Response to Reviewer #1 Jack Williams

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.

1.) Description of model

The key innovation of this study is described in Section 3.1 where it is outlined how the area and slip rate (i.e., a moment rate) of two different seismogenic structures can be combined with a G-R relationship to determine the recurrence interval of an earthquake that ruptures both structures. As far as I can tell, there is nothing inherently wrong with the approach itself, however, I have several recommendations for how the presentation of this model could be improved.

We appreciate the reviewer's very helpful recommendations. We considered the reviewer's comments and responded in the following.

Immediately after equations 8 and 9 (Line 129), the meaning D_{L1} *(original L1 slip rate measurement) is given, but it is* D_{L1}' *(slip rate for L1 single structure events) that is used in these equations. I would also present the equations for C1 (partitioning coefficient between* D_{L1+L2}^{L1} *and* D_{L1}'*, currently eqs. 10 and 11) and* D_{L1}' *(currently eqs. 12 and 13) before the equation for* D_{L1+L2}^{L1} *(slip rate of L1 in L1+L2 events) given that you need these parameters to calculate* D_{L1+L2}^{L1}*.*

To clearly describe our algorithm for evaluating 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 can be obtained (described in lines 123-140).

I appreciate that the authors use the Hsinhua and Houchiali faults to provide an example of how their workflow is applied. However, showing the application of each equation to each structure in the text can get repetitive. I would suggest using a table to illustrate these equations, with a column for each structure. Another table could also be used for description of the model where >2 structures are considered (i.e., the example of the Chiayi, Meishan, and Tainan structures in Section 3.2).

In the previous manuscript, this example is provided to demonstrate the procedure of the workflow. To simplify the description of the calculation, this example has been removed.

When using the examples from the TEM, the values are provided to a high, and probably unjustified level of specificity (e.g. slip rates to 0.01 mm/yr, source areas to 0.01 km2, recurrence intervals to 1 year). I suggest rounding these values to a level appropriate with the uncertainty of this analysis.

We followed the reviewer's comment and revised Table 1 accordingly. Now the slip rate and slip area are rounded to one decimal place and the nearest whole number, respectively. Note that we keep recurrence intervals to 1 year, since some structures (e.g., the Milun fault) obtain short recurrence intervals (<100 years).

Finally, the Wells and Coppersmith (1994) scaling relationships are increasingly out of date given that we now have nearly 30 more years' worth of observed earthquakes to refine these relationships. I would recommend that either a more up to date set of scaling relationships is used (e.g., Leonard 2010, Thingbaijam et al 2017), or a sensitivity analysis is made to see if using the updated scaling relationships changes the model outcomes.

To validate the sensitivity of our procedure to scaling, we also implemented alternative relationships proposed by Yen and Ma (2011), who investigated the rupture parameters of the earthquakes mainly from the Taiwan orogenic belt. 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). Note that 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 similar maximal magnitude of each seismogenic structure estimated from the relations of Wells and Coppersmith (1994) and Yen and Ma (2011). We provided more detailed descriptions in lines 214-223, 292-298.

Multi-structure earthquakes are considered here only in terms of static Coulomb stress triggering between neighbouring faults. However, it is worth acknowledging in Section 4.2 that multi-structure earthquakes may also be generated by dynamic stress triggering from seismic waves (e.g., Brodsky and van der Elst 2014, Ulrich et al 2018). I think this may what is being discussed at Line 280 (?), though note the reference is to a manuscript (Jiao et al 2020) that was not accepted for publication.

We followed the reviewer's comment and indicated dynamic models could also constrain the behaviors of multiple-structure ruptures (lines 242-245). Note that the paper by Jiao et al. has been published in 2022.

A key assumption in this study is that the magnitude-frequency distribution (MFD) of events along a single multi-structure systems follow a G-R scaling. Although that is certainly possible, one could also argue that at the scale of a single multi-structure system, the MFD follows a characteristic shape (Youngs and Coppersmith 1984; Hecker et al 2013; Stirling and Zungia 2017), or that the MFD is neither characteristic nor G-R (Geist and Parsons 2019; Page et al 2021). In either case, a deviation from a G-R scaling will affect the recurrence intervals calculated through this model.

