12th North American Masonry Conference
Masonry: Science • Craft • Art
Denver, Colorado May 17 – 20, 2015

USE OF THE SENSITIVITY ANALYSIS IN THE SEISMIC ASSESSMENT OF EXISTING BUILDINGS FOR DEFINING PROPER CONFIDENCE FACTORS

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Abstract

The common approach adopted by standards or guidelines to account for the uncertainties involved in the seismic assessment of existing buildings is in the framework of a deterministic procedure. It is based on the definition of a discrete number of *Knowledge Levels* and on the application of a *Confidence Factor* to one specific parameter, usually assumed *a priori* by the code. At present, such procedures do not consider explicitly the use of sensitivity analysis that, on the contrary, is an essential tool allowing to optimize the plan of investigations and tests and to be aware of the propagation of uncertainties in the final outcome of the assessment. To this aim, the paper proposes how to implement the sensitivity analysis in a systemic way, in order to: i) identify the parameters that most affect the structural response allowing to optimize the investigation plan; ii) explicitly include in the methodological path the evaluation of aleatory and epistemic uncertainties, as well as the model error; iii) properly select the parameter (or set of correlated parameters) for the application of CF and calibrate its value. The feasibility of the proposed procedure is illustrated through an application to an existing masonry building hit by the l'Emilia, 2012 earthquake.

Keywords: sensitivity analysis, confidence factor, existing buildings, seismic assessment

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Introduction

One main feature distinguishing the assessment of existing buildings from the design of new ones is that many epistemic uncertainties, due to the limited knowledge and reliability of models, add up to the aleatory ones. Thus, it becomes crucial to have, on one hand, effective procedures to optimize the investigation protocol in term of cost-invasiveness-benefit and, on the other one, reliable approaches to account for the residual uncertainties in the final assessment. The common approach adopted by standards or guidelines for the seismic assessment of existing buildings [e.g. at international levels, Eurocode 8 2005 and ASCE/SEI 41/13 2014] does not explicitly account for the probabilistic issues of the problem, being in the framework of a deterministic procedure (at least concerning the capacity). It is based on the definition of a discrete number of *Knowledge Levels* (KL), achievable as a function of information gathered to overcome the incomplete knowledge, and on the application of a *Confidence Factor* (CF) to one specific parameter, assumed *a priori* by the code as being the most critical in affecting the outcome of the assessment. The CF aims to take into account the evaluation of parameters to be adopted in the analysis could be biased in presence of an incomplete knowledge. Several critical issues have been raised by various authors on the current approach proposed by codes, concerning both the method for the as-built information step and the meaning of CFs [e.g. in Franchin 2010, Jalayer 2011, Tondelli 2012]. In particular, numerical simulations of the entire assessment procedure have been carried out both on reinforced concrete [Franchin 2010] and masonry [Tondelli 2012] structures, showing that sometimes the actual code-based procedure may lead to unsafe results.

The alternative would be to frame the problem by including the propagation of uncertainties (epistemic and aleatory) within a probabilistic approach for the performance-based assessment of existing buildings [as proposed in SAC FEMA – Cornell 2002 and, more recently, in CNR DT212 2013]. Although such approach is certainly rigorous and represents the actual trend at research level, it requires a higher computational effort and, in addition, it is still not widespread in the engineering practice. Thus, still within the context of a CF-based approach, this paper proposes several and significant modifications to the procedure currently adopted in codes in order to overcome some of the drawbacks discussed above [Cattari 2015a]. The most distinctive feature of the proposed procedure is the introduction of sensitivity analysis as essential tool for a reliable seismic assessment of existing buildings. In particular, its use is codified and explicitly implemented within the assessment path, that is how to perform it and what to do with obtained results.

