Using Winkler Hypothesis in ETABS Software for the Case of Building Structures with Raft Foundation

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Abstract. The purpose of this paper is to determine the correct method to simulate the seism behavior of a structure with a raft-type foundation, taking into account the elasticity of the soil using the Winkler hypothesis. This paper presents a comparison between two methods of modeling in the ETABS program a B + 7S structure that take into account the Winkler hypothesis for simulating soil elasticity. The first method includes in the FEM model, both the superstructure and the basement with raft foundation. The second method treats separately the two components of the resistance structure: the superstructure and the basement with raft foundation. Comparing the obtained results, the second analysis case is the recommended one for such building simulations in ETABS.

Keywords: Winkler · ETABS · Raft Foundation

1 Introduction

In order to determine the bending moment diagrams in the foundations of buildings, the analysis with the finite element method programs must take into account the elasticity of the soil under the foundation. The best-known model for modeling the elasticity of the foundation soil is the Winkler model. This model considers the soil made up of a set of springs on which the foundation of the analyzed building rests. In this case, the soil is considered a continuous elastic and homogeneous environment that causes reactions in the foundation proportional to the compaction of the soil (Fig. 1).

The fundamental equation of the Winkler model is as follows: (Fig. 2).

$$p(x, y) = k \cdot w(x, y) \quad (1)$$

where:

p(x,y) – the reaction that occurs in the soil [kN/m^2];
k – bed coefficient (Winkler coefficient) [kN/m^3];
w(x,y) – soil compaction [m].

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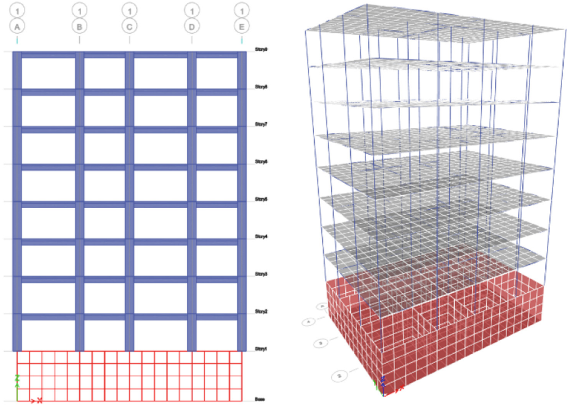

Fig. 1. Case no. 1 - finite element model.

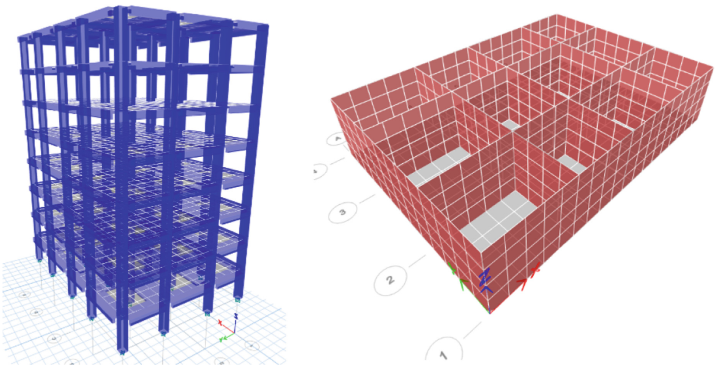

Fig. 2. Case no. 2 - two models with separate finite elements.

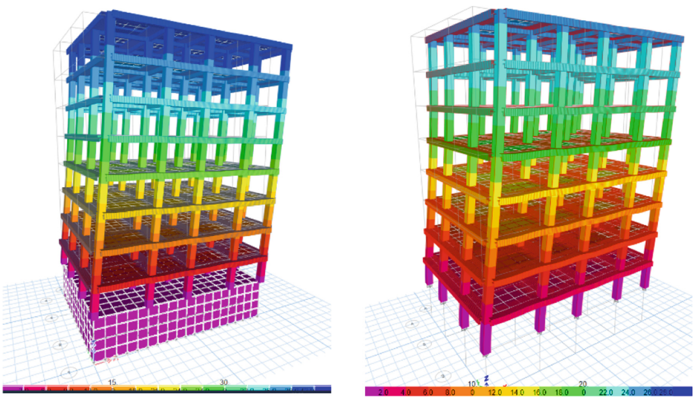

Fig. 3. Earthquake displacements - Ox [mm] (both cases).

The differential equation of the beam resting on such an elastic soil has the following form: (Fig. 3).

$$E \cdot Iz \cdot \frac{d^4 w(x)}{dx^4} + k \cdot w(x) = p(x) \tag{2}$$

2 Finite Element Models in ETABS

The analyzed building has seven floors, a ground floor and a basement, and the foundation is of the raft type (Fig. 4). For the comparative study we developed two models with finite elements of this building (Fig. 5).

