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TUDOR OFFICE CENTER, IAŞI

BY

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Abstract. This work briefly describes the project of a dual structure building with structural walls and frames made of cast-in-place reinforced concrete, located in Iaşi, having the height classification Underground + Ground floor +8 Levels. The impact of the interaction between the soil and the construction on the earthquake response is being analysed. The constructed area of the building is A_c = 770 m^2, the gross building area is A_d = 7.863 m^2, and the level height: underground – 2.65 m, ground floor, E_i – 3.10 m resulting a total height, H = 30.55 m. The location, with 3.0% slope from North to South, is part of the hilly areas of Iaşi so that the general stability is ensured. The building was exclusively designed for office spaces.

Key words: tudor; office; center; walls; dynamic; coefficient of soil reaction.

1. Introduction

The construction was designed and executed between 2007 and 2009 (Fig. 1).

The sizes of the building are listed below (Fig. 2):

1^o plain view:

a) in longitudinal direction: 6 spans × 6.00 m + 1 span × 7.10 m (central span with ladder and elevators) – L = 43.40 m;

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b) cross-section: three openings: – 5.525 m + 6.80 m + (5.525 m… 2.525 m) – variable B = 18.15…15.15 m;

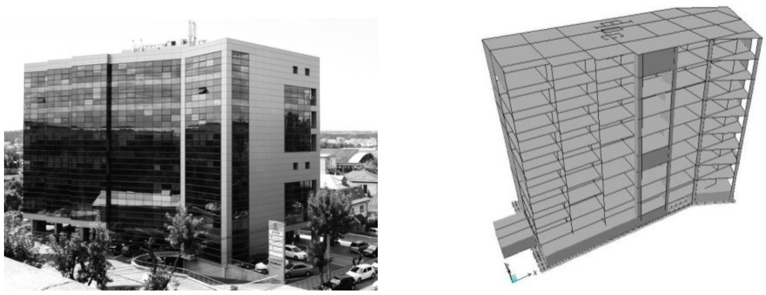

Fig. 1 – Tudor Office Center, Iaşi.

2^{o} vertically, it is developed on 10 levels (underground – h_d = 2.65 m and ground floor + 8 levels – h_e = 3.10 m) – H = 30.55 m.

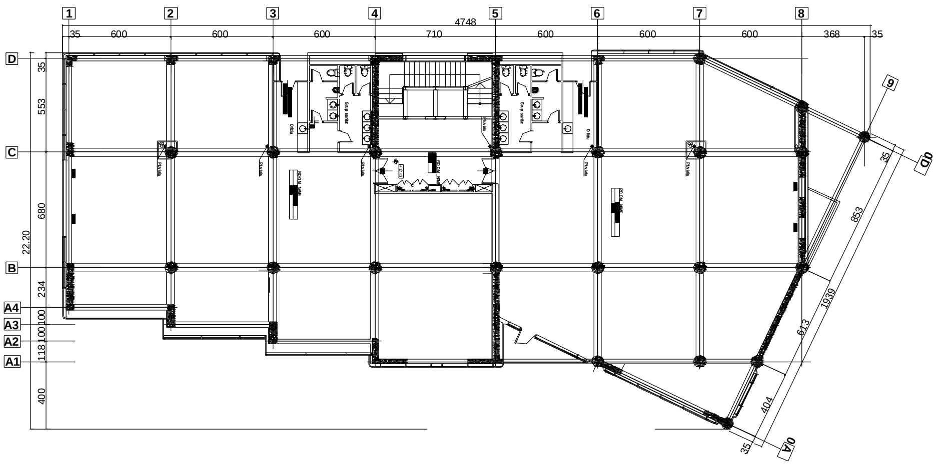

Fig. 2 – Architecture current plan.

The real estate was designed with a dual structure provided with structural walls and frames made of cast-in-place reinforced concrete. The architectural restrictions of the façades and the availability of the parking places at the underground have lead to a solution with a structural conformance in longitudinal direction – “mainly frames” and in cross-section – “mainly structural walls”.

