeatedly from the same source*" – Charles F. Richter, 1977, March 15th, Letter to the Romanian Government.

Bucharest, the capital city of Romania, is sited in the central part of the Romanian Plain at a distance of around 160 km from the epicentral region of Vrancea (Marmureanu et al., 2001). The town is the largest country's cultural and economical center with 228 km^2 urbanized area and approximately 2 millions population (10% of the population of Romania and 18 % of the urban population of the country). During the last century, Bucharest was shaken by the four strong Vrancea earthquakes above mentioned. Bucharest has about 110,000 buildings: 5000 high-rise reinforced concrete buildings (≥8 stories, including the ground floor), 8000 mid-rise reinforced concrete and masonry buildings (3-7 stories) and 97,000 low-rise masonry buildings (1-2 stories). The periods of building construction were classified according to the period of validity of the Romanian seismic codes, as follows: before 1920, 1921÷1948, 1949÷1963, 1964÷1977, 1978÷1981, 1982÷1992, after 1992. In Fig. 1 the evolution of the overall seismic coefficient, according to the Romanian codes for aseismic design is presented.

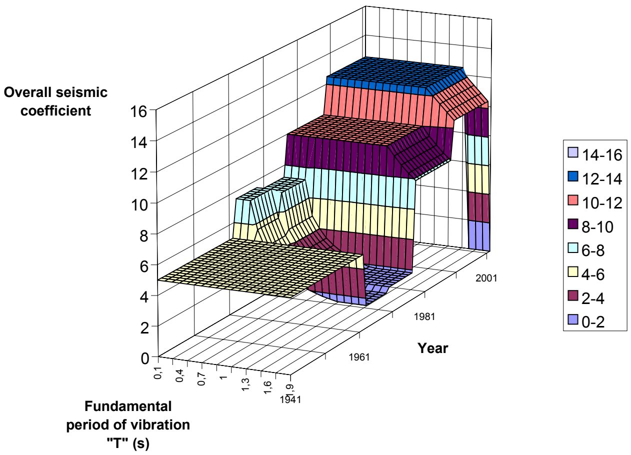

Fig.1 Evolution of the overall seismic coefficient

The foundation soil of Bucharest consists of fluvial-lacustrian loesslike and alluvial deposits. The fluvial-lacustrian deposits are formed of fragments of quartz, micaschists, gneiss and sandstone. The loesslike deposits, extending on over 10% of the city area, are formed of 13% sand, 47% silt and 40% clay. The greatest thickness of these deposits (10÷16m) is to be found in the Cotroceni-Vacaresti and Pipera-Pantelimon plains and the thinnest cover (3÷4m) in the Bucharest plain. The alluvial deposits, particularly encountered on the meadow of the Dambovita River, show a high granulometric variety ranging from clay, silty clay of high plasticity to sandy silt. The geotechnical conditions and the physico-mechanical features of the foundation soil are well known, due to the many geotechnical drillings performed on the city area (Marmureanu et al., 2001).

The first code for aseismic design of buildings and other engineering structures was approved in 1963, based on the knowledge available at that time. The building, whose foundation system is subject of this paper, was designed by applying this standard.

SHORT DESCRIPTION OF THE BODY "C2", BELONGING TO THE "EMERGENCY HOSPITAL", BEFORE STRENGTHENING

From the architectural point of view the existing building has 9 levels (basement, ground floor and 7 floors). The structural system of the building is reinforced concrete moment resisting frame type.

The technical assessment of this building, that is included in the hospital complex (called building "C2"), was imposed by the following reasons:

- the building has supported the past seismic events (1977, 1986 and 1990), which led to a cumulative structural and non-structural damage;
- after the 1977 strong motion, very severe damage was reported, and the woks consisted in strict local repairing of damaged elements (without having a general concept of strengthening);
- the body "C2" has an unfavorable plan layout (Fig. 2), elastic and inertial dissymmetry;
- a general state of visible damage was present (cracks and fissures);
- the building was designed in 1967, by applying the first Romanian seismic standard approved in 1963 at that time.

