Contribution of Identified Active Faults to Near Fault Seismic Hazard in the Flinders Ranges

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Abstract

We performed a seismic hazard analysis at a site near an active fault in the Flinders Ranges. Two categories of earthquake sources were used to represent the seismic hazard at the site. The first consists of active faults, and used estimates of fault slip rate from Quigley et al. (2006) to quantify the seismic activity rate on the faults. The second earthquake source category consists of distributed seismicity. For this category, we used two alternative models: the AUS5 model of ES&S (2005), and the Risk Frontiers model of Hall et al (2007). Each of these models was used in conjunction with the active fault model. Quigley et al. (2006) identified a system of four faults which include (from North to South) the Wilkatana, Depot, Nectar Brook and Crystal Brook faults in the Central Flinders ranges. The site is located about 700 metres east of the inferred location of the Crystal Brook fault. We assumed that the Nectar Brook and Crystal Brook faults have dip angles of 67 degrees. Seismicity in the Central Flinders ranges extends to about 20 km depth. From these estimates of depth extent and dip angle, we estimated the widths of the faults. We assumed that the relationship between rupture area and earthquake magnitude derived for eastern North American earthquakes (Somerville et al., 2001) also applies in South Australia. This relationship is $Mw = \log_{10} A + 4.35$. Using this relationship, we calculated maximum earthquake magnitudes of the faults. Single event surface fault displacements on Central Flinders Ranges faults measured by Quigley et al. (2006) lie in the range of 4 to 8 metres, consistent with our estimates of fault rupture area. From the information on neotectonic displacements, ages and slip rates provided by Quigley et al. (2006), we estimated the median value of the slip rate of the faults to be 0.15 mm/year. To represent uncertainty in the slip rate, we used a distribution of values, giving a weight of 0.6 to the median value of 0.15 mm/year, and weights of 0.2 to values of 0.075 mm/year and 0.30 mm/year. At return periods of 10,000 years and longer, the largest hazard comes the Crystal Brook fault. There are also significant but smaller contributions from the other two active fault segments. The spatially distributed sources also contribute significantly to the hazard at 10,000 year return period, and at shorter return periods, these sources dominate the hazard at the site.

Key Words: Active faults, seismic hazards

1. Introduction

Until recently, seismic hazard analysis in Australia has been based primarily on historical seismicity. However, in recent years, an increasing amount of information has become available about active faults in Australia (Clark and McCue, 2003; Clark, 2006; Quigley and Sandiford, 2006; Leonard and Clark, 2006). If slip rate estimates are available, they can be used directly to estimate the seismicity of identified active faults.

To date, fault slip rates have not been used directly in the estimation of ground motion hazard in Australia. Ninis and Gibson (2006) developed a procedure in which seismicity in the vicinity of an active fault is subtracted from the background zone in which it resides and allocated to the active fault. For example, in their study of seismic hazards in the Flinders Ranges, SRC (2001) subtracted the presumed fault-generated earthquakes from the Flinders Ranges source zone in which the fault system lies, and created a fault source zone. In this study, we have combined the earthquakes derived from the slip rates of the active faults with the earthquakes from the spatially smoothed earthquake sources, without modifying the earthquake catalogue. This assumes that the background seismicity contained in the historical earthquake catalogue does not occur on the active fault system. This is a more conservative assumption than the one used by SRC (2001). Presumably, the actual seismic potential lies somewhere between these two models.

The objective of this paper is to assess the contribution of slip rate information on mapped active faults to seismic hazards at a near fault site in the Central Flinders Ranges. Two categories of earthquake sources were used to represent the seismic hazard in the region. The first consists of active faults, and uses estimates of fault slip rate to quantify the seismic activity rate on the faults. We used newly available information from Quigley and Sandiford (2006) to characterize these active faults. The second earthquake source category consists of distributed seismicity. For this category, we used two alternative models, the AUS5 model (Brown and Gibson, 2004) and one from Risk Frontiers (Hall et al., 2007). Each of these models was used in conjunction with the new active fault model.

2. Active Fault Sources

We derived a model of active fault sources of earthquakes in the Central Flinders Ranges from the work of Quigley et al. (2006). They identified a system of four faults, shown in Figure 1, which include (from North to South) the Wilkatana, Depot, Nectar Brook and Crystal Brook faults. Of these four fault segments, the most detailed information is available on the Wilkatana fault (Quigley et al., 2006). Sandiford and Quigley (2007) provided an integrated interpretation of the system of four faults. We combined the Wilkatana and Depot Creek faults into a single fault segment, because the offset between these segments is small, and we consider it likely that they can rupture in a single event.

