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Discussions

Interactive comment on "Tsunami evacuation plans for future megathrust earthquakes in Padang, Indonesia considering stochastic earthquake scenarios" *by* Ario Muhammad et al.

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We highly appreciated the constructive comments given by the reviewer 2 for our submitted manuscript. The following are detail response of the reviewers comments. C1: When dealing with building vertical evacuation, is it also considered the possibility of building collapses due to the earthquake itself? Such major earthquake often have considerable effects on edifice stability and integrity.

Answer:

Agreed. Considering the reviewer recommendations, we have re-assessed the vul-

nerability of tsunami evacuation shelters (TES) considering both seismic and tsunami loadings. A new section Section 2.2. vulnerability assessment of tsunami evacuation shelters has been added in the methodology section of the revised manuscript to explain the shaking and tsunami vulnerability assessments. The results from these assessments are also included in the results and discussion section. To facilitate the communications with the editor and the reviewers, a summary of the TES vulnerability assessment procedure and the assessments results are detailed in the supplement file (i.e. NHESS-2017-75-suplement.pdf). It is an extensive response, so the PDF attachment is needed.

C2: Explain the choice of the magnitudes (8.5-8.75-9) for the stochastic simulations. Does it mean that for lower values no tsunamis are generated?

Answer:

We used Mw 8.5 as the minimum scenario magnitude in our study because the tsunami hazard produced from the magnitudes less than this level, e.g. Mw 8.25 and Mw 8.0, are considered to be relatively small (below 1 m wave height in the coastal areas; McCloskey et al., 2008; Muhammad et al., 2016). From Figure 1 in this document, we see the relatively minor effects in Padang due to Mw 8.5 tsunami . It shows the tsunami wave heights at three stations, i.e. Tabing, Purus, and Teluk Bayur, at a depth of 5 m. The median wave heights produced from 100 tsunamigenic scenarios are about 1 m which is small and will have minor impact on land (see Muhammad et al., 2016). The impact becomes more insignificant if we consider the Mw 8.25 scenario. Therefore, we choose the Mw 8.5 as the minimum magnitude scenarios.

For the maximum scenarios (i.e. Mw 9.0), it was selected based on the existing research studies from geodetic, paleogeodetic, and paleotsunami investigations. These studies indicated that the accumulated slip in the Mentawai segment of the Sunda subduction zone may generate the tsunamigenic earthquake with the magnitude ranging from Mw 8.8 to Mw 9.0 (Zachariasen et al., 1999; Natawidjaja et al., 2006; Sieh et al., 2008). We did not consider a extreme scenario like the 2004 Indian Ocean tsunami (which is very long) because the tsunami sediment records in North of Sumatra indicated that the recurrence time of destructive tsunamis from the Aceh-Andaman sources is at least 600 years in comparison to ∼200 years for the Mentawai segment (Natawidjaja et al., 2006; Monecke et al., 2008) and hence, the Mw 9.0 consider to be more likely than the scenarios such as the 2004 Indian Ocean tsunami. However, such long ruptures are a possibility in the Mentawai segment – we simply did not consider such an assumption.

Based on Reviewer's recommendations, we have added to the methodology section of the revised manuscript the following descriptions regarding the choice of our magnitude scenarios in the revised manucript as follows:

The use of magnitude Mw 8.5 as the minimum scenario is because the tsunami hazard produced from the magnitude below this level, e.g. Mw 8.25 and Mw 8.0 is relatively small (below 1 m wave height in the coastal areas; see Muhammad et al., 2016). The maximum magnitude scenario (Mw 9.0) is based on the recommendation from geodetic, paleogeodetic, and paleotsunami studies confirmed that the accumulated slip in the Mentawai segment of the Sunda subduction zone may generate the tsunamigenic earthquake with the magnitude range from Mw 8.8 to Mw 9.0 (Zachariasen et al., 1999; Natawidjaja et al., 2006; Sieh et al., 2008).

