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Towards Improved Considerations of Risk in Seismic Design (Plinius Medal Lecture)

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The aftermath of recent earthquakes is a reminder that seismic risk is a very relevant issue for our communities. Implicit within the seismic design standards currently in place around the world is that minimum acceptable levels of seismic risk will be ensured through design in accordance with the codes. All the same, none of the design standards specify what the minimum acceptable level of seismic risk actually is. Instead, a series of deterministic limit states are set which engineers then demonstrate are satisfied for their structure, typically through the use of elastic dynamic analyses adjusted to account for non-linear response using a set of empirical correction factors. From the early nineties the seismic engineering community has begun to recognise numerous fundamental shortcomings with such seismic design procedures in modern codes. Deficiencies include the use of elastic dynamic analysis for the prediction of inelastic force distributions, the assignment of uniform behaviour factors for structural typologies irrespective of the structural proportions and expected deformation demands, and the assumption that hysteretic properties of a structure do not affect the seismic displacement demands, amongst other things. In light of this a number of possibilities have emerged for improved control of risk through seismic design, with several innovative displacement-based seismic design methods now well developed. For a specific seismic design intensity, such methods provide a more rational means of controlling the response of a structure to satisfy performance limit states. While the development of such methodologies does mark a significant step forward for the control of seismic risk, they do not, on their own, identify the seismic risk of a newly designed structure. In the U.S. a rather elaborate performance-based earthquake engineering (PBEE) framework is under development, with the aim of providing seismic loss estimates for new buildings. The PBEE framework consists of the following four main analysis stages: (i) probabilistic seismic hazard analysis to give the mean occurrence rate of earthquake events having an intensity greater than a threshold value, (ii) structural analysis to estimate the global structural response, given a certain value of seismic intensity, (iii) damage analysis, in which fragility functions are used to express the probability that a building component exceeds a damage state, as a function of the global structural response, (iv) loss analysis, in which the overall performance is assessed based on the damage state of all components. This final step gives estimates of the mean annual frequency with which various repair cost levels (or other decision variables) are exceeded. The realisation of this framework does suggest that risk-based seismic design is now possible. However, comparing current code approaches with the proposed PBEE framework, it becomes apparent that mainstream consulting engineers would have to go through a massive learning curve in order to apply the new procedures in practice. With this in mind, it is proposed that simplified loss-based seismic design procedures are a logical means of helping the engineering profession transition from what are largely deterministic seismic design procedures in current codes, to more rational risk-based seismic design methodologies. Examples are provided to illustrate the likely benefits of adopting loss-based seismic design approaches in practice.