Based on the experimental data obtained during the 1977 Vrancea earthquake (mainly on the accelerogram recorded at INCERC station), the standard has been replaced by a new version in 1978.

The main deficiencies of the original standard (1963) were underlined by the characteristics of the Vrancea records and by the response of different structural systems, such as: R.C. moment resisting frames, R.C. shear walls and unreinforced masonry walls. These were:

1. The modal response requirements of the first code have been established based on El Centro response spectra envelope, according to the Soviet seismic standard that was at the base of the Romanian standard. The Vrancea earthquake proved that the ground motion response spectra maxima appeared in the 1.0÷1.5 seconds range.
2. Based on the above considerations, the seismic intensity of Bucharest area was under-evaluated with more than 1 degree on Mercalli intensity scale.
3. The combined deficiencies presented in the paragraphs 1 and 2 show that for hire-rise buildings which have the predominant period greater than 1 sec, the design seismic forces, computed based on the revision of the standard, are at least 5 times greater compared with the same forces computed based on the 1963 version.
4. The 1963 standard didn't take into account the "structural ductility" and the consideration of favorable energy dissipation mechanism that is based on the favorable placement of the plastic hinges.

Due to the combined deficiencies on many reinforced concrete structural systems, with insufficient ductility, partial damage or even collapse was noticed.

All the elements pointed out in this paragraph were present at the moment when the technical assessment of the building "Corp C2" began.

According to the P100-92 standard, the following steps must be taken during the inspection of a damaged building after an earthquake:

- visual examination and possible emergency measures;
- sketching of all kinds of damage on existing, or new, drawings (special attention is given to all load-bearing elements);
- localization of possible gross errors in the structural conception of the, in the construction and detailing and in the maintenance and possible misuse;

- collection of information regarding previous condition of the buildings: pre-existing damage, behavior of the building during previous earthquakes, possible earlier repair work etc.;
- examination of similar buildings in the vicinity, for purposes of differentiating diagnosis;
- study of design documents of the building.

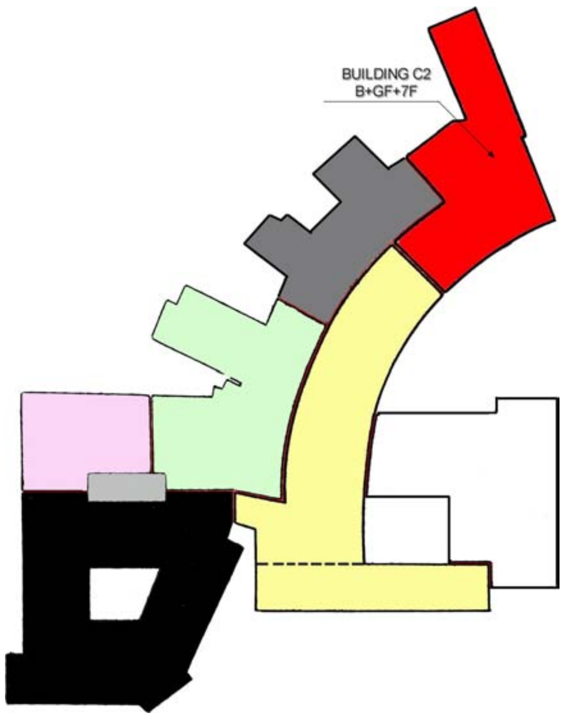

Fig. 2 General drawing of the buildings belonging to the Bucharest "Emergency Hospital"

In several cases, instrumental measurements may be needed, both in order to quantify the degree of damage and to complete the information regarding the condition of the building before damage:

- geometrical measurements (leveling and eccentricities, widths of cracks, residual deflections, in time evolution of the above mentioned characteristics);
- ambient vibration measurements of damaged masonry buildings (natural periods, modal shapes and damping);
- brick and mortar strength evaluation (non-destructive tests).

