UNCERTAINTY AND QUALITY RATING IN ANALYTICAL VULNERABILITY ASSESSMENT

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ABSTRACT

Fragility curves represent a major component of seismic risk and vulnerability assessment of buildings and infrastructure facilities. A recently conducted extensive literature review under the framework of developing the "*GEM Guide for Selecting of Existing Analytical Fragility Curves and Compilation of the Database*", shows that there is a wealth of existing analytically derived fragility curves that can be used for future applications. However, the main challenge in using these curves is how to identify and, if necessary, combine suitable fragility curves from a pool of curves with different characteristics and, often unknown, reliability. The present article introduces a rating system that has been developed following detail review and critique of the various methodologies on the derivation of analytical fragility curves that have been generated in the past two decades. The main scope is to provide guidance, either in choosing suitable and robust existing fragility curves or in generating new fragility curves. The quality rating system rates the quality of a curve according to the effect that various parameters, simulation procedures and assumptions on the reliability of fragility curve. It also assists and steers potential analysts towards a better identification and quantification of expected uncertainties throughout the process.

INTRODUCTION

Fragility curves are important components of seismic risk and vulnerability assessments of buildings and infrastructure. A recently conducted extensive literature review under the framework of developing the "*GEM Guide for Selecting of Existing Analytical Fragility Curves and Compilation of the Database*" (D'Ayala and Meslem, 2012), shows that there is a wealth of existing analytically derived fragility curves. However, the main challenge in using these curves for future applications is how to identify and, if necessary, combine (Rossetto et al., 2014) suitable fragility curves from a pool of curves with different characteristics and, often unknown, reliability. In fact, it has been noticed that a number of academics as well as engineers have attempted to construct fragility curves based on simplified assumptions in order to reduce data gathering and calculation efforts. Such simplifications may greatly decrease the reliability of the obtained curves (Fig. 1).

The main scope of this article is to define a quality rating framework, able to provide guidance in choosing suitable and robust analytically derived fragility curves available in literature when performing risk assessment at regional level. In this respect, the first part of the article reviews the extensive literature available on the derivation of fragility curves in the past decades, considering the salient steps of the process of construction of a fragility curve; the choice of the basic relationship

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between damage and intensity measure, the characterization of the damage, the choice of the analytical approach to determine the structural response and the implications for data quality, the identification and quantification of uncertainties throughout the process. For each of these steps indications are given on the merits of the various choices.

On the basis of this review, the second part of the article presents a rational quality rating system based on four attributes: representativeness, data quality, rationality, and quality of documentation. For each attribute a number of criteria are identified as being critical to the selection of fragility curves for a given building typology and for each criteria the influential parameters defining the quality are listed. A quality rating is defined by considering three qualitative classes, i.e. High, Medium and Low. For each attribute the overall rating is determined as the rating most commonly assigned to the criteria within the attribute.

REVIEW OF EXISTING LITERATURE ON THE DERIVATION OF ANALYTICAL FRAGILITY CURVES

The process of analytical vulnerability assessment is essentially based on two components (Fig. 1), i.e. the ground motion intensity parameter-to-structural response functions, $P(SR/IM)$, and the structural response-to-damage state functions, $P(DS/SR)$. These functions are the products of two independent processes, i.e. the *Structural Analysis* and the *Damage Analysis*. Different methodologies for the derivation of analytical fragility curves are available in the literature, covering different building typologies and locations worldwide (D'Ayala et al, 2014). Analytical fragility curves are derived using a variety of approaches and assumptions that employ diverse structural modelling and analysis techniques, damage models, damage scales and numbers of damage states. A range of sampling methods has also been applied to parameters of the structural models and seismic demand to account for uncertainties and intrinsic differences observable in the building stock and its response to seismic loading. It can therefore be difficult to compare and appraise existing analytical curves, even when derived for the same structural class. In this context, the literature on analytical fragility curves is reviewed in the context of the main factors thought to influence the form of the analytical functions, their quality and reliability. These factors, grouped in categories that represent the steps of the fragility curves construction process, are shown in Table 1.
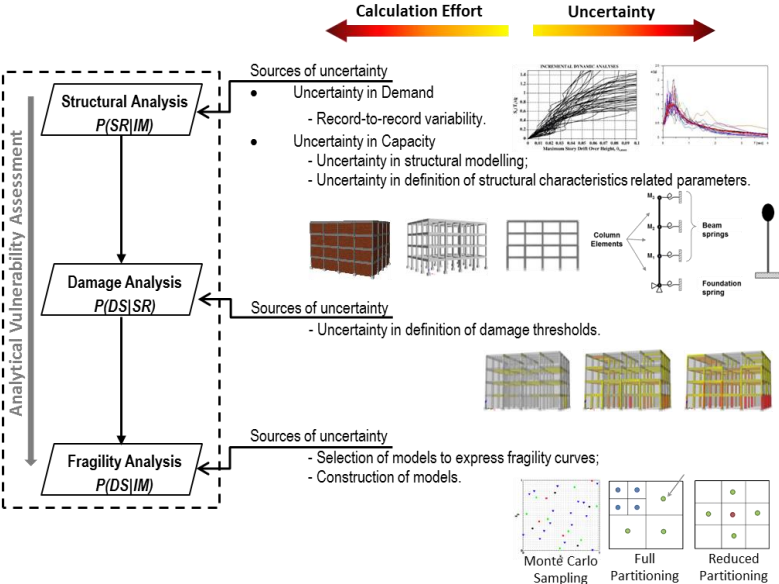

