Quotation of the general comment 1: “The state of the art chapter is not as complete as it should be. Important references from the international literature are missing, namely the work in GEM, PAGER, SYNER-G, PERPETUATE etc.”

Response: Thank you for this very good suggestion. Although our focus is on building types and damage data within China, it’s always worthwhile to conduct necessary comparison with similar projects worldwide. Therefore, we checked their manuals and projects reports carefully. Comparison details are as follows:

(a) For European PERPETUATE project, its main goal was to develop European Guidelines for evaluation and mitigation of seismic risk to cultural heritage assets, applicable in the European and other Mediterranean countries. The assessment of heritage buildings requires the assessment of both architectonic and artistic assets contained in them, which needs improvement in methods of analysis and assessment procedures rather than in intervention techniques. Besides that, a verification approach in terms of displacement rather than in terms of strength is more reliable and effective for heritage building. However, the fragility we collected in this work is mainly macroseismic intensity or PGA related. Therefore, the fragility outputs are not so comparable.

(b) For European SYNER-G project, the mainly studied building types are also masonry and RC and it has highly similar focuses as to our work, namely (1) to collect existing fragility functions (2) to identify categories for grouping buildings (3) to harmonize different intensity measures and limit states. And finally, all their fragility outputs are related to PGA, with some converted from macroseismic intensity, SA related fragility functions.

    What’s more, there are only two referred damage limit states in their output, namely yielding and collapse. For instance, if three limit states are considered (LS1, LS2 and LS3), the user can decide to assign LS1 to yielding and LS3 to collapse. Otherwise, he/she can also decide to assign a mean between LS1 and LS2 to yielding limit states. Hereafter, we use LS2 and LS4 to represent the “yielding” and “collapse” damage state in SYNER-G project.

    It’s worth to note that, SYNER-G project proposed a new modular form building taxonomy, based on difference in building resisting mechanism and material, floor/roof system, height level, code level etc., which is more expandable compared with existing building taxonomies like PAGER (tailored for worldwide structures) and RISK-UE (suited to Europe).

    From our point of view, besides the epistemic and aleatory uncertainties imbedded within the standard fragility generation process itself, the conversion from intensity/SA to PGA and the simplification in damage state harmonization in SYNER-G project’s fragility outputs inevitably add extra uncertainty to the final output fragility results.

In spite of the differences in building classification, damage state harmonization between SYNER-G and our work, we plotted the fragility outputs together in Fig. 1 for masonry building type and in Fig. 2 for RC building types. Two obvious characteristics can be found in Fig. 1 and Fig. 2. Firstly, the fragility in SYNER-G project is much higher than ours, both for masonry and RC building types; Secondly, for SYNER-G RC building types, the fragility difference is very subtle for yielding damage state (LS2).

The reason for this obvious fragility difference between Chinese masonry/RC and European masonry/RC is difficult to fully examine, as aforementioned, it may due to the difference in usage of ground motion indicator (part of SYNER-G's PGA-related fragility outputs are converted from intensity, SA related fragility functions). Besides, building classification difference is difficult to accurately calibrate. Furthermore, the damage limit state harmonization in SYNER-G (only yielding and collapse damage states) makes it more difficult to compare the fragility for nominally similar building type for each damage state.