The floors of the current levels consist of boards of 16 to 18 cm thickness, made of cast-in-place reinforced concrete, supported by a net of internal beam girders having the section of 50 × 50 cm and beams having the section of 30 × 70 cm on the construction's contour. The central columns have a constant circular section of Ø70 cm and the marginal columns have variable rectangular sections between 40 × 130 cm and 40 × 200 cm, the thickness of the structural walls of the current levels being equal to 40 cm.

The building's foundation was designed on a general raft consisting in a net of beam girders with the section of 1.10 m × 1.50 m and in 50 cm thick boards (Fig. 3).

The underground structure consists of 40 cm thick reinforced concrete walls having a cell-type distribution, along with the general raft and the floor, build up a subassembly having the rigidity needed by the structural conformance to take over and transfer to the foundation soil level the static and dynamic earthquake loads.

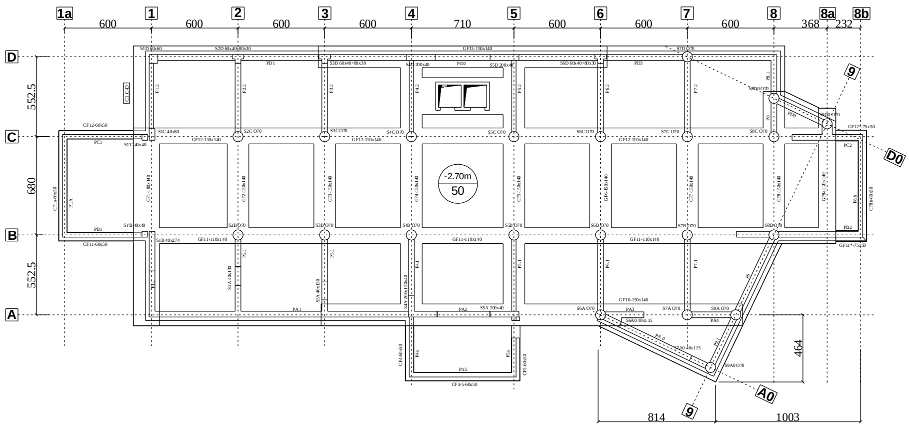

Fig. 3 – Foundation plan.

To increase the parking area a lateral outbuilding, Axe 1A/1, was executed at the underground, independently from the building's structure. The geological bedding includes, on an approx. depth of 6.50 m cohesive plastic hard soils – powdery clays and argillic powders, that are highly compressible beds. To lower the compactions, the first bed of powdery clays was replaced by compacted local soil, forming a cushion of variable thickness in steps from 1.00 m to 2.00 m, flared against the construction's area by approx. 1.00 m.

2. Calculation and Design of Structure

The structure was calculated (statically and dynamically) with the help of the space calculation software ETABS version 9.2.1 (ETABS, 2007). The seismic survey was conducted according to the design code P100-1/2006 (P100/1, 2006) by using the vertical and horizontal calculation ranges for a behaviour factor $q = 1$ (Fig. 4), appropriate to the location in Iaşi, characterized by $a_g = 0.2$g and by the period $T_c = 0.7$ s.

For the analysed structure the behaviour factor, $q = 3…4$, and the damping, $\xi = 5\%$, of the critical damping were taken into account. The construction's class of importance and exposure to earthquake (offices of more than 400 individuals) is II, with the importance factor $\gamma_I = 1.2$. The survey considered the construction's behaviour in two hypotheses: fixed foundation and foundation supported by a distortable medium (raft supported by an elastic Winkler-type medium having the coefficient of soil reaction corresponding to the consistent plastic cohesive beds $k_z = 2k_x = 2k_y = 20,000…40,000$ kN/m^3).

