Response to Reviewer #2 João Fonseca

We greatly appreciate the reviewer’s insightful comments and have revised our manuscript, nhess-2022-46, entitled, “Quantifying the probability and uncertainty of multiple-structure rupture and recurrence intervals in Taiwan,” accordingly. Below, we have quoted the comments in italics and provided our detailed responses. All the changes are underlined in the revised manuscript.

The authors apply an analytical procedure inspired in Chan et al. (2020), which stems from the notion that when two faults interact each one gives part of its slip rate to the multiple-rupture process, while retaining the remaining slip rate to its individual-rupture process. Starting from this basic notion – the “partitioned slip rates” of Chan et al. (2020) - the authors use Kanamori’s (1977) definition of moment magnitude, the definition of seismic moment, Wells and Coppersmith’s (1994) scaling relations of moment magnitude with rupture area and the Gutenberg-Richter relation to obtain return periods for multiple ruptures and for individual ruptures on each fault. Key to the authors' reasoning is their assumption that the slip rate of each fault is partitioned between individual and multiple ruptures according to a “partitioned rate” given by their equations 10 and 11, which include "the magnitude of the multiple-structure rupture” (line 135) and “the displacement of the multiple-rupture structure” (line 136). This terminology reflects the fact (not explained in the manuscript) that the catalog used in the study considers characteristic ruptures only. The expression for C ifeatures the b-value of the Gutenberg-Richter relation. The authors present the expression for C as a logical conclusion of the Gutenberg-Richter relation, although I was not able to follow that logic. I was able to trace the definition of the partitioned rate C to Chan et al. (2020), but there too it was introduced without an explanation.

I replied this comment through three aspects, algorithm description, scaling relation, and assumption of characteristic ruptures, detailed below.

To clearly describe our algorithm for evaluating the recurrence interval of multiple-structure ruptures, we first introduced the slip rate partitioned to individual structure ruptures (equations 8 and 9), followed by the obtained partitioned rates (equations 10 and 11). By combining them, the slip rate partitioned to the multiple-structure rupture from the original structures could be obtained (described in lines 122-140).

Although the scaling relations proposed by Wells and Coppersmith (1994) have been questioned by many modern models, especially for large megathrusts, Wang et al. (2016^{b}) concluded a similar maximal magnitude of each seismogenic structure estimated from the relations of Wells and Coppersmith (1994) and Yen and Ma (2011), obtained from regressions of the rupture parameters of the earthquakes mainly from the Taiwan orogenic belt. Besides, to validate the sensitivity of our procedure to scaling, we implemented alternative relationships proposed by Yen and Ma (2011). Based on this relation, recurrence intervals for each multiple-structure rupture pairs were evaluated (Table 5). Comparing these with those obtained by Wells and Coppersmith's relations, shorter recurrence intervals were obtained, especially for those with larger magnitude. These results can be attributed to a smaller average displacement obtained for a large event that led to a shorter recurrence interval for the multiple-structure rupture (based on equation 17). We provided more detailed descriptions in lines 214-223, 292-298.

The estimate of the multiple-rupture displacement is formally correct, albeit highly convoluted. But the estimate of the multiple-rupture slip rate through a sum defies logic, in my view (why sum slip rates interesting separate faults?) Also, as pointed out above, each parcel relies on a coefficient that was not sufficiently explained.

To clearly describe our algorithm for evaluating the recurrence interval of multiple-structure ruptures, we have modified the manuscript to first introduce the slip rate partitioned to individual structure ruptures (equations 8 and 9), followed by the obtained partitioned rates (equations 10 and 11). By combining them, the slip rate partitioned to the multiple-structure rupture from the original structures can be obtained (described in lines 122-140).

The estimate of the multiple-rupture slip rate through a sum is based on the assumption that the slip of an earthquake is equal to the cumulative slip during an interseismic period. Since the slip of a multiple-structure rupture is the result of contributions from different structures, we sum the slip rates contributed from the individual structures.

In section 3.2 the authors enlarge their approach to include more than two faults in interaction, increasing the complexity while inheriting the obscurity from the previous section.

Earthquakes could be attributed to multiple (more than three) structures, for example, the 2010 El Mayor-Cucapah, US, earthquake; the 2016 Mw7.8 Kaikōura, New Zealand, earthquake. The procedure we proposed in Section 3.2 could quantify the return period of these earthquakes.

In sections 3.3 and 4, the authors discuss some implications of their analysis for seismic hazard. Around line 245, the authors conclude that the possibility of multiple-rupture earthquakes reduces the hazard at the shorter return periods while increasing it at longer return periods. In line 255, the authors observe that "structures that pair with several cases of multiple-structure ruptures might be difficult to rupture solely". These observations are so clearly at odds with empirical evidence – which points to single-

fault rupture as the dominant contributor to hazard – that they should be regarded as indicating flaws of the approach.

The description mentioned here is based on the comparison between models with and without multiple-structure ruptures. That is, the return period of a seismogenic structure could be longer if a part of its coupling rate will contribute to the multiple-structure rupture. Note that based on our procedure, a shorter return period is expected for a rupture on one individual structure than for a multiple-structure rupture. For example, we obtained a return period of 6,640 and 11,953 years for the Hsinchu fault and multiple-structure rupture of the Hukou fault and Hsinchu fault, respectively.

The authors base their approach on a simplified view of stress transfer between faults: they ignore dynamic effects, pore-fluid effects and – surprisingly in view of published evidence – restrict the range of stress transfer to 5km. Although the title promised a quantification of the uncertainties, very little is done to quantify the errors that derive from such simplifications. In line 263 the authors state that their approach is a physics-based one. Unfortunatelly, it seems to have strayed strongly from the geological reality of earthquake generation. The authors recognize, to their credit, that the "analysis could be further improved through better understanding seismogenic structures" (line 278). I would take this conclusion even further and say that the analysis needs to be reformulated starting with a better understanding of seismogenic processes. For example, exploring empirical evidence of the occurrence and characteristics of multiple-rupture earthquakes in the available databases, in order to be able to subject their model to a reality check.

We followed the reviewer's comment and included some more discussion on various physics-based components, including effective coefficient of friction (Table 6, lines 259-267), rake angle rotation (Table 8, lines 282-285), stress threshold of ΔCFS (Table

3, lines 89-94, 268-272), and distance threshold (Tables 3 and 7, lines 89-94, 268-272, 273-281). Note that we explained our model without implementing a poroelastic assumption, since previous studies (e.g., Chan and Stain, 2009) concluded that the differences in their results were trivial for assuming reasonable values of Skempton's coefficients (in between 0.5 and 0.9) and dry friction (0.75). Our approach indicated various rupture pairs and quantified uncertainties. These outcomes could be incorporated into a probabilistic seismic hazard assessment through a logic tree.

In the present stage of development, I regret to conclude that I don't consider this research ready for publication.

We appreciate the reviewer's very helpful comments. We hope the adjustments we have made accordingly to the manuscript meet the standards of *Natural Hazards and Earth System Sciences* and have made the manuscript to now ready for publication.