Current format of CF-based procedures proposed in codes

According to well recognized standards at international level in the field of the assessment of existing buildings, like as the Eurocode 8 [2005], at European scale, and the ASCE/SEI 41/13 [2014], at American one, a subdivision in three different KLs is usually adopted. Such KLs are differentiated depending on the amount and quality of collected information, which are usually related to: 1) geometry; 2) structural details (indicated as “condition assessment” in ASCE/SEI 41/13); 3) material properties. In most cases the reaching of a certain KL implies an equivalent state of knowledge on all different abovementioned aspects: for example, in

Eurocode 8 the level of completeness associated to three aforementioned levels is classified as *limited*, *extended* and *comprehensive*. Then the obtainment of a certain KL, through an appropriate investigation plan, leads to the assumption of the corresponding CF value (set in the range of 1.35 to 1.0) and, in some cases, to some limitations on the method of analysis that must be used. In general, CF must be applied to the parameter selected *a priori* by each standard and implicitly identified as that mostly affecting the structural response. Some distinctions are introduced in these documents as a function of the failure mode occurred in masonry panels (if classified as ductile or brittle, that is deformation or force controlled). In ASCE/SEI 41/13, in the case of deformation controlled mode (prevailing rocking behavior) CF is applied to the drift limit, whereas in the case of force controlled mode (diagonal shear behavior) it is applied to strength parameters. In the case of Eurocode 8 all the considered failure modes of masonry panels are classified as ductile, by introducing a proper different value in terms of drift limit: despite this, CF is applied only to strength parameters. It is worth noting that in the case of local mechanisms associated to a prevailing out-of-plane behavior of masonry, the Italian building Code [NTC 08], that presents a general framework common to that of Eurocode8, advises to apply CF directly to the structural capacity; this is due to the fact that usually strength parameters do not influence so much the capacity, which is mainly related to geometry and constraints. A more detailed review of analogies/differences in such codes is presented in [Cattari 2014a]. In general, main drawbacks of the current approach based on the use of CF can be summarized as follows:

- in most cases, a given KL is assigned to the whole building, thus implicitly assuming that sensitivity to all groups of parameters is equivalent; on the contrary, it would be advisable to reduce CF even if some parameters are not investigated in an *extended* or *comprehensive* way but if the sensitivity is low;
- the CF is conventionally applied to a predetermined parameter: depending on the properties of the structure, this assumption should be verified by a sensitivity analysis;
- the value of CF is conventionally proposed as a function only of the reached KL: while it should be related both to the variability of the parameter, in the case of an incomplete knowledge, and to the sensitivity of the response to the parameter itself.

Proposed procedure

With respect to the current procedures based on the use of CF, the most innovative aspect of the procedure herein proposed is the introduction of a codified use of the sensitivity analysis. This procedure has been originally developed within the context of the PERPETUATE project [Lagomarsino 2015] focused on the protection of masonry monumental buildings, but its principles are general and applicable to any type of existing buildings. In particular, it allows improving some fundamental issues such as:

- to identify the parameters that most affect the structural response allowing to optimize the investigation plan and strengthen the link between knowledge and assessment;
- to explicitly include in the methodological path the evaluation of aleatory and epistemic uncertainties, as well as the model error;
- to properly select (instead of *a priori*) the parameter (or set of correlated parameters) for the application of CF and calibrate its value (instead of assuming it conventionally).

The method, instead of assigning a given KL for the whole building, defines which KL (still graduated into three levels) should be achieved for each single parameter, calibrated on the basis of the actual sensitivity of the seismic response to it. The sensitivity is assessed with respect to a selected Structural Performance Indicator (SPI). Among the different possible choices and according to the final aim of the seismic PBA, the maximum Intensity Measure compatible with the fulfillment of performance levels (IM_{PLi}) has been selected as SPI. The sensitivity can be computed according to nonlinear static procedures based on overdamped or inelastic spectra. The IM_{PLi} represents the mean value of this variable and is obtained by adopting for all parameters their mean values: being in the context of a semi-probabilistic procedure, the actual dispersion of parameters is not explicitly considered. Hence, CF is applied to take into account the uncertainty in the estimation of the mean value of the selected parameter.

Basic steps of the proposed procedure

Figure 1 illustrates a flowchart that summarizes the main steps of the procedure.