Figure 1. Process of analytical vulnerability assessment with respect to calculation effort and uncertainties

Table 1. Categories of factors determining the reliability of analytical fragility curves

Factors	Description
Intensity measure	Hazard parameters; e.g.: PGA, $S_a(T)$, $S_d(T)$
Damage characterization	Damage model: Damage Index
	Damage Indicators
Class definition and sample size	Sample size (multiple buildings; randomisation of parameters; single building)
	Sampling method; e.g. Monte Carlo, Latin hypercube, random
Data quality	Analysis Type: e.g. Nonlinear Dynamic (NDA) or Static (NSA), Simplified Method (SM))
	Numerical modelling (completeness of model, definition of material properties, configuration and geometry)
	Seismic Demand (real ground motion records, code based spectra)
Derivation method	Treatment of uncertainty (sources of uncertainty, quantification)
	Fitting methods for fragility curves

Intensity Measure

In literature, a variety of intensity measure types have been used to define fragility curves. Peak ground acceleration (PGA), Spectral acceleration ($S_a(T)$) and spectral displacement ($S_d(T)$) are the most commonly used Intensity Measure Types in fragility functions. S_a and S_d are most easily correlated with the structural response and hence are considered as the most suitable variable for damage functions, especially in the case of capacity spectrum methods (CSM) and incremental dynamic analysis (IDA) methods. However, the relatively modest availability of Ground Motion Prediction Equations (GMPEs) at regional level and over the whole spectrum of magnitudes for S_d, limits its use in practice. Methods based on limit state analysis and simplified methods tend to use PGA, also for ease of correlation with empirical vulnerability assessment studies.

Damage Characteristics

Several procedures have been implemented in literature for the characterization and determination of damage thresholds; this by determining the damage state at elemental level, then obtaining damage at global level as a progression of local damage through several elements (ASCE, 2000; CEN, 2004), by using some conservative simplified formula (ASCE 2000; Kappos et al, 2006), or by using damage models which have been developed on the basis of post-earthquake damage observation. Damage indices are numerous and vary in terms of proposed formulation and type of correlation, and they can be categorized as either local or global damage indices. However, when using damage indices attention should be paid to the consistency between the damage model/damage index and the level of complexity of the structural model, the type of analysis, and the damage indicator to which the damage level is correlated to. With regard to the damage indicator, inter-storey drift (ISD) and top drift (TD) are the most relevant parameters to ensure the robustness in the derivation of analytical fragility curves. For frame structures, ISD is able to capture soft-storey modes of failure of irregular or non-seismically designed buildings; for wall structures or structures which are subjected to overturning failures, TD might be a more appropriate parameter.

