Comparison Between the Results Obtained in Static and Modal Seism Simulations of Tall Buildings Using ETABS

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Abstract. This paper presents the seism analysis of a tall building structure (33 m) made of reinforced concrete frames performed according to Romanian Design Code P100–1/2019. This design code allows the seism analysis of a building to be done with the method of equivalent static forces and with the modal method with response spectra. The purpose of this study is to determine the differences between the results obtained with these two methods in order to highlight which results are more trustful. We have chosen to use Finite Elements Method program ETABS, which allows the two analyzes to be performed by specifying the coefficient of the base shear force for static analysis and the response spectrum for modal analysis. In order to highlight the differences between the results obtained with these two methods, the values of the efforts on beams and columns were compared. The analysis of the comparisons made showed that the values of the efforts obtained in the static seism analysis, in the case of this building, are on average 10% higher than those obtained in the modal analysis with response spectra. This certifies that static analysis offers results which cover the results obtained with modal seism analysis.

Keywords: Finite Elements Method · Static Analysis · Response Spectra

1 Seism Buildings Analysis Using F.E.M.

Depending on the structural characteristics and the importance of the construction The Romanian Design Code P100–1/2019 [1] recommends the use of one of the following simulation methods for the current design:

– the method of lateral forces associated with the fundamental vibration mode, for the buildings that satisfy the regularity conditions in plan and vertical;
– method of modal calculation with response spectra, generally applicable to all types of buildings.

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Among the criteria of structural regularity in plan we mention:

- The construction must be approximately symmetrical in plan in relation to two orthogonal directions, in terms of lateral stiffness distribution, strength and mass capacities;
- The construction has a compact shape, with regular contours;
- The rigidity of the floors in their plane should be high enough compared to the lateral rigidity of the vertical structural elements, so that the deformation of the floors will have a negligible effect on the distribution of horizontal forces between the vertical structural elements.

Among the criteria of vertical structural regularity, we mention:

- The structural system develops monotonously vertically, without significant variations from the foundation to the top of the building;
- The structure does not show, at any level, reductions in lateral stiffness greater than 30% of the stiffness of the level immediately above or immediately below;

2 The Method of Equivalent Static Forces in Seism Simulation

The base shear force corresponding to its own fundamental mode, for each main horizontal direction considered in the building calculation, is determined as follows [1]:

$$F_b = \gamma_{I,e} \cdot S_d(T_1) \cdot m \cdot \lambda \tag{1}$$

where:

$S_d(T_1)$ - the ordinate of the design response spectrum corresponding to the fundamental period T_1:

T_1 - the fundamental period of vibration of the building in the plane containing the horizontal direction considered;

m - the total mass of the building calculated as the sum of the level masses m_i;

$\gamma_{I,e}$ - the importance factor of construction;

λ - correction factor which takes into account the contribution of its own fundamental mode by the actual modal mass associated with it, the values of which are:

$\lambda = 0,85$ if $T_1 \leq T_C$ and the building has more than two levels and.

$\lambda = 1,0$ in other situations.

The effects of the seismic action are determined by applying the horizontal seismic forces associated with the levels with the masses m_i for each of the two plane calculation models. In this case the horizontal level forces are given by the relation [1]:

$$F_i = F_b \cdot \frac{m_i \cdot z_i}{\sum_{j=1}^{n} m_j \cdot z_j} \tag{2}$$

where z_i and z_j represents the height up to level i and j respectively measured from the base of the construction considered in the model, and n is the total number of levels.

3 The Modal Dynamic Seism Analysis with Response Spectra

In the modal calculation method, the seismic action is evaluated based on the response spectra corresponding to the unidirectional translational movements of the terrain described by accelerograms.

The modal calculation with seismic response spectra determines only the maximum response of the structure under the seismic action. This method involves calculating the maximum response of the structure for each proper mode of vibration, obtaining the maximum modal responses. The maximum modal responses are determined based on the values in the spectrum.

The maximum total response of the structure is determined by the statistical combination of the maximum modal responses (displacements, efforts).

The ETABS program allows the use of four methods for combining maximum modal responses [2, 3]:

- square mean (SRSS - radical of the sum of squares);
- complete quadratic combination (CQC) - the most commonly used and recommended;
- general modal combination (GMC);
- the combination by summing the absolute values (ABS) - offers excessive coverage results.

