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FUTURE DIRECTIONS FOR REINFORCED CONCRETE WALL BUILDINGS IN EUROCODE 8

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Abstract: The current Eurocode 8 belongs to one of the most advanced international seismic design codes. This leading edge should be maintained in future revisions of the code while the code should become as user friendly as possible. This article makes several proposals in which way the reinforced concrete wall sections in future versions of the Eurocode can be extended in its scope but simplified in its application. The topics raised concern: (i) Capacity design rules including shear amplification factors, (ii) the reduction of the number of ductility classes, (iii) the out-of-plane failure of reinforced concrete walls, (iv) engineering demand parameters for displacement-based approaches, (v) displacement-capacity estimates for new and existing reinforced concrete members, (vi) the design of mixed structural system, (vii) the design of new structural solutions with reinforced concrete members such as rocking walls.

Introduction

The current Eurocode 8 (EC8) was largely driven by considerations on reinforced concrete (RC) construction (Fardis, 2013). This is reflected in the number of pages dedicated to the guidelines for RC buildings in EC8-Part 1 (CEN, 2004) as well as in EC8-Part 3 (CEN, 2005), which are significantly larger than for any other structural type. From all structural types, the RC guidelines of EC8-Part 1 and 3 are therefore probably the most complete and contain many approaches that are internationally leading (Booth and Lubkowski, 2012). Future directions should focus on keeping this cutting edge approach. At the same time the code should become as user friendly as possible (Booth and Lubkowski, 2012). It is the author's opinion that this is best achieved by finding a good balance between simplicity and accuracy and by making underlying engineering models transparent. It is the objective of this paper to raise first thoughts on the future direction of design provisions for RC wall buildings. The following points outline some aspects that could be considered in future revisions of the code. The list also contains some points raised in the discussions following the special session "Future directions of EC8" organised by E. Booth at the Second European Conference on Earthquake Engineering and Seismology in Istanbul in August 2014. The list is certainly not complete and further input is sought from the reader.

Capacity design principles

Capacity design principles are one of the corner stones of EC8 and one of the most successful concepts in improving the robustness and collapse prevention of structures (Park and Paulay, 1976). Guidelines to incorporate these principles have been well developed for cantilever walls with rectangular or barbelled sections. In the future, capacity design guidelines need to be extended to cover a larger range of wall systems and sections. This concerns both the computation of the shear demand as well as the shear and flexural capacity. On the demand side, the shear amplification factors should be revisited and new formulae introduced that cover a larger range of shear wall systems. Current shear amplification factors in EC8 were derived for cantilever wall systems and should be extended to other very common structural systems, such as coupled wall systems or systems with frames and walls. Such studies are already underway or even completed (e.g., Sullivan,

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2010; Fox et al., 2014; Rejec et al., 2014) and results of these studies should be incorporated in the revision of the code.

Since no code provisions will be able to cover all types of structural configurations, guidelines on the modelling of walls would also be desirable. These guidelines should focus on models that are applicable in engineering practice and are general enough so that they are not connected to a particular modelling approach (e.g. recommendations on considerations of shear deformations). Such guidelines would also be helpful when preparing models for nonlinear static or dynamic analyses, which the author anticipates will become a common tool if EC8 continues to move as expected towards displacement-based design and assessment approaches.

On the capacity side, current design rules are mainly based on results of experimental tests on walls with rectangular or barbelled cross-sections. The existing rules should be carefully reviewed with regard to their applicability to walls with T-, L- and U-sections or even more complex cross sections of core walls (Reynouard and Fardis, 2001). For such walls, guidelines, for example, with regard to the assessment of the compression zone depth that need to be confined or the assessment of the sliding shear resistance. However, also new aspects that are not relevant to walls with rectangular cross sections need to be addressed. In particular: (i) The direction of excitation that is critical for the design of the wall. (ii) The distribution of shear forces between wall sections that are parallel. Reynouard and Fardis (2001) and Beyer et al. (2008) showed for U-shaped walls subjected to diagonal loading that the shear forces are carried mainly by the flange in compression. Designing each flange therefore for half the shear force can be non-conservative.

Further considerations, both with regard to modelling and design should be given to the slabs. At present the effect of the out-of-plane strength of slabs on the flexural strength of coupling beams as well as on the axial force in walls is often neglected. Such modelling assumptions might, however, be non-conservative in the framework of capacity design. The design engineers requires therefore simple and robust guidelines on when and how the out-of-plane stiffness and strength of RC slabs should be considered when analysing RC wall systems. Moreover, capacity design guidelines for flat slab systems that are often combined with RC walls and gravity columns including prediction of design forces in slab-column connections and slab-wall interfaces are at present missing and should be added to the code (Fardis, 2013).

Reduction of the number of ductility classes

At present there are three ductility classes for RC walls: Low (DCL), which is designed according to EC2, medium (DCM) and high (DCH) plus the wall type “Large lightly reinforced walls” as subclass of DCM. For the future, it would be desirable to reduce the number of ductility classes. It is proposed here that two ductility classes could be sufficient. The first of the two ductility classes could be placed between today’s DCL and DCM (in the following referred to as DC1) and another one between DCM and DCH (DC2).