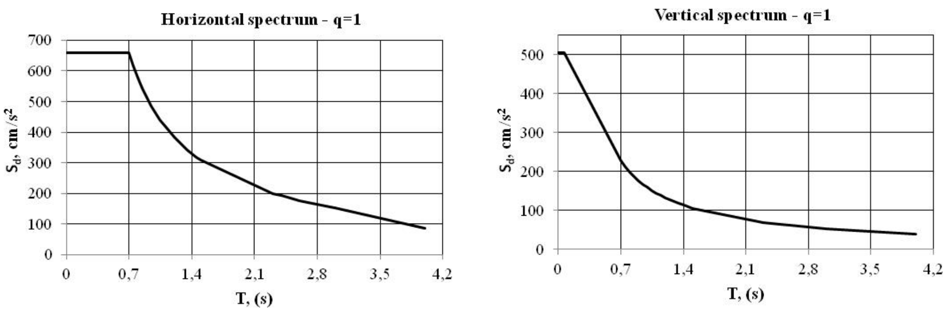

Fig. 4 – Design spectra.

To evaluate the impact of the interaction between the soil and the structure, the survey was performed on more than one determination model, where parameters k_z, q were varied to obtain a number of eight models denoted by M1*a,b* (fixed foundation model), M2*a,b*…M4*a,b* (models with foundation supported by elastic medium).

Main results of the dynamic response are shown in the Table 1.

The rigidities of the equivalent monomassic models for any structure could be approximated with the relation

$$R = \frac{mG_S}{\mathrm{g}}\left(\frac{2p}{T}\right)^2, \tag{1}$$

where: G_s is the gravity loads composing the seismic weight of the construction, [kN]; g – gravitational acceleration, [cm/s^2]; μ – gravity loads reduction coefficient; T – period of the 1st mode of vibration, [s].

In case of the analysed structure, it results that

a) the rigidities of the fixed foundation model in the two main directions, x and y, are

Table 1
Results of Dynamic Response

Specification	M1*a*	M1*b*	M2*a*	M2*b*	M3*a*	M3*b*	M4*a*	M4*b*
k_z, [kN/m^3 ×10^3]	∞	∞	40	40	30	30	20	20
q – behaviour factor	3	4	3	4	3	4	3	4
T_{1x}, [s]	1.175	1.175	1.294	1.294	1.315	1.315	1.360	1.360
T_{2y}, [s]	0.775	0.775	1.099	1.099	1.147	1.147	1.223	1.223
$T_{3\theta}$, [s]	0.600	0.600	0.797	0.797	0.823	0.823	0.865	0.865
T_{4ifx}, [s]	0.395	0.395	0.405	0.405	0.407	0.407	0.412	0.412
S_{x0}, [kN ×10^4]	1.628	1.224	1.651	1.241	1.644	1.236	1.612	1.212
S_{x2}, [kN ×10^4]	1.564	1.176	1.529	1.150	1.524	1.146	1.484	1.116
S_{y0}, [kN ×10^4]	2.171	1.632	1.883	1.416	1.835	1.380	1.740	1.308
S_{y2}, [kN ×10^4]	2.107	1.584	1.717	1.291	1.660	1.248	1.532	1.152
Δ_x, [cm]	14.4	14.4	21.12	21.12	21.12	21.12	21.12	21.12
Δ_y, [cm]	19.2	19.2	22.08	22.08	22.08	22.08	22.08	22.08
d_{rx}, [cm]	2.976	2.976	2.976	2.976	2.976	2.976	2.976	2.976
d_{ry}, [cm]	2.139	2.139	2.139	2.139	2.139	2.139	2.139	2.139

