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THE INFLUENCE OF FOUNDATION SOILS CONCERNIG THE BEHAVIOUR OF BUILDINGS

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ABSTRACT:

An issue more and more important in construction science represents the rehabilitation of structures placed on difficult soils. This paper presents the behaviour analysis of an existing structure and summarizes several consolidation solutions at both levels of a severely damaged construction placed on a shrinking and swelling soil, located in Arad County - Romania, situated on 55 Revolutiei Avenue. These types of soils are known in specialty literature as shrinking fields, expansive or active soils, having the property to modify sensitively their entire volume when there are variations of moisture, being spread on a large scale in Romania. After the assessment of seismic safety for a section of the damaged structure, which is characterized by a high risk of collapse from seismic action, reason for which it has been proposed to immediate by consolidate the damaged construction.

1. INTRODUCTION

A series of buildings from all over the world are founded on difficult soils. One of this soil is represented by those who present shrinkage and swelling properties (the abbreviation in Romanian language is PUCM).

These type of soils are known as shrinking fields, expansive or active soils, having the property to exhibit large volume changes when their water content changes (Ito, 2010). These kinds of soils due to the alternative process of shrinkage and swelling due to seasonal climatic variations lead to development of significant degradations in the civil infrastructure system.

This movement in the soil results in structural damages especially in lightweight structures such as sidewalks, driveways, basement floors, pipelines and foundation (Tawfiq, 2009).

The variation of volume for these types of soils does not occur uniformly across the entire built area, so supporting structures are submitted for further actions - supports disposals against soil shrinkage and swelling pressures on the surface of foundation base at the process of soil expansion (NP 126-2010).

Expansive soils owe their characteristics to the presence of swelling clay minerals. As they get wet, the clay minerals absorb water molecules and expand; conversely, as they dry they shrink, leaving large voids in the soil. Swelling clays can control the behaviour of virtually any

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type of soil if the percentage of clay is more than about 5 percent of the weight. Potentially expansive soils can typically be recognized in the lab by their plastic properties. Inorganic clays of high plasticity, generally those with liquid limits exceeding 50 percent and plasticity index over 30, usually have high inherent swelling capacity (Das, 2014).

In case of contractile fields, as a result of swelling due to moistening and of shrinkage due to drying, it may appear the risk of degradation or foundation breaking, phenomenon followed by the occurrence of fissures in brick walls or cracks in the structural masonry walls (Popa, 2013).

In Romania, until now were identified the following areas where shrinking and swelling soils are located: in Carpathian areas of Oltenia, Muntenia, Banat, and isolated areas in Dobrogea and Muntenia; particular in the Transylvanian plateau to the north, in the hilly areas of western plains, in meadow areas and terraces of rivers, especially in the Moldovan plateau and in some areas of meadow and Danube Delta (NE 001-96).

2. CASE STUDY

The present paper has the objective to analyze the behaviour of a damaged building, realized from masonry, located Arad County, situated on 55 Revolutiei Avenue, which shows significant damages as a consequence of soil failure under a section of the building, as well as the structural weaknesses of the resistance structure.

Existing structures built before 1970s are gravity load designed with inadequate lateral load resistance because earlier codes specified lower levels of seismic loads and many of these structures are still in service beyond their design life. On the other hand, some deterioration of component parts of buildings is encountered in old structures due to the actions of different factors (Dan, 2006).

The damaged building illustrated in figure 1, was analyzed in accordance with the requirements of "Seismic Design Code - Part III - Provisions seismic evaluation of existing buildings, Sings P100- 3/2008", in order to place the construction in seismic risk classes.

Figure 1. The analyzed masonry building

The main damages of the resistance structure can be grouped in 2 categories. The first category is represented by the cracks in the masonry bearing walls as seen in figure 2 and some cracks at the interior corners of the walls as seen in figure 3. The second category is illustrated by the corrosion and deformation of some metallic elements from the interior courtyard balconies and some slabs.

