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Discussions

Interactive comment on "Earthquake-induced ground failures in Italy from a reviewed database" *by* S. Martino et al.

S. Martino et al.

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The Authors wish to thank the two referees for his useful suggestions and contributions provided during the on-line Discussion for improving this paper. In the following, we report the replies to the referee and the actions that we're going to carry on in the reviewed version of the manuscript and of the figures, according to all the suggestions given. Moreover, the Authors decided to improve the completeness of the submitted study by including and discussing the most recent data referred to the last 2012 Emilia earthquake; the reason of this choice is due to the fact that, during the time of the on-line Discussion, some papers were already published by other Authors on the induced ground effects due to the Emilia earthquake. Moreover accordingly to the aforemen-

tioned data addition and to provide more explanation on the topics suggested by the two referees, in the reviewed version of the paper the Author: 1) will upgrade all the graphs and figures which report percentage and statistics; 2) will add two more figures (already proposed in the following reply document to the referees) ; 3) will insert a "Discussion" section before the "Conclusion" one.

Reply to Referee W. Murphy's comments and Actions taken

Comment 1. The epicentral errors listed in the work by Pospichl (1985) can be substantial. For older events this can be as large as 200km. The authors correctly mention the lack of surface rupture data which means that using this to constrain location is generally impossible. While I recognise that such large errors relate to the pre-1400(ish) events even the Calabrian earthquake sequence errors are of the order of 25-50km and when the authors start talking about modal epicentral distances to landslides of 10-20km (page 2053, line 12) and up to 30 km (p2053, line 19) it means that such errors become substantial for the older events. I recognise that these may relate to younger and more precisely constrained earthquakes but this really needs some discussion. Reply 1. Epicentral errors as large as hundreds kilometers were reported by Postpischl for the PFG earthquake catalogue (1985), a catalogue compiled on the basis of previous historical catalogues (Bonito 1691, Baratta 1901, Cavasino 1931-1935, Iaccarino 1968-1971, Carrozzo 1973, Peronaci 1973, ENEL 1979). In 1990's the Italian seismological community launched a program to provide a reliable earthquake catalogue for the seismic hazard map of Italy, resulting in the NT4.1 earthquake catalogue (1997) and the following CPTI series of earthquake catalogues (1999, 2004 and 2011: http://emidius.mi.ingv.it/CPTI/). Starting from the former CPTI99 catalogue, historical epicenters were determined using the Boxer method by Gasperini et al. 1999 (BSSA-89-1-94) and the method by Bakun and Wentworth 1997 (BSSA-87-1502). Nevertheless, a formal error for macroseismic determination of epicentral coordinates cannot be computed, depending, from time to time, on the number of felt points and on their azimuth and spatial distribution. Therefore, as stated by the Boxer's Authors (BSSA-

1999, appendix 1) “Unfortunately the uncertainty associated with the algorithm cannot be estimated a priori nor a posteriori, but only assessed in terms of internal consistency of the full procedure. For this purpose, the sum of square residuals between the coordinates of the selected localities and the coordinates of the inferred epicenter are calculated for every earthquake. This parameter cannot be directly used as an estimate of the uncertainty in the location because it also reflects the size of the mezoseismal area, however, it may be used as a parameter controlling the reliability of the estimate: for example, a large value may implicitly indicate the existence of highly anomalous intensity points or the incompleteness of data distribution (e.g., when the epicenter falls offshore or in a sparsely populated area).” As far as the location error of the ground effects is concerned, in the database an error is assigned to each location on the basis of the spatial extent of the site area according to the following ranking scheme: 1) Site (GPS measurement): no error or negligible 2) Locality (area extent of square kilometers): average error 1 km 3) Town (area extent of tens of square kilometers): average error 3 km 4) City (area extent of hundreds of square kilometers): average error 10 km 5) Province (area extent of thousands of square kilometers), comparable to US county or England shire: average error 30 km In Italy, locality, town, city and province refer to places of progressively increasing importance from the territorial and administrative point of view. Of course, the elder the effect, the higher the error (e.g., site error is assigned only to the ground effects detected after the 1990 AD). Action 1. Epicentral and ground effect location errors (as well as for magnitude) are introduced and discussed in the main text of the paper as described in the reply section above. Moreover, a new figure (Fig. 15) shows the different meaning of location error with reference to the most recent earthquake listed in the CEDIT catalogue (Emilia 2012).