The fault parameters of the three faults are summarized in Table 1. We assumed that the Nectar Brook and Crystal Brook faults have dip angles of 67 degrees, based on the steeper dip angle (70 degrees) noted on the southern Wilkatana fault (Quigley et al., 2006). Seismicity in the Central Flinders ranges extends to about 20 km depth. From these estimates of depth extent and dip angle, we estimated the widths of the faults listed in Table 1.

We assumed that the relationship between rupture area and earthquake magnitude derived for eastern North American earthquakes (Somerville et al., 2001) also applies in South Australia. This relationship is:

$$Mw = \log10\ A + 4.35.$$

Using this relationship, we calculated maximum earthquake magnitudes of the three faults as listed in Table 1.

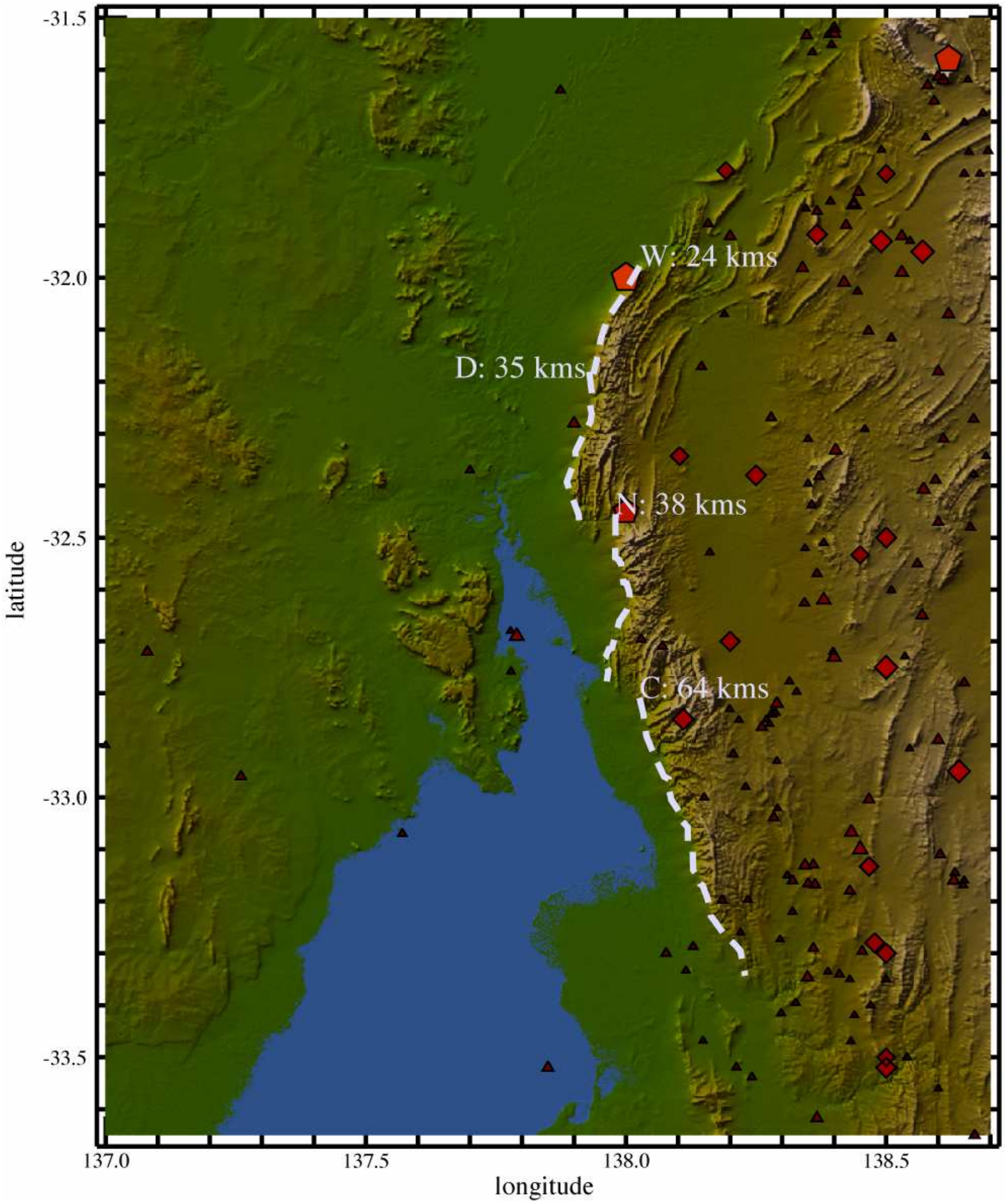

Figure 1. Central Flinders Ranges faults. Source: Sandiford and Quigley (2007). The three fault segments, from north to south, are the Wilcatana-Depot, Nectar Brook and Crystal Brook Faults. The site is located at the head of the black arrow just east of the northern end of the Crystal Brook Fault.

Single event surface fault displacements on Central Flinders Ranges faults measured by Quigley et al. (2006) range from 4 to 8 metres. It is possible that these surface fault displacements represent multiple events and may be overestimates of single event displacements. These measured displacements are compatible with the fault displacements implied by the fault models in Table 1.

Table 1. Fault Parameters of Central Flinders Ranges Faults

Fault	Dip (Degrees East)	Length (km)	Width (km)	Mmax Mw)	Displacement (m)
Wilcatana- Depot Creek	46	59	28	7.5	4.7
Nectar Brook	67	38	22	7.3	3.9
Crystal Brook	67	64	22	7.5	4.7

From information on neotectonic displacements, ages and slip rates developed by Sandiford and Quigley, we estimated the median value of the slip rate of the faults to be 0.15 mm/year. This slip rate corresponds to a recurrence interval of about 25,000 years for large earthquakes on these faults. If this relatively high slip rate reflects recent temporal clustering of large earthquakes on these faults, it may overestimate the long term average slip rate. It lies within the range of 10,000 to 100,000 years or more for active faults in Australia estimated by Clark (2006). To represent uncertainty in the slip rate, we used a distribution of values, giving a weight of 0.6 to the median value of 0.15 mm/year, and weights of 0.2 to values of 0.075 mm/year and 0.30 mm/year.

3. Spatially Distributed Earthquake Source Models