Class Definition and Sampling Size

As fragility curves are usually derived with reference to building class, the attribution of a given building or set of buildings within a building stock under assessment to the correct building class is fundamental when choosing the appropriate fragility function. With respect to sample data, the larger the number of buildings considered as being representative for a class in the generation of fragility curves, the more accurate is the confidence interval in relation to the representativeness of the simulation in respect to the real variability within a given typology in the region or site of interest. However, this will depend on which parameters have been varied, and how and whether such variation correctly represents the conditions of the analysed building stock. Ideally, the size and distribution of a sample representing a class at a given site should be based on evidence collected from an exposure study of the site. The approaches followed in literature to define a class and the sample size of the simulations significantly vary from study to study: studies that consider non-engineered buildings tend

to be based on an accurate survey of a relatively large number of buildings (e.g. D'Ayala et al. 1997, Erberik 2008, D'Ayala & Paganoni 2010). Alternatively when the building stock under analysis is more standardized, typically "average" characteristics are chosen and a full statistical approach with randomization of the parameters is employed with the use of either a full Monte Carlo or a Latin Hypercube sampling technique (e.g. Pagnini et al. 2008, Rota et al. 2010). Very often, however, studies have focused on a single or very few index buildings that were more or less arbitrarily chosen as being representative (e.g. Barbat et al. 2006, Shahzada et al. 2011).
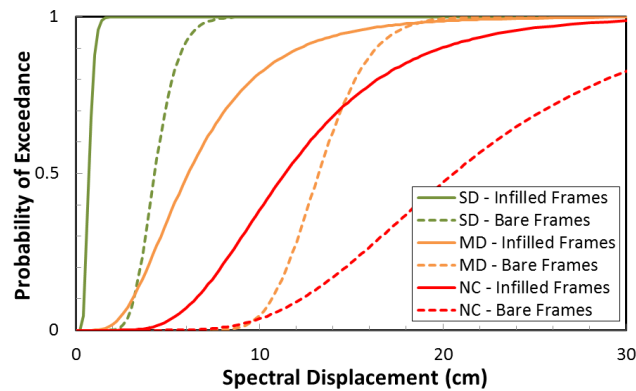

Figure 2. Comparisons of fragility curves of the structures with and without considering the contribution of masonry infill walls

Data Quality

The discriminant attributes which affect data quality are the *Analysis Type*, the *Modelling* of the structural response, and the *Seismic Demand*. Different choices are possible in each of these remits and the quality of the fragility curve is a function of the consistency of the choice made across them.

With respect to *Analysis Type* different approaches have been implemented in literature to generate analytical fragility curves. The procedures vary from simplified, non-numerically based analyses, to nonlinear static and dynamic numerically-based analyses of increasing complexity and accuracy. A detailed review is provided in D'Ayala et al. (2014).

For *Numerical Modelling*, factors affecting the seismic fragility curves can be classified into model type (simulation of the post-linear behaviour), model completeness (i.e. all relevant behaviour modes are considered), and model details (i.e. inclusion of construction details in the simulations which affect important behaviour and failure modes). One of the issues in existing fragility curves of RC buildings is that, for some cases, details regarding the presence of masonry-infill panels and whether they have been accounted in creating the mathematical model, have not been reported. In fact, a number of researchers have attempted to conduct vulnerability assessment of infilled RC frame buildings using bare frame models without modelling the infill walls, in order to reduce the calculation efforts (D'Ayala and Meslem, 2012). Depending on the level of stiffness and structural capacity of the infill walls and their connection to the main structural system, such simplifying assumption may render the fragility curves as being non-representative (Fig. 2). Also, structural models may be regarded as incomplete if two-dimensional modelling is used instead of three-dimensional modelling for buildings with significant irregularities. In case of masonry buildings, the main issue that has been noticed in structural models was ignoring the possibility of out-of-plane behaviour that usually lead to damage and collapse. This would result in lower median and larger standard deviations in relation to the fragility curves (D'Ayala and Meslem, 2013a).

With regard to *Seismic Demand*, existing fragility curves can be classified into two broad categories, i.e. curves generated using real earthquake ground-motion records and curves generated using code-based spectra. Ideally, the best rated fragility curves should be the ones generated based on the use of ground-motion records obtained from/near the site of the assessed building/building class. On the other hand, the derived fragility curves using code-based spectra are considered less accurate. There are still some discussions and questions regarding the minimum number of records to be selected for the analysis in order to properly catch the dispersion associated with the response (record-to-record variability). Several studies (e.g. Rota et al., 2010; Bradley, 2011) have reported that a

minimum of seven records must be applied in order to determine accurately the average IM. FEMA P-695 (2009) suggested that at least 20 records should be considered for every IM level.