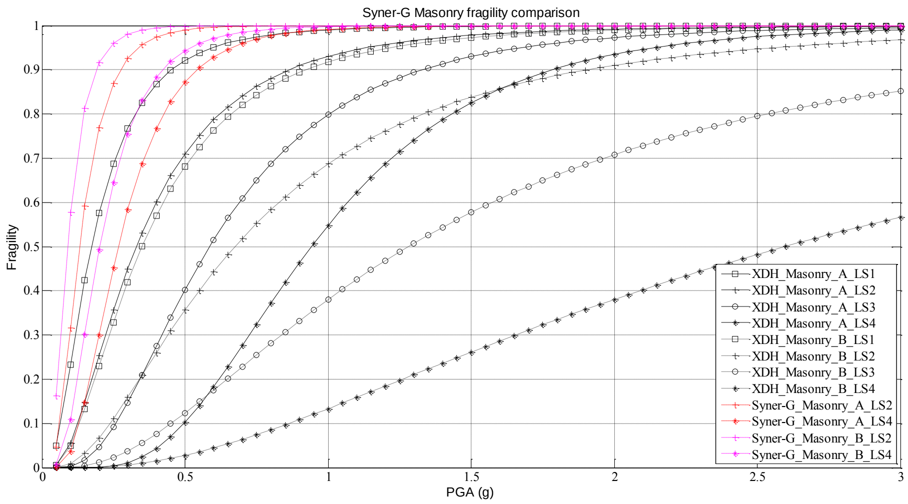

Figure 1: Fragility comparison between SYNER-G project outputs and our work for masonry building. In SYNER-G project, Masonry_A, Masonry_B refer to the low-rise, mid-rise building type, respectively; LS2 and LS4 specially refer to yielding state and collapse state, respectively.

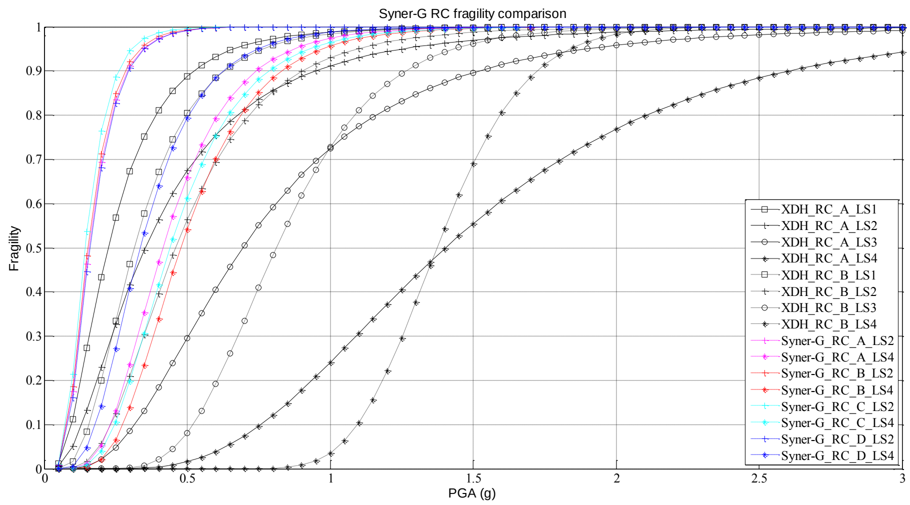

Figure 2: Fragility comparison between SYNER-G project outputs and our work for RC buildings. In SYNER-G project, RC_A, RC_B, RC_C, RC_D refer to four RC subtypes, namely RC mid-rise with moment resisting frame (RC_A), RC mid-rise with lateral load design (RC_B), RC mid-rise with bare moment resisting frame with lateral load design (RC_C), and RC mid-rise with bare non-ductile moment resisting frame with lateral load design (RC_D); LS2 and LS4 specially refer to yielding state and collapse state respectively.

(c) For US's PAGER project, it's an automated system mainly for rapidly estimating the shaking distribution, the number of people and settlements exposed to severe shaking, as well as the range of possible fatalities and economic losses. During this process, vulnerability functions are used, which are different from the fragility functions we focus on in this work. That is, vulnerability functions can be derived directly from historic damage information, or derived indirectly from fragility function using consequence functions, which describe the probability of loss given a level of performance (e.g. collapse damage state). Therefore, direct comparison between the outputs of PAGER and our fragility functions is not straightforward.