C3: Provide some more details on tsunami numerical simulation (finite difference? Inundation with moving boundary?)

Answer:

Agreed. We have added the detail regarding numerical simulation in the revised manuscript which are the following:

A finite-difference method incorporating staggered leap-frog scheme is adopted to solve the governing equations (Goto et al., 1997). In addition, in Goto et al. (1997)

code the moving boundary approach developed by Iwasako and Mano (1797) is used for inundation modelling.

C4: The paper refers to the 1797 event when reconstructing the fault geometry: for sure, it is one of the most reasonable mechanism, but it is not the only one and different events with different characteristics can produce different tsunamis.

Answer: Agreed. The geodetic, paleogeodetic, and paleotsunami studies confirmed that two significant tsunamigenic events occurred in 1797 and 1833 events (Natawidjaja et al., 2006; Sieh et al., 2008; Philibosian et al., 2014) and hence, the scenario may not only follow the 1797 event. We absolutely aware that the possible event from the 1833 source may occur as well. Moreover, a significant tsunamigenic event generated from any point in the Sunda subduction zone is also possible. However, current literature has suggested that the tsunamigenic event from the 1797 scenario may produce the most devastating effects in Padang areas (Borrero et al., 2006; Natawidjaja et al., 2006; McCloskey et al., 2008; Muhari et al., 2010,2011; Griffin et al., 2016). The historical record regarding the effects of the 1833 and the 1797 events in Padang also confirmed that the 1797 produce more damage than the 1833 event (Natawidjaja et al., 2006). Subsequently, since we consider the worst scenario for the future event, the 1797 event is chosen.

We have a short description regarding the reason of choosing this scenarios in the revised manuscript: Note that the 1797 event was found to produce more significant tsunami impacts in Padang than the 1833 event (Borrero et al., 2006; Natawidjaja et al., 2006; McCloskey et al., 2008). Consequently, in this study, the 1797 asperity zone is adopted to generate the future stochastic earthquake source models.

C5: The probabilistic approach surely presents some advantages with respect to the deterministic one, taking into consideration also different possible features that the second cannot contemplate, but suffers from some main limitation: first of all, it can be applied only in coastal areas with a detailed knowledge of the seismic structures and a populated seismic and tsunami catalogue. Please mitigate in general the sentences concerning the probabilistic vs deterministic approaches, highlighting also the problems of the first. The text repeatedly reminds that the deterministic approach produces oversimplification, but this is true for over-simplified applications of this methodology, not meaning that the whole procedure is wrong.

Agreed. We have added the following texts to outline this problem:

In the past, two types of earthquake source scenarios have been mainly considered to develop tsunami risk mitigation plans in Padang: deterministic scenarios (Borrero et al., 2006; Schlurmann et al., 2010; Muhari et al., 2010, 2011) and probabilistic scenarios (McCloskey et al., 2008; Griffin et al., 2016). These two methods have both advantages and disadvantages. For instance, the deterministic approach is more communicable to the authorities for developing post-hazard recovery and mitigation plans (McGuire, 2001). However, Implementation of deterministic scenarios may oversimplify the tsunami hazards and risks, leading to inaccurate mitigation plans (Mueller et al., 2014; Griffin et al., 2015). On the other hand, the probabilistic scenario approach requires the proper consideration of regional earthquake characteristics, including uncertainties in size of the rupture plane and spatial heterogeneity of earthquake slip. Therefore, extensive and detail data regarding the regional seismological characteristics are essential to adopt the probabilistic scenario.

Answer:

C6: How do you expect authorities should use such probabilistic results? Can a decision-makers deal with scientific concepts like probability?