Two spatially distributed earthquake source models were used in this study. The first is the AUS5 source model. This model is based on the approach of Brown and Gibson (2004), which uses geological criteria to identify zones of uniform seismic potential, and then uses historical seismicity to characterize the seismic potential of each zone by means of the a-values and b-values of the Gutenberg-Richter earthquake recurrence model, together with an estimate of the maximum magnitude of earthquakes in each zone.

The second earthquake source model was derived by Risk Frontiers (Hall et al., 2007) based on the spatial smoothing of historical seismicity. This approach is similar to the main approach used to describe the seismic potential of the eastern United States in the U.S. National Probabilistic Seismic Hazard Maps (Frankel et al., 2007). This spatially distributed earthquake source model was derived from the spatial smoothing of historical seismicity using the earthquake catalogue described by Leonard (2008). It is intended that this model complement other models, such as Brown and Gibson (2004) and Ninis and Gibson (2006), which use geological criteria to identify zones of uniform seismic potential, and Clark (2006), which uses neotectonic data.

The spatial smoothing approach has the advantages of simplicity and of avoiding uncertainty in the geological definitions of zones, but has the disadvantage of not making use of potentially informative geological data. The spatially distributed earthquake source model is in the form of a-values and b-values on a 10 km x 10 km grid throughout Australia. The b-values for each of the five zones in Leonard (2008) were generated using completeness intervals based on his work: Southeastern Australia (SEA), Southwestern Australia (SWA), South Australia (SA), Northwestern Australia (NWA), and the rest of Australia. The a-value grids for each region were derived from the smoothed spatial distribution of seismicity, using the b-value for that zone and the number of earthquakes greater than or equal to a certain magnitude within each grid cell. We used three lower magnitude cutoff values: M3, M4 and M5, and averaged the results. Separate a-value grids were calculated for each zone. For each a-value grid point, the number of events ≥ M0 was calculated, and the grids for each region were summed to give country-wide coverage of the number events ≥ M0. Kernel density algorithms were used to calculate smoothed seismicity density for each input data set. In regions with longer completeness intervals and hence higher densities of events (SEA, SWA, SA and NWA), a correlation distance of 100 km was applied. Further details of the Risk Frontiers model are described in Hall et al. (2007). The site is located within the South Australia zone. Both the AUS5 source model and the Risk Frontiers source model assumed a maximum earthquake magnitude of Mw 7.5 throughout Australia.