(d) For US's HAZUS project, with the vision to provide local, state and regional officials with the tools necessary to plan and stimulate efforts to reduce risk from earthquakes and to prepare for emergency response and recovery from an earthquake, HAZUS offers a series of fragility curves for typical building types based on HAZUS taxonomy. Here, we extracted the equivalent PGA related fragility curves for four typical building types (RM1M, RM2M, C1M, C2M) from HAZUS Earthquake Technical Manual (from their Table 5.16a-d) and compare them with the fragility curves we developed for masonry in Fig. 3, Fig. 4 and for RC in Fig. 5, Fig. 6.

It's worth to note that, the present HAZUS curves represent median values of equivalent-PGA fragility curves. They are based on median values of spectral displacement of the damage state of interest and an assumed demand spectrum shape that relates spectral response to PGA. As such, median values of equivalent PGA are very sensitive to the shape assumed for the demand spectrum. The reference spectrum represents ground shaking of a large-magnitude (i.e., M ≅ 7.0) western United States (WUS) earthquake for soil sites (e.g., Site Class D) at site-to-source distances of 15 km, or greater.

From Fig. 3, we can see that the order of fragility is basically as follows (given same PGA level, which building type is more "fragile"):
For damage state LS1, LS2, LS4, RM1M_Highcode<XDH_Masonry_A< RM1M_Modecode;
For damage state LS3, RM1M_Modecode<XDH_Masonry_A<RM1M_Lowcode;
For damage state LS1, LS2, LS3, LS4, XDH_Masonry_B< RM1M_Highcode.

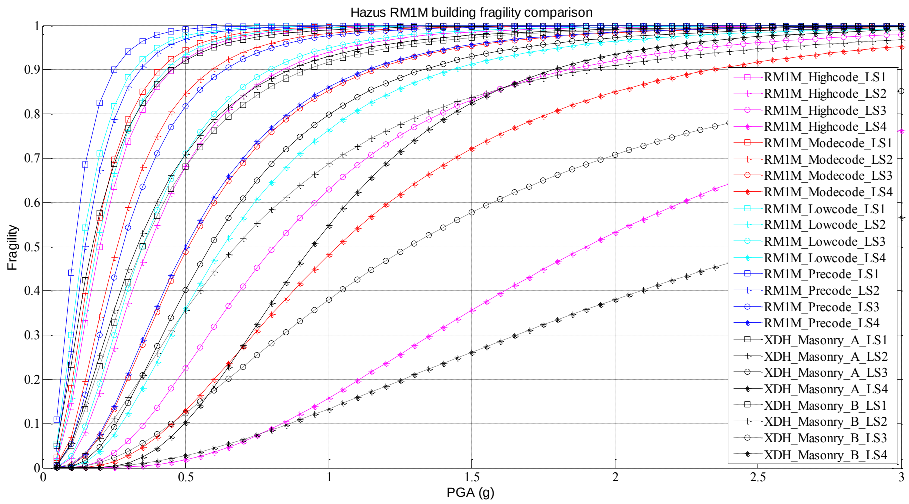

Figure 3: Fragility comparison between HAZUS RM1M building and our work for RC buildings. In HAZUS project, "RM1M" refers to Mid-rise Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms; LS1, LS2, LS3, LS4 refer to slight damage, moderate damage, extensive damage and collapse damage states.

From Fig. 4, we can see that the order of fragility is basically as follows:
For damage state LS1, LS2, XDH_Masonry_A< RM2M_Highcode;
For damage state LS3, RM2M_Highcode <XDH_Masonry_A< RM2M_Modecode;
For damage state LS4, RM2M_Modecode<XDH_Masonry_A<RM2M_Lowcode;
For damage state LS1, LS2, LS3, LS4, XDH_Masonry_B< RM2M_Highcode.