Answer:

The work in this manuscript is a preliminary step to implement into more practical implementation for disaster risk reduction. The following work that may be carried out in the near future regarding our methodology is Probabilistic Tsunami Hazard Analy-

sis (PTHA) in Padang, Indonesia considering the stochastic tsunami simulation. The PTHA may produce the tsunami hazard maps showing the annual probability of experiencing a tsunami with a specific tsunami intensity hazard, e.g. height, depth and velocity. Through this approach, we may effectively use to communicate with the authorities for improving the tsunami mitigation systems in Padang, Indonesia. Moreover, several preliminary works regarding the PTHA using the stochastic tsunami simulation have been successfully implemented in Japan and Mexico (De Risi et al., 2016 and Mori et al., 2017) and hence, it is possible to produce such results.

C7: Figures 9 to 12: what is intended for "inundation height in the coastal line"? Is it the height of the wave on the coast, before land flooding? Or is it the maximum inland elevation reached by the water? In the first case it should be addressed as "maximum wave height on the coast", in the second it is simply "run-up height". Please clarify this point.

Answer:

It is the maximum wave height on the coast. We have corrected in the revised manuscript: instead of only the inundation height along the coastal, we have changed to the maximum wave height on the coast.

C8: Line 338: is the Padang population referred to an average value? Does this esteem take into account tourist period, seasonal variation and so on?

Answer:

It is only the average value of Padang population without considering other condition, e.g. tourist period.

Subsequently, we have added these texts into the revised manuscript:

Noted that, the capacity (in persons) of the TES calculated in this study only consider the average population number of Padang excluding other conditions, e.g. tourist period and seasonal variation.

C9: TECHNICAL CORRECTIONS

(1) Instead of using the word "depth" when referring the water column, use "flow depth". Agreed. It has been changed accordingly. (2) Line 43: Mueller et al paper year is 2015, not 2014 (ok in references) (3) Line 78: "improve" instead of "improving" Line 160: "basing" instead of "based" (4) 372-3: ". . . to estimate the tsunami hazard level in Padang adopting three magnitude scenarios (Mw 8.5, Mw 8.75, and Mw 9.0) (5) " FIGURES 3 to 8: use different palettes for the different figures, addressing different quantities (slip, land elevation, elevation difference, inundation-tsunami depth), it can create confusion.

Answer: Agreed. The technical corrections have been included in the revised manuscripts.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-75/nhess-2017-75-AC2-supplement.pdf

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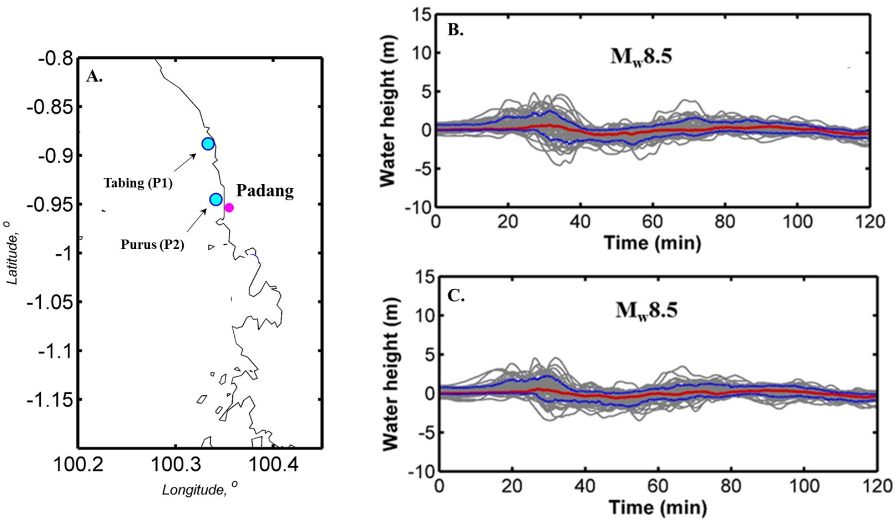

Fig. 1. Tsunami wave height profile near coastal line of Padang: (A) site location. (B). Tabing (P1) station). (C). Purus (P2) station.