N o t a t i o n s: T_{1x} – proper vibration period of the 1st mode (oscillations in the *x* -direction - Fig. 5); T_{2y} – proper vibration period of the 2nd mode (oscillations in the *y*-direction – Fig. 5); $T_{3\theta}$ – proper vibration period of the 3rd mode (torsional oscillations – Fig. 6); T_{4ifx} – proper vibration period of the 4th mode (oscillations with an inflection on the *x*-direction – Fig. 6); S_{x0}, S_{x2} – seismic cutting force at the level of the floor above the underground, and, respectively, at the level of the floor above the first level (*x*-direction); S_{y0}, S_{y2} – seismic cutting force at the level of the floor above the underground, and, respectively, at the level of the floor above the first level (*y*-direction); Δ_x, Δ_y – maximum displacements of the level E8 – lev. + 30.55 m (*x*-direction, respectively *y*-direction); D_{rx}, Δ_{ry} – maximum relative displacements of levels (*x*-direction, respectively *y*-direction).

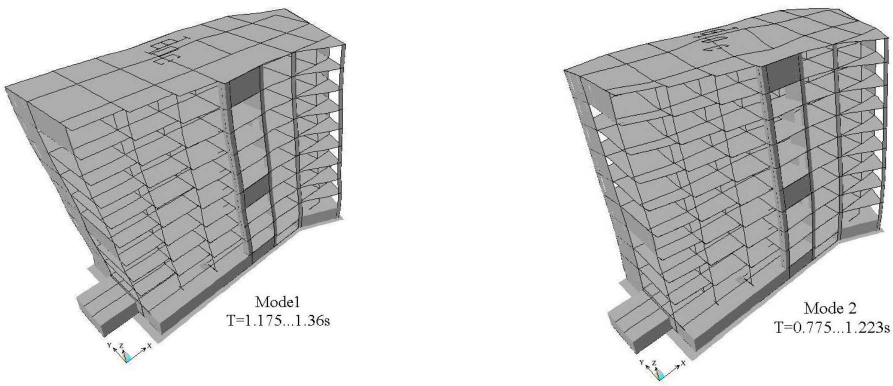

Fig. 5 – Vibration modes 1 and 2.

$$R_x = \frac{0.8\times121{,}250}{981}\left(\frac{2\pi}{1.175}\right)^2 = 2{,}820 \text{ kN/cm},$$

$$R_y = \frac{0.8\times121{,}250}{981}\left(\frac{2\pi}{0.775}\right)^2 = 6{,}500 \text{ kN/cm};$$

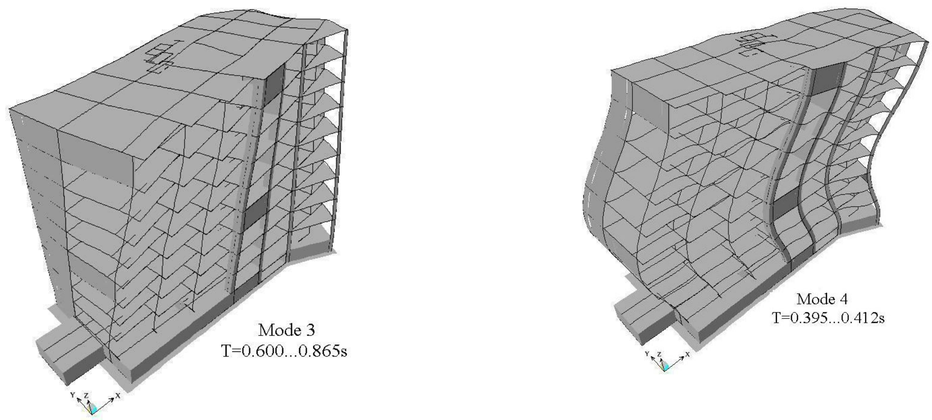

Fig. 6 – Vibration modes 3 and 4.

b) the rigidities of the model with interaction between the soil and the structure, (k_z = 20,000 kN/m^3) are

$$R_x = \frac{0.8\times121{,}250}{981}\left(\frac{2\pi}{1.36}\right)^2 = 2{,}110 \text{ kN/cm},$$

$$R_y = \frac{0.8\times121{,}250}{981}\left(\frac{2\pi}{1.223}\right)^2 = 2{,}610 \text{ kN/cm}.$$

From the above shown analysis it results that the difference between the rigidities in the two directions fades out when the impact of the interaction between the soil and the structure is considered, resulting a more balanced behaviour.

