COMMENTS ON EUROCODE 8 TORSIONAL PROVISIONS

MARIO DE STEFANO
Department of Constructions, University of Florence
Piazza Brunelleschi, 6 – 50121 Firenze, ITALY

AURELIO GHERSI, EDOARDO MICHELE MARINO, PIER PAOLO ROSSI
Department of Civil and Environmental Engineering, University of Catania
Viale A. Doria, 9 – 95125 Catania, ITALY

ABSTRACT

The paper briefly discusses the evolution of the European seismic code, Eurocode 8 (EC8), regarding design of irregular structures, with particular reference to those related to plan asymmetric buildings (torsional provisions). The effort aimed at eliminating contradictions and ambiguities has been successful, but it appears to have led to an over-simplification of the problem. The outcome of research on seismic behaviour of plan irregular structures conducted by researchers all over the world in the last two decades should be taken into account for further improvement of effectiveness of EC8 torsional specifications.

INTRODUCTION

Fifteen years after the first edition of EC8 (1988), it is now ready a new version (2002), largely modified with respect to the previous one (1993) in order to take into account the result of a public enquiry which it had been submitted to.

The 2002 version of Eurocode 8 denotes a thorough work of revision, starting from the global organisation of the text and its subdivision into sections. Although based on an accurate reading of the whole code, this paper discusses only the aspects related to the design of irregular structures, with particular reference to the provisions for plan asymmetric buildings (torsional provisions).

The 1993 EC8 torsional provisions had been widely criticised (e.g. see [4]) because they presented many ambiguities in the definition of plan regularity and in its connection to torsional effects in asymmetric buildings, which were particularly evident when comparing part 1.2 and

Annex A. This led sometimes to evident contradictions, as when the use of a planar model (which considers no deck rotation) was allowed and, at the same time, the evaluation of torsional effects (i.e. of plan rotation) was required. Indeed, this part of the text appeared to be the uncoordinated work of different code-writers, which followed different approaches and sometimes used the same words (e.g. planar model) with different meanings.

Furthermore, 1993 version of Eurocode 8 allowed, like most seismic codes, the evaluation of the torsional effects in the elastic range by using static analysis together with additional (corrective) eccentricities. Unfortunately, it proposed a quite complex formulation of the corrective eccentricity, based on studies by Müller and Keintzel [10], without taking into account the limits of their approach (torsionally rigid systems; structural eccentricity connected to the torsional-lateral stiffness ratio), clearly stated in their paper.

Finally, no reference was made in 1993 version of Eurocode 8 to the problem of the inelastic behaviour of plan irregular buildings. Anyway, at those days, this lack was common to all the contemporary seismic codes, because the peculiar influence of asymmetry on the building inelastic response started to be investigated since the eighties only.

The effort of the 2002 version of Eurocode 8 to eliminate ambiguities and contradictions, which has led, for instance, to the elimination of Annex A with its corrective eccentricities, might be considered successful. The new text is much clearer and simpler than the previous one. Anyway, this appears to have led to over-simplified provisions for irregular buildings, which can be improved by considering recent research studies in the field.

PLAN REGULARITY

Criteria provided by the 2002 version of Eurocode 8 (4.2.3.2) for defining regularity in plan may be summarised as follows:

- The building structure should be approximately symmetrical in plan with respect to two orthogonal axes.
- The floor decks should be compact and rigid in their own plane.
- The structure should be torsionally stiff (torsional radius of stiffness r_x greater than radius of gyration of the floor in plan l_s).
- The structural eccentricity e_{ox}, distance between the centre of stiffness and the centre of mass measured along the direction x, normal to the direction of analysis considered, should not be excessive ($e_{ox} \leq 0.3\ r_x$, that in many cases means $e_{ox} \leq 0.1\ L$ approximately, being L the building x-direction plan dimension).

A significant problem, related to the above criteria, is the difficulty of judging the degree of symmetry and evaluating structural eccentricity, centre of stiffness and torsional radius of stiffness. As a matter of fact, these quantities may be properly defined only for one-storey systems. Eurocode 8 proposes a simplified definition for multi-storey buildings that is somehow vague and cumbersome, considering "certain quantities, proportional to a system of forces, having the distribution specified in static analysis and producing a unit displacement at the top of the individual lateral load resisting systems". Moreover, such simplified definition is applicable only to few buildings, because it requires that deflected shapes of the individual systems under horizontal loads are not very different, thus excluding dual systems (frames and walls) and frames with large variability of beam stiffness (frames with flat beams together with frames with rigid beams). On the other side, it must be recalled that simpler and more effective procedures have been suggested in order to evaluate the afore-mentioned structural eccentricity and torsional radius of stiffness (e.g. see [3] and [11]).

STRUCTURAL MODEL

According to EC8, the immediate consequence of plan regularity is the possibility of analysing the building by means of two planar models, one for each main direction (4.3.1). The importance given to the possibility of using planar models appears to be nowadays excessive. The general principle "the model of the building shall adequately represent the distribution of stiffness and mass", correctly stated by Eurocode 8, could be sufficient for the designer in order to choose the more suitable computational model, within the large number of available and reliable computer codes. Furthermore, it is highly questionable the possibility of using planar models as structural eccentricity reaches values up to 0.1 L, even if the building is torsionally rigid.