The pathological image of the structure, assessed by means of the above-mentioned inspection and instrumental methods, has to be completed by an estimation of the seismic forces, which have acted on the structure.

Obviously, among other structural parameters, the strength has a decisive influence on the seismic response. For this reason, the adequate determination of the seismic design forces, in order to reasonably limit the structural damage, represents one of the most important objectives of the design (Vlad I, 2001).

THE STRATEGY ADOPTED FOR THE STRENGTHENING SOLUTIONS FOR THE BUILDING "C2"

After performing the technical assessment of the building, according to the present technical legislation, the existing defavorable "spectral positions" were modified, in order to reduce the requirements for displacements, ductility, energy dissipation, by:

- shortening of the fundamental period of vibration;
- increasing of the capacity of structures to earthquake resistance.

As the activity of the hospital was not to be disturbed, the most reliable solution for strengthening of the building was the execution of an extension on the N-W corner of the existing building, where to place the main structural walls, necessary to strengthen the building on both directions (Fig. 3).

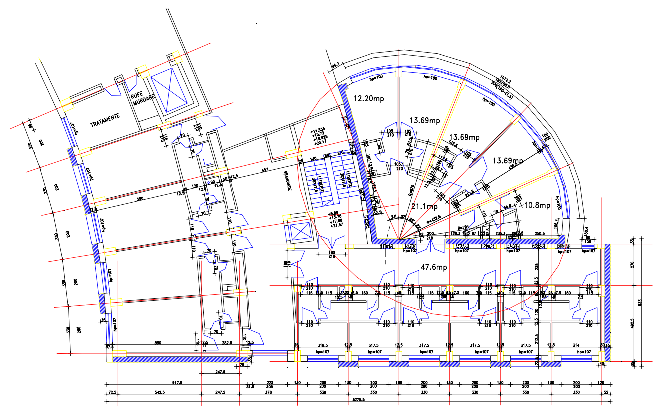

Fig. 3 Architectural drawing of the building "C2" (strengthening solution by extension)

SOIL INVESTIGATIONS AND SOIL TESTING

In view of establishing the lithological structure of the soil and of determining its main geotechnical characteristics, a drilled well of 12m depth was performed on the site. Two Swedish weight-sounding tests were accomplished. Starting from the grade towards the bottom, the lithology of the soil layers was, as follows:

0.00÷3.20m	dark colored heterogeneous loose backfill, consisting of remains of building materials included in clay mass, with N_{20}=1÷4 blows, Rd=6÷22 daN/cm^2;
3.20÷7.90m	backfill consisting of clay particles, gray-green colored, smelling like silt, thin sandy lens, limestone, with N_{20} = 2÷7 blows, Rd=9÷30 daN/cm^2;
7.90÷8,30m	brown silty-sandy clay, soft, with very high compressibility;
8.30÷9,60m	brown sands presenting rare gravel, loose near the surface of the layer and dense in depth, with N_{20}=6÷18 blows, Rd=24÷68 daN/cm^2;

9.60÷10.9m	brown-red medium sand with gravel, dense, with N_{20}=35÷45 blows, Rd=130÷160 daN/cm^2;
10.9÷13.0m	gravel with dense and very dense sand, with N_{20} = 50÷110 blows, Rd=170÷340 daN/cm^2.

Considering other previous drills in the nearby area, between 13.00÷23.00m intermediate cohesive deposits of clay develop, with dense brown silty sands up to 18.00m and with gray stiff plastic-state clays, between 18.00 and 23.00m. Between 23.00m and 30.00m there are consecutive silty/clay sands, dense, and stiff plastic-state clays. The hydrostatic level of water was established at 7.00m below the surface level. The information obtained as a result of the geotechnical study, the evaluation of bearing capacity and settlements led to the concept of earthquake resistant design of the foundation structures, based on the concept of dynamic and inelastic behavior of the components of the complex structural system (superstructure + substructure –2 levels + foundation structure + massif of soil).

