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STUDY ON THE INFLUENCE OF THE STRUCTURAL ASYMMETRY ON THE TORSIONAL RESPONSE

BY

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Abstract. For the composition and the structural design to lateral loads, the distribution of horizontal lateral forces on vertical structural elements is an important issue, which can become complicated, depending on the considered structural system. In this paper is presented a study regarding the influence of the asymmetry on the response of a mix structure (frame with coupled walls). The structure has 11 floors and is analysed in three different cases of walls positioning, in order to verify their influence on the lateral rigidity and torsional response of the structure.

Key words: structural asymmetry; eccentricity; torsional response.

1. Introduction

Consequences of previous earthquakes show that structural damages can be caused by the supplementary unexpected torsional movement which appears in addition to lateral movement for which the structures were designed [1]. In case of a torsional unbalanced building, due to geometrical asymmetry, mass rigidity or mass distribution, its response is influenced by supplementary forces and deformation.

The current codes provide regularity restrictions in order to reduce the consequences of the torsional earthquake effect. Although most of the design provisions stipulate a regular design of structures in plane and in elevation, multiple cases of building with structural and mass asymmetry are designed.

2. Case Study

2.1. Geometrical Characteristics

The building is a structure with 11 floors and asymmetric in elevation. In this paper the influence of the plan asymmetry of the building on the seismic assessment. The plane dimensions of the structure are 14 m, respectively 30 m. The height of the first level is 4 m and 3 m for the rest of the floors. The columns have a rectangular cross section of 25 × 60 cm for the first three stories, and 25 × 50 cm for the other ones. The beams have a rectangular cross section of 25 × 50 cm and the slab thickness is 15 cm. After the first three stories the structure has vertical setbacks, their amount representing 27% of the first floor plan dimension.

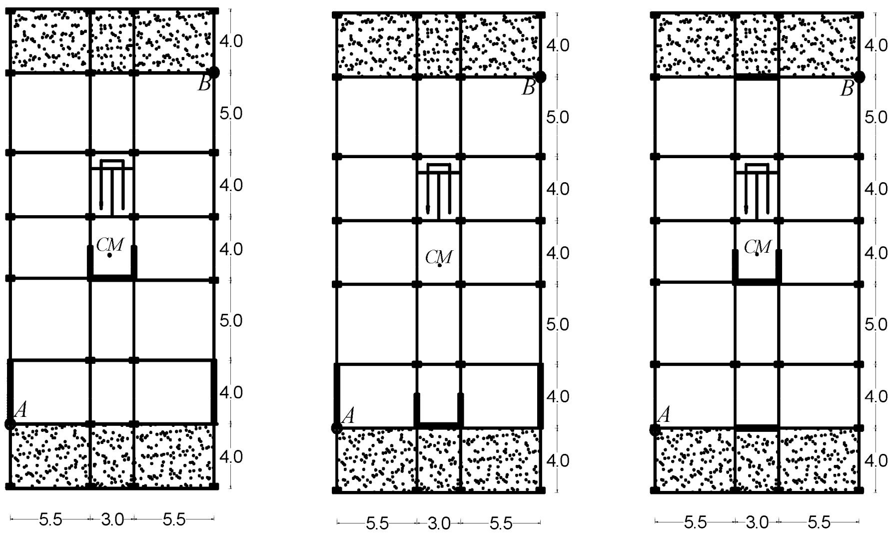

Fig. 1 – Structure plan view – all three cases of structural walls position.

The slabs are considered to be infinite rigid in their own plane. As a consequence, the system moves in the horizontal plane as a rigid body, having three degrees of freedom, namely x and y–translation of the mass centre and floor rotation about vertical axis.

The structure was analysed for three different layouts, corresponding to different positions of the shear walls. The purpose is to check the influence of the walls on the lateral rigidity of the structure, and also on the torsional response of the structure.

The accidental torsion is taken into consideration according to current codes [2], considering the following eccentricities:

$$e_x = 0.05B, \quad e_y = 0.05B, \tag{1}$$

where B is the structure's dimension perpendicular on the direction of the seismic action.