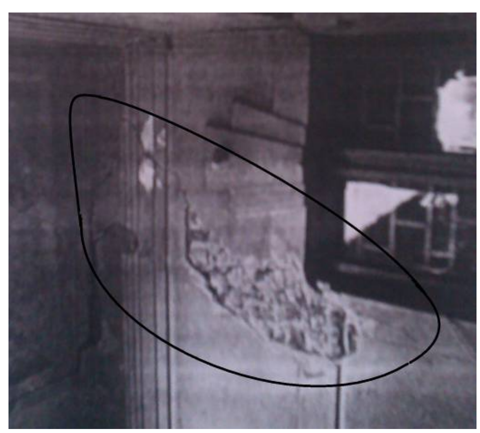

Figure 2. Cracks in masonry bearing walls

Figure. 3 Cracks at interior corners of the walls

By the configuration and orientation of those cracks it can be concluded that the part of construction situated between axes B 1-3 and E 1-3 as seen in figure 4, was affected by a strong subsidence, with more pronounced tendency of subsidence at the blind wall E 1-3. This is illustrated by both cracks: first is an oblique crack from the blind wall, positioned on the building section D- E of row 1, second crack is in the lintels of the analyzed section.

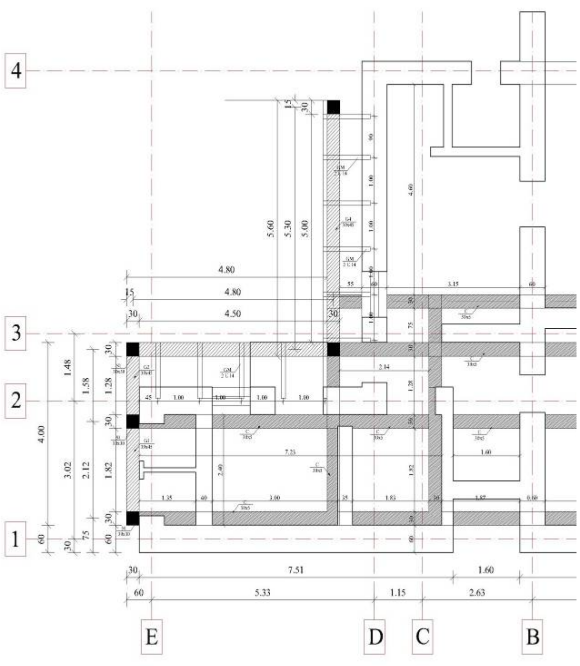

Figure 4. Section analyzed between axes B 1-3 and E 1-3

3. THE DEGRADATION CAUSES ON A SECTION OF BUILDING

From the inspection of the damaged building were evidenced the main causes of degradation.

3.1. Arranging basement of a building

The arrangement work of the building basement took place in 2001 and involved 2 major operations which have contributed to volume changes in the contractile ground.

First operation is represented by repairing the sewage equipments, which led to a decrease of water level in the ground under the construction.

The second operation was represented by lowering the floor level at the basement construction on a specific area, by removing a significant amount of soil, which contributes to easier water evaporation from the soil situated under construction and to a decrease of the allowable pressure of the ground.

3.2. The presence of some trees near construction

Another factor that contributed to the degradation of the analyzed section is represented by the presence of a walnut tree about 15 m height placed near the blind wall E 1-2, which is found at the distance of 1.9 m from the analyzed building, as well as a tree placed at 7 m from the building.

One of the most important sources which generate soil drying by absorbing moisture from the ground is represented by placing vegetation too close to the construction, through the effect of dewatering process produced by trees (Roman, 2010). Over 80% of the damages caused to a construction founded on contractile clay soils are due to the existence or planting trees and shrubs (NP 126-2010).

The zone of influence for changing the soil moisture, owed to the dewatering phenomenon, it is both spread in depth and horizontally in the ground at (0.5 - 1.00) H, where H is the height of the tree. The area of influence through the effect of dewatering concerning the analyzed construction extends to 7-15 m.

This degradation factor is highlighted by the fact that the phenomenon of subsidence, that led to the occurrence of fissures and cracks, occurred predominantly in the influence area of the tree, on the section B 1-3 and E 1-3, as well as the building residents statements, like there were "slight fissures and apparent cracks" before 2001, when the arrangement of the building basement started.

The level oscillation of the landing in the stairwell, have appeared probably from the swelling of the contractile soil, where the phenomena of dewatering and descending water level in the foundation soil did not occur, because this area is far away from the factors that produce the loss of moisture.