For the modal-dynamic analysis a Spectrum function is defined. Spectrum function - defined by points is the design spectrum which is calculated based on the elastic response spectrum which is given in P100 as a function of T_c with the following formulas [1].

$$S_d(T) = a_g \cdot \left[1 + \frac{\frac{\beta_0}{q} - 1}{T_B} \cdot T \right], \text{for} 0 < T \leq T_B \tag{3}$$

$$S_d(T) = a_g \cdot \frac{\beta_0}{q}, \text{ for} T_B < T \leq T_C \tag{4}$$

$$S_d(T) = a_g \cdot \frac{\beta_0}{q} \cdot \frac{T_C}{T}, \text{ for} T_C < T \leq T_D \tag{5}$$

$$S_d(T) = a_g \cdot \frac{\beta_0}{q} \cdot \frac{T_C \cdot T_D}{T^2}, \text{for} T > T_D \tag{6}$$

4 ETABS Seism Simulation Results

For the Analysis, a Building with a Reinforced Concrete Frame Structure for Offices Was Considered, Located in Craiova ($a_g = 0.20$g and $T_c = 1$s), with a Height of B + 10S with Three Openings of 5 m in the Direction *Ox* and Three Openings of 4 m in the Direction of *Oy*, Level Height 3 m, Cross Section of the Beams of 50x30 cm, Cross Section of the Columns 100x100 cm, Thickness of the Plates at All Levels 20 cm.

Figure 1 shows the finite element model of the considered structure which was analyzed using the two methods of seism analysis. Figure 2, 3 and 4 presents the effort

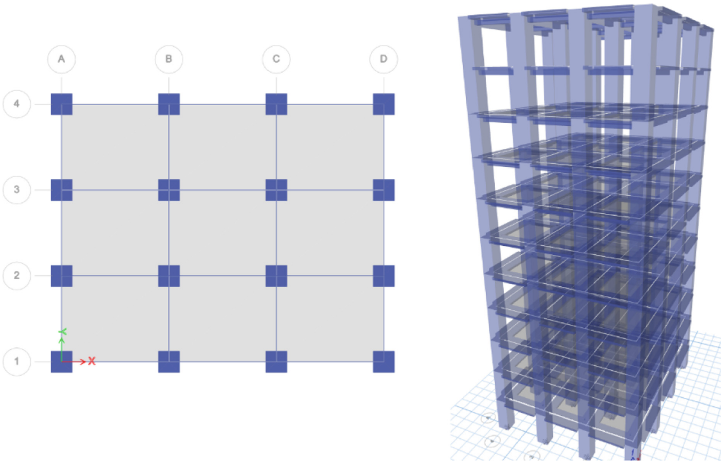

Fig. 1. ETABS F.E.M. model of the building.

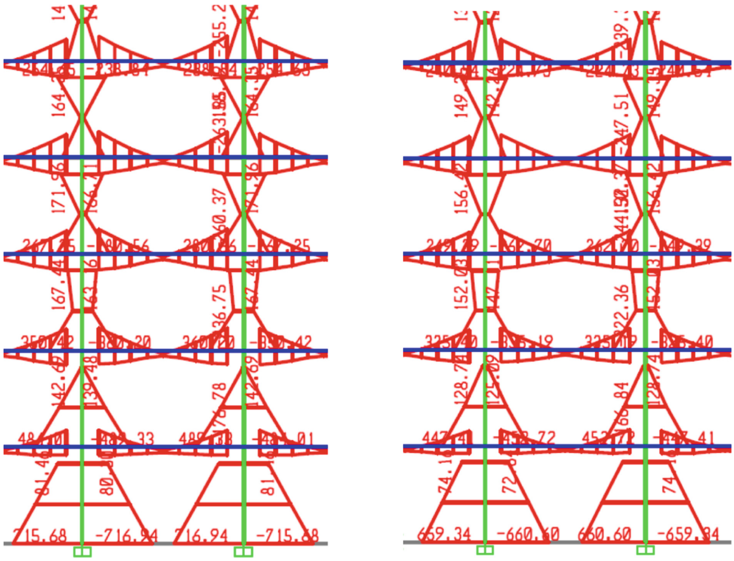

Fig. 2. The bending moment diagram (envelope) [kNm] for static method (left) and for modal method (right).

diagrams obtained using the two methods. The figures show the most important areas of the structure in order to be compared. The results that interest us are: bending moments on beams and columns, shear forces on beams and columns, axial forces on columns.

The structure was loaded with: 4 KN/ml on the perimeter beams at the current level; 3 KN/ml on the perimeter beams on the top level (attic); 2.5 KN/m^2 on current level floors; 6 KN/m^2 – on the floors of the last level; utile load: 3 KN/m^2 on current level floors; 1 KN/m^2 on the floors of the last level.