LATERAL FORCE METHOD OF ANALYSIS

According to Eurocode 8, any building may be designed by using static analysis – named "lateral force method of analysis" in the 2002 version of EC8 (4.3.3.1), provided that its response is not significantly affected by contributions from higher modes of vibration (4.3.3.2.1). The 1993 version allowed static analysis for asymmetric buildings only under specific limitations and together with the use of corrective eccentricities. On the contrary, in the last version of EC8 the general condition for using static analysis is considered to be satisfied if the building is regular in elevation and its fundamental period is smaller than given limits, without any reference to the plan regularity of the scheme. This approach might be not adequate, as shown in a large number of studies which pointed out the necessity of proper corrective eccentricities in order to make static analysis as safe as modal analysis. Nearly all other seismic codes provide simple formulations for estimating the value of corrective eccentricity. Many researchers have proposed more reliable formulations or procedures (e.g. see [1] and [3]). One issue still to be fully addressed by researchers is the relation existing between stiffness variation along the height of the building, which makes it non regularly asymmetric, and approximation in using static analysis (e.g. see [2]).

LOW-RISE BUILDINGS

Static analysis with planar models is allowed even if criteria for regularity in plan are not met provided that the building height does not exceed 10 m, the centres of lateral stiffness and of mass are each approximately located on a vertical line, the structure is torsionally rigid (more precisely, the condition is: $r_x^2 > l_s^2 + e_{ox}^2$). Aim of this is to allow a simpler, although less exact, approach for the low-rise buildings. Nevertheless, such requirements are substantially similar to those used for defining in-plan regularity, although differently expressed. This may ingenerate confusion, without any significant benefit for the designer.

INELASTIC RESPONSE

As in the previous version, also the 2002 edition of Eurocode 8 neglects inelastic seismic behaviour of irregular structures. For this reason, asymmetric buildings designed according to EC8 show the worst inelastic response, in comparison with buildings designed according to other codes [5]. While this might be understandable ten years ago, the development of research on this subject has clarified the main aspects of the inelastic response, giving both simple and more complex suggestions for design purposes. In particular, it is widely recognised the fact that in the inelastic range of behaviour, floor rotations of asymmetric structures are smaller than in the elastic range. This observation has resulted in the evaluation of the design internal actions as the envelope of more loading conditions, including schemes with pure floor translation or schemes in which the mass is considered applied at a distance e_d (design eccentricity) from the actual position of mass centre [9].

CONCLUSIONS

A lot of work has been done for improving Eurocode 8, giving it a more rationale formulation and eliminating ambiguities and contradictions. Nevertheless, as regards the design of irregular and complex structures the work may not be considered completed. In the last decade the research has gone further than the code, clarifying the seismic behaviour of such structures and giving useful indications for their design. The authors believe thus advisable a joined effort of all the researchers involved on this subject, in order to provide guidelines on the subject "structural regularity", which may point out to researchers and practical engineers the aspects clearly stated and the point which require more investigation, and may be useful for preparing new versions of seismic codes.

REFERENCES

[1] Anastassiadis, K., Athanatopoulos, A. and Makarios, T. (1998). "Equivalent static eccentricities in the simplified methods of seismic analysis of buildings", *Earthquake Spectra*, 14, 1-34.

[2] Bosco, M., Ghersi, A., Marino, E. and Rossi, P.P. (2002). "Effects of in-elevation irregularity on the elastic seismic response of in-plan asymmetric buildings", *Proceedings of the Third European Workshop on the Seismic Behaviour of Irregular and Complex Structures*, Florence, Italy.

[3] Calderoni, B., D'Aveni, A., Ghersi, A. and Rinaldi, Z. (2002). "Static versus modal analysis of asymmetric buildings: effectiveness of dynamic eccentricity formulations", *Earthquake Spectra*, 18(2), 219-231.

[4] Calderoni, B., Ghersi, A. and Mazzolani, F.M. (1996). "Critical analysis of EC8 approach to face the problem of structural regularity", *Proceedings of the First European Workshop on the Seismic Behaviour of Asymmetric and Set-back Structures*, Anacapri, Italy.

[5] De Stefano, M., Faella, G. and Ramasco, R. (1993). "Inelastic response of code-designed asymmetric systems", *European Earthquake Engineering*, VII(3), 3-17.

[6] European Committee for Standardization, CEN (1988). "Eurocode 8: Earthquake resistant design of structures", ENV 1998, first edition.

[7] European Committee for Standardization, CEN (1993). "Eurocode 8: Earthquake resistant design of structures", ENV 1998, second edition.

[8] European Committee for Standardization, CEN (2002). "Eurocode 8: Earthquake resistant design of structures", prEN 1998, third edition, final draft.

[9] Ghersi, A. and Rossi, P.P. (2000). "Formulation of design eccentricity to reduce ductility demand in asymmetric buildings", *Engineering Structures*, Elsevier Science Ltd, 22, 857-871.

[10] Müller, F.P. and Keintzel, E. (1978). "Approximate analysis of torsional effects in the new German code DIN 4149", *Proceedings of the sixth European Conference on Earthquake Engineering*, Dubrovnik, 2, 101-108.

[11] Moghadam, A.S. and Tso, W.K. (2000). "Extension of Eurocode 8 torsional provisions to multi-storey buildings", *Journal of Earthquake Engineering*, 4.1, 25-41.