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THE TORSIONAL ECCENTRICITY OF THE STRUCTURES IN MISCELLANEOUS DESIGN CODES

BY

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Abstract. Structures rarely achieve structural symmetry. Even in symmetric structures, the asymmetric position of the structural components tends to produce an effective asymmetric structure. Such an asymmetry even if is small, can produce a torsional response coupled with translational response. In the torsional analysis, the provisions of the seismic norms are based on determining the static eccentricity. In this paper is presented a general way of computing the eccentricity in torsional design. The purpose of this article is to make a comparison of the general rules used to determine the eccentricity and their values. Are taken into account the norms from: Romania, Europe, Japan, Germany and the United States of America.

Key words: eccentricity; torsion.

1. Introduction

The reflection of the torsion effect in the design codes provisions, which often have critical accents and improvement suggestions, was the subject of several studies. The norms establish principles of compliance, computation methods and constructive rules for designing safe buildings considering the seismic hazard associated with the site. Any new structure designed and built in a seismic area must fulfill certain requirements which are correlated with the medium recurrence period of the seismic action. In order to prevent the damages and the collapse of the buildings each seismic design code defines a set of medium recurrence periods and a corresponding set of requirements. In case of damages the structure is considered in the elastic domain, while in case of collapse, postelastic strains are permitted.

The design processes for the torsion effects must consider several factors that are difficult to predict and assess [1]. Most of the current structural design provisions require to consider the torsional behavior using the design eccentricities, which take into account both natural and accidental sources of torsion. The natural eccentricity is generally defined as the distance between the center of mass (CM) and the center of rigidity (CR) for a considered floor, while accidental eccentricity generally accounts for factors such as the rotational component of ground motion about the vertical axis, the difference between computed and actual values of the mass and rigidity and an unfavourable distribution of live load mass.

These factors lead to the appearance of some accidental eccentricities and are not taken into account in the seismic analysis with no coupled torsion, determine that the seismic response in a coupled torsion structure to be amplified compared with the response obtained using the torsion moment.

2. Eccentricity Provisions in Different Codes

In Romanian code P100-2006 [2], in case of structures with rigid floors in their own plan, an additional accidental eccentricity is introduced through the effects generated by the uncertainties associate with the distribution of the mass level and/or the spatial variation of the ground seismic movement [2]. This is considered for each design direction and for each level and also is related to the center of mass. The accidental eccentricity is computed with the relationship

$$e_{1i} = \pm 0.05 L_i , \tag{1}$$

where: e_{1i} is the accidental eccentricity of mass for storey i from its nominal location, applied in the same direction at all levels; L_i – the floor dimension perpendicular to the direction of the seismic action.

In Eurocode 8 [3], if the lateral stiffness and mass are symmetrically distributed in plan and unless the accidental eccentricity is taken into account by a more exact method (modal analysis with response spectrum), the accidental torsional effects may be accounted by multiplying the loads effects for individual resisting elements with the δ factor given by

$$\delta = 1 + 0.6\frac{x}{L_e} , \tag{2}$$

where: x is the distance from the considered element to the center of mass of the building in plan, measured perpendicularly to the considered direction of the seismic action; L_e – the distance between the two outermost lateral load resisting elements, measured perpendicularly to the direction of the seismic action considered.

In Eurocode 8, Annex A, is presented an alternative method for the one presented above, an approximately method for the torsion effects. Two planar models, each one for every direction, are used. Torsion effects for each of these two directions are determined separately. To take into account the dynamic effects of simultaneous vibration of translation and torsion and to include the uncertainties associated to the mass level distribution and spatial variation of the ground seismic movement, beside accidental eccentricity, the CM will be displaced from the initial position with a real eccentricity and an additional eccentricity.

The additional eccentricity is equal with the minimum values of the followings two relationships:

$$e_2 = 0.1(L+B)\sqrt{10\frac{e_0}{L}} \le 0.1(L+B), \tag{3}$$

and

$$e_2 = \frac{1}{2e_0}\left[l_s^2 - e_0^2 - r^2 \sqrt{\left(l_s^2 + e_0^2 - r^2\right) + 4e_0^2 r^2} \right], \tag{4}$$

where: e_2 is the additional eccentricity; e_0 – the real eccentricity, calculated as the distance between the CM and the CR; r^2 – the ratio between the torsional rigidity and the lateral rigidity (square of torsional radius); l_s^2 – the square of the gyration radius,

$$l_s^2 = \frac{L^2 + B^2}{12}. \tag{5}$$

The torsion effects can be determined as the envelope effects resulting from the analysis of two loading situations with torsion moment, situations described in Fig. 1; where e_1 is the accidental eccentricity previously defined.