In the specialized literature is stipulated that the effect manifests itself more intensely, leading to the appearance of cracks in the upper part of the walls (NP 126-2010).

3.3. Structural weaknesses of the resistance structure

The vulnerability of existing structure may be due to structural system weaknesses and specific detailing. Structural weaknesses are characterized by various irregularities and discontinuities or by structural vulnerabilities (Bob, 2006).

Structural weaknesses of the resistance structure owed to the period when it was realized (1870) is a quite important cause that led to the development of cracks and to the emphasized deformations of the resistance structure.

Main structural system weaknesses:

1. Absence of reinforced concrete beams at each level;
2. Absence of reinforced concrete pillars;
3. Sharp asymmetry in plan in both directions. The section D-E 1-3 has a much lower rigidity, compared to the main section;
4. The irregular setting of diaphragms, like the big distance between them;
5. The slabs made of metallic beams, with little arches of brick do not provide sufficient rigidity in horizontal plan;
6. Significant level heights.

3.4. The lack of protection of some metallic elements

Corrosion and the deformation of some metallic elements of the balconies resulted in a long period of time, as a consequence of electrochemical corrosion processes. In case of external humidity (RH > 70%) the electrochemical corrosion process of metallic elements with micro crystals occurs at higher or lower speeds, in case of an improper protection (EN 1993-1-1:2006).

The steel beams of the balconies were not protected for a long period of time, by covering or painting them regularly, which led to their degradation even to removing them from service.

4. ASSESSMENT OF BUILDING SAFETY THROUGH CALCULATION

The evaluation of seismic safety and the classification of seismic risk classes are made on 3 categories of conditions which make the object of investigations and analyses performed within assessment.

The final decision regarding the safety of structure (including classification of seismic risk class of the construction) and the required intervention measures are guided in the way that the 3 categories of conditions are satisfied, quantified through 3 indicators: (P100-1/2013).

R_1 - the degree of achieving the conditions of structural conformation;
R_2 - the degree of structural damage;
R_3 - the degree of seismic structural insurance.

According to the value resulting from the conditions of structural conformation $\mathbf{R_1=0.40}$, the construction corresponds to the seismic risk class RS II.

From the conditions of structural damage of the degree value $\mathbf{R_2=0.35}$, the construction is framed in the seismic risk class RS I.

The degree of seismic structural insurance, denoted with R_3 represents the ratio between the seismic capacity and the seismic structural requirements, expressed in terms of resistance (P100-1/2013 and P100-3/2008).

The loading for the affected part of the analyzed building - section BE 1-3 was considered as the sum of the loads of walls, the roof truss (including snow), the loads of the slabs weight (permanent and variable loads), resulting a total load $m=3778kN$.

The value of seismic action, according to P100-1/2013 in the design of existing buildings resulted $F_b=856\ kN$.

$$F_b = \gamma_1 \cdot S_d(T_1) \cdot m \cdot \lambda \tag{1}$$

$$S_d = \frac{a_g \cdot \beta_0}{q} \tag{2}$$

$$q = 1.5\frac{\alpha_u}{\alpha_I} \tag{3}$$

$$T_1 = c_t \cdot H^{3/4} = 0.343s \quad (4)$$

where: $\gamma_I = 1$ - factor of importance / exposure;
$S_d(T_1) = 0.27$- the ordinate of design response spectrum, corresponding to the fundamental period T_1;
$c_t = 0.045$ - depending on the type of structure;
$H = 15m$ - building height in meters;
$T_1 = 0.343s$ - fundamental vibration period of the building;
$T_c = 0.7s$ -control corner period of the elastic response spectrum;
$\lambda = 0.85$ - correction factor ($T_1 = 0.343s < T_c = 0.7s$);
$q = 1.65$ - behaviour factor;
$\frac{\alpha_u}{\alpha_I} = 1.10$ - factor which takes into account the over strength of the building, especially the redundancy of the structure;
$a_g = 0.16g$ - the land design acceleration;
$\beta_0 = 2.75$ - elastic response spectrum normalized.

