# Reply to the comments of the Reviewer #2

*A: We thank the Reviewer for a positive review of the manuscript, his/her valuable comments. We respond hereafter to the specific comments of the Reviewer and point out, how we would tackle the raised issues in the revised manuscript.*

General comments:

[*] I suggest you include a model uncertainty factor in the MCS

*A: This is not quite clear to us what sort of the model uncertainty factor is meant here to be used in the Monte Carlo simulation. So far, we have considered the uncertainty in the geometrical and geotechnical dike parameters by taking into account their moments and typical probability distributions available in the literature. Considering the model (structure) uncertainty requires alternative model formulations i.e. different equations, which are not available in our case. Thus, we do not see, how we can consider model structure uncertainty unless the reviewer means something different under model uncertainty factor.*

[*] I think you need to consider more frequently occurring water levels, not just the ones with very high return periods. The more frequent occurring water levels have higher likelihood of occurring in combination with an earthquake event.

*A: Thanks for this comment, which goes in the same direction with the Reviewer #1. Indeed, smaller flood events are more likely, thus the probability of the coincidence with earthquakes would be higher. In terms of risk (probability x damage), the damage from small floods is however smaller. In any case, this is a valid comment, but the probabilities of floods/flood scenarios will be considered in a subsequent analysis, where we plan to integrate the entire flood and earthquake risk in a Monte Carlo analysis. In this subsequent study, the here developed fragility curves will be used for assessment of dike failures and subsequent inundation. We shall consider also scenarios with smaller return periods than 100. We shall relax this statement in the manuscript and mentioned return periods of 50 or 20 years.*

[*] Please write out in more detail how you get to failure probabilities. I get the feeling you multiply annual flood probabilities (T=200 means p=0.005) with annual PGA probabilities. This is not allowed, which can be seen from the fact that the product has the unit year^-2, which has no meaning.

If that is the case, the method is incorrect. You need to take into account that if in year Y both a flood event and an earthquake event occur, it is more likely that they occur at different times in the year than that they happen at the same time. This needs to be taken into account in the computation. This strongly decreases the failure probability.

Additionally, you need to take into account the recovery (repair) time of the dike after an earthquake. This increases the failure probability.

It appears you did not take these factors into account. Apologies if you have, but in that case I propose you elaborate more on this

[*] I feel this paper should at least do one complete risk computation. Suggesting that it is "reasobale to think that the combination leads to higher risks", as you do near the end of the paper, is not doing the rest of the paper justice. And it should not be that much extra worrk.

Furthermore, your whole introduction is about how important it is to consider the combination of the two hazards (which I agree with). Then the least I expect is a comparison of failure probabilities of [a] a flood risk analysis, [b] an earthquake risk analysis and [c] a combined risk analysis

*A: We thank the reviewer for pointing for the two above comments. We would prefer to address them together as they partly relate to each other. In fact, we envisage a subsequent study doing a full-scale multi-risk assessment of "simultaneous" occurrence of floods and earthquakes by running a coupled 1D-2D hydrodynamic model for the Rhine and considering dike breaches (by the way not only due to liquefaction, but also due to overtopping and piping). As partly proposed by the reviewer we intend to compare the marginal change in flood risk due to multi-hazard load in relation to single-flood risk curve. This is, however, much more work contrary to the expectation of the Reviewer since the hydrodynamic and dike breach simulations are complex, run also probabilistically in Monte Carlo simulation and the variety of results need to be evaluated from various perspectives (see e.g. Vorogushyn et al., 2010). We therefore abstain from merging this research with the here proposed methodological development on the derivation of fragility curves for liquefaction in one manuscript. In the analysis we consider the "simultaneous" occurrence of floods and earthquakes if the latter occurs within 30 days period – a typical duration of a flood wave on the Rhine. For the subsequent analysis, we have developed synthetic flood hydrographs of 30 days duration. We shall modify the equation (3) to make this point clear. Yes, the Reviewer is right that multiplying the annual probabilities of earthquake and floods is wrong. Assuming the time window of 30 days, we undertake several assumptions. First, the probability of liquefaction depends on the development of the water table within a dike during the onset of the flood event. We treat this probability as uniform for the sake of brevity, otherwise we would need to carry out the dynamic modelling of water front propagation, which is an additional serious complication. Second, during the flood event no dike repair actions are taken into account, which might reduce the overall flood risk. This effect is however very difficult to estimate. The assumption of "no repair" during an entire year would be very unrealistic as mentioned by the reviewer. Such an assumption for the 30 days period might be reasonable, but in any case this represents the conservative risk assessment.*

*Minor and editorial remarks: the Reviewer #2 proposed several editing changes in the text using the change track mode in the pdf file. We shall carefully address them all in the revised manuscript, but we do not summarize them here in this reply letter.*

**Refrences:**

*Vorogushyn, S., Merz, B., Lindenschmidt, K.-E., and Apel H. (2010): A new methodology for flood hazard assessment considering dike breaches, Water Resources Research, 46 (8), 2010, doi:10.1029/2009WR008475*