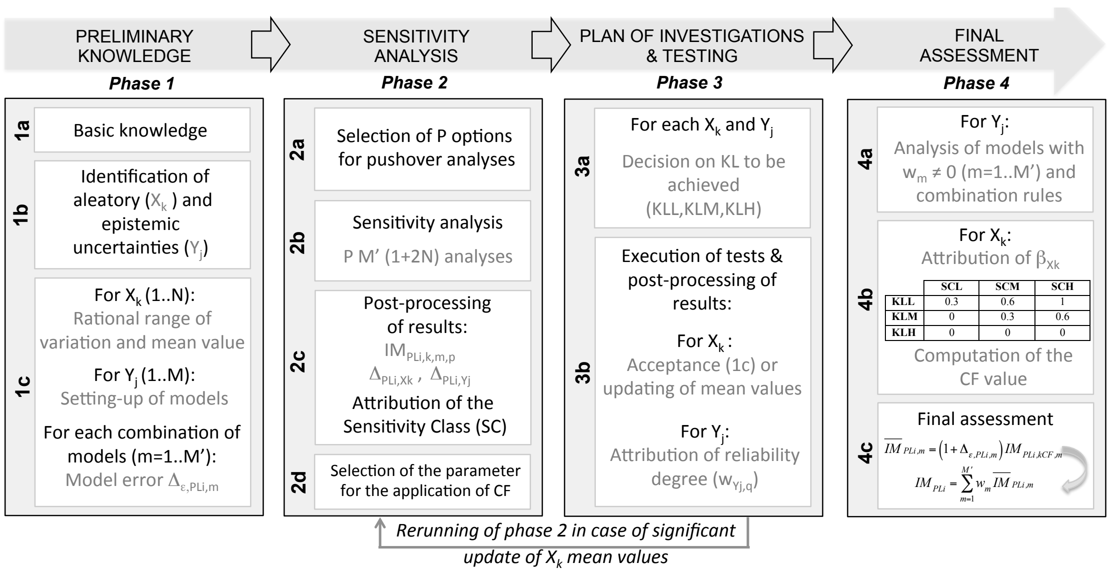

Figure 1. Flowchart of the proposed procedure

The Preliminary knowledge is addressed to the achievement of a *basic* knowledge level and identification of all uncertainties involved in the building response. It requires the following sub-steps:

1a) Achievement of a *basic* knowledge level: it is addressed to preliminarily identify the most suitable model (or models) to be adopted for the seismic assessment and collect all necessary data for the analyses.

1b) Identification of aleatory and epistemic uncertainties, which are related to parameters involving geometry, mechanical parameters and structural details as well. Aleatory uncertainties are associated to parameters that are treated as variables X_k (k=1..N, where N is the total number parameters or groups of parameters). Epistemic uncertainties are usually related to constructive or modeling factors Y_j (j=1..M), which are treated through the logic tree approach. The former parameters might vary in a defined range. Each factor Y_j leads to the adoption of two or more possible models (q=1..m_j); the number of possible alternatives may be different for each factor. If only two alternatives (m_j=2, $\forall$ j=1..M) are considered for each factor (quoted as A and B), 2^M models, obtained by the factorial combination of all possible configurations, have to be considered: each one of them may be identified by a specific sequence of letters given by the corresponding choice on the j-th factor (e.g. in case of M=2: AA, AB, BA and BB). In the following, the possible combinations (M') are synthetically identified by the counter m (m=1..M', where M'=2^M only if two alternatives are considered for each Y_j factor).

1c) For each variable X_k: identification of a rational range of variation, that is a lower and upper bound ($x_{k,low}$ and $x_{k,up}$) of the mean value of the parameter. Although the method proposed does not strictly require any probability distribution for random variables, if these are available for a wide population, the definition of the interval can refer to one standard deviation confidence levels. Once the range of variation is specified, it is possible to define:

$$\bar{x}_k = \frac{x_{k,low} + x_{k,up}}{2}$$
$$f_k = \frac{x_{k,up} - x_{k,low}}{x_{k,up} + x_{k,low}} \quad \textbf{[1]}$$

where $\bar{x}_k$ is the plausible mean value and f_k will be used to calibrate the CF on the basis of the actual variation expected for each parameter.

For each combination of factors Y_j (M' in total): setting-up of the model.