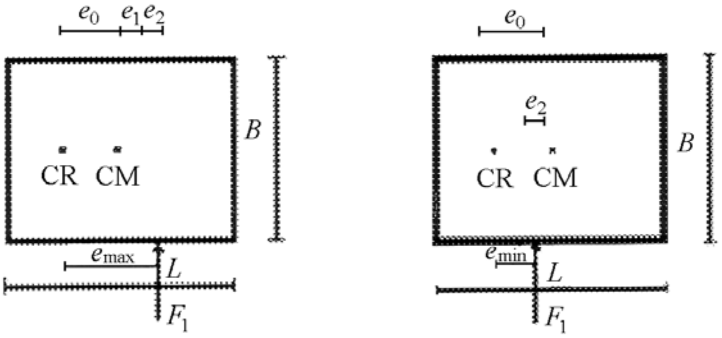

Fig. 1 – The establishing of the application of seismic force.

Some design codes require the torsion effects consideration by applying torsional moments on each level (multiplying the level seismic loads with a design eccentricity).

In the most analysed norms, the design eccentricity is obtained by superimposing the static eccentricity (defined as the distance between the CR and the CM), possibly multiplied by a coefficient (amplification coefficient for elements on the flexible side and a reduction coefficient for elements on the rigid side) and an accidental eccentricity, computed as a percentage of the building's dimension perpendicular to the earthquake direction [5]

$$e_d = \alpha e_s + \beta L_i, \tag{6}$$

$$e_d = \delta e_s - \beta L_i, \tag{7}$$

where: e_s is the real eccentricity; L_i – the floor dimension; α, β, δ – the coefficients specified in various design codes.

The values of the coefficients α, β, δ varies in codes like Uniform Building Code (UBC), Mexico City Building (MCBC), National Building Code of Canada (NBCC); these values are presented in Table 1.

Table 1

The Values of the Coefficients α, β, δ in Norms

Code	α	β	δ
UBC	1	1	0.05
MCBC	1.5	1	0.1
NBCC	1.5	0.5	0.1

For each element, the e_d value is used leading to a maximum computing force. The first term of these relationships is called the *dynamic eccentricity* and takes into account the coupled lateral – torsional response obtained from the symmetry absence. The second term considers the torsion effects due to factors which are not explicitly specified (such: the rotational component of the ground motion about the vertical axis, differences between calculated and actual values of the stiffness, unfavourable distribution of loads).

The specific eccentricities use different relationships in norms; they are presented in Table 2.

Some codes, like UBC [4], stipulate lateral force application at the $\pm\beta B_i$ distance from the CM, which would lead to $\alpha = \delta$. In this case the position of the CR on the various levels of the structure is not necessary to be determined. The codes that consider in the eccentricity relationship α or $\delta \neq 1$, as MCBC, the position of the center of rigidity seems to be necessary to be determined. Unlike buildings with a single level, buildings with more levels have problems with the level position of the CR, unless these belong to the special classes of the proportional buildings.

Table 2
The Eccentricities

Design codes	Primary design eccentricity	Secondary design eccentricity
USA	$e_0 + 0.05L_i$	$e_0 - 0.05L_i$
Bulgaria	$e_0 + 0.02L_i$	$e_0 - 0.02L_i$
Canada	$1.5e_0 + 0.1L_i$	$0.05e_0 - 0.1L_i$
Europe	$e_0 + 0.05L_i$	$e_0 - 0.05L_i$
Greece	$e_0 + 0.05L_i$	$e_0 - 0.05L_i$
Mexico	$1.5e_0 + 0.1L_i$	$e_0 - 0.1L_i$
Romania	$e_0 + 0.05L_i$	$e_0 - 0.05L_i$

In the German norm provisions [5], the eccentricity, e, of the application point of the resultant of the horizontal seismic loads related to the center of rigidity have the following relationships:

$$e_{\max} = e_0 + e_1 + e_2\,, \qquad e_{\min} = e_0 - e_1\,, \tag{8}$$

where: e_0 is the distance between the CR and the CM; e_1 – the additional eccentricity which takes into account the coupling of the translation vibrations of buildings with the torsion vibrations,

$$e_1 = 0.1(A+B)\sqrt{\frac{10e_0}{B}}, \tag{9}$$

with the following condition:

$$e_1 \le 0.1(A+B). \tag{10}$$

If this condition is not fulfilled, the eccentricity, e_1, is computed with the relationship

$$e_1 = \frac{1}{2e_0}\left[i^2 - e_0^2 - d^2 + \sqrt{\left(i^2 + e_0^2 - d^2\right) + 4e_0^2 d^2}\,\right], \tag{11}$$

where

$$i^2 = \frac{A^2 + B^2}{12}, \tag{12}$$

$$d^2 = \frac{K_t}{K_y}; \tag{13}$$

K_t is the torsion rigidity of the considered level; K_y – the translation rigidity of the considered level.