In order to take into account the possible non-hysteretic damping sources, a viscous damping coefficient of 5% was considered.

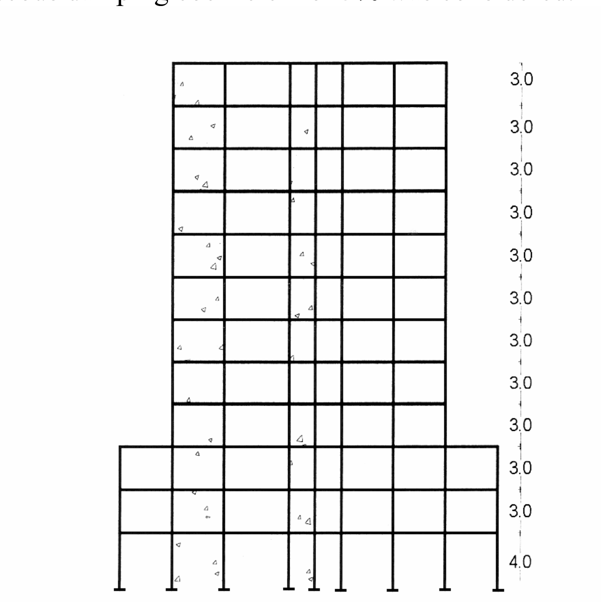

Fig. 2 – The cross section of the structure

The forces acting on the structure are: the dead load with a magnitude of 150 daN/m^2 and the live load of 300 daN/m^2 for each floor and 200 daN/m^2 for the terrace. The snow load and self weight of the structure are also taken into consideration. The seismic action on both directions, x and y, is evaluated according to the Romanian Seismic Code P100/2006 with the following characteristics:

a) the peak ground acceleration, a_g = 0.2 g;

b) the behaviour factor of the structure (for moment resisting frame systems), $q = 3.5 \times 1.35 = 4.725$;

c) spectral acceleration amplification factor for 5% viscous damping:

d) $\beta_0 = 2.75$;

e) $T_b = 0.07$;
f) $T_c = 0.7$;
g) $T_d = 3$.

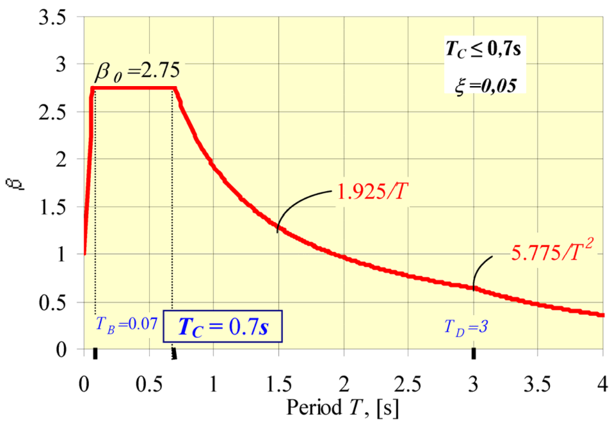

Fig. 3 – The design response spectrum used in the analysis.

The load combinations are defined according to CR0/2005 code, for both the ultimate limit state and the service limit state [3].

Initially the supports of the structure were considered fixed. For the comparison the elastic soil characteristics were introduced, which were calculated with the following relationship:

(2) $$K_{\theta} = \frac{\pi b\left(1 + \frac{a}{4b}\right)E_t}{18\left(1 - \mu^2\right)},$$

where: a,b represent the foundation dimensions; μ – the friction coefficient, is equal to 0.3 and $E_t = 7 \times 10^5$ kN/m^2 – soil elastic modulus.

For the analysis the Robot Millenium 2010 software was used [4]. This is a structural analysis program able to run linear and nonlinear static analysis, to compute the eigenvalues and linear and nonlinear dynamic analysis. For the case study a linear dynamic analysis is performed.

A sufficient number of vibration modes are considered in order to have the sum of the effective participating mass factors for each mode on x- and y-directions exceed 90% of the total mass of the building.