For the model error $\Delta_{\varepsilon,PLi,m}$: attribution of its rational estimate. $\Delta_{\varepsilon,PLi,m}$ refers to the evaluation of each PLi by the model corresponding to the m-th combination of the Y_j factors. It is assumed as a percentage of variation of the expected mean value of the actual seismic capacity in comparison with the value IM_{PLi} given by the model; hence, this parameter should be considered when the adopted model is clearly and systematically on the safe side ($\Delta_{\varepsilon,PLi,m}$ >0) or to the detriment of safety ($\Delta_{\varepsilon,PLi,m}$ <0). It is worth noting that, at present, model error is generally neglected; anyhow, the proposal is to consider it only when it is expected to be relevant in comparison with the effect of other uncertainties.

Once identified the uncertainties to be considered it is possible to proceed to the *Sensitivity analysis*, main core of the procedure which is illustrated more in detail in the following, and then to the *Plan of investigations and testing*.

Finally the *Final assessment* is assessed through the following steps:

4a) Considering epistemic uncertainties, the final selection of models to be adopted and rules for their combinations.

4b) Considering aleatory uncertainties, the evaluation of the residual incomplete knowledge and computation of CF value to be adopted for each model.

4c) Execution of pushover analyses for the final assessment and combination of results from various models.

A more detailed description of all steps is illustrated in [Cattari 2015a], while in the following only the most peculiar features of the procedure are briefly presented.

Sensitivity analysis

The main aim of sensitivity analysis is to identify the parameters/factors that most affect the structural response among those selected at the end of phase 1 (Figure 1). To this aim, the basic tool adopted is the execution of nonlinear static analyses. In particular, for each m-th model (as a function of the Y_j factors identified), 2N+1 analyses must be performed, that is:

- a first one by adopting as reference for all the parameters the plausible mean value $\bar{x}_k$;
- a set of 2N analyses in which each parameter (or set of parameters) is changed one by one according to the lower ($x_{k,low}$) or higher ($x_{k,up}$) bound of the rational range, as defined in step 3a.

The execution of a pushover analysis presupposes a choice on many different combinations of conditions related to: the load pattern (e.g. proportional to mass, to the mass and height product or to the first modal shape), the main directions of the building footprint, the positive or negative sense of each direction and the accidental eccentricity (usually proposed by codes as the 5% of the maximum length in the direction orthogonal to that examined). Although in the final assessment different options have to be considered (as expressly indicated also by standards), it seems worthwhile to select the worst conditions in order to limit the number of analyses to be performed: to this aim, it is useful to perform some preliminary analyses in order to select one or more basic options related to direction, load pattern, accidental eccentricity and control node (enumerated by the counter p=1..P). These preliminary analyses may be performed, for each m-th model, by assuming the plausible mean values $\bar{x}_k$ for all variables X_k. Thus, by considering also the number of models (M') and possible options (P), a total of M'P(2N+1) analyses should be performed. Indeed, in order to investigate the sensitivity by considering the cross correlation of parameters X_k, it should be more accurate to perform a multivariate second order factor analysis: although certainly more rigorous, it is evident it implies a huge computational effort (2^N analyses rather than only 2N).

If the given PLi is considered, the result of each analysis is $IM_{PLi,k,m,p}$, where the subscript k (related to the k-th parameter) is followed by "-low" or "-up" depending on the assumed value; when for all variables the plausible mean is assumed, this field is replaced by "mean". Then, for each m-th model and p-th option, it is possible to evaluate the corresponding values of $IM_{PLi,k\text{-}max}$ and $IM_{PLi,k\text{-}min}$ as:

$$
\begin{aligned}
IM_{PLi,k-\min} &= \min\left(IM_{PLi,k-low}, IM_{PLi,k-up}, IM_{PLi,mean}\right) \\
IM_{PLi,k-\max} &= \max\left(IM_{PLi,k-low}, IM_{PLi,k-up}, IM_{PLi,mean}\right)
\end{aligned}
\quad \textbf{[2]}
$$

where the subscripts m and p have been omitted in the following for simplicity.

Finally, the sensitivity to variables X_k and Y_j is assessed through the variable $\Delta_{PLi,Xk}$ and $\Delta_{PLi,Yj}$ computed as:

$$\Delta_{PLi,Xk} = 2\frac{IM_{PLi,k-\max} - IM_{PLi,k-\min}}{IM_{PLi,k-\max} + IM_{PLi,k-\min}}$$

$$\Delta_{PLi,Yj} = 2\frac{max\left(\mu_{j,IMPLi,mean,q}\right) - min\left(\mu_{j,IMPLi,mean,q}\right)}{max\left(\mu_{j,IMPLi,mean,q}\right) + min\left(\mu_{j,IMPLi,mean,q}\right)} \quad q = 1,..m_j \tag{3}$$

where $\mu_{j,IMPLi,mean,q}$ is the mean of the IM_{PLi} values (computed by assuming the mean value for all random variables) resulting from the branches of the logic tree associated to the q-th option for the factor Y_j.