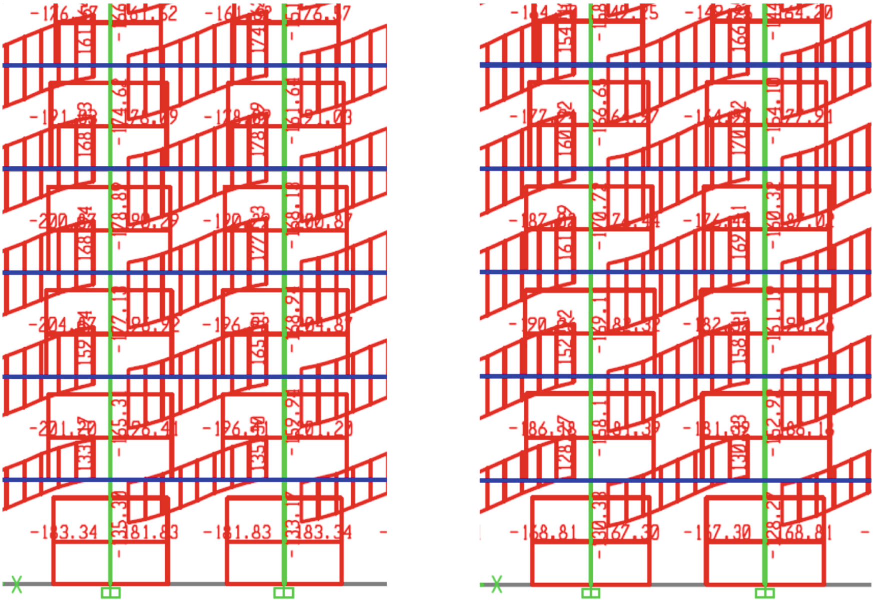

Fig. 3. Shear force diagram (envelope) [kN] for static (left) and modal method (right).

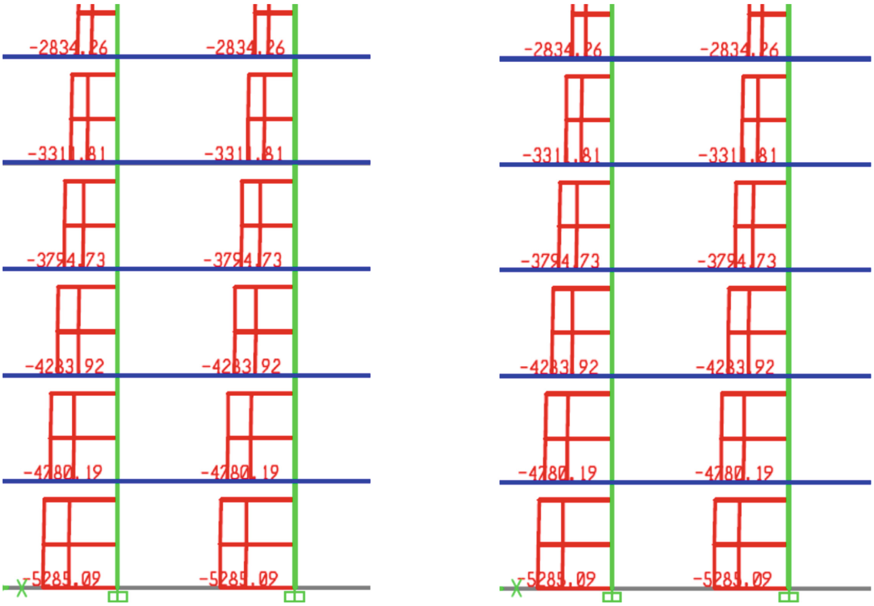

Fig. 4. Axial force diagram (envelope) [kN] for static method (left) and modal method (right).

The shape of the diagrams is identical, and the numerical values resulting for the efforts are very close [4, 5], the maximum differences being presented in Table 1.

Table 1. Maximum differences between the results obtained with the two methods

The type of result obtained	Equivalent static force method	Modal-dynamic method	Maximum Difference (%)
Bending moment on the beams	171.96	156.42	9.04
Bending moment on the poles	353.66	323.86	8.42
Shear force on the beams	168.94	161.50	4.40
Cutting force on poles	−183.34	−168.81	7.92
Axial force on columns	−3889.28	−3889.28	–
Average differences			7.445

5 Conclusions

The Romanian seismic design codes recommend the static method and the modal method with response spectra for buildings seism analysis. For buildings with a high degree of regularity, both methods can be applied. The results obtained with the two methods are not identical and we have obtained some differences.

The largest differences were obtained at the bending moments on the beams (9.04%), and the smallest at the shear force on the beams. (4.40%). When comparing the axial forces obtained with the two methods, as expected, the results are identical.

In conclusion, the numerical values from the diagrams of bending moments and shear forces obtained in static analysis are relatively higher (maximum 10%) than those obtained in modal-dynamic analysis, which shows that static analysis provides covering results [6].

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