We are aware of the importance of the magnitude-frequency distribution (MFD) on a single-structure rupture, and the MFD could be in various forms, including the Gutenberg-Richter law and the characteristic earthquake model. In this study, we evaluated the rupture recurrence interval as the ratio of slip of a characteristic earthquake (with maximum magnitude of the structure) and slip rate based on the assumption proposed by the TEM seismogenic structure database and the TEM PSHA2020. Note that this factor could be replaced by other magnitude-frequency distributions since the recurrence interval of the multiple-structure rupture in our procedure is based on slip rate partitioned from individual structure ruptures (shown as equations 8-9, 14, 18, and 20). We provided more detailed descriptions in lines 101-104, 299-307.

This model should also be discussed in the context of other studies that have attempted to incorporate multi-structure ruptures in PSHA. For example, there are many studies that divide mapped multi-structure systems into smaller sub-fault scale segments, and then essentially allow ruptures to 'float' across theses smaller segments in such a way that they fit a regional MFD target (Field et al 2014; 2021; Chartier et al 2019; Geist and Parsons 2019). These studies are therefore distinct from the model described here, which is quite prescriptive about the number of configurations that structures in the TEM can rupture in (i.e., as single or multi-structure events only, and no events may be smaller than a single structure). It would benefit this study if the pros and cons of these different techniques could be discussed in Section 4.3.

Based on the assumption of the TEM PSHA2020, every rupture on a seismogenic structure results in a characteristic earthquake (with maximum magnitude of the structure), that is, small earthquakes (with magnitude smaller than the maximum magnitude of the structure) are attributed to shallow background sources. Following this assumption, we did not consider ruptures on small segments of a structure.

Minor Comments

Lines 7-21: The abstract does not mention that this study is using faults incorporated into the Taiwan Earthquake Model to perform this analysis. Suggest revise, Line 11 could be revised to:

'……the probability of Coulomb stress triggering between seismogenic structures included in the Taiwan Earthquake Model.'

We followed the reviewer's comment and revised the text accordingly.

Lines 64-68: What value is used for the effective coefficient of friction (µ') in the Coulomb stress modelling?

We first assumed a fixed μ' of 0.4. To quantify deviation on determining multiple-rupture pairs, we further considered μ'=0.2 and 0.5, the boundaries of its reasonable range determined from focal mechanisms in Taiwan. Considering the stress threshold of ΔCFS$\geq$0.1 bar and a distance threshold of 5 km, the potential paired structures were identified (Table 6). The results suggest slight differences within the reasonable effective friction coefficient (lines 54-56, 259-267).

Line 115: These scaling relationships between magnitude and rupture area are presumably from Wells and Coppersmith (1994)? If so, they should be cited as such (though also see major comment #1)

We followed the reviewer's comment and cited the reference accordingly.

Line 144: Replace 'integrating' with 'combining,' to avoid any connotations that you are actually performing an integration in these equations.

We followed the reviewer's comment and revised the text accordingly.

Lines 220-221 (and 335): When referring to the Kaikōura earthquake, reference should be made to Hamling et al (2017). This is the original reference to this event and written by authors who made the primary observations of this multi-fault earthquake.

We followed the reviewer's comment and cited the reference accordingly.

Line 258: I think there is a typo here for describing the numeric value if the Hukou and Hsinchu fault recurrence intervals as '4.4 and 5.3'?

We have revised the text as "their recurrence intervals become 4.4 and 5.3 times, respectively, longer than the cases without considering multiple-structure ruptures" (lines 212-213).

Figures: Figure 1 presents only a generic case of Coulomb stress changes around a fault. I would recommend also including a figure to show an example of this stress modelling from faults in the TEM. Maybe using the example of faults that are described further in Section 3.1?

This figure has been removed.