Once the sensitivity analyses have been completed and all results post-processed, it is possible to proceed to step 2c, that is the attribution of a Sensitivity Class (SC), for each k-th parameter and j-th factor (as a function of the i-th performance level). To this aim, it is necessary to define some conventional criteria for establishing the high, medium and low sensitivity. A possible criterion for each m-th model is the following:

- firstly ,a reference value of the sensitivity parameter $\Delta_{PLi,max}$ is calculated as max[$\Delta_{PLi,Xk}$], by referring only to the sensitivity to variables X_k, taking into consideration the P options for the pushover analysis;
- then, SC to each parameter/factor is conventionally given as a function of $\Delta_{PLi,max}$, for example according to this rule: High sensitivity (SCH) for $\Delta_{PLi,Xk}$ (or $\Delta_{PLi,Yj}$) > 2/3 $\Delta_{PLi,max}$; Medium sensitivity (SCM) for 1/3 $\Delta_{PLi,max} \leq \Delta_{PLi,Xk}$ (or $\Delta_{PLi,Yj}$) $\leq$ 2/3 $\Delta_{PLi,max}$; Low sensitivity (SCL) for $\Delta_{PLi,Xk}$ (or $\Delta_{PLi,Yj}$) < 1/3 $\Delta_{PLi,max}$. These ranges could be differently calibrated or established by the seismic assessor.

It is worth noting that the sensitivity class of the k-th aleatory variable could be different for each m-th model, as well as the sensitivity parameter $\Delta_{PLi,max}$ can be very different from model to model.

Definition of the plan of investigation and the confidence factor

Results from the sensitivity analysis (phase 2, Figure 1) are useful to optimize and reliably plan investigations and tests to be performed (phase 3). Indeed the objective of defining sensitivity classes is to identify the need for more investigation for the parameters that most significantly affect the seismic performance of the building. Thus, in order to overcome some limits noticed on current standards, distinct KLs are planned for each parameter as a function of its specific SC, rather than for the specific "knowledge aspect" as a whole (geometry, material and structural details): this allows to improve the knowledge only where it is relevant.

Regarding the knowledge levels for each single parameter, a division into three levels is proposed, as in Eurocode 8 [2005], which are quoted as KLL (low), KLM (medium) and KLH (high). Moreover, tools useful to achieve a certain KL are classified as follows: i) "qualitative" investigations based only on in situ survey, visual inspections, data available from archive records; ii) "indirect" investigations based on not destructive tests on both materials and structural details (such as pulse sonic tests, thermography etc.); iii) "direct" investigations based on minor or destructive tests on both materials and structural details (such as coring of samples, double flat jack test, diagonal compression test, endoscopy, etc.).

The objectives of the detailed investigations are: i) in case of X_k parameters, to confirm/update the plausible mean value to be adopted in the final assessment; ii) in case of Y_j factors, to acquire enough data to choose the most suitable model or, at least, to attribute to each one a subjective probability $w_{Yj,q}$ $\left(\sum_{q=1}^{m_j} w_{Yj,q} = 1\right)$, related to the level of reliability of each choice. Then the residual uncertainties are treated: i) through the application of the CF, in case of aleatory variables (X_k); ii) through the logic tree approach, in case of epistemic uncertainties (Y_j factors). Moreover, the model error can also be considered.

In case of Y_j factors, when the final assessment is slightly affected by epistemic uncertainties, it is suggested to make a choice among the alternatives considered (that most conservative – in case of KLL – or that most reliable – in case of a higher KL achieved) in order to limit the final computational effort. On the contrary, when the SC is higher (SCM and SLH) and the data acquired are sufficient to assign w_{Yj_q}, the combination through the logic tree approach is advisable to improve the reliability of the PBA.

