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Sensitivity of PSHA results to ground motion prediction relations and logic-tree weights

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Abstract

Epistemic uncertainty in ground motion prediction relations is recognized as an important factor to be considered in probabilistic seismic hazard analysis (PSHA), together with the aleatory variability that is incorporated directly into the hazard calculations through integration across the log-normal scatter in the ground motion relations. The epistemic uncertainty, which is revealed by the differences in median values of ground motion parameters obtained from relations derived for different regions, is accounted for by the inclusion of two or more ground motion prediction relations in a logic-tree formalism. The sensitivity of the hazard results to the relative weights assigned to the branches of the logic-tree, is explored through hazard analyses for two sites in Europe, in areas of high and moderate seismicity, respectively. The analyses reveal a strong influence of the ground motion models on the results of PSHA, particularly for low annual exceedance frequencies (long return periods) and higher confidence levels. The results also show, however, that as soon as four or more relations are included in the logic-tree, the relative weights, unless strongly biased towards one or two relations, do not significantly affect the hazard. The selection of appropriate prediction relations to include in the analysis, therefore, has a greater impact than the expert judgment applied in assigning relative weights to the branches of the logic-tree.

Keywords: Probabilistic seismic hazard analysis; Ground motion prediction models; Seismic wave attenuation; Epistemic uncertainty; Aleatory variability; Logic-tree weights

1. Introduction

Seismic hazard analysis, a field operating in the area between science and engineering [1,2], has undergone major yet quite uneven developments, since its gradual initiation almost a century ago. Only deterministic analyses were used before 1970 when the first simple probabilistic analyses were introduced, following the seminal work of Cornell [3]. Then, from about 1985, the use of logic-trees was introduced together with a better understanding of uncertainties [4,5], followed by a further sophistication in methods and approaches related to the development of the SSHAC Level 4 methodology [6], where a well-balanced use of experts was a central component [7–9].

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While probabilistic seismic hazard analyses (PSHAs) in this way have developed significantly in complexity and sophistication over the years, simpler approaches, including deterministic analyses, are still called for at times. In neither case, however, will there normally, in an engineering project, be room for any detailed sensitivity analysis of the different parts of the model, even though a simple disaggregation is now usually included in most cases, where PSHAs are employed. The present paper will to this end specifically address some sensitivity questions that are related to ground motion models and to logic-tree weights.

Predictive relations for estimating the values of particular ground motion parameters for future earthquakes for particular magnitudes and distances constitute an essential element in any PSHA, in particular since much of the uncertainty is driven by these models. The recognition of epistemic uncertainty in ground motion prediction relations, most simply expressed through the differences between median values, is one of the key elements here.

As a consequence of this it is now common PSHA practice to combine a number of relations in a logic-tree, even if there is one or more models that have been derived specifically for the region in question [10]. The hazard calculations are then performed following all the possible branches through the logic-tree, each analysis producing a single hazard curve showing ground motion against annual frequency of exceedance. The relative weighting of each hazard curve is then determined by multiplying the weights along all of the component branches. The results allow the definition of a mean and a median hazard curve, as well as similar curves for different confidence intervals. At any particular exceedance frequency the ground motions across the range of confidence levels are usually close to log-normally distributed.

The most critical parts of a logic-tree setup for ground motion prediction relations are the selection of the relations and the assigning of weights that reflect the relative confidence in their being the best estimate. Procedures for selecting relations and for judging their relative merits in a particular application are discussed in Refs. [11–13]. Fortunately, due to the expansion of strong-motion networks, the number of proposed ground motion prediction relations has increased significantly during the last decade [14].

From the available relations derived in recent years, nine are selected for this study, either on basis of being widely used or recently published in order to carry out PSHA sensitivity analyses. The objective of this paper is to explore the sensitivity of the hazard results to the selection of those relations and, for a given suite of relations, to the weights assigned in the logic-tree branches.

As different relations use different definitions both of the predicted variable (such as the selection of a single value from the two horizontal components of motion) and of the independent variables (distance, magnitude, site classification, and style-of-faulting), adjustments need to be made to achieve compatibility amongst the relations [12]. To ensure a basic consistency and to enable different ground motion models to be used together in a logic-tree PSHA, some simplified empirical adjustments of the dependent and independent variables are adopted. The source model in this case is less interesting, but since that model also influences the sensitivities to some extent, we have used two generic sites in this study, characterized by high (Site 1) and moderate (Site 2) seismicity, respectively. The sites are real, thus allowing actual source zones and seismicity relationships to be employed, but their location is not specified since no inferences should be made about the suitability of the candidate ground motion models to the particular regions.

For each site and for each ground motion parameter considered, the distribution of the hazard curves were investigated with different approaches for the selection of the weights assigned to each of the ground motion relations. The overall purpose of the study is thereby to investigate which parts of the model are most critical, or sensitive, with two specific purposes in mind: to understand, where the main effort should go when performing a PSHA, and to understand in which direction future research should be taken.

2. Source zones and earthquake recurrence rates

Two real (yet not specifically identified) Italian sites characterized, respectively, by high and moderate seismicity have been selected. We considered it essential in this study to use real seismicity, represented by two quite different sites, but as explained above we have made the sites anonymous because we did not want to indicate that the suite of selected ground motion models is necessarily applicable to the particular location in question. Fig. 1 shows, for each site, the seismogenic zones considered for the hazard calculation, together with the earthquake epicenters. We emphasize, however, that the connection of the two sites to a real case is neither important nor interesting in the present context; on the other hand, in choosing between an artificial and a real source model, the latter is still to be preferred.

Site 1 shows a case of very high seismic hazard, with magnitudes up to 7.5. Site 2 has, in contrast, a moderate level of seismicity, with magnitudes up to 5.5, but also with influences from stronger and more distant earthquakes (∼85 km, magnitudes up to 7.0). Besides the differences in activity levels and maximum magnitudes the two regions also differ significantly in terms of *b*-values, where Site 2 has a value of around 1.3 and Site 1 around 0.6, indicating that the latter area is more dominated by large but infrequent events. Such a difference normally also indicates quite different stress regimes in the two areas, in turn also affecting the slopes of the respective hazard curves.

While the recurrence parameters in this way are selected from a real case, we have made a simplification in that we are assuming all the source zones contain only strike-slip faults with dips varying between 80 and 90° and with dimensions as taken from the median values of the empirical relations of Wells and Coppersmith [15]. This is done in order to simplify the distance and style-of-faulting corrections described in Section 3 which can be done since the scope of this paper is not to investigate such effects but only those more specifically related to the effects of the selection of ground motion relations and associated logic-tree weights.

3. Selection and adjustments of ground motion models

From the large number of ground motion relations now available we have selected nine of the most recent and commonly used ones to be included in our sensitivity analyses. We have selected as many as nine relations in order to establish a certain statistical basis for our results and in order to ensure that we catch a realistic range in terms of ground motion prediction relations and thereby also