The first model contains both the superstructure and the basement with a raft foundation, and the second model separately (Fig. 6) analyzes the fixed superstructure at the base of the columns and the basement with a raft foundation loaded with the reactions of the fixed superstructure (Fig. 7).

For the earthquake analysis, the method of equivalent static forces was used considering PGA $a_g = 0.3$g, the behavior factor $q = 6.75$, (Fig. 8) the maximum dynamic amplification factor $\beta_0 = 2.5$, the correction factor $\lambda = 0.85$ (Fig. 9).

To simulate the elasticity of the soil, we used Spring finite elements [1, 2] distributed on the entire surface of the raft foundation, using for the Winkler coefficient the value $k = 15000$ kN/m^3 which corresponds to a soil with average elasticity [3, 4] (Fig. 10).

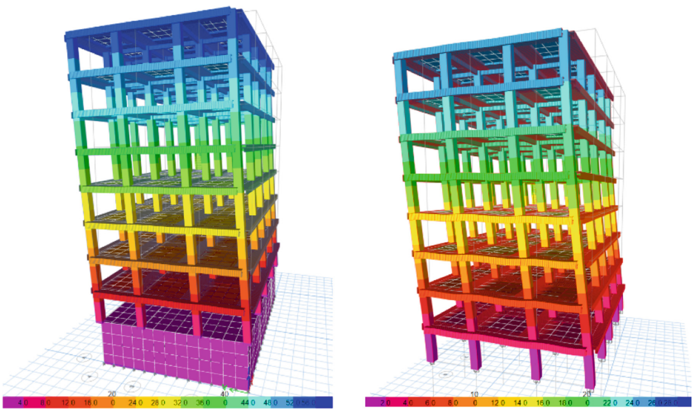

Fig. 4. Earthquake displacements - Oy [mm] (both cases).

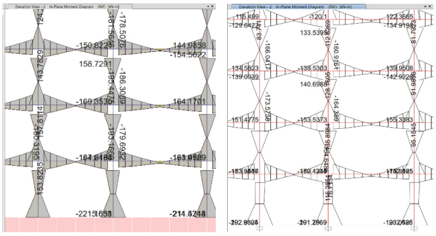

Fig. 5. Bending Moment diagrams [kNm] - Envelope on Ox, both cases.

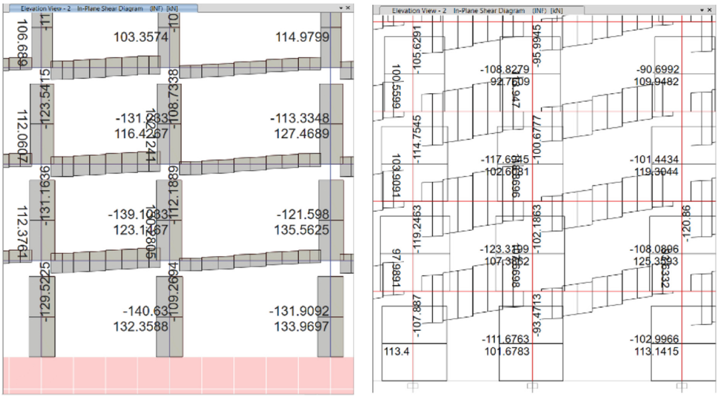

Fig. 6. Shear Force diagrams [kN] - Envelope on Ox, both cases.

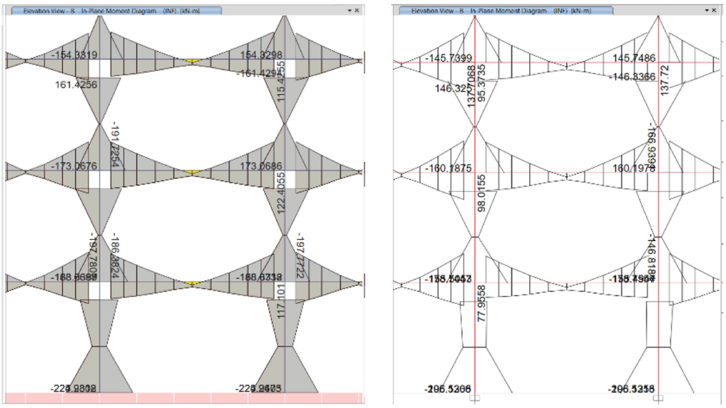

Fig. 7. Bending Moment diagrams [kNm] - Envelope on Oy, both cases.

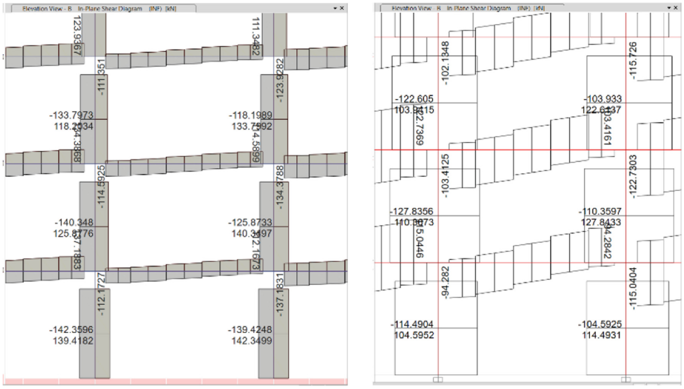

Fig. 8. Shear Force diagrams [kN] - Envelope on Oy, both cases.