Comment 2. One significant omission is data on the depth of the events in question. Looking at the distribution of seismicity in figure 7 all of the quakes listed are likely to be shallow focus. There has however been large magnitude events in the Tyrrhenian Sea associated with down dip compression of the relict subduction zone. It would be useful to comment on this as some of these have been felt (and I think some shal-

lower ones may have caused damage). It became apparent after the 22nd Feb 2011 Christchurch earthquake that even within “shallow” earthquakes, the detail of the depth is hugely significant. Reply 2. All earthquakes listed in table 1 refer to crustal earthquakes (depth less than 30 km) and most of them are shallower than 20 km. Moreover, no deep earthquake belonging to the crustal slab beneath the Southern Tyrrhenian Sea has been documented having produced ground effects (this doesn’t mean they didn’t produce, only there is no documentation about). A reliable assessment of earthquake depth is available only from the beginning of the last century, that means only for instrumentally detected earthquakes. Sure the different number of ground effects produced by the two mainshocks of the Emilia 2012 earthquakes (20 and 29 May) can have many explanations, including the different depth (6 vs. 10 km) of the two shocks though of similar magnitude (5.9 vs. 5.8) and the same focal mechanism (reverse), although other reasons including the soil compaction of the first shock could have played a significant role in the lesser ground effects produced by the second shock. Action 2. A sentence clarifying the role of the earthquake depth has been put in the main text and the available instrumentally detected depth of earthquakes has been inserted in Table 1.

Comment 3. I think the way in which the lithological data has been tied to the landslides is weak. Again I recognise the issues with the imprecision of the map sources and having tried to do this for the 1783 earthquake sequence I recognise the difficulties. I used the rather excellent set of geological maps of Calabria published by La Case per il Mezzogiorno but they were devilishly difficult to get a hold of and their coverage was incomplete. The imprecision of the map data casts significant doubt on the lithological interpretations. The authors are not blind to this, and it is discussed, but it weakens this section somewhat. Equally the precision of the landslide location is difficult – some of the sketches of landslide dammed lakes for the 1783 events helps, but this is a rare luxury when it comes to a list of ground failures. It may be that nothing can be doneabout this but why was such coarse data used? With so many uncertainties I would have thought that this was one thing to try and constrain as tightly as possible.

Reply 3. Of course, the errors in the effect location (i.e. including the landslides) cannot be negligible especially for the more ancient seismic events (as previously discussed and replied in this document) and, in this regard, the reviewed version of the paper will take into account the location error (as previously explained). Lithology was attributed referring to the center of gravity of the ground effect location taking into account the error ranking scheme reported in the reply to comment 1, above. The adoption of the most appropriate lithological map derived from the following selection criteria: 1) the geological map had to have been be officially approved; 2) it had to be available for the whole country; 2) the transposition of the geological data into the lithological data had to have followed a homogeneous approach. According to the selection criteria the most suitable lithological map resulted to be the official geological map of Italy at scale 1:250 000 edited by the Geological Survey of Italy in 2012, which is a synthesis of geological maps at scale 1:100 000 and 1:50 000, where available. In particular, the 1:50 000 maps are the most recent Italian geological maps even if not still available for the whole country, that are being realized in the framework of a project aimed to update the geological maps of Italy. This map includes also geological information and comments that are suitable for attributing the seismically-induced ground effects to the lithologies which are reported in Fig.8. Action 3. A thorough explanation of the criteria adopted for the lithological assignment to the ground effects is now provided in the main text, along with the proper references to the source maps.