Regarding X_k variables, CF has to be applied to one "main parameter" (or group of parameters) X_{kCF} selected among those associated to the sensitivity class high (SCH) for the m-th model. The value of the intensity measure of the seismic input ($IM_{PLi,kCF,m}$) that produces the performance level PLi is obtained from the model in which all parameters have been set to the plausible mean value and the CF is applied to X_{kCF}. The final evaluation provided by each m-th model (and a given p option for the execution of the pushover analysis) is computed as:

$$\overline{IM}_{PLi,m} = \left(1+\Delta_{\varepsilon,PLi,m}\right) IM_{PLi,kCF,m} \quad \textbf{[4]}$$

where $\Delta_{\varepsilon,PLi,m}$ is the model error related to the m-th branch of the logic tree; it is mainly related to the capacity of model adopted of describing the specific examined asset and should usually assume a negative value or more rarely a positive one.

The evaluation of CF has to take into account: i) the actual variability of the parameter to which CF is applied, by considering f_k (eqn.[1]); ii) the residual uncertainties associated to the incomplete knowledge process, which is measured by a factor β_m, defined on the basis of different KLs on all parameters. Hence a β_{Xk} factor is introduced to measure the residual uncertainty on each parameter and ranges from 1 to 0 [Cattari 2015a]. The introduction of such factor aims to guarantee equal percentiles of safe outcomes, independently of the reached KL. Considering each m-th model, it is possible to assign to each parameter X_k the corresponding $\beta_{Xk,m}$ value. Hence, the maximum value β_m (β_m=max[$\beta_{Xk,m}$, k=1..N]) is assumed as reference to compute the CF value to be applied to the X_k parameter (or set of parameters) in the m-th model ($CF_{XkCF,m}$) as follows:

$$CF_{XkCF,m} = \begin{cases} 1+\beta_m f_{kCF,m} & if\, IM_{PLi,k\text{-}min} = IM_{PLi,k\text{-}up} \\ 1 & if\, IM_{PLi,k\text{-}min} = IM_{PLi,mean} \\ 1-\beta_m f_{kCF,m} & if\, IM_{PLi,k\text{-}min} = IM_{PLi,k\text{-}low} \end{cases} \quad \textbf{[5]}$$

The nonlinear analyses are then performed adopting for parameter X_{kCF} the product of the corresponding plausible mean value $\bar{x}_{kCF}$ by $CF_{XkCF,m}$. The CF value is defined in such a way to limit the selected parameter within the originally assumed plausible range (the low or up value is used in case of a high SC with a low KL).

Finally, by considering the effect of CF application and the combination of results through the logic tree, for each given p-th options examined, the value of IM_{PLi} is computed as:

$$IM_{PLi} = \sum_{m=1}^{M'} w_m \overline{IM}_{PLi,m} \quad \textbf{[6]}$$

where w_m represents the weigth of each branch of the logic tree as resulting from the product of weigths associated to the options of Y_j factors that define the m-th model.

Application of the proposed procedure

In the following, the application of the proposed procedure to a real building located in San Felice sul Panaro, seriously damaged by the earthquake of 20th May, 2012 (M_L=5.8, depth 9.6 km with epicenter near Mirandola) is briefly presented (Figure 2a). The modeling has been carried out by using Tremuri program [Lagomarsino 2013] and adopting the piecewise-linear constitutive laws for masonry panels [Cattari 2013]; they allow to describe the non linear response until very severe damage levels (from 1 to 5) through progressing strength decay in correspondence of assigned values of drift, differentiating the behavior as a function of the main prevailing failure modes (if flexural, shear or mixed one) and the element type (if pier of spandrel). Diaphragms are modeled as 3- or 4-nodes orthotropic membrane finite (plane stress) elements. For the computation of IM_{PLi} a procedure based on the use of overdamped spectra [Freeman 1998] has been used by defining the position of PLi on the pushover curve according to the multiscale approach recently proposed in [Lagomarsino 2015]; in particular, reference is made in the following to PLs associated to the Damage Limitation (DL) and Near Collapse (NC) conditions. Results here discussed refer exclusively to the methodological path herein proposed based on the use of sensitivity analysis and its potential use in the engineering practice, while more detailed information on modeling, seismic response and final assessment of the building may be found in [CNR DT212-2013 Annex B and Cattari 2013]. In this case, the equivalent frame approach has been evaluated reliable and effective since the building is characterized by a very regular openings pattern and by a prevailing box behavior (as testified also by the real damage occurred).