The verification of strength capacity for the entire section of building B 1-3 and E 1-3 was performed on both directions, according to the formula (5).

$$R_3 = \frac{S_{cap}}{F_b} \quad (5)$$

where:

$$S_{cap} = A_z \cdot \tau_k \cdot \sqrt{1 + \frac{2\sigma_0}{3\tau_k}} \quad (6)$$

$$\sigma_0 = \frac{N}{A_{zx} + A_{zy}} \quad (7)$$

where: S_{cap}- seismic shear force capacity;
F_b - conventional seismic load (seismic base shear force)
$A_{zx} = 9.23$ m^2 - area of the masonry on direction x;
$A_{zy} = 5.76$ m^2 - area of the masonry on direction y;
$\tau_k = 0.04$ N/mm^2 -major damages, reduction 25-30%;
$\sigma_0 = 0.251$ N/mm^2- unitary axial stress;
$N = 3778$ kN - total axial load.

The indicator values on both directions resulted $\mathbf{R_{3y} = 0.612}$ and $\mathbf{R_{3x} = 0.98}$, therefore the analyzed section of the building frames the entire construction in the seismic risk class RS II.

5. CONSOLIDATION SOLUTIONS PROPOSED FOR THE ANALYZED CONSTRUCTION

Following the technical expertise which lay behind the rehabilitation project, the following stages were proposed to consolidate the building, in chronological order:

1st stage. Cutting and uprooting the two trees located near the building. It is known that the tree roots remain active a long period after cutting the trees.

2nd stage. Soil consolidation by injection of laitance - bentonite in the ground under foundations, to increase the bearing capacity of the soil and to decrease the deformation capacity. There will be realised 144 points of injection of a cement-bentonite suspension under the existing foundations.

3rd stage. Execution of isolated foundations under the new columns of the reinforced concrete frame.

4th stage. Realization of reinforced concrete frames, with the purpose to stabilize the entire ensemble of the building.

5th stage. The reinforced concrete frames are connected to the existent structure through flat girdles 30x5cm (30cm wide and 5cm trick) placed at each level.

6th stage. Consolidation of walls with cracks or fissures, by fitting gibs Ø6 – Ø8 mm on the channel of fissures and injecting them with epoxy resins SIKA REPAIR.

After the structure consolidation by performing the reinforced concrete, each of the five columns of reinforced concrete placed on the affected outline section are characterized by the capacity efforts:

- Flexural Moment Capacity: $M_{cap} = 34.34$ kNm;
- Shear Force Capacity: $T_{cap} = 21.73$ kN.

Were obtained on both directions x, and y, the shear force capacity:

$$S^{cons}_{cap,y} = 524.50 + 5 \cdot 21.73 = 633.15kN \quad (8)$$

$$S^{cons}_{cap,x} = 840.5 + 5 \cdot 21.73 = 905.7kN \quad (9)$$

where:

$S^{cons}_{cap,y}$ - seismic shear force capacity on direction y for the consolidated structure;

$S^{cons}_{cap,x}$ - seismic shear force capacity on direction x for the consolidated structure.

It was verified the resistance capacity for the entire ensemble of the consolidated section B1-3 and E1-3 on both directions, where were obtained the indicator values of the level of seismic structural safety $\mathbf{R_{3y} = 0.74}$ and $\mathbf{R_{3x} = 1.06}$. The consolidated building is framed from the point of view of the seismic structural safety in the RSIII risk seismic class.

6. CONCLUSIONS

By cutting and uprooting the two trees near the building, is eliminated one of the most important factor which produces the ground drying, by the effect of dewatering produced by trees.

The soil injection aims to fill the ground voids, creating a mixture from the injected solution and soil particles, which by strengthening leads to a mass of stabilized soil. A really good improvement for the foundation soil will be achieved, characterized by an increase of the bearing capacity of the soil, as well as by a decrease of deforming capacity by performing 144 points of injections made of a suspension of cement - bentonite.

The reinforced concrete frames are designed to stabilize the entire ensemble of the building. On the other hand, by connecting them to the existing structure by the means of flat girdles and by consolidating the building walls, by fitting gibs Ø6 – Ø8 mm on the route of fissures and injecting them with epoxy resins SIKA REPAIR, the percentage of vertical and horizontal damaged surfaces will decrease considerably. The values of the indicators R_1 and R_2 will be sensitively improved, following to include the construction into another seismic risk class.

As last and most important conclusion, the consolidated structure fits in seismic risk class RS III "Constructions at which are expected structural damages, which do not affect significantly the structural safety".

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