Derivation Method

The discriminant criteria which affect this attribute (i.e. *Derivation Method*) concern the *Treatment and Quantification of Uncertainty*, and *Fitting Method*. The extent and way in which uncertainty associated with all the steps introduced in the previous subsections may vary significantly depending on the analysis and modelling approach chosen. The uncertainties concern both the capacity of the examined building as well as the demand. The uncertainty in the demand is introduced by the record-to-record variability, which captures the variability in the complexity of the mechanism of the seismic source, path attenuation and site effects of the seismic event. This uncertainty is taken into account by the majority of studies reviewed either by the selection and scaling of ground-motion records or by generating artificial records. This uncertainty is considered significant and can, in theory at least, be reduced by the use of more efficient intensity measure types.

The uncertainty in the capacity is introduced by geometrical, mechanical, structural and modelling parameters. Typically, uncertainty in the capacity is almost always accounted in terms of assuming that one or more parameters are random variables following a predefined probability distribution with given parameters (e.g. concrete compressive strength or strength of steel reinforcement, etc.) are commonly assumed either as normally or lognormally distributed variables (e.g. in Jiang et al., 2012; Dolsek, 2009; Bakhshi and Karimi, 2006; Rossetto and Elnashai, 2005).

Note that some studies have simply implemented default values that are suggested by some guidelines and other references (i.e. FEMA-NIBS, 2003; Kappos, 2006, Liel et al., 2009) in order to account for these uncertainties in capacity and demand. In literature, there are two main forms of analytical fragility curves: the cumulative lognormal distribution used by most studies and the normal probability distribution. In some studies, where the lognormal or normal assumption did not provide a good fit to the data obtained from the convolution of damage and structural response, multi-linear piecewise functions have been used instead to express the fragility curves.

The contributors to the overall uncertainty are often considered independent and introduced in the expression of fragility curves by the summation of the lognormal variances, which accounted for the uncertainty in each component β_i:

$$\beta = \sqrt{\sum_i \beta_i^2} \tag{1}$$

The number of the components (β_i) used in eq.1, their description and their values varies according to the needs of the study. An overall view of the component included in several studies is presented in Fig. 3. Rarely are all components accounted for in a single study. Dispersion in the attenuation relation might need to be removed when considering risk analysis, as this is usually explicitly accounted for in the hazard component.
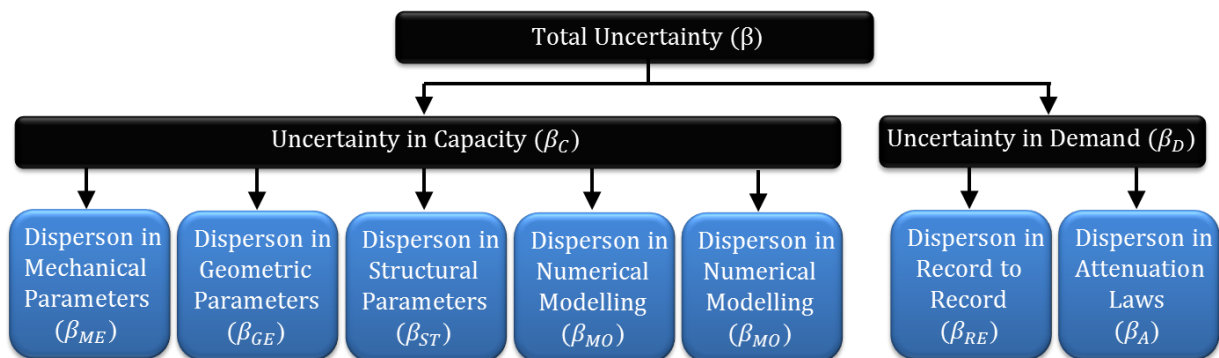

Figure 3. Classification of different sources of uncertainty for fragility curve derivation

For this total uncertainty, FEMA P-58 (2012) suggested a default value of 0.6. On the other hand, FEMA-NIBS (2003), AUTh group (Kappos and Panagopoulos, 2010) suggested values of 0.75, 0.70, and 0.65 for buildings designed to old, moderate, and modern codes, respectively. Studies that adopted this procedure often estimated numerically only one component of the overall uncertainty, i.e. the record-to-record variability.