A set of 8 aleatory variables X_k (or groups of correlated parameters) and two epistemic uncertainty (Y_j factor, M=2) have been considered. The first ones involve: the mechanical parameters of masonry (composed by clay brick and hydraulic mortar joint, X_1); the stiffness and masses of diaphragms and timber roof (sets X_2, X_3 and X_4, X_5, respectively); the parameters necessary to describe the nonlinear behavior of masonry panels, in terms of drift thresholds and strength decay of piers (X_6) and spandrels (X_7), according to the adopted piecewise-linear constitutive laws; the coefficients that rule the damping correlation law assumed [Blandon 2005] for the computation of overdamped spectra (X_8). In Table 1, the resulting values of f_k are summarized: those quite high associated to variables X_2 and X_3

reflect the uncertainty associated to the effectiveness of wall to diaphragms connection. The epistemic uncertainties regard: the equivalent frame idealization of masonry walls, related to the effective height assumed for piers (see Figure 2d/e that illustrate two options considered); the effectiveness of wall to wall connection, simulated by calibrating the link between interior and exterior walls by equivalent beams (see Figure 2f) at the floor level (also in this case two options have been considered, representative of a good and poor connection quality).

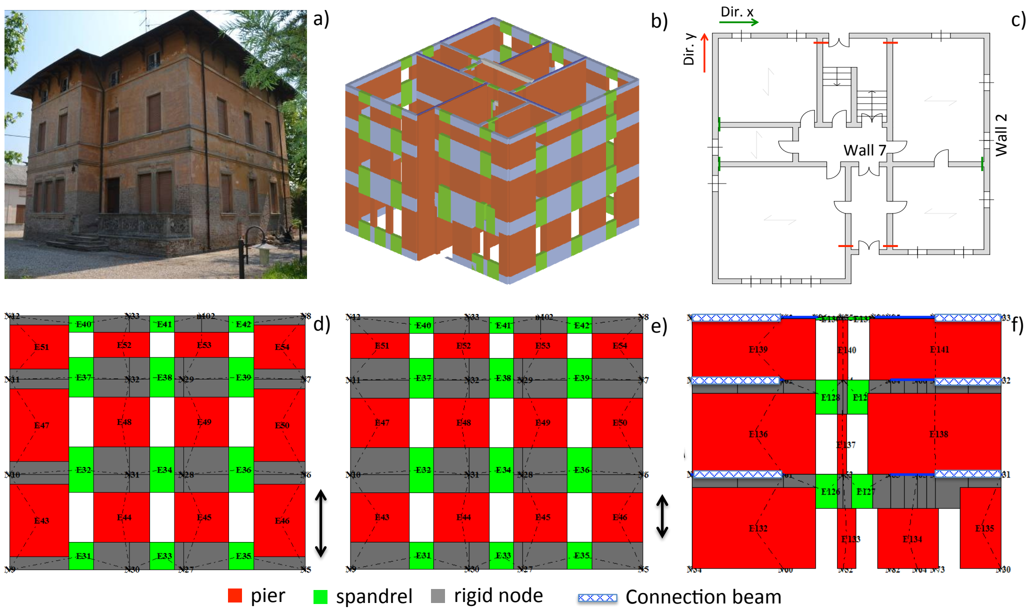

Figure 2. a) View of the real building; b) 3D equivalent frame model; c) plan view; d,e) two mesh options adopted (Wall 2); f) equivalent frame idealization of Wall 7 with the indication of beams adopted to simulate the effectiveness of walls to walls connection

For each model, a total of 17 analyses (2N+1) have been performed for each direction (X/Y), sense of direction (positive/negative) and load pattern; regarding this latter, only that proportional to masses has been considered according to the evidences achieved from the execution of some nonlinear dynamic analyses and a major agreement with the observed response [CNR DT212-2013, Annex B]. Table 1 briefly summarizes results from steps of the procedure proposed as listed in Figure 1. In general, it may be pointed out the following:

- between the two epistemic uncertainties considered, that associated to the effectiveness of wall to wall connection turned out to be more relevant. Indeed, in this case also the evidence of the real damage occurred (that highlighted no cracks between interior and exterior walls) supported the adoption of the "good quality connection" for the final assessment.
- among the aleatory variables, the mechanical properties of masonry revealed a recurring parameter associated to an high SC. However, as a function of the PL examined, also the relevance of other parameters has been highlighted, like as, in the case of DL, the parameters aimed to rule the progressing of nonlinear response of spandrels or that aimed to define the equivalent damping of the structure. In this latter case, the execution of cyclic nonlinear static analyses may support the assumptions on the dissipative properties of the structure.