FOUNDATION STRUCTURES

The foundation system and the substructure of the building "C2" was established mainly by:

- the strengthening solution adopted for the superstructure of the building, that is *reinforced concrete structural walls* type;
- significant values of the stresses resulted from the special combination of loads, together with the loads produced by the seismic actions;
- the geotechnical study conclusions.

The solution for the system of foundation is presented in Fig. 4 and Fig. 5.

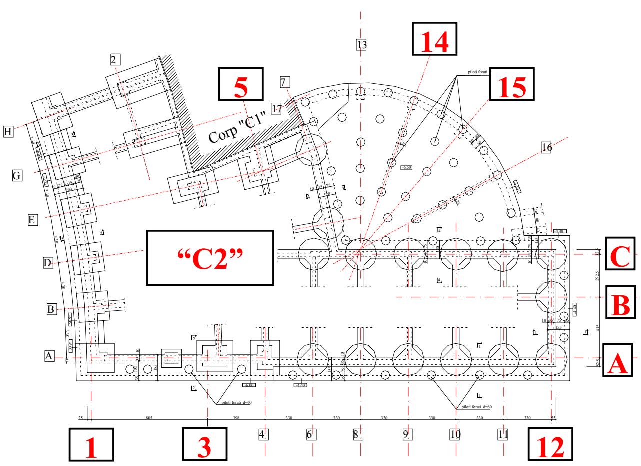

Fig. 4 Foundation structures of the building "C2" in view of strengthening

For the *existing building* foundation beams were realized on the height of the basement, connected between them, which become the support of new reinforced concrete structural walls of the superstructure. Generally, the foundation beams are more extended in plane, in comparison with the structural walls limits (the length of the foundation beams is greater than the height of the structural wall section, so that the overturning moment generated by the seismic action may be taken over).

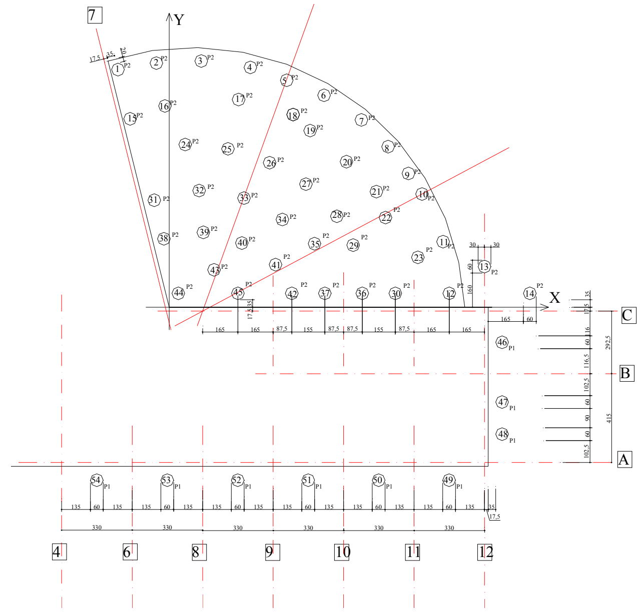

Fig. 5 Pile drawing for the extension of the building "C2"

The foundation system consists in (Fig. 4):

- new footings of reinforced concrete inserted in the existing foundations, along the axes "1" and "A" (between axes "1" and "4"), which will become the support for the foundation beam of the new structural wall. The new footings develop vertically up to the level of the existing foundations and up to the existing foundation beams that are support for the existing basement wall;
- along axis "A" (between axes "4" and "12"), as well as along axis "12", both new reinforced concrete footings together with new piles (Φ=60 cm, drilled up to 13.50m depth from the soil surface) were accomplished, inserted among the colonnade foundations (Φ=220cm and/or Φ=200cm, Fig. 6) and the existing footings;
- for the intermediate transversal wall in axis "5", in the staircase, a foundation raft of about 2.50m thickness and reinforced concrete walls on the height of the basement were realized, connected to the existing walls and columns of the basement in the mentioned area;
- in the new extension zone (between axes "C" and "7"), a general foundation raft solution was adopted (thickness = 1.0m); it rests on a pile network (2.25m x 2.25m) of drilled piles (Φ=60cm, drilled up to 13.50m depth from the soil surface). The foundation level of the raft is -6.50m, corresponding to the foundation level of the existing "C2" building in the same zone. Along the axes "C", "7", "14" and "16", as well as on the curve contour of the extension,