The lower ductility class DC1 should cater for the needs of a simple design in regions of low to moderate seismicity. Many experimental studies on RC walls in the past have shown that walls typically reach a displacement ductility of 2.0 even if no strict capacity design rules were applied. Considering an overstrength ratio of 1.5, this would correspond to a behaviour factor q of 3.0. To include some conservatism and to distinguish it clearly from the second ductility class, it is recommended that DC1 is based on a behaviour factor of 2-2.5. The design of these walls should follow in general EC2-guidelines but with some additional detailing rules for the plastic zone (e.g. a minimum confinement of the compression zone, good confinement and longer length of reinforcement splices, increased shear reinforcement ratio, minimum wall thickness,…). No strict capacity design would be required, i.e., the shear demand would not be computed based on the moment capacity of the wall.

The higher ductility class DC2, on the other hand, should be based on very stringent capacity design rules, which would allow to reach a significant displacement ductility without loss of strength. For regular RC cantilever wall buildings, as basic value of the behaviour factor of q=4-5 is proposed for this ductility class. Following the compression failures of RC walls that were observed after the recent earthquakes in Chile and New Zealand, the detailing rules should be revisited. For this purpose, the results of the working group "wall detailing" of the wall workshops organised by Prof. J. Wallace will be of significant interest.

Out-of-plane failure of RC walls

The recent earthquakes in Chile and New Zealand revealed also unexpected failure modes that relate to the out-of-plane failure of RC walls (Fig. 1; Wallace et al., 2012; Kam et al., 2011). Some of these failure modes might have surfaced as other—more disastrous failure modes—such as shear failure of RC walls were avoided through the implementation of capacity design rules in previous versions of codes (Sritharan et al., 2014). Research is needed to judge whether the design provisions of EC8-Part 1 can avoid such failure modes and whether EC8-Part 3 can predict these failure modes—the larger challenge being clearly related to the latter. At present, a number of research projects are underway that address these issues experimentally (Rosso et al., 2015; Fig. 1) and numerically (Dashti et al., 2014). The results of these and future research projects should be considered when revisiting current slenderness criteria for RC walls. It should further be decided whether a failure criterion that links the maximum tensile strain to the out-of-plane stability of the wall should be included. Such criteria have been proposed by Paulay and Priestley (1993) and Chai and Elayer (1999).

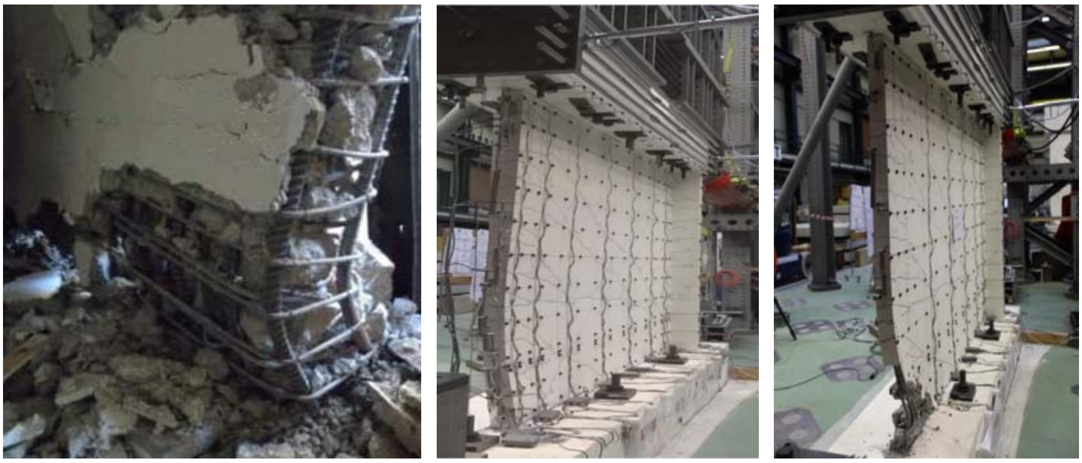

Fig. 1 Examples of out-of-plane induced damage in a RC wall after New Zealand earthquakes (Sritharan et al. 2014, left). Test on a thin wall with a single layer of vertical and horizontal reinforcement (Rosso et al., 2015): Deformed shape of around zero in-plane drift (centre) and at the end of the test, after failure (right).

Engineering demand parameters for displacement-based approaches

EC8-Part 3 opted for the chord rotation as engineering demand parameter for the displacement demand, which is in particular suitable for nonlinear static analysis of equivalent frame models. As nonlinear time history analysis and more complex membrane, shell or solid element models might become common in seismic analyses, future codes might reconsider the application of other, more local engineering demand parameters as, for example, strains knowing, however, that such engineering demand parameters call for advanced regularisation techniques before they can be used for seismic assessment (Bazant, 1976).

