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INFLUENCE OF BUILDINGS STOCK KNOWLEDGE ON SEISMIC CAPACITY OF R.C. STRUCTURES

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SUMMARY

This paper presents a procedure for seismic vulnerability assessment of classes of r.c. buildings at a large scale. The method is mechanistic based, i.e. determines building capacity starting from simple analytical models. Building stock of a given area is reproduced starting from knowledge of main parameters as collected in an inventory phase. Once the building stock is generated, lateral strength and drift supplies are determined based on prefixed collapse mechanisms. The influence of model parameters on response is evaluated considering the response surface for the capacity. Adopting parameter distributions derived from building inventory, vulnerability curves are derived for building class.

INTRODUCTION

The assessment of seismic vulnerability of existing buildings is a relevant problem for all earthquake prone areas; in Italy, and in the regions where large part of the built environment is not respective of modern seismic codes [1],[2], this issue is of crucial importance.
One of the most exhaustive programs recently developed for the prediction of the effects of potential earthquakes within urban areas or across large regions is represented by HAZUS [3],[4]. In HAZUS, structural performance evaluation rely on a simplified version of the capacity spectrum method, where capacity curve for a building class is based on significant structural parameters that are derived by the best estimate of design properties versus structural category and code class. However, such comprehensive vulnerability assessment methodology require considerable amounts of time and research to collect and compile the detailed data necessary to perform a complete study; moreover, building *Inventory* module is based on north-American construction typologies, and suggested capacity thresholds for the parameters used in the evaluation procedure (ductility, inter-storey drift etc.) are statistically derived from observational data relative to these typologies. When limited financial and temporal resources are available less demanding strategies are needed; in addition, referring to an Italian regional or sub-regional scale, building typologies can be generally restricted mainly to masonry and reinforced concrete (r.c.) buildings, among which ulterior classification may be done.
Calvi [5] proposed an alternative simplified seismic vulnerability approach, which adopts displacements as the fundamental indicator for damage and a spectral representation of the earthquake demand. The author presented a displacement-based method for deriving the capacity of column-sway reinforced

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concrete frames, starting from basic principles of structural mechanics and seismic response to arrive at an estimation of seismic vulnerability of classes of buildings. The procedure presented by Calvi has the un-negligible merit of sensibly simplifying the mechanical model for the evaluation of the capacity of a building class; on the other hand, the drastic reduction of model parameters limits the possibility of investigating on the influence of other geometrical/structural/mechanical parameters that can be significant for building response. Because in the study of seismic vulnerability at a territorial scale our level of knowledge of building stock characteristics may be more or less detailed, depending on the source of information and on effort available for thorough investigations, it should be possible to include in the analysis model much data as possible (among those that are relevant for structural response) and to investigate on output (building capacity) variation depending on the amount and quality of input data.

In the present work, starting from the idea that the analysis results should be influenced by the level of information on input parameters, a new procedure to evaluate seismic capacity for a building class is proposed that enables to reduce dispersion on results depending on the knowledge level of the built environment. Only r.c., rectangular shaped, frame buildings are considered, but in principle the procedure could be extended to other structural systems.

Building classes are defined by construction age (i.e. code class) and number of storeys. First parameter enables to link constructions of a certain area to building codes applying at the time of construction, and consequently to actions and prescribed rules considered in design; second parameter is chosen because of its direct influence on capacity. Building class capacity is determined in terms of base shear coefficient and global drift. To this end, adopting basic geometric, structural and mechanical parameters, simple frame building models are generated respecting code design rules, and their response is analysed. Fundamental to the procedure is the utilization of information on building parameters made disposable from building inventory; input variable distributions derived from the statistical treatment of inventory data are considered.

When some data is unavailable, engineering judgement is applied to fill the gap, but this lack of knowledge is paid in terms of a major dispersion on results. In fact, for example, when very limited budget for the analysis is disposable, only speed investigations, such as consultation of public databases, may be done; for this typical case only geometrical data (global dimensions) for buildings of a certain class may be collected. However, considering the possible variation (theoretically infinite, realistically, limited only by engineering judgement) of other parameters that may influence building response, this first 'knowledge level' corresponds to a large variation of the estimated building capacity; this, clearly, gives a measure on how much (or how few) we can rely on results based on such poor input data. On the other hand, if some more data is made disposable from surveys or from specific investigations the proposed procedure allows to consider explicitly such information and to reduce results dispersion. In the following sections the main features of the procedure are presented.

In *Building Inventory* survey forms for building data collection are introduced; such forms are organised in a multilevel format, so that collectable data are distinguished based on their major or minor availability.

Generation of the Building Class describes the procedure adopted to generate building models based on few, representative parameters. Building capacity is determined in terms of lateral strength and drift supplies for a building class (i.e. for the generated building models of the class) adopting prefixed collapse mechanisms; however, any other analysis method, if simple, can be used to determine building capacity.

Seismic capacity of a building class at a territorial scale resumes the entire process (building generation, evaluation of capacity, probabilistic treatment of input data and results) at a territorial scale. Depending on parameters variability in a class a number of building models for the class are generated; they constitute the sample for which response is investigated. Adopting response surface method, then, the probability of attaining prefixed capacity levels may be found.

An illustrative *Example* completes the presentation of our work.

