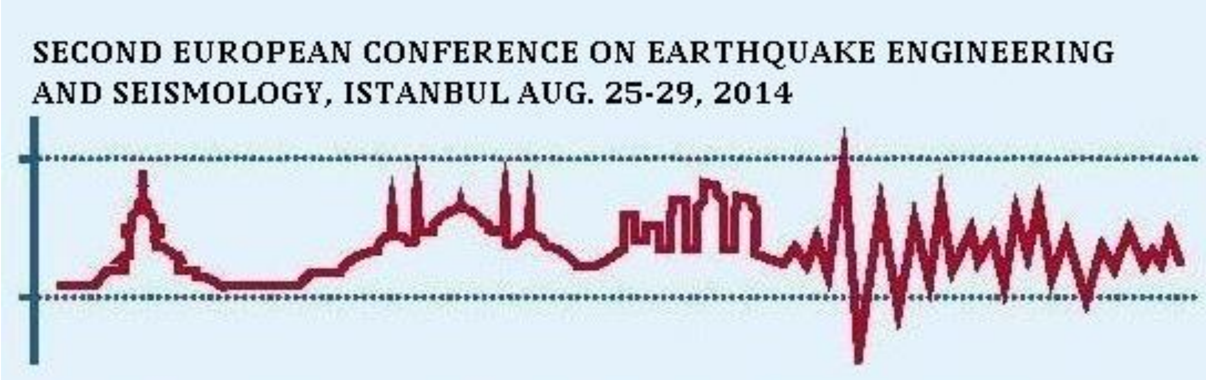

ANALYSIS METHODS FOR PERFORMANCE BASED DESIGN IN FUTURE VERSIONS OF EN1998

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As our knowledge and ability to control the response of buildings in earthquakes increase, so too do public expectations for high performance building solutions. Clients see the value of performance-based design solutions that are tailored to meet their needs, and promising tools are emerging for the quantification of new performance-measures, such as the likely casualties, monetary losses, and repair time (commonly referred to as deaths, dollars and downtime) due to an earthquake. In parallel to this, a number of limitations with current code force-based design and analysis methods have been identified (Priestley, 1993; Priestley et al. 2007) and displacement-based design and assessment procedures have been proposed as a rational alternative. As an initial contribution to a Working Group (Booth, 2014) that is considering how the seismic Eurocode, EN1998 (hereafter EC8) should develop in the future, the following paragraphs explore how recent developments in the field of performance-based design could be embraced by future generations of the EC8. It is hoped that the points made will stimulate discussion, and the author welcomes comments and suggestions.

The current edition of EC8 part 1 (for buildings) offers two linear elastic structural analysis methods and two non-linear methods. Of these, the non-linear methods require knowledge of the building strength and, hence, are essentially assessment methods. The linear elastic methods (the equivalent lateral force method and modal response spectrum analyses) are therefore commonly adopted for seismic design, only requiring an estimate of the building period of vibration and a structural typology-dependent behaviour factor. However, as pointed out by Priestley (1993), such force-based design (FBD) methods possess a number of fundamental shortcomings; neglecting the effect that structural proportions have on relationships between local and global ductility (demand and capacity), ignoring the influence of hysteretic properties on inelastic displacement demands, struggling greatly with dual systems, and overlooking the dependence of a building's period of vibration on its strength, amongst other things. Consequently, various displacement-based design (DBD) procedures have been proposed as a rational alternative and the Direct DBD approach is currently the most developed, with a text (Priestley et al. 2007) and model code (Sullivan et al. 2012) on the subject. DBD guidelines have now been developed and tested (to varying extents) for a wide range of structural typologies, from traditional frame and wall structural systems through to innovative systems possessing re-centering technology, base-isolation and/or added damping. In fact, a strong feature of the DBD procedure is the ease with which it can be adapted to a wide range of structural systems, including soil-structure systems. Given this, a future version of the EC8 should look to address the limitations of FBD methods, and include DBD as a possible alternative.

As it is anticipated that the verification of seismic performance via non-linear analyses is likely to increase in popularity, a future version of EC8 should also aim to provide more detailed requirements for non-linear analysis methods. Current code clauses tend to be quite general, with the consequence that different engineers are likely to make quite different modelling and analysis decisions that could have a significant impact on the assessed performance. One example relates to the manner with which elastic damping is incorporated within non-linear dynamic analyses, since Priestley et al. (2007), amongst others, have shown that this assumption alone can greatly affect both

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the predicted deformations and internal force demands. By providing more detailed guidance for non-linear static and dynamic analyses in a future version of EC8 it is envisaged that non-linear modelling and analysis errors could be reduced.

Another important area for the development of EC8 will be to provide more accurate analysis guidelines for the assessment of demands on non-structural elements. This is a particularly important challenge for performance-based design since it is well recognized that non-structural elements can greatly affect the performance of a building (Filiatrault and Christopoulos, 2002). Non-structural elements are typically classified (FEMA E-74) as either displacement-sensitive or acceleration-sensitive components. Considering this, drift demands on displacement-sensitive components could be obtained from standard structural analysis methods whereas for acceleration sensitive components, it has been shown (Sullivan et al. 2013) that the current EC8 equations (Section 4.3.5.2) for the estimation of floor acceleration spectra are erroneous. It should also not be overlooked that European guidelines for the evaluation of the capacity of non-structural elements appear to be severely lacking. With this in mind, future versions of EC8 should endeavour to make a large number of developments to better facilitate the performance based design (or assessment) of non-structural elements.

Finally, it is considered that analysis methods within future versions of EC8 should renew emphasis on the uncertainties involved in earthquake engineering and the probabilistic nature of seismic risk, by incorporating the treatment of uncertainty in demand and capacity in a simple, transparent and consistent manner. Large steps have been made towards more probabilistic performance assessment methods in the U.S., with the FEMA P-58 (2012) guidelines now indicating how performance parameters such as deaths, dollars and downtime can be estimated for a building, within a probabilistic framework. However, as the FEMA P-58 procedure would represent a significant departure from current seismic engineering practice in Europe, the challenge for the EC8 would be to provide a simple means of realising equivalent performance assessments that maintain an emphasis on the importance of good engineering fundamentals. More research is needed to achieve this idea but there are signs that simplified approaches should be possible (Porter et al. 2004; Fajfar and Dolsek, 2010) including displacement-based procedures (Welch et al. 2014), and their development for eventual implementation within EC8 might represent a valuable means of obtaining more uniform-risk solutions.

Concluding therefore, it is proposed that future generations of EC8 address limitations with force-based design, provide more detailed guidance for non-linear analyses, address the subject of non-structural elements, and offer means of quantifying more tangible performance measures (such as deaths, dollars and downtime) with reasonable consideration of the uncertainties in demand and capacity. While these proposals could clearly appear to be quite challenging at present, research developments have been moving in this direction and the achievement of these objectives would represent a valuable contribution to the reduction of seismic risk.

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