We consider that both the AUS5 (Brown and Gibson, 2004) and the Risk Frontiers (Hall et al., 2007) models are equally viable alternative models of spatially distributed earthquake activity, so we use both of them in order to represent uncertainty in how that seismicity occurs. We use the active fault model described in Table 1 in conjunction with both of the distributed earthquake source models described above.

4. Probabilistic Seismic Hazard Calculations

We performed a probabilistic seismic hazard analysis for a site located about 0.7 km from the Crystal Brook fault. In recent years, considerable work has been devoted to characterizing earthquake ground motions in Australia for use in seismic hazard analyses. However, no response spectral ground motion models have been developed for Australia to date. Accordingly, we selected ground motion models from other regions that are considered to be potentially applicable in Australia. We expect the ground motion characteristics at the site are intermediate between those for the western United States and eastern United States. Accordingly, we have given them equal weight. The four NGA models for the WUS, described further below, were each given the same weight (0.125), or a total weight of 0.5, and the Toro model was given a weight of 0.5. We excluded the contributions of earthquakes having magnitudes smaller than 5, because we consider that the ground motions of such small earthquakes have insignificant damage potential.

The hazard curves for spectral acceleration at a period of 0.2 seconds, deaggregated by source, are shown in Figure 2. The grey hazard curve, which lies above all the others, is the sum of all of the individual contributions. One set of contributions comes from the three individual faults – these are shown by the dark blue and black lines having relatively large contributions and relatively gentle slopes. The other set of contributions comes from spatially distributed seismic sources – these have relatively steep slopes, and only two are relatively large. The fault sources are shown with full weight, but the distributed sources are shown with half weight, because there are two equally weighted distributed source models. One is the Risk Frontiers model (number 22), shown by the brown curve, which is large because it is combined in a single curve. The other is the AUS5 model, which is broken down into curves from its component source zones. The largest of these is from the Flinders Ranges source zone, shown in light blue. If the AUS5 curves were summed together, they would result in a hazard curve like the Risk Frontiers curve.

At return periods of 10,000 years and longer, the largest contribution to the hazard comes from the Crystal Brook fault, which is the closest fault to the site. There are also significant but smaller contributions from the other two active fault segments. The spatially distributed sources also contribute to the hazard at 10,000 year return period.