PROPOSED QUALITY RATING SYSTEM FOR SELECTING ANALYTICAL FRAGILITY CURVES

The factors discussed in the previous section have been considered in the development of a quality rating system that can aid analysts to select a fragility function appropriate for their application scope. The proposed framework for curve selection and underlying rating scheme adopts the four Attributes for assessment suggested by Porter (2011), and also implemented by Rossetto et al. (2013) to devise a rating system for empirical fragility curves. However, the proposed rating system for analytical fragility curves differs from these in the criteria it considers within each attribute.
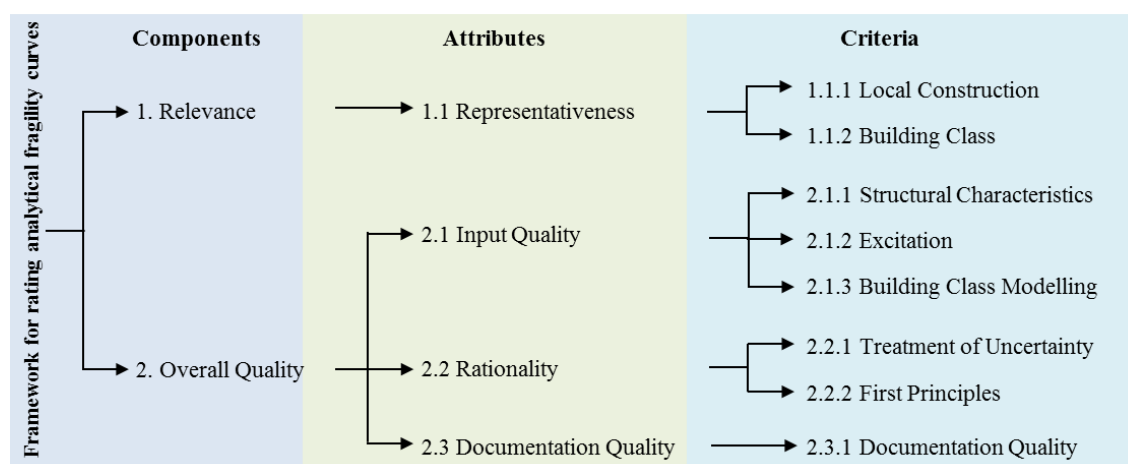

Figure 4. Components, attributes and criteria for quality rating of analytically-derived fragility curves

The four Attributes used are (see Fig.4): the curve *Representativeness* of the characteristics of the assets and seismicity in the location being assessed, the *Input Quality* used to generate the fragility curves, the *Rationality* of the procedures followed to construct the curves, and the *Documentation Quality*. The Attributes are grouped into two Components: **Relevance** and **Overall Quality**. These Components are assumed to contribute equally to the determination of the usefulness and reliability of a fragility curve for a particular seismic risk assessment (Rossetto et al., 2014). The four Attributes are also subdivided into sets of criteria for the attribute evaluation. Details on each of these criteria and the factors identified in the previous section as affecting the reliability of the analytical fragility curves are described in Tables A.1 and A.2 (see Appendix).

Table 2. Description of the criteria ratings applied within each component (Rossetto at al., 2014)

Rating	Component	Description
H	Overall Quality	The work is of excellent quality and little if anything could have been done better.
	Relevance	The fragility curve is highly relevant for the needs of the future application.
M	Overall Quality	The work is of acceptable quality, though there are areas for improvement or further research.
	Relevance	Existing functions are moderately relevant to the needs of the future applications.
L	Overall Quality	The work is acceptable for use but only if there are no practical alternatives; and much improvement or further research is needed.
	Relevance	Existing functions are not relevant for the application.
NA	Overall Quality	The rating cannot be applied.
	Relevance	The rating cannot be applied.

To aid the assessment and comparison of fragility curves, each criterion is assigned a rating of High (H), Medium (M), or Low (L). The description of the criteria ratings differs according to the component to which the criteria belong, as per Table 2. However, the rating is not aggregated further than at the Attribute level, leaving it to the analyst to make a choice informed by the relevance of one or other attribute in relation to his/her specific application. In the following, details on the two *Components* are provided below (for more details see Tables A.1 and A.2).

Relevance

The assessment of Relevance aims to the identification of the analytical curves which are more representative and therefore more relevant to a given application. This component is assessed by considering the two criteria:

- *Local Construction*: this criterion accounts for site-specific and ground-motion intensity. The relevance of a fragility curve according to this criterion is assessed according to: whether the ground motions used to construct the fragility curve are derived from the same region and tectonic environment as the one assessed, and whether record-to-record variability has been taken into account.