foundation beams on the height of the two new basements were realized, that rest on the drilled piles (Φ=60 cm).

Fig. 6 Photo of the foundation of the existing building

In Fig. 7 a general view of the foundation system after the achievement of the drilled pile network is presented.

Fig. 7 Photo after the execution of the piles

The new footings, foundation beams having the same height as the basement, together with the heads of the new drilled piles, join with the structural elements of the existing infrastructure of the building “C2” (foundations, basement walls, columns). The adopted solution consists of reinforced concrete anchors, having adequate dimensions and reinforcement, and chemical connectors (epoxy resin type).

In conclusion, the infrastructure of the building consists of:

- foundation system (existing foundation with corresponding foundation beams and colonnade foundations, new footings, new foundation raft on the extension zone and new piles), which leads to allowable limits of remanent deformations of the soil;
- *basement structural walls on both principal directions* (existing basement walls and the new foundation beams over the height of the basement, under the reinforced concrete structural walls of the strengthening solution);
- *floor over the basement*.

The structural elements that make the “C2” building infrastructure have dimensions, reinforcement and resistance capacity, more superior compared to the levels of the superstructure, assuring a “rigid zone” at its base level.

Both infrastructure and the soil beneath it are capable of taking over the efforts induced by the superstructure, at the floor over the basement level, without significant remanent deformations.

Fig.8 Photo during the execution of the foundation beam (axis “A”)

In Fig. 9 and Fig. 10 aspects of the works at the superstructure are shown.

Fig. 9 Photo during the execution (axis “1”)

Fig. 10 Photo during the execution of the building extension

CONCLUSIONS

1. The strengthening reinforced concrete structural walls of the superstructure, positioned in the axes “1”, “A”, “12”, “C”, “7”, “14” and “15”, have a common base, being tied together under the ±0.00m level by foundation beams, having the same height as the basement (Fig. 8). The foundation beams mainly rest on new footings, in order to assure the necessary resting surface on soil, tacking into account the special combination of loads, together with the loads produced by the seismic actions, and also on the existing foundations.

2. The adopted solution, for the foundation system of the existing building and of the newly designed extension, by ensuring a common base for the strengthening structural walls (realized by the foundation beams of the same height as the basement), offers the following important advantages:
   - the pressures on the soil are reduced, in case of the seismic actions, as a significant fraction of the overturning moment is taken over by the foundation beams of the strengthening reinforced structural concrete walls;
   - an important part of vertical load of the building contributes to the structural system stability under horizontal seismic loads; consequently, tension stresses do not occur in the new drilled piles and/or in the existing colonnades, and the foundation soil doesn’t yield before the resistance capacity of the structural walls is reached.

3. The analytical structural model for the infrastructure was a plane beam network on elastic media. The raft foundation of the extension of the building was also considered a beam network on elastic media, by considering elements with the same width, parallel with the axes “C” and “7”.

4. The raft foundation, corresponding to the strengthening structural transversal wall in axis “5”, is 2.50m thick and is extended in all the corresponding area of the staircase. For balancing the foundation in order to eliminate and/or decrease its detachment from the soil, the majority of the columns in the basement zone were involved (gravitational loads). As a result, uniform pressures on the ground, increase of stability, decrease of the rotational trend of the structural wall basis under horizontal seismic loads, were obtained.

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