Comment 4. I think surface rupture should be removed from the discussion. Some of this is either unrecorded or prone to misinterpretation, could have been offshore (e.g. slip on the Messina-Commiso fault – excuse me if this is a spelling error but I am not in a position to check this at the moment – causing the 1908 Straits of Messina earthquake) or has patterns of distributed strain which means that slip is partitioned onto multiple faults (e.g. Irpinia, 1980 – only 0.1m was noted at Piano di Pecore). Reply 4. Although surface faulting is a primary effect of fault rupture, whereas ground failures such as landslides and liquefaction are secondary effects resulting from the ground response to the seismic shaking, we have chosen to preserve this feature due to its

primary importance for the active faults recognition and the implications for the seismic hazard (e.g., surface faulting is a primary cause of site rejection in many building codes, especially in the case of critical facilities such as NPPs). As far as the Irpinia surface faulting is concerned, Pantosti and Valensise 1990 (JGR 95-B10-15319) recognized a fault scarp as high as 0.7 m (see picture below) for a distance as long as 15 km.

Action 4. We retained surface faulting even if it has been excluded from some analyses (e.g. site intensity and distance distributions).

Comment 5. What do the authors mean by “ground changes”? Is this a neotectonic effect or some form of undifferentiated slope movement? This needs to be defined. Reply 5. The term “ground change” is not referred to neotectonic evidences as this kind of information is reported in another Italian catalogue, named ITHACA and available at the web site http://www.isprambiente.gov.it/it/progetti/ithaca-catalogo-delle-faglie-capaci. In this catalogue the neotectonic evidences (where available) are directly referred to the seismogenetic faults. In the CEDIT catalogue the term “ground change” is more specifically used with reference to seismically-induced subsidence (these last one including underground collapses and/or sinkhole generation) and relevant morphological changes (i.e due to river damming, lake formation and so on). Action 5. The meaning of the term “ground change”, as used in the CEDIT catalogue, will be more clearly explained in the reviewed version of the manuscript and an explicit reference will be provided to the considered effects.

Comment 6. EMS – I think this should be European not Environmental (page 2045, line 18). I could be wrong about this and I would ask the authors to check this. Reply 6. No, the catalogue of the Earthquake Environmental Effects issued by ISPRA (http://www.eeecatalog.sinanet.apat.it/terremoti/index.php) has been aimed to support the ESI scale, the Environmental Seismic Intensity scale, that has been set up just to integrate the EMS (European Macroseismic Scale: Grunthal, 1998 http://www.gfz-potsdam.de) that doesn’t consider any environmental effect. Action 6. No action.

Comment 7. There are significant problems with trying to correlate Intensity with magnitude (page 2050, lines 9-14) as depth, duration and site conditions are all likely to affect intensity. The authors give ranges for estimated magnitudes based on intensity but I think there needs some supporting citations to support this. Reply 7. The correlation provided between magnitude and epicentral intensity (not site intensity) comes directly (with small adjustments) from the relationships provided by the CPTI04 earthquake catalogue (Working Group CPTI, 2004), thus it has been specifically calibrated for Italian earthquakes. Action 7. The proper citation has now been added to the main text and the reference list upgraded.

Comment 8. Fig 12 needs some further discussion. It has anything of up to 15% likelihood of some form of ground failure at MCS=VI but different ground failure effects are criteria for intensity classifications in addition to building response. Does this not make the discussion rather circular? Have a think about this. Reply 8. As for the building damage, site intensity is assessed not only on the basis of the ground effect (or damage degree) but also on their relative abundance. Indeed, a weak motion can produce few ground effects in those soils alone that are already close to their failure state when the earthquake occurs, opposite to a strong motion that can produce many ground effects bringing to the failure state even soils that are very stable in static conditions. Indeed, figure 12 is aimed to provide the likelihood that given a site intensity (that represents a relative measure of ground shaking) a ground effect can be produced (see reply to comment 9, below). Action 8. In figure 12 the relative frequency of each ground effect as a function of the site intensity has now been added and the probability axis renamed according to the reply to comment 9 below:

Comment 9. Figs 12 and 13 need some discussion about the methodology for the production of these. I suspect that this involves some over-interpretation of the available data but it is difficult for me to judge this without more discussion of this. The X axis scale on Fig 13 should be clearly stated as being logarithmic. Reply 9. Figs 12 and 13 make use of the Weibull distribution to compute the cumulative distributions of ground

effects as a function of site intensity and distance, respectively. Thus, figure 12 shows the probability that a ground effect can be observed at a site intensity equal to or lesser than a given value, whereas figure 13 shows the probability that a ground effect can be observed at a distance equal to or greater than a given value. They can be used to assess the reliability to observe a certain ground effect given a site intensity (assessed independently through the EMS scale, for instance) or further a given distance, even if this latter relationship is better expressed by figure 14 (see reply to comment 10, below) because depending on the earthquake magnitude, too. The X-axis of figure 13 is an ordinal scale (not a ratio scale), thus it doesn't require to specify it being logarithmic. Action 9. The meaning and use of the Weibull distributions are now clearly explained in the main text. Figure 12 has now the y-axis labeled as non-exceedance probability and also shows the frequency distribution of each category. In figure 13 the probability curves have been discarded since attenuation with distance depends on magnitude, too, and therefore better represented by relationships such as those shown in figure 14 (see reply to comment 10, below).

Comment 10. I would like to see some error bars on figure 14. Reply 10. Correct, even if: magnitude error is quite difficult to be established especially for the historical (pre-instrumental) earthquakes for the same reasons reported for the epicentral error location (see reply to comment 1, above). A crude estimate of the relationship between error and magnitude value as derived from the CPTI catalogue, shows how error tends to be inversely proportional to the magnitude value and progressively decreasing with time, due to the increase of macroseismic information. The distance error is in turn a joint function of the error in the epicentral location and the error in the ground effect location. Being impossible to quantify the former, only the latter has been considered according to the ranking scheme of the location error of ground effects reported in the reply to comment 1, above. Action 10. Figure 14 is now splitted into two figures, one for liquefaction and one for landslide, each one separating data before and after the instrumental era (since 1908 AD). This allows taking into account the greater accuracy of the most recent data with a look at the effect exerted by completeness on increasing the precision of the inferred relationships. Error bars are now shown in figure 14 along with other magnitude-distance relationships (Keefer 1984 for landslides and Galli 2000 for liquefaction) for a comparative discussion.

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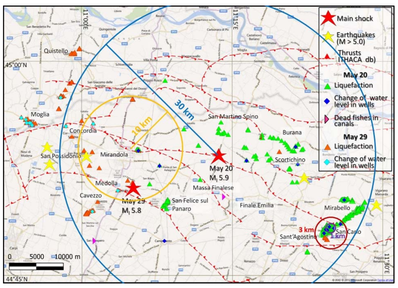

(modified from Di Manna et al., 2012 – Annals of Geophysics 55-4-697)

Fig. 1. Action 1

Fig. 2. Action 4

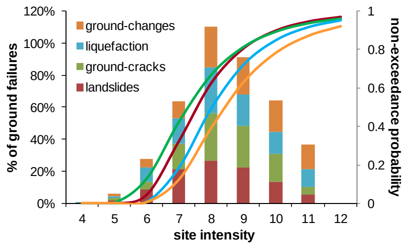

Fig. 3. Action 8

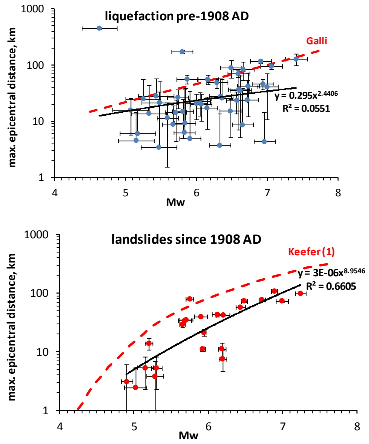

Fig. 4. Action 10