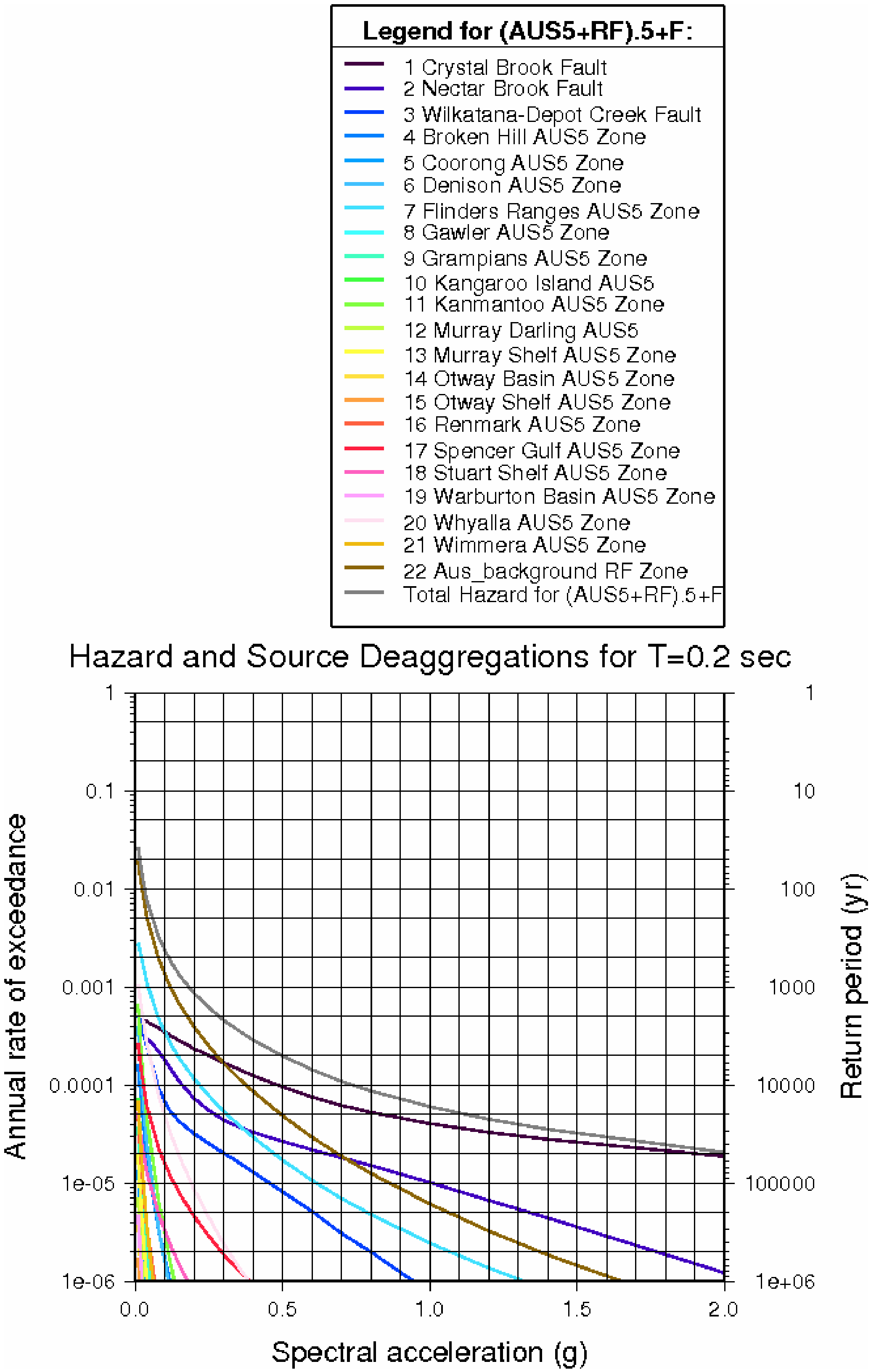

Figure 2. Disaggregation of the hazard curve by faults and source zones for spectral acceleration at 0.2 seconds period.

At a return period of 475 years, the hazard contributions from the active fault sources and the distributed seismicity sources are approximately equal. The spatially distributed sources dominate the seismic hazard at return periods shorter than 475 years.

Figure 3 compares the hazard for the AUS5 source model, the Risk Frontiers source model, and the average of these two models for a response spectral periods of 0.2 seconds. The hazard estimates of the two models at a return period of 10,000 years are in fairly close agreement, with the RF model values about 10% higher than those of the AUS5 model. At a return period of 500 years, the RF values are almost twice as large as the AUS5 values. This may be due to the fact that earthquakes were removed from the Flinders Ranges source zone by SRC and placed onto the identified faults system, whereas in the Risk Frontiers model, the active faults were superimposed on the spatially smoothed seismicity without any depletion of it.

We examined the disaggregation of the hazard by earthquake magnitude and distance. Distant earthquakes of moderate and small earthquakes contribute a significant part of the hazard at a return period of 475 years, but the hazard is increasingly dominated by smaller earthquakes at closer distances as the return period increases to 10,000 years. At this return period, the hazard at short periods is dominated by small local earthquakes, but for 1 second period, the hazard is dominated by larger earthquakes, and there is a significant contribution from large earthquakes on the identified active faults near the site.

5. Conclusions

The objective of this paper is to assess the contribution of slip rate information on mapped active faults to seismic hazards at a near fault site in the Central Flinders Ranges. Two categories of earthquake sources were used to represent the seismic hazard in the region. The first consists of active faults, and uses estimates of fault slip rate to quantify the seismic activity rate on the faults. We used newly available information from Quigley and Sandiford (2006) to characterize these active faults. The second earthquake source category consists of distributed seismicity. For this category, we used two alternative models, the AUS5 model (Brown and Gibson, 2004) and one from Risk Frontiers (Hall et al., 2007). Each of these models was used in conjunction with the new active fault model.

At return periods of 10,000 years and longer, the largest hazard comes the Crystal Brook fault. There are also significant but smaller contributions from the other two active fault segments. Thus identification of active faults and estimation of their slip rates are important for reliable estimation of ground motion hazards at long return periods, for example for critical structures such as dams located at near fault sites. The spatially distributed sources also contribute to the hazard at 10,000 year return period.

