

## Performance- and Risk-based Design Approaches for Seismic Safety

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Until recently, the engineering design of new structures to resist earthquakes, and the quantification of seismic risk for existing structures, had been relatively unconnected topics within earthquake engineering. New structures were typically designed for a site-specific ground shaking intensity from either a deterministically-defined earthquake scenario or a single chosen level of probabilistic seismic hazard (i.e., a chosen mean rate of exceeding the shaking intensity). Although seismic safety was implied, the seismic risk for such structures (e.g., in terms of mean rate of seismically-induced failure) was not explicitly quantified in the design process or in the development of the design process by regulators. In contrast, earthquake engineers and scientists have worked together for decades now to quantify the seismic risk for existing structures. This is done by coupling probabilistic ground shaking hazard results (at a wide range of hazard levels) from earthquake scientists with probabilistic structural performance assessments from engineers; the latter is based on the performance of similar structures in past earthquakes and/or numerical simulations. The ground shaking hazard results, summarized in a “hazard curve” for a given site, provide mean rates of exceeding a wide range of potential shaking intensities (including the intensity used in design). In turn, the structural performance assessment needed for risk quantification relates these shaking intensities to conditional probabilities of failure of the structure in question, in the form of a “fragility curve.” The convolution of such hazard and fragility curves is an application of the total probability theorem, and it is often referred to (by earthquake engineers and scientists) as the risk integral.

The presentation introduced herein describes recently-developed seismic *design* regulations that make explicit use of the *risk* integral. The recent regulations include a “performance-based” approach to defining ground shaking intensities for nuclear power plants (US Nuclear Regulatory Commission Guide 1.208) and “Risk-Targeted” Maximum Considered Earthquake Ground Motions for designing new buildings and other structures (American Society of Civil Engineers Standard 7-10 and the 2012 International Building Code).

This presentation also describes the ongoing development of next-generation performance-based seismic design procedures for new and existing buildings (Applied Technology Council Project 58, funded by the US Federal Emergency Management Agency). Over and above the risk of structural failure, these procedures compute the mean rate of earthquake-induced casualties, repair costs, and loss of use, via a generalization of the risk integral. Moreover, the resolution of the procedures is such that the fragility curves they quantify depend on details of individual elements of the structure of interest (e.g. column dimensions), not just the design ground shaking intensity. Implications of this and the other performance/risk-based approaches on aspects of seismic design other than ground shaking intensities, and on design for hazards other than earthquakes, are discussed in the presentation.