Despite the high SC associated to set X_1, a KLM has been planned to be reached in order to limit the execution of too invasive tests on the structure. In Table 1, also the final values of CF to be applied to the parameters turned out as those mostly affecting the response (marked in grey) are illustrated. Although in this case the mechanical parameters revealed to have a dominant role (as usually assumed a priori by codes) it not represent a general result for all structures (as evidenced in other applications as that illustrated in Cattari 2014b) and the procedure is capable to highlight the influence of other parameters as well.

Table 1. Summary of application of proposed procedure in case of examined building

Definition of parameters (phase 1)		**Attribution of SC (phase 2)**				**Plan of investigations (phase 3)**	**Final assessment (phase 4)**		
		Aleatory Uncertainties					**Attribution of β_{Xk}**		
		Dir.Y (DL)		**Dir.Y (NC)**			**Dir.X $^{(+)}$**	**Dir.Y**	
X_k	**f_k**	**Δ_{Xk}**	**SC**	**Δ_{Xk}**	**SC**	**KL**	**PL=NC**	**PL=DL**	**PL=NC**
X_1	0.14 -0.25	0.086	**H**	0.301	**H**	KLM	(H) 0.6	0.6	0.6
X_2	0.82	0.012	L	0.068	L	KLL	(L) 0.3	0.3	0.3
X_3	0.82	0.016	L	0.001	L	KLL	(L) 0.3	0.3	0.3
X_4	0.20	0.041	**H**	0.055	L	KLH	(L) 0	0.3	0
X_5	0.20	0.004	M	0.006	L	KLM	(L) 0	0.3	0
X_6	0.14-0.38	0.089	L	0.191	M	KLL	(L) 0	0.3	0.3
X_7	0.25-0.40	0.089	**H**	0.089	L	KLL	(L) 0	1	0.3
X_8	0.20	0.081	**H**	0.139	M	KLM	(M) 0.3	0.6	0.3
Y_j (*)		**Epistemic Uncertainties**					**Definition of CF**		
		Dir.X (NC)		**Dir.Y (NC)**					
Y_1		0.013	**L**	0.035	**L**	KLL	0.88-0.91	0.6-0.75	0.88-0.91
Y_2		0.501	**H**	0.495	**H**	KLH			

Notes: $^{(*)}$ Y_1 – mesh solution; Y_1 – effectiveness of wall to wall connection; $^{(+)}$ in brackets the sensitivity class resulting from Phase 2.

Conclusions

The critical issue of how taking into account the incomplete knowledge in the seismic assessment of existing masonry structures is usually faced in standards through a procedure based on the use of Confidence Factors. In the paper, the codified use of the sensitivity analysis is proposed in order to improve the methodological path nowadays outlined in standards, leading to the following main original contributions: i) Knowledge Level is tuned on each parameter or constructive detail in connection with its influence on the seismic behavior rather its assignment at global scale; ii) the value of Confidence Factor is not conventional but is obtained in a consistent way, by considering the actual variability of the parameter to which is applied, besides the residual incomplete knowledge. Moreover the optimization of investigations and testing protocol that follows to the data acquired by the sensitivity analysis allows reducing costs but also the impact of semi-destructive in-situ tests. Although the method requires the execution of many nonlinear static analyses, it is feasible as it can be easily implemented in an automatic software procedure.

Acknowledgments

The research was funded by PERPETUATE project (FP7/2007-2013 under Grant Agreement n° 244229 www.perpetuate.eu). Results related to the application were achieved in the national research project ReLUIS III 2013 –2014 (www.reluis.it), supported by the Italian Civil Protection Agency.

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