2.2. Structural Analyses – Results

The structure has to possess lateral rigidity and strength to horizontal actions in any direction as the horizontal seismic motion is a bidirectional phenomenon. The structural systems may be different on the two directions.

The monitored nodes are *A*, *B* and *CM* (Fig.1).

The natural frequency and the cumulative mass participating factor in *x*- and *y*-directions are presented in Table 1.

Table 1
Natural Frequencies and Cumulative Mass Participating Factor (fixed supports in all three cases)

Mode	Case *a*			Case *b*			Case *c*		
	Period s	ΣU_x %	ΣU_y %	Period s	ΣU_x %	ΣU_y %	Period s	ΣU_x %	ΣU_y %
1	1.21	0.02	76.11	1.29	70.66	0.36	1.53	83.49	0
2	1.12	68.74	76.12	1.2	71	77.42	1.06	83.49	73.94
3	0.96	68.89	77.13	0.94	71	77.43	0.91	83.49	74.12
4	0.37	68.89	92.12	0.38	71.11	91.18	0.5	96.32	74.12
5	0.31	79.44	92.12	0.35	88.76	91.32	0.31	96.32	89.2
6	0.3	85.35	92.13	0.28	88.89	92.55	0.29	96.32	90.45
7	0.19	85.37	95.82	0.22	88.95	95.79	0.27	98.6	90.45
8	0.17	86.06	96.12	0.16	95	95.89	0.17	99.08	90.45
9	0.16	86.17	96.12	0.15	95.02	95.89	0.16	99.19	90.45
10	0.15	92.54	96.12	0.14	95.05	95.9	0.16	99.19	92.22

In Tables 2 and 3 are presented the values of the displacement along *x*- and *y*-directions, at the top of the building in all three cases. The comparison is realized between the two different types of boundary conditions.

Table 2
Displacements along x-Direction (mesh step 2 m)

Node	Fixed supports			Partially released supports		
	Displacement					
	case *a* cm	case *b* cm	case *c* cm	case *a* cm	case *b* cm	case *c* cm
A	3.1	3.3	3.4	3.2	3.4	3.5
CM	3.1	3.4	3.6	3.1	3.5	3.5
B	3.1	3.4	3.8	3.2	3.6	3.8

Table 3
Displacement Values in y-Direction (mesh step 2 m)

Node	Fixed supports			Partially released supports		
	Displacement					
	case *a* cm	case *b* cm	case *c* cm	case *a* cm	case *b* cm	case *c* cm
A	3.0	2.0	2.4	3.3	2.3	3.4
CM	3.1	3.0	2.8	3.1	3.0	2.8
B	2.9	4.2	3.2	3.0	4.0	3.3

It is necessary to observe that the rigidity of the supports has a significant influence on the structure, resulting larger displacements and higher torsional effect in the case with partially released supports than in the case with rigid supports. Depending on the selected characteristics of the structure (mesh step or modelling walls with beam as finite element type) different results are obtained (Tables 4 and 5; Fig. 4).

Table 4

Displacement along x- and y-Directions (mesh step 0.5 m)

Node	*x*-direction			*y*-direction		
	Displacement					
	case *a* cm	case *b* cm	case *c* cm	case *a* cm	case *b* cm	case *c* cm
A	3.2	3.6	3.6	3.4	2.5	2.5
CM	3.1	3.5	3.6	3.1	3.1	2.8
B	3.1	3.5	3.6	2.8	4	3.3

Table 5

Displacement along x- and y-Directions (walls considered as beams)

Node	*x*-direction			*y*-direction		
	Displacement					
	case *a* cm	case *b* cm	case *c* cm	case *a* cm	case *b* cm	case *c* cm
A	3.7	3.9	4.4	4.8	4.8	3.6
CM	3.7	3.9	4.4	3.2	3.3	3.3
B	3.7	3.9	4.4	2.4	2.5	3.1