- *Building Class and Region*: this criterion accounts for the structural characteristics of the buildings which include the geometric and material properties of the examined class as well as the dominant structural system and its design. The relevance of the fragility curve with regard to the structural characteristics is assessed according to how close the description of the building class for a fragility curve is to the required class, as well as how the variability in building characteristics has been considered, and how representative the location of these buildings is with respect to the required location.

In the Relevance assessment, fragility curves with one or more criteria that have been assigned an 'L' rating are considered irrelevant to the needs of the application and are disregarded. The remaining moderately or highly relevant fragility curves form a pool of candidate curves, whose usefulness to the future application are determined by their assessment under the *Overall Quality* component (Rossetto et al., 2014).

Overall Quality

The Overall Quality of analytical fragility curves is assessed on the basis of three main attributes: the *Input quality*, the *Rationality* and the *Documentation Quality* (see Fig. 4).

The *Input Quality* attribute for the analytical fragility curves adopts the following criteria:
- *Structural Characteristics*, which refer to whether the selected structural details, material and geometrical characteristics correspond to the typical range of the characteristics of the considered building class.
- *Excitation*: this criterion assesses whether the real ground motions have been considered, the spectra, or the more generic design-code spectra have been adopted instead.
- *Building Class Modelling*: type of mathematical model used to simulate the building class, whether all the failure mechanisms have been taken into account.

With regard to the *Rationality* attribute the analytical fragility curves are assessed on the basis of the following criteria:
- *Treatment of uncertainty*: this criterion examines the quantification of the uncertainty in the ground motion, the structure capacity and damage model, as well as the sampling techniques adopted in order to model them.*First Principles*: the assessment considers the type of analyses and damage models (whether they have been obtained from analysis of progress of local damage, or use of damage model, or simplified formula) and whether the study is consistent to the strengths and limitations of the adopted analyses. For instance, it violates first principles to use a damage model based on hysteretic behaviour if the structural analysis used is nonlinear static without adaptive material constitutive laws.

The *Documentation Quality* attribute appraises whether sufficiently detailed and complete information is provided by the authors of the fragility function for an independent researcher to be able to reproduce the study.

EXAMPLE APPLICATION OF THE QUALITY RATING SYSTEM

In the following we have selected fragility curves that were found in three published sources, with the purpose to illustrate the procedure of the proposed rating system framework. The selected curves cover different regions (i.e. Italy, China, and Turkey) and structural typologies (i.e. masonry and RC buildings). Their main characteristics as well as their rating scores are summarized in Table 3.

- ***Masonry Building, Italy***
The first application has been conducted for the fragility curves of low-rise Italian masonry building as provided by Rota et al. (2010). Regarding the relevance/representativeness attribute, which accounts for the appropriateness of the building typology description, and for the nature and type of the selected ground motions to represent the specific site amplification characteristics, the quality of entries are evaluated between Medium to High, as the referenced ground motion do not relate to the building location. With regard to the quality attribute, the Building class modelling criterion has been rated as Medium, principally due to the omission of out-of-plane failure modes. Furthermore, the criteria of Structural characteristics and Excitation have been rated as High, given that the structural characteristics represent the assessed building class, and the seismic demand is represented by real ground-motion records. With regard to the rationality attribute, which accounts for the type of implemented analysis in deriving fragility curves, definition of damage, sampling method, and how uncertainties have been taken into account and treated, most of the assigned entries (a part for damage definition which has been rated as Medium due to the use of simplified assumption) are rated as High. For the documentation quality attribute, which accounts on whether the different assumptions, in the choice of analysis type, in treating uncertainties, in sampling, the implemented procedure, and whether the parameters of fragility functions have been clearly documented, the overall documentation representativeness has been rated as High.