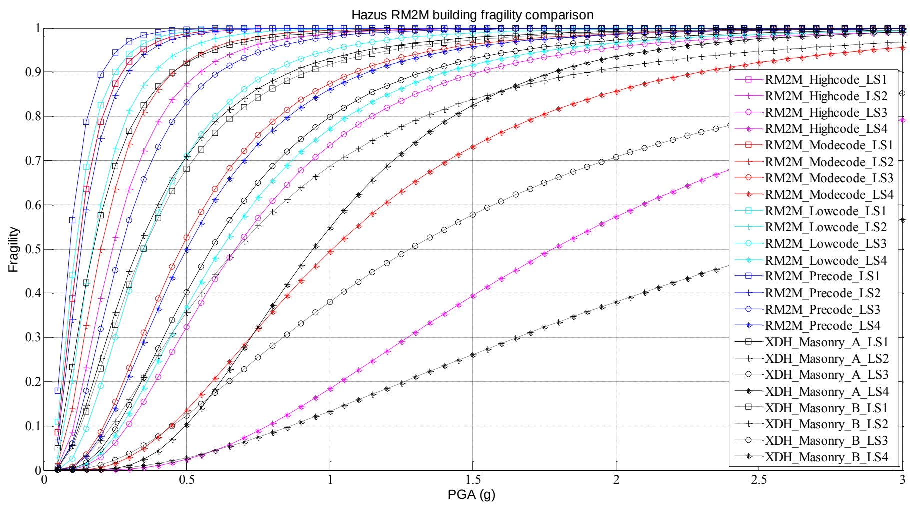

Figure 4: Fragility comparison between HAZUS RM2M building and our work for RC buildings. In HAZUS project, "RM2M" refers to Mid-rise Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms; LS1, LS2, LS3, LS4 refer to slight damage, moderate damage, extensive damage and collapse damage states.

Based on the analysis in Page 8, Line 1-17 in the manuscript, the fragility curves of LS1-LS4 of RC_A and LS4 of RC_B are not so reliable; therefore, we mainly compare the fragility curves of LS1-LS3 of RC_B with HAZUS C1M building type in Fig. 5 and C2M building type in Fig. 6.

From Fig. 5, we can see that the order of fragility is basically as follows:

For damage state LS1, LS2, XDH_RC_B<C1M_Highcode;

For damage state LS3, XDH_RC_B≈C1M_Highcode.

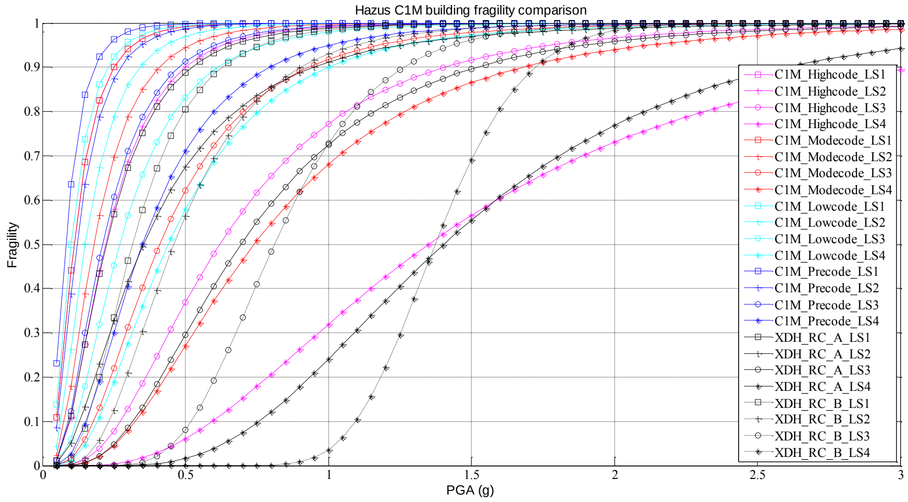

Figure 5: Fragility comparison between HAZUS C1M building and our work for RC buildings. In HAZUS project, "C1M" refers to Mid-rise Concrete Moment Frame; LS1, LS2, LS3, LS4 refer to slight damage, moderate damage, extensive damage and collapse damage states.