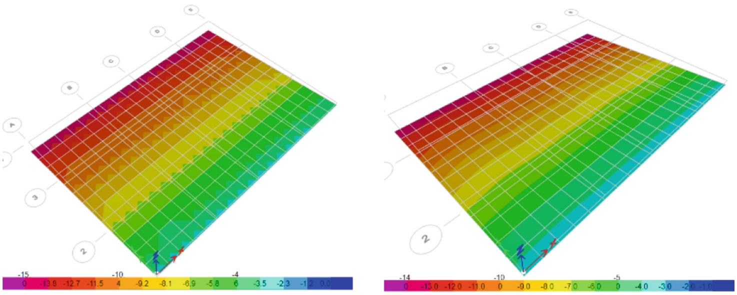

Fig. 9. Displacement Uz [mm] - case 1 and case 2 (earthquake on Oy).

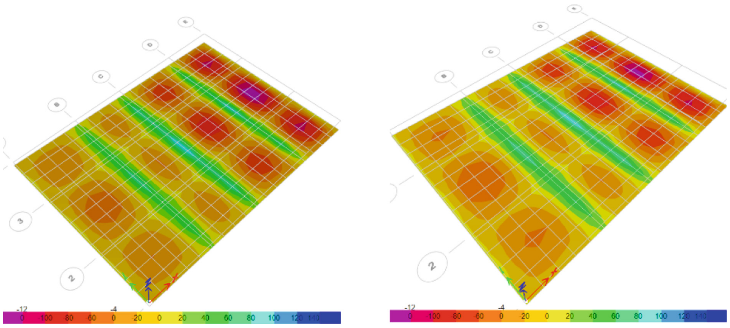

Fig. 10. Bending moment M11 [kNm] - case 1 and case 2 (earthquake on Ox).

3 Conclusions

The results of the comparison (SF - Share Force and BM - Bending Moment) between the two cases of analysis using the Winkler method are presented in Tables 1–4 where B26 and B24 are the beams from the 3rd story and C13 is the column from the 2nd story

Table 1. The results of the analysis - case 1 and case 2 for the seism on Ox direction.

Case no.	Value	B26 story 3		B24 story 3		C13 story 2	
		SF [kN]	BM[kNm]	SF [kN]	BM [kNm]	SF [kN]	BM [kNm]
1	Min	-131.163	-195.447	-112.2	-186.3	-140.6	-221.15
	Max	132.124	157.811	112.2	117.25	132.35	215.6
2	Min	-119.24	-175.57	-102.18	-164.39	-111.67	-201.26
	Max	118.8	135.89	101.95	95.15	101.67	191.79

Table 2. Percentage difference between case 1 and case 2 for seism on direction Ox.

	Value	B26 story 3		B24 story 3		C13 story 2	
		SF [%]	BM[%]	SF [%]	BM [%]	SF [%]	BM [%]
Diff.	Min	9.09	10.17	8.93	11.76	20.57	8.99
	Max	10.08	13.89	9.13	18.84	23.18	11.04

Table 3. The results of the analysis - case 1 and case 2 for the seism on Oy direction.

Case No.	Value	B27 story 3		C7 story 2	
		SF [kN]	BM[kNm]	SF [kN]	BM [kNm]
1	Min	-114.59	-191.7	-128.17	-209.28
	Max	114.59	122.4	141.25	221.25
2	Min	-103.41	-166.94	-102.83	-192.64
	Max	103.41	98.02	113.38	202.86

Table 4. Percentage difference between case 1 and case 2 for seism on direction Oy.

	Value	B27 story 3		C7 story 2	
		SF [%]	BM[%]	SF [%]	BM [%]
Diff.	Min	9.76	12.92	19.77	7.95
	Max	9.76	19.92	19.73	8.31

for the earthquake in the Ox direction and B27 is the beam and C7 is the column for the earthquake in the Oy direction.

As shown in the values in Tables 1–4, the bending moments and shear forces in the beams and columns of the superstructure are higher in case 1 than in case 2, although the values obtained in case 2 should be higher due to the fixed points at the base of the columns, which is the worst case scenario [5, 6]. The differences between case 1 and case 2 are between 8% and 23% for the superstructure. And in the case of the basement the results obtained in case 1 are higher than in case 2 by 8–10%. For this reason it is recommended that the use of the Winkler hypothesis be realized according to case 2 by making two separate models with finite elements, one that contains only the superstructure fixed at the base of the columns and the second that contains only the basement with raft foundation and Spring-type finite elements for simulating soil elasticity.

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