

The impact of topography on seismic amplification during the 2005 Kashmir Earthquake

Saad Khan^{*1,2}, Mark van der Meijde², Harald van der Werff², Muhammad Shafique³

¹Department of Geology, Bacha Khan University Charsadda

²Faculty of Geo-information and Earth Observation (ITC), University of Twente

³National Center of Excellence in Geology (NCEG), University of Peshawar

*Correspondence email: saadkhan@bkuc.edu.pk

We are thankful for the reviewer's comments and have taken care of addressing all of them. Below you will find replies to each comment individually, and references to the locations in the manuscript where the suggestions have been incorporated (underlined where changes/improvements are made).

Reviewer 2		
Comment (Major)	Reply	Manuscript Reference
Authors calculated the topographic effect using 3-D model once with topographic effect and once without topographic effect. The topographic effect should include the effects due to the present valleys on the ground motion, thus the selected plain surface should be free of the valleys' effects. Authors should provide the characteristics of their selected datum.	<p>We consider the zero elevation surface to be the datum. It is sampled with a 270 m mesh resolution and DEM resolution. This zero elevation surface removes any impact of valleys.</p> <p>It should be noted that a choice for any other datum (e.g. the valley bottom) would actually give the same output, as long as that the reference datum is below the (deepest) valley floor to ensure that all topography and geomorphological characteristics are included in the model with topography and excluded in the model without.</p> <p>This additional information about the datum has been added to the manuscript for clarification.</p>	Line 34 on page 3. Lines 1-3 on page 4.
The paper lacks the description of both depth of the earthquake and depth of the valleys to be sure that these valleys are really shadow zones preventing seismic waves from reaching high areas on the other sides. Detailed description of low areas is required.	We agree that this can be explained in more detail, the present description can possibly lead to confusion. Information about the depth of earthquake and deep valleys causing shadow effects is now provided in the manuscript.	Lines 31 on page 2. Lines 31-32 on page 5. Lines 1-2 on page 6. Lines 27-31 on page 8.
Many factors can amplify ground motion. To have accurate correlation between the topography and the observed damage in the	We agree with this comment; it is now better clarified in the manuscript.	We added an explanation to lines 25-32 on page 6 and lines 1-2 on page 7.

region, all other factors should be neutralized in advance to be sure about the effectiveness of topographical contribution. This is not clear in the current manuscript.		
It seems that authors modeled the seismic source as a point, which is totally unreliable, as the rupture direction could be an effective parameter at short distances. Details on the fault rupture direction, rupture length, and observed surface displacement should be provided.	<p>Details on the fault rupture direction, rupture length, and observed surface displacement has been provided along with justification for using a point source in the manuscript. Previous studies (e.g. Raghukanth, 2008) have shown that there is a strong correlation with the CMT location (i.e. point of maximum energy release) and damage patterns. We also believe that this maximum energy release, and thereby the max PGA/PGV/PGD will be the dominant trigger for the occurrence of landslides, so amplification in relation to CMT location is assumed to be the most dominant direction for amplification related damage and secondary hazards.</p> <p>We have added text on this issue in the discussion session of the paper.</p>	<p>Lines 4-9 on page 4. Lines 30-32 on page 6.</p>
As the earthquake is relatively recent, field observations of such earthquake should be available. Therefore, verification of the calculated values with the recorded observation should be provided to be sure about the accuracy of the used model (including input uncertainty) and the results. Numerical modelling alone is not enough.	<p>Unfortunately, the region has a poorly developed seismic network and therefore we do not have any recorded seismic data to compare with. The only verifiable data from the field we could access is the damage data (Shafique 2012) and landslide data (Shafique 2008) collected right after the event (E.g. Figure 1 and Figure 2 here in this document); Apart from this, there are some COSI-Corr (Leprince et al., 2008; Avouac et al., 2006) and InSAR based studies (Pathier et al., 2006; Wang et al., 2007) to compare with. COSI-Corr can only measure horizontal component while InSAR only vertical component of displacement. All these comparisons have been discussed and cited in the manuscript, and we have found that our amplitudes are of the same order as theirs.</p> <p>Any limitations resulting from this drawback are, however, clearly discussed in detail in discussion section. We realize that this leaves maybe some discussion on the final interpretation, which we extensively describe in the discussion section. But on the other</p>	<p>Lines 20-35 on page 4. Lines 1-2 on page 5. Lines 7-20 on page 7. Lines 27-35 on page 7. Lines 1-22 on page 8.</p>

	hand, this is the only possible way to understand better the effects of earthquakes in remote areas.	
Comment (Minor)		
Use the past tense in the abstract section.	Done	Abstract
Rewrite line No. 10 in page 1, modifying the position of the word "and" and removing the word regolith as it is a part of the site specific geology.	Done	Line 10 on page 1.
Line 20 page 1. Seismic risk cannot be mitigated. Use risk instead.	You are right, we changed the phrasing to: <i>Incorporating the topographic impact on seismic response is thus important for seismic shaking prediction, seismic hazard assessment and risk mitigation.</i>	Changed in line 19-20 on page 1.
Page 3, line 9, elastic waves.	Done	Line 8 on page 3.
Page 3, lines 30 and 31, use velocity instead of speed.	Done	Lines 29-30 on page 3.
Title of section 4 should be Results.	Done	Line 3 on page 5.
Page 5, lines 12 and 13, give possible reasons.	Done	Line 25 on page 7.
Page 6, line 18, found instead of find.	Done	Line 5 on page 7.



Figure 1: Impact of topography on building damages during 2005 Kashmir earthquake in Balakot (Pakistan). It can be observed that the building on ridge are completely destroyed while those at the ridge toe are still intact, despite the fact that building material and construction was similar.



Figure 2: Impact of topography on building damages during 2005 Kashmir earthquake in Muzaffarabad (Pakistan). Same observation as in Figure 1.