For rigid structures with vertical structural walls the square distance is computed with the relationship

$$d^2 = \frac{\sum_m I_m d_m + \sum_p I_p d_p}{\sum_m I_m}, \tag{14}$$

where: I_m is the inertia moment of the structural walls, m, parallel to the direction of the seismic action; I_p – the inertia moment of the structural walls p, perpendicular on the seismic action; d_m, d_p – the distances from the centers of gravity of the structural walls m and p to the considered center of rigidity; $e_2 = 0.05L_i$ – the accidental eccentricity that takes into account the inaccuracies of the building erection, some errors in the evaluation of the distance e_0 and asynchronous nature of the seismic movement at the level of the structure foundation which leads to torsional oscillations.

For $d^2 > 5(e_0^2 + i^2)$ the structure is stiffened for torsion and in this situation the eccentricity e_1 can be neglected.

For structures with symmetrical disposal of vertical structural elements $e_0 = e_1 = 0$.

In the Japanese recommendations [6] is provided that the stiffness eccentricity of each level, R_e, have to satisfy the condition

$$R_e = \frac{e}{r_e} < 0.15, \tag{15}$$

where: e is the distance between the CM and the CR; r_e – the elastic range, defined as the ratio of the square root of the torsional rigidity and lateral stiffness. The lateral rigidity, R_s, varies on each level, fulfilling the condition

$$R_s = \frac{r}{\overline{r}} > 0.6, \tag{16}$$

where: r is the lateral rigidity, defined as the ratio between the height of the floor and its displacement produced by the lateral seismic force, for moderate seismic movements; $\overline{r}$ – the medium lateral rigidity defined as the average of the lateral rigidities of the levels above the ground floor level.

The Mexican design code, MCBC-95 [7], requires the consideration of the torsion effects at each level through a torque level equal to the shear force multiplied by the most unfavourable of the following eccentricities:

$$1.5\, e_s + 0.1b \quad \text{or} \quad e_s - 0.1b. \tag{17}$$

The computation eccentricity must be at least equal with the maximum value of e_s of the lower floors.

3. Conclusions

Eurocode 8 uses a method of additional eccentricity in defining the computed primary eccentricity that controls the computation of the strength of the elements on the flexible side. All other norms realize a similar effect amplifying the structural eccentricity with a coefficient effect in order to take into account the dynamic effects of the torsion.

Unlike other norms, the value of the additional eccentricity presented in EC8 depends on the configuration of the building in plan, and on the ratio of the total torsion rigidity over the CR compared to its total lateral rigidity. In addition, all this norms base the strength amplification from the flexible side of the element on the structural eccentricity.

Unfavourable global behavior of buildings to strong earthquakes can be substantially influenced by improper arrangement of the masses on the height of the building and in plan. Thus, the poorly functions of the establishment in a building plan may lead to pronounced lop-sided location of the masses in the construction plan and therefore to substantial increase of the distance between the CM and the CR.

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EXCENTRICITATEA LA TORSIUNE A STRUCTURILOR ÎN DIVERSE NORME INTERNAȚIONALE

(Rezumat)

Aşa cum sunt construite, structurile ating rareori o simetrie structurală. Chiar în structurile simetrice dispoziția asimetrică a componentelor nestructurale tinde să producă o structură efectiv asimetrică. O astfel de asimetrie, chiar dacă este redusă, poate produce un răspuns torsional cuplat cu răspunsul de translație. Aplicarea prevederilor normativelor de proiectare antiseismică în analiza torsională se bazează pe determinarea excentricității statice.

Se prezintă modul general de determinare al excentricității privind calculul la torsiune. Articolul îşi propune să realizeze o comparație a normelor la nivel mondial cu privire la valorile şi la modul în care este determinată excentricitatea. Se iau în considerare normele din: România, Europa, Japonia, Germania şi Statele Unite.