Displacement-capacity estimates

EC8-Part 3 contains already chord rotation capacity equations for a large range of element configurations such as RC walls with and without lap splices in the plastic zone and smooth or deformed bars. Such equations need to be continuously refined and validated against new research; a first revision of these equations is already available (CEN, 2013). The further development of these equations should aim at (i) developing limits for engineering demand parameters for new limit states that are introduced in future versions of the code; (ii) reducing the variability of the predicted to observed displacement capacity and quantifying this variability while maintaining at the same time a good balance between simplicity and robustness, (iii) reinforcing mechanical approaches for the prediction of the displacement capacity as they can be extrapolated to element configurations where the data basis is very thin, such as core walls, (iv) addressing the displacement capacity of degrading systems considering realistic cumulative damage demands.

Mixed systems

New versions of the code should also account for the fact that real construction might result in mixed structures, such as the classical RC wall-frame structure but also across building materials, such as RC walls combined with steel frames or load-bearing masonry walls. It is expected that the portion of such mixed structures within the entire building stock will increase in the future (i) due to seismic retrofit interventions, and (ii) because structures might be altered or extended rather than completely new structures built. Such mixed structures are more complex to assess than structures with a single structural system and guidelines of the latter cannot simply be extrapolated to mixed systems.

Displacement-based procedures are very well suited to deal with mixed structural system (Priestley et al., 2007). The nonlinear static assessment procedure included in EC8 can therefore be readily applied to mixed structural systems. However, for the design of new structures it would be also desirable to develop a force-based design approach for mixed structural systems. This design approach needs to account for the characteristics of mixed structural systems with regard to the stiffness and strength of the subsystems that are coupled. One idea of approaching these mixed systems is based on the elastic shear-flexure cantilever beam, for which deformed shape and internal force distribution closed form solutions exist. This model has been applied to the displacement-based assessment of systems with URM walls and RC walls (Paparo and Beyer, 2015; Fig. 2) and current work at EPFL investigates the development of behaviour factors for mixed systems based on this model.

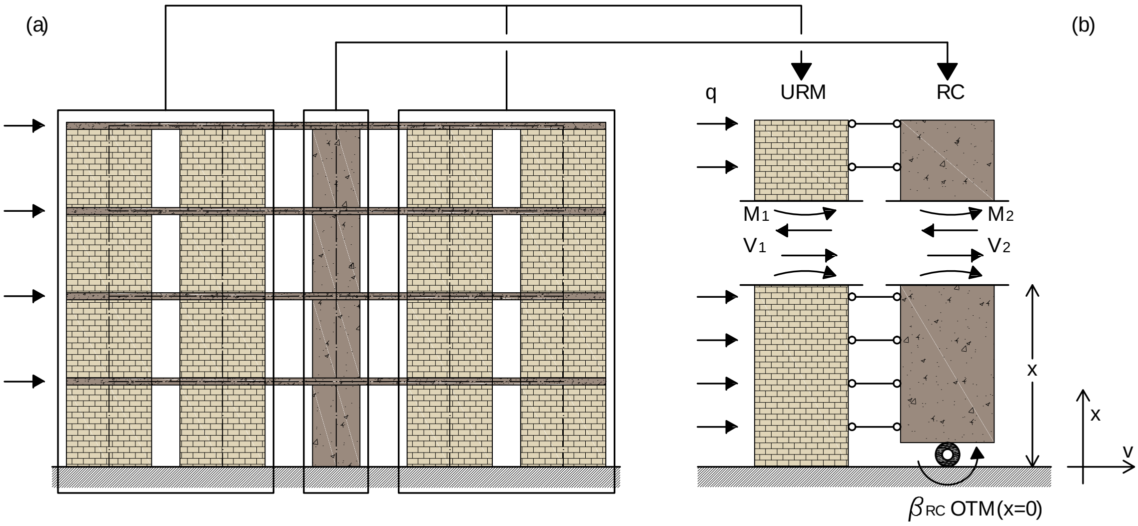

Fig. 2 Mechanical model for mixed structural system: Example of a system with RC and URM walls that is modelled by a shear-flexure cantilever beam model (Paparo and Beyer, 2015).

New systems

The code should include provisions for new structural systems constructed from RC elements that have the potential to reduce damage and therefore costs, in particular also during small and frequent events. Such systems can be, for example, post-tensioned rocking wall systems (e.g. Priestley, 2000) or fibre reinforced concrete elements (e.g. Parra-Montesinos et al., 2012) but also the design practice of classical RC elements can be re-evaluated aiming at reinforcement details that limit, for example, crack widths in small events (Sritharan et al., 2014).

Conclusions

A future revision of Part 1 and 3 of Eurocode 8 shall keep the cutting edge approach of today’s code and make it as user friendly as possible (Booth and Lubkowski, 2012). In this paper a number of issues were raised with regard to the design provisions of reinforced concrete wall systems that could be addressed in such a revision. For some of these first ideas on the new directions were presented. The author looks forward to receiving comments on these proposals as well as input on further issues that should be addressed in such a revision.

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