

Review article: Physical Vulnerability Database for Critical Infrastructure Multi-Hazard Risk Assessments – A systematic review and data collection

This manuscript provides a systematic literature review on - and accompanying extensive database of - fragility and vulnerability curves for different types of critical infrastructure and hazards. I commend the authors for their significant efforts in creating this review and developing the associated database that will undoubtedly prove helpful for various risk modelling applications. Furthermore, I believe that the manuscript would be of interest to readers of this journal. However, I provide below a number of comments that I think should be addressed before the manuscript could be published.

Main comments:

1. While I appreciate the authors' efforts in developing such a comprehensive database and review, there are certain (sometimes questionable) limitations that need to be more explicit in the text, as well as some ambiguity on its scope that needs to be removed:
 - a. The review does not mention multi-hazard vulnerability curves. These curves either account for one intensity measure per hazard or assume a state-dependent format that tracks the evolving vulnerability of the asset as hazard events occur. (Please see Section 2.1.4 of <https://doi.org/10.1016/j.ijdr.2022.103365> for a more thorough description of these types of curves). Given the ever-increasing focus in the field of risk analysis on multi-hazards, this seems like quite a substantial oversight and I would like the authors to at least justify this decision.
 - b. It is not clear from the review that single-hazard vulnerability curves may also use more than one intensity measure. (For instance, see: <https://doi.org/10.1016/j.res.2020.106971>, which presents flood fragility functions that make use of both flood depth and flood duration information). It is not clear whether such vector-valued approaches were considered in this review.
 - c. The review does not explicitly cover damage-to-loss (or, more broadly, "damage-to-impact") models. (Please see Section 2.1.3 of <https://doi.org/10.1016/j.ijdr.2022.103365> or <https://doi.org/10.1002/eqe.2687>, for instance). These types of models act as a crucial link between fragility and vulnerability curves (as implied by equation 1), and therefore it should be made clear that they are outside the scope of this specific review. (I understand from line 181 that information on these models is made available in the database if they are included within the original source of a fragility/vulnerability curve, but they are not reviewed explicitly as a separate entity).
 - d. It is important to note that while vulnerability curves can be used to capture losses for individual critical infrastructure *components* (nodes or assets), they are not the only ingredient necessary to quantify losses and damage for distributed critical infrastructure *systems*. The vulnerability analysis also needs to account for interdependencies between the multiple components that underly the system as well as the individual functionalities of each component, for instance.
 - e. When it comes to curves for buildings in particular (under the health and education category), it is not clear what the review covers in terms of building-

level versus component-level resolution and structural versus non-structural damages.

- f. It is surprising that there is no section devoted to the definition of each type of critical infrastructure considered in the review (i.e., what types of underlying components are assumed to comprise each), to clarify the scope of the various subcomponents intended to be captured by the database. Currently, it is not clear whether the absence of some infrastructure subcomponents from Section 3 is due to the lack of availability of curves or whether these types of subcomponents were deemed to be outside the scope of the review.
 - g. I may have missed it, but I could not find any details on the years of publication covered by the review.
2. There is various terminology used throughout the manuscript that requires more accurate, rigorous treatment:
- a. Line 25: the phrase “at risk to natural hazards” does not make sense, since a hazard is itself a fundamental underlying component of risk
 - b. Line 40: To avoid confusion around the differences between fragility and vulnerability functions, the output of a vulnerability function should be referred to as “loss” rather than “damage”. This would avoid confusion between the terms “damage factor” (that is used to describe the output of a vulnerability curve at line 39) and “damage state” (that is used when describing the output of a fragility function at line 41). It is important to clearly distinguish between the terms “damage” and “loss”; they are not equivalent. Fragility functions provide a prediction of a binary outcome related to some binary failure criterion (e.g., collapse/no collapse, breach/no breach, breakage/no breakage), whereas vulnerability curves quantify some continuous consequence outcome (e.g., repair cost, repair time).
 - c. It is important to specify that the term “cost” as used in this context is not limited to monetary cost; vulnerability curves can be used to measure repair time, for instance . It would be more appropriate to use a term like “consequence”.
 - d. I think it is important that vulnerability “data” is not conflated with vulnerability “curves” – data are used to fit the curves, thus the two are not equivalent. Furthermore, I would suggest describing them as “curves” or “functions” (e.g., as at line 57) but not both.
 - e. Line 122: It is not clear to me what is meant by the term “risk indicator”.
3. For a systematic review, I find Section 3 to be surprisingly disorganised. There does not appear to be a consistent structure used for any of the subsections. For instance:
- a. A definition of transport is provided in Section 3.1.2, but no such definition is provided for energy in Section 3.1.1.
 - b. The terms “damage function” (line 236) and “depth-damage function” (line 244) are both used in Section 3.1.2, but it is not clear what the distinction between these two functions is.
 - c. There does not seem to be any systematic division between discussions on vulnerability curves and fragility curves in any given subsection
 - d. The types of components covered for each critical infrastructure are not consistent across the different hazards. For instance, telecommunications covers broad “communication systems” for flooding, whereas it covers

“monopile towers”, “central offices” and “broadcasting stations” for earthquakes.

- e. Studies and their associated curves are described to various degrees of detail, even within a given subsection. For instance in Section 3.1.1, we are told that a fragility curves for certain transmission towers were developed “using a reliability analysis based on kriging”, yet in the same section we are told that another study “evaluated the fragility of a transmission tower-line system” with no more details provided.

The lack of organisation and consistency across Section 3 makes the section difficult to read and digest. I would suggest that the section could be improved through the use of tables that summarise pertinent information on the curves for different critical infrastructure and hazards (e.g., subcomponent that it relates to, country of origin, method of development, types of losses/damage captured, hazard intensity measure, other important specific notes) in a consistent manner. Furthermore, it would be useful if each subsection was consistently divided into a separate discussions on fragility curves and vulnerability curves.

More minor comments:

1. Given the nature of the paper, I think the abstract could benefit from an explicit definition of the term “vulnerability”
2. Equation 1: It seems a bit strange to use “E” to denote a probability when this variable is normally reserved for referring to expected values. I would suggest that the authors either formulate equation 1 as an expected (or mean) value (using “E”) or a probability of exceedance using “p” instead of “E”.
3. I believe that the term “intensity measure” is more common in the literature than “intensity metric” and the authors might want to consider switching to the former.
4. Line 43-45: I think the statement made here about fragility versus vulnerability curves incorrectly implies that vulnerability curves are not used extensively in earthquake risk analyses (e.g., see <https://doi.org/10.1193/011816EQS015DP>)
5. Line 55: “limited represented” - fix the grammar here
6. Line 160: Are the cost values country specific? If so, this should be made clear in the database.
7. Section 2.2: Please clarify if the database contains information on the mathematical form of each curve and the associated parameters.
8. The conclusions section mentions that the authors encourage more contributions to the database “for a wide range of building types”. But this would not necessarily comply with the critical infrastructure focus of the database.
9. The DOI provided for the database in the preprint did not work when I clicked on it. I used the DOI provided in the manuscript review centre instead, so I am not sure if there is any error with the address provided in the preprint.