At a return period of 475 years, the hazard contributions from the active fault sources and the distributed seismicity sources are approximately equal. Thus identification of active faults and estimation of their slip rates is still important at short return periods, for example for ordinary structures located at near fault sites. The spatially distributed sources dominate the seismic hazard at return periods shorter than 475 years.

These conclusions pertain to faults with slip rates of about 0.15 mm/yr and recurrence intervals of about 25,000 years between large earthquakes. For more active faults, the accurate representation of active fault sources would become important for shorter ground motion return periods.

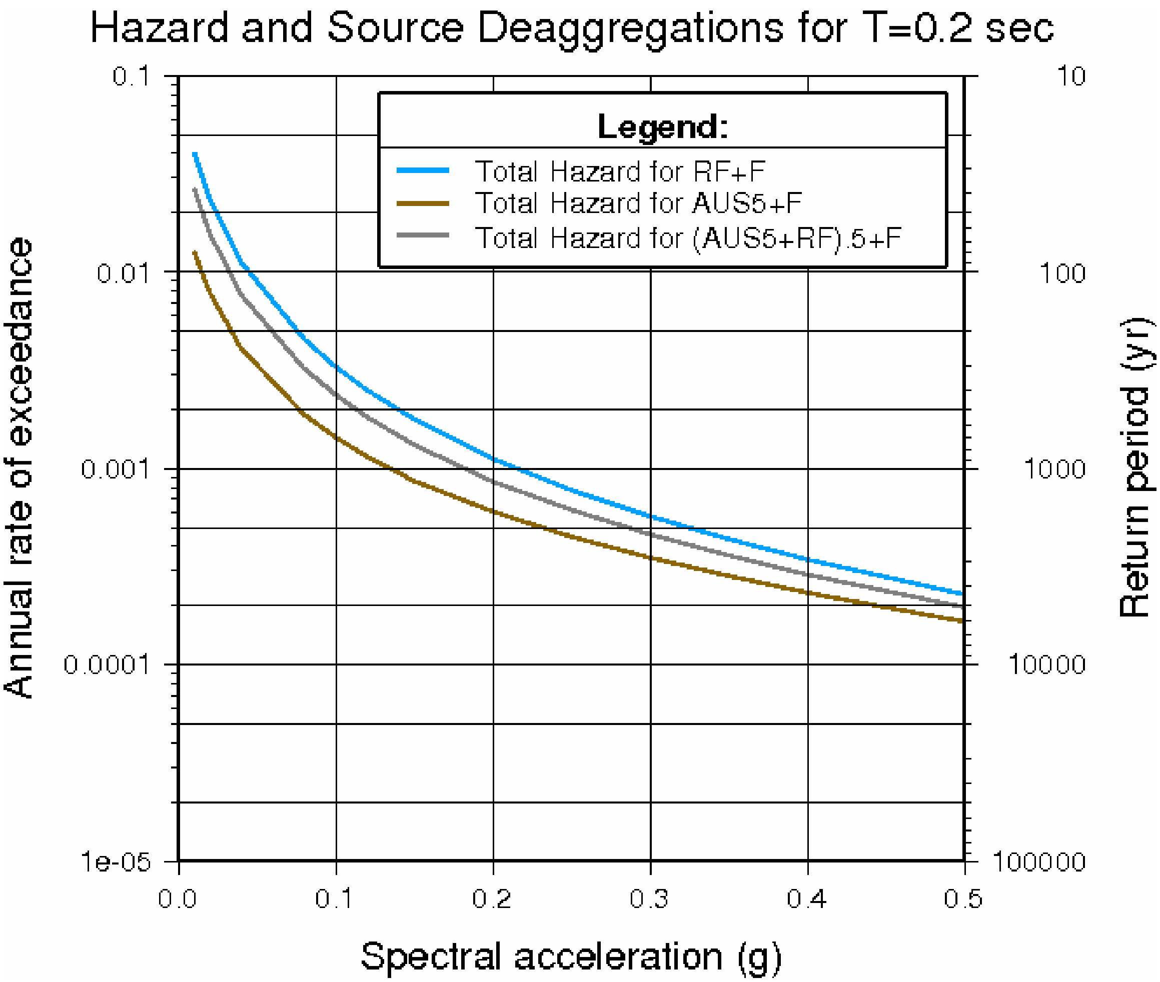

Figure 3. Hazard curves for 0.2 seconds for the two source models and the average of the two source models.

6. Acknowledgments

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