From Fig. 6, we can see that the order of fragility is basically as follows:

For damage state LS1, LS2, XDH_RC_B<C2M_Highcode;

For damage state LS3, XDH_RC_B≈C2M_Highcode.

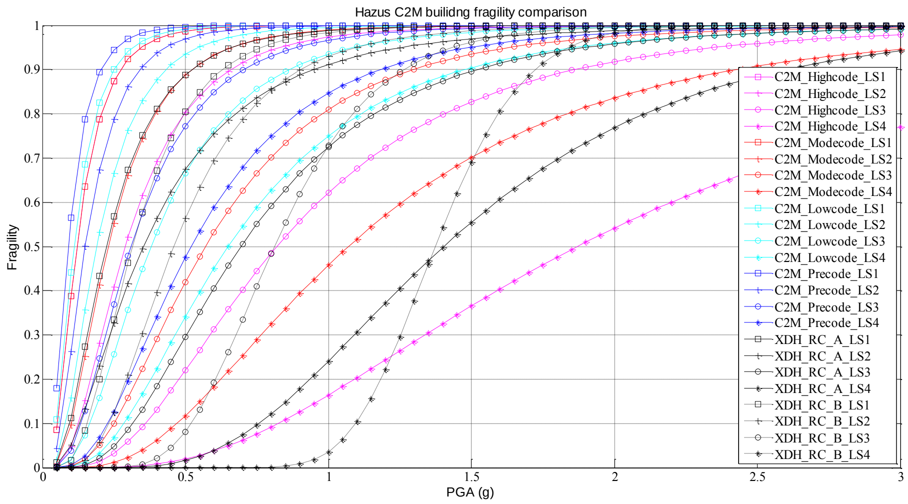

Figure 6: Fragility comparison between HAZUS C2M building and our work for RC buildings. In HAZUS project, "C2M" refers to Mid-rise Concrete Shear Walls; LS1, LS2, LS3, LS4 refer to slight damage, moderate damage, extensive damage and collapse damage states.

To summarize, due to the difference in building classification and seismic resistance level harmonization between HAZUS and our work (as we only have level A and B), it's difficult to whose "masonry" or "RC" is more "fragile" than another.

(e) For the currently undergoing global-scale GEM project, it's involved in outputs from 3 European programs: SHARE, SYNER-G and NERA. SHARE focuses on seismic hazard harmonization in Europe and covers all of Europe and the Maghreb countries, and the hazard model is developed with the OpenQuake Engine. SYNER-G partners are developing a unified methodology and tools for systemic vulnerability assessment in Europe. NERA focuses on creation of a European research infrastructure for risk assessment and mitigation.

    Besides the fragility outputs of SYNER-G project, GEM online fragility database also integrates those many fragility curves generated by HAZUS. Therefore, we don't repeat the comparison of these data. For mainland China, the fragility curves integrated in GEM database is solely from Tang et al. (2011), only for RC building and related to SA. Therefore, to avoid uncertainty introduced from converting SA to PGA, here we don't list and compare the fragility either.

Quotation of the general comment 2: "The methodologies applied in the different steps are clearly described and the reviewer has no major comment on that except that to his opinion the various uncertainties are treated, probably inevitably, in a quite simplified way. A comment on that should be useful."

Response: Thank you for specially pointing this out. We do spare quite a few efforts in charactering the uncertainty transmission from the fragility curve to the PGA-intensity relationship based on the data in the Appendix. To avoid the manuscript to appear to be too sparse and extensive, we didn't extend this uncertainty characterization process and only provide a reference uncertainty value of "0.3" in Page 9 line 9 for Eq. (5). However, for your further check, we put this methodology description in additionally uploaded file "Methodology of uncertainty transmission.pdf".
(This file is available at https://app.box.com/s/lwlqajpogxqlau72ravew4db7y47drtk)

Quotation of the general comment 3: "The classification of the buildings in only two categories and two sub classes is an over-simplification, probably a reasonable one, for sub or underdeveloped countries, but maybe not for China any more. To the reviewer's opinion if the results of this interesting and useful work, mainly considering the huge efforts made to collect and synthesize all these data, will be generalized for any building type in China, and furthermore used for risk analysis, the final outcome will be heavily biased."