The impact of the interaction between the soil and structure on the maximum seismic response is insignificant in case of non-braced frame elastic structures unlike the case of the rigid constructions equipped with central braced walls or frames that the seismic forces at the construction's foundation could be by 15%...30% lower against the fixed foundation model.

The structure was designed up based on Romanian norms (P100/1, 2006, STAS 10107/0-1990), European codes (EN 1992-1-1, 2004) and American standards UBC (UBC–97, 1997), by using distinct structural behaviour factors in the two main directions (q = 4 – x-direction, q = 3 – y-direction).

3. Conclusions

From the analysis results of the dynamic response it results that the structure shows higher fluctuation periods in case of models supported by elastic medium, and, respectively, lower seismic cutting forces, against the models supported by fixed foundation. The analysis of the models supported by elastic medium leads to lower seismic cutting forces – lower efforts in the structural elements, and, respectively, reduced material consumption, and, in the end, smaller investment costs.

The coefficient of soil reaction, k_z, is difficult to appraise in compliance with the size and shape of the foundation area, geological bedding, soil consistency and nature (cohesive/noncohesive), rigidity of the assembly made of construction and foundation, etc. The professional literature suggests manifold equations for determination of coefficient of soil reaction, k_z, equations that lead to levels framing within a surprisingly large field, fact that embarrasses us to approach a level close to the reality of the actual case. The norm NP 112 (2004) recommends for each and every location a determination of the compaction rigidity of a board with relatively low sizes (30 × 30 cm) resulting an elastic coefficient, $k_z^{'}$, “benchmark” used to evaluate the half-space's elasticity. Therefore, it is recommended to conduct appropriate researches purposed to prepare a theoretical experimental evaluation methodology of the coefficient of soil reaction, k_z, based on the main factors shown above against the innocent proposals available in the actual norms.

In case of this structure an accurate analysis was required in terms of the plain view distribution of rigidities in correspondence with the weights of the dynamic model, with the scope to lower the twist impact and relative level drifts by adding reinforced concrete structural walls at the ends of the construction as well as on the contour of the area designed for vertical traffic.

Relative level drifts are not affected by the rigidity of the connection between the foundation and the soil. Maximum levels have resulted in the longitudinal direction of the seismic action, these meeting on the edge the levels set-up by the norm P100/1 (2006), section 4.6.3.2.a, buildings with non-structural elements made of fragile materials attached to the structure

$$v \times d_r \leq 0.005h \rightarrow 0.5 \times 2.976 < 0.005 \times 310 \rightarrow 1.488 \text{ cm} < 1.55 \text{ cm}.$$

The shapes of the vibration modes 1 to 4 are not significantly affected by the rigidity of the connection between the foundation and the foundation soil.

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TUDOR OFFICE CENTER, IAŞI

(Rezumat)

Se prezintă pe scurt proiectul unei clădiri cu structură duală tip cadre şi pereți structurali din beton armat monolit, amplasată în Iaşi, cu regim de înălțime Subsol + Parter + 8E. Se analizeazeză efectele interacțiunii teren – construcție asupra răspunsului seismic. Sprafața construită a clădirii este A_c = 770 m^2, suprafața desfăşurată, A_d = = 7.863 m^2, înălțimea nivelelor: subsol –2.65 m, P, E_i – 3.10 m rezultănd o înălțime totală H = 30.55 m. Amplasamentul, cu o pantă de 3.0% pe direcția N-S, face parte din zonele colinare ale Iaşului cu stabilitatea generală asigurată. Clădirea este destinată exlusiv spațiilor pentru birouri.