- ***RC building, China***
The second application is conducted for the fragility curves of low-, mid- and high-rise Chinese RC moment frames with different design and site conditions, as provided by Jian et al. (2012). With respect to the representativeness attribute, authors have selected 10 pairs of natural earthquake records (for each frame structure) in order to account for the variability in ground motion. Although the sources and the locations of the used records are not well documented, the authors have mentioned that these records were carefully selected in line with the design acceleration spectra specified in the Chinese seismic design code. Accordingly, the rating has been evaluated as Medium+. With regard to the building class attribute, the quality is evaluated as High due to the fact that the variability in building characteristics has been accounted for by randomising the material strength. With respect to the input quality attribute, the structural characteristics criterion is well satisfied in terms of representativeness of the used parameters with respect to the assessed building class; hence, it has been rated as High. The excitation criterion is also evaluated as High because of the use of natural ground-motion records. For the building modelling criterion, it is not clearly described whether the buildings were modelled as infilled or just as bare frames, and the type of dimensional space that was implemented (i.e. 3D, 2D…etc.). Accordingly, the rate has been evaluated as Medium. Regarding the Rationality attribute, the overall quality has been rated as High. Indeed, the analysis was conducted considering the uncertainty of structural material strength and earthquake ground motions. For the sampling method, Latin hypercube samplings were implemented, and in total 59,400 numerical simulations for the 72 reference structures (low-, mid- and high-rise) were conducted. With respect to the first principles criterion, the curves are generated by the use of nonlinear time-history analyses; hence the sampling method criterion is High. The damage levels are derived by regression analysis using the nonlinear least-squares method (using damage index which reflects the effects of individual structural components and the maximum inter-story drift ratio), and the curves corresponding to different damage states for a given building class do not cross. With respect to the documentation

quality attribute, it was noted that the different assumptions used in analysis, the implemented procedure as well as the parameters of fragility functions were not clearly documented. In particular, the locations and sources of the selected earthquake ground-motion records and the assumption adopted in modelling the buildings (i.e. infilled frame or bare frame system; type of dimensional space…etc.) have not been mentioned. In addition, the lack of the values of the parameters of the fragility curves makes it difficult to reproduce the study by an independent researcher. For these reasons, the overall documentation representativeness is assigned Medium.

- ***RC buildings, Turkey***

The final application was conducted for the fragility curves of Turkish RC buildings of different height class and design quality, as provided by Ay and Erberik (2008). The results of application of the rating system exhibit the following: with respect to the relevance and representativeness, it is not clear whether the selected ground motions characterize the region and the location of the buildings; however, since they have selected 20 records with considering different level of intensity, the criterion of local construction has been rated as Medium. A rate of High is also assigned for the building class attribute as the class/region and variability in building characteristics have been satisfied. For the structural characteristics criterion in the input quality attribute, a rate of High has been assigned as the distribution in structural and material characteristics (account for the variability) has been considered in the analysis, as well as for the excitation criterion by selecting real ground-motion records. However, for the building modelling criterion, a rate of Low has been assigned as the buildings, which are infill RC frames structures, are modelled as bare frame ignoring the contribution of masonry infill walls in the seismic response of the buildings. With respect to the rationality, the treatment of uncertainty criterion has been evaluated as High as the uncertainties in structural characteristics and record-to-record were taken into account. The authors implemented Latin Hypercube sampling in the analysis. For the first principles, a nonlinear time-history was implemented to extract the inter-storey drift-damage relationship and generate fragility curves. Accordingly, the quality criterion is evaluated as High. With respect to the documentation quality attribute, some details on the implementation of the numerical modelling (e.g. whether infills have been considered or not) and on sources and locations of the selected ground-motion records were not clearly documented; hence, the overall documentation representativeness has been rated as Medium.

Table 3. Rating for existing analytical fragility curves proposed for Italian, Indian, and Turkish buildings.

Region	Reference	Building Class		Hight Class	IM	1.Relevance		2. Overall Quality					
		PAGER STR-ID	Lateral Load System			1.1. Representativeness		2.1. Input Quality			2.2. Rationality		2.3. Doc. Quality
						1.1.1	1.1.2	2.1.1	2.1.2	2.1.3	2.2.1	2.2.2	2.3.1
Italy	Rota et al. (2010)	UFB5	Load Bearing Masonry Wall	Low-rise	PGA	H	M	H	H	M	H	M	H
China	Jiang et al. (2012)	C1L	Moment Resisting RC Frame	Low-rise	PGA	M+	H	H	H	L	H	H	M-
		C1M	Moment Resisting RC Frame	Mid-rise	PGA	M+	H	H	H	L	H	H	M-
		C1H	Moment Resisting RC Frame	High-rise	PGA	M+	H	H	H	L	H	H	M-
Turkey	Ay & Erberik. (2008)	C1L,C3L	Moment Resisting RC Frame	Low-rise	PGV	M	H	H	H	L	H	H	M
		C1M,C3M	Moment Resisting RC Frame	Mid-rise	PGV	M	H	H	H	L	H	H	M
		C1H,C3H	Moment Resisting RC Frame	High-rise	PGV	M	H	H	H	L	H	H	M