Response: In our initial fragility data collection work, we actually collected fragility data for more buildings types, including soil-wood, brick-wood, brick-concrete, RC, industrial frame, stone-wood, chuandou-timber, wood, stone and soil; but analytical fragility data is only available for masonry and RC. Since another focus of our work is to explore PGA-intensity relationship using fragility as conversion, that's why finally only masonry and RC data are further used. Due to the uncertainty in the synthetization process, we agree that if more building types are to be used, the final outputs can be quite different. Here the usage of fragility as the bridge to derive intensity-PGA relationship, instead of aiming to provide a precise relationship, is more targeted at presenting a new trail to regress intensity-PGA relation.

Quotation of the general comment 4: "The accuracy of the results (fragility curves) depicted in Figures 7 (empirical) and 8 (analytical) are to the reviewer' opinion "too optimistic". The derived fragilities seem to be very low for these intensity levels, either in terms of IM or PGA and in particular for masonry structures (A or B). There are many reasons for that depending on the scatter of the data but also to the method used in particular regarding the treatment of uncertainties. The authors should compare their curves with other curves from the international literature (i.e. GEM, PAGER, SYNER-G etc). In any case they should comment on that important point."

Response: Thank you for this suggestion. We checked the fragility database of those several projects and detailed comparison can be referred to first Response to comment 1.

Quotation of the general comment 5: "According to the authors IM-PGA empirical expressions are generally region-dependent and have large scatter. This is not entirely correct. If region-dependency should mean soil conditions dependency as well, then this should be probably partially fine; but region-dependence is a much broader definition (i.e. spatial variability of ground motions etc.) and to the reviewer's opinion this simplification is a certain source of huge uncertainties. PGA values are strongly dependent on site and local soil conditions. Furthermore， the typology of buildings and their seismic quality in terms of seismic resistance is another crucial parameter, which again is practically "crushed" and downgraded in the regression analysis This is obvious in the results where the difference between the different approaches is very small. In few words the reviewer is very sceptical to the use of IM-PGA relationships in earthquake engineering and risk analysis in particular. Saying that the criticism is not made on the methodology and tools applied but on the philosophy (i.e. principles) of this methodology and the accuracy of the wished outcome."

Response: In our PGA-related analytical fragility database, the PGA parameter used actually is not the real instrumental records as used in traditional PGA-intensity relationship development method, which are collected from the same geographical range as macroseismic intensity records. Therefore, from this point of view, the regional dependence (here we mainly refer to site condition), which contributes to the scatter of traditional PGA-intensity relationship, is not a source of uncertainty in our relationship. Besides that, as aforementioned, the combination and synthetization of fragility from different building types makes the final PGA-intensity relationship become a very general one and not representative of any individual building type.

We'll further emphasis the limitation in potential application of our relationship.

Quotation of the general comment 6: "To the reviewer's opinion if the results of the present work i.e. the IM-PGA tables, should be used as recommended values for IM-PGA ranges in China, it should be clearly stated that this is just for preliminary evaluations and the scatter may be very important."

Response: Yes. Due to the scattering in originally collected fragility datasets and simplification in using median fragility to derive PGA-intensity relation, the potential application of the preliminary PGA-intensity relationship should be with caution. For engineering purposes, it is best to use regional relationships wherever available, as they are better calibrated for the areas in which they apply.

Quotation of the general comment: "In table7 (Recommendedintensity-PGA relationship in China (GB17742-2008/1980)) there is an obvious error in the suggested value for Intensity X."

Response: We appreciate your careful check very much. We'll rectify this from 0.1 to 1.0.

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