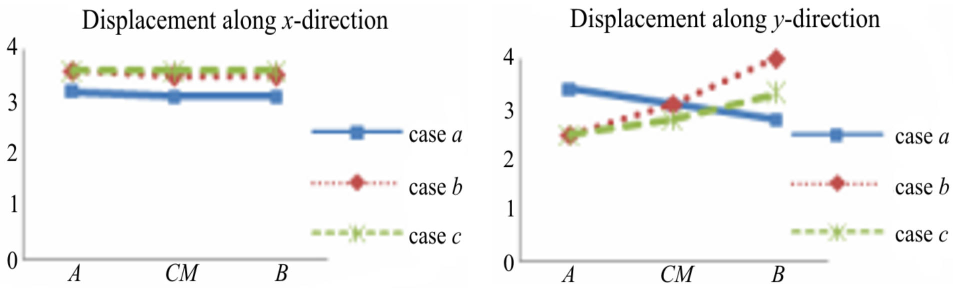

Fig. 4 – Displacement values – mesh step 0.5 m.

On the obtained graphs it can be observed that the structure behaves best in case *c*, from torsional behaviour point of view. This is due to the fact that the structure is symmetric along *x*-direction and approximately symmetric along *y*-direction.

From seismic behaviour point of view, the most unfavourable situation is for the structure in case *a*, explaining the necessity of a system as symmetric as possible to transmit lateral loads on both directions.

In order to assess the torsional phenomenon is necessary to normalize the edge displacement values with respect to those of the centre of mass. In Fig. 5 the torsional response along *x*- and *y*-direction are presented.

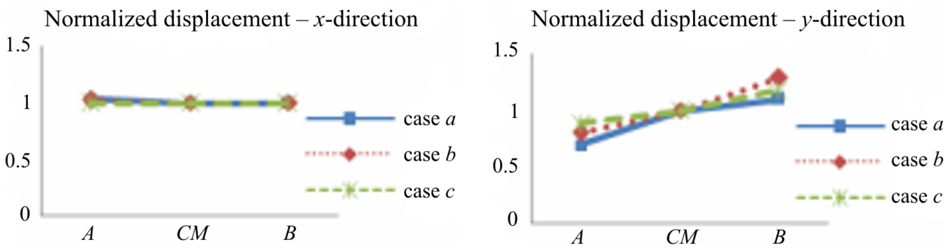

Fig. 5 – Torsional response along *x*- and *y*-direction.

3. Conclusions

The current buildings rarely are designed as symmetric structures. Even in symmetric structures, the asymmetric position of non-structural components (dividing walls and service systems) tends to generate an asymmetric structure. Even if this kind of asymmetry is small, can generate a coupled torsional response with translational response and can have a significant effect on the general behaviour of the structure.

It is known that the principal parameter to characterize the seismic response, satisfying both life safeties as well as limiting damages, is the lateral displacement. Therefore is required to ensure a sufficient lateral rigidity of the structure from the design stage.

In this paper it can be observed that the structure behaves best in case *c*, from torsional behaviour point of view because is approximately symmetric along *x*- and *y*-directions, and the most unfavourable situation is for the structure in case *a*. Therefore to have a structure with adequate torsional behaviour is necessary a system as symmetric as possible to transmit lateral load on both directions.

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STUDIU PRIVIND INFLUENŢA DISIMETRIILOR STRUCTURALE ASUPRA RĂSPUNSULUI TORSIONAL

(Rezumat)

La alcătuirea şi calculul clădirilor la acţiuni laterale, o problemă o constituie repartizarea forţelor laterale orizontale la elemente structurale verticale, care poate deveni deosebit de complicată, funcţie de sistemul constructiv adoptat. În ciuda faptului că majoritatea prescripţiilor de proiectare prevăd realizarea unor structuri regulate în plan şi în elevaţie, există diverse motive pentru care clădirile au disimetrii structurale.

Se prezintă rezultatele unui studiu de caz privind influenţa simetriei asupra răspunsului unei structuri mixte (cadre cu pereţi structurali) P+11 niveluri. Structura este analizată în trei cazuri de poziţie a pereţilor structurali pentru a se urmări influenţa acestora asupra rigidităţii laterale şi a răspunsului torsional al structurii.