CONCLUSIONS

This article presents results of a research study conducted within the framework of the project "Global Vulnerability Estimation Methods" funded by the Global Earthquake Model (GEM) foundation. The main scope is to provide guidance for the rational selection of suitable and robust analytically derived

fragility curves for future applications. In this respect, a quality rating system has been developed following detail review and critique of the various existing analytical fragility assessment methodologies that have been developed and presented in the past two decades. The quality rating system is based on four main attributes: Representativeness, Input Quality, Rationality, and Quality of Documentation. For each attribute, a number of criteria are identified as being critical to the determination of a fragility curves for a given building typology. Finally, the rationale behind the rating system can also be used to evaluate future development of analytical fragility.

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APPENDIX

Table A.1 Rating system of the Relevance of analytically-derived fragility curves

Attribute	Criterion		Conditions	Rate
1.1.	1.1.1.	Local Construction	Ground motion - Database at location of building. Spectra Regional Level - Spectrum from existing record from the required area.	H
			Ground motion - Spectrum compatible synthetic record. Spectra National Level - Uniform hazard model.	M+
			Ground motion - Database unrelated to required location. Spectra Regional/National Level - Standard spectra.	M-
			Fragility from direct capacity curve definition.	L
		Variability in ground motion	Variability in ground motion is taken into account.	H
			Variability in ground motion is not taken into account.	L
	1.1.2.	Building class and region:	The qualitative description of the building class and region for which the curve has been obtained is exactly the same as with the required class.	H
			The building class of the curve is a subset or includes the required class. The same applied to region.	M
			The qualitative description of the building class and region for which the curve has been obtained is substantially different than the same as with the required class.	L
		Variability in building characteristics	Multiple Buildings or Randomisation of geometrical or material parameters.	H
			Limited number of buildings.	M
			Single Building.	L

Table A.2 Rating system of the Overall Quality of analytically-derived fragility curves

Attribute	Criterion	Conditions		Rate
2.1.	2.1.1.	Structural characteristics:	Representative of the characteristics of the assessed building class.	H
			Not representative of the characteristics of the assessed building class.	L
	2.1.2.	Excitation	Real ground-motion records.	H
			Code-based spectra.	M
			No excitation (fragility from direct capacity curve definition).	L
	2.1.3.	Building Class Modelling	Structural Modelling-3D element-by-element.	H
			Structural Modelling-2D element-by-element.	M+
			Structural Modelling-2D storey-by-storey.	M-
			Structural Modelling-1D global model.	L
			Infill RC building - Modelled as infill frames.	H
			Infill RC building - Modelled as bare frames.	L
			Masonry buildings: Performance Criteria – Out-of-Plane failure mechanism - Considered.	H
			Masonry buildings: Performance Criteria – Out-of-Plane failure mechanism - NOT considered.	L
2.2.	2.2.1.	Parameters Accounted for Uncertainties:	Calculated.	H
			Default: capacity + demand + damage thresholds are considered.	M+
			Default: 2/3 parameters are considered.	M-
			Default: 1/3 parameters is considered.	L
		Sampling Method:	Monte Carlo or Latin hypercube sampling.	H
			Full Partitioning.	M
			Reduced Partitioning.	L
			Simplified Methods/Direct capacity Curve Definition (Non-numerically-based).	L
	2.2.2.	Analysis type:	Nonlinear Dynamic Analysis Methods.	H
			Nonlinear Static Analysis Methods.	M
			Simplified Methods/Direct capacity Curve Definition (Non-numerically-based).	L
		Fragility curves:	The curves corresponding to different damage states for a given building class do not cross. The curves follow expected trends.	H
			Not applicable.	M
			Obtained curves violate the first principles, e.g. fragility curves corresponding to different damage states for a given building class cross.	L
		Definition of damage states:	Obtained from analysis of progress of local damage at elements level.	H
			Use of damage model (to be consistent with analysis type).	M
			Use of simplified formula (based on simplified bilinear capacity curve) /or Use default values.	L
2.3.	2.3.1.	Documentation Quality	Reproducible study.	H
			Only some parameters of the fragility functions are clearly defined.	M
			Insufficient information is provided to the fragility function or the methodology.	L