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Spectrum-consistent a_g-based fragility curves

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ABSTRACT

In the field of earthquake engineering, Fragility Curves (FCs) have become indispensable for regional risk assessments due to their efficacy in estimating the failure probabilities of diverse structures, including buildings and bridges, based on certain intensity measures. FCs are typically derived from either mechanical simulations or on-site observations, encapsulating crucial information about local stratigraphy and topography. The dependency of FCs on these local parameters, such as soil and topographic conditions, may vary depending on the selected intensity measure. When a spectral ordinate at a specific period is used as an intensity measure, FCs tend to be largely site-independent. On the other hand, if the intensity measure is chosen to be the acceleration a_g at the bedrock substrate, as often occurs, then the FC is site-dependent. This distinction implies that identical structures at different locations, or even the same location with different soil and topographic conditions, have different FCs. This can significantly influence the results of regional risk studies, as using FCs for a specific building type at diverse locations with different hazards, stratigraphy, and topography can result in significantly different failure probabilities. The goal of this study is to develop a method so that a_g-based FCs, developed at a certain location, can be used at any other location and on any other soil, preserving consistency in terms of spectral ordinate. This is done by a fully analytical approach, using a spectrum-consistent transformation. As an application, risk maps for Italy are generated and compared with an alternative method based on shifting the hazard curve.

1. Introduction

Fragility curves (FCs) have emerged as a valuable tool in the performance-based evaluation of diverse structures, providing probabilities of exceeding specified damage thresholds [1–5]. FCs are essential for risk assessment, performance-based design, and emergency management planning in earthquake-prone regions [6]. FCs in seismic engineering are tools that represent the probability of a structure, such as a building or a bridge, of exceeding a certain damage level given a seismic event of a certain intensity measure (e.g., [7–11]). AFC, mathematically, is a conditional probability function $\mathcal{F}(D|im)$, where D represents a damage level or Limit State (LS) and im represents an intensity measure of the earthquake. The curve essentially provides the probability of exceeding a specific damage state given a certain earthquake intensity. The damage state is typically quantified as function of an engineering demand parameter (edp), such as inter-story drift ratio, peak floor acceleration, or absolute displacement. A FC is typically modeled using a lognormal cumulative distribution function [12], with parameters defining the median intensity measure causing damage (location parameter) and the standard deviation, which represents the uncertainty or dispersion in the data (scale parameter). FCs can also be described by different functions, such as in the case of physics-based fragility functions that do not require simplifying assumptions on the shape of the fragility function [13–15]. In this case, FCs are developed through structural analysis (e.g., [16,17]) or empirical data (e.g., [18,19]) and the resulting curves can have any functional form. The parameters of the FC can also be derived using a machine-learning approach [20]. In seismic engineering, the im adopted in fragility curves usually refers either to the bedrock acceleration a_g or to a spectral ordinate $S_e(T)$ at a given period T. The im provides a proxy to quantify and condense into a single number the severity of the ground motion during a seismic event.

The chosen im impacts the site-dependency of fragility curves, influencing their relevance to specific local conditions, such as soil stratigraphy and topography [21]. As a matter of fact, different ims can have different levels of correlation with edp [22,23]. Ensuring a strong correlation between edps and ims is vital to the effectiveness of fragility curves in predicting structural damage due to seismic events [1]. In particular, if the seismic performance is expressed in the form of the Median Interstorey Drift Ratio (MIDR) or the Average Interstorey Drift Ratio (AIDR), the correlation coefficients are larger for the spectral

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