BUILDING INVENTORY

Each survey form (see Figure 1, 2 and 3) collects different kind of data for a building: global geometrical data (base plant dimensions, number of storeys etc.), global structural data (number of bays and number of plane frames in the two main directions, stairs number and position, column main orientation etc.), detailed structural data (elements mean dimension at the first floor, infill type etc.). As it will be shown in the next section (building generation), not all of the information contained in the form is actually used in our model; nevertheless, we preferred to include also other parameters that could be considered in a future enhanced, yet simple, model. In principle, the forms may be compiled adopting any source of information: public databases, urban cartography, census parcels data, national statistic data on population and buildings (ISTAT data for Italy), aero-photos, field survey, interviews etc. Because the availability of the requested data is different (some parameters are easily disposable from public databases or by exterior survey, some other request an interior, more or less time consuming, inspection) survey forms are organised in multilevel sections; going from first to third section the requested data have a lower availability level and the form filling time elongates. Depending on the temporal and financial resources, survey forms for the investigated area can be filled just in the first section, in first and second or in all the sections.

Survey form

SECTION 1

Construction age *(changes in Italian seismic code)*	Year ___; period: ante '35 ; '36-'37 ; '38-'62 ; '63-'74 ; '75-'81 ; post '82
Plant dimensions	L_y=______ [m] L_x=______ [m]
Elevation data	Building height L_z ____; Floor number *(total, in and out ground)* n_z ____; Mean inter-story high [m] ____; N^r of floors with equal inter-story high ____;
Use	Total units ____; n^r main residence ____; n^r secondary resid. ___; n^r production activity___

Figure 1: Survey form – first section

First section of the form (Figure 1) contains information collectable from public databases or by rapid, exterior survey. Such data allow the assignment of the building to the relative class (defined by construction age, i.e. code class, and number of storeys) and its morphologic/geometric identification. When only this first section of the form is compiled, there is no information on the structural system and engineering judgement has to be applied to build a model; given a building of assigned dimensions (L_x and L_y), for example, there may be more structural systems (that, for example, depend on the number and amplitude of the bays in both directions) that fit such base plant and in theory all the "possible" structural configurations have to be considered.

The information of main *Use* of the building is not relevant for the model; however it is important if exposition of the built environment is evaluated.

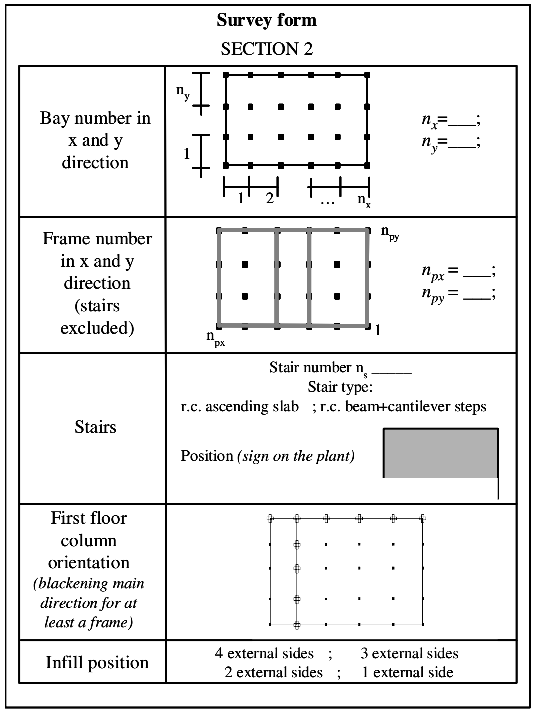

Figure 2: Survey form – second section

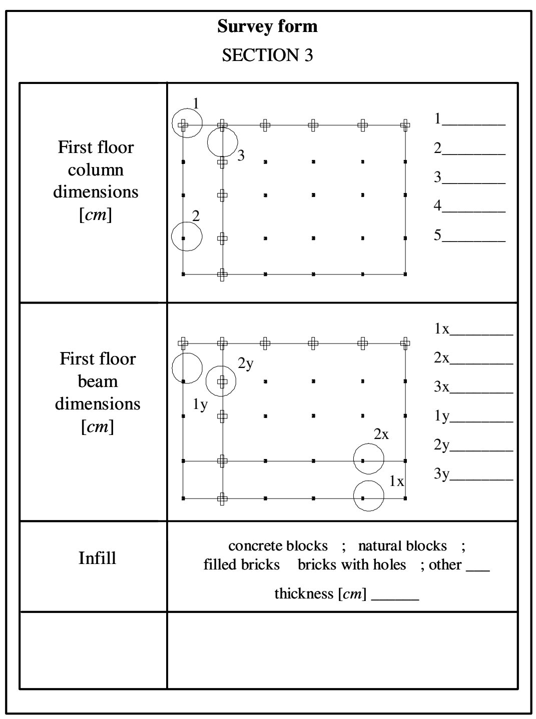

Figure 3: Survey form – third section

Second section of the form (Figure 2) goes towards the structural identification of the building; it requires interior, even if speed, inspection. In particular, as it will be shown in the next paragraph (generation of the building class), structural system is identified through the definition of a three-dimensional mesh in x, y and z (elevation). This is made possible by the knowledge of the number of bays n_x and n_y in the two main directions of the building, and the number of storeys n_z; moreover, depending on the number of plane frames in x and y direction n_{px} n_{py}, the horizontal resisting elements (beams) are located. Second section requires also information on the number of stairs and on their type, and on main orientation of the columns at the first storey. Main column orientation can have a significant influence on building lateral strength, especially for tall buildings. The distribution of infills in plant and elevation, too, may have a significant influence on the global seismic behaviour of the building; although not explicitly modelled at this stage, then, such information is collected for future developments.
Third section (Figure 3), finally, allows the enhancement of the definition of the structural model. It contains information such as mean dimensions of the structural elements at the first storey that can help to build a model much more inherent to the real building. More data on infills type and on their thickness are also collected.
After the form is compiled in some or in all its parts, data for a building class (i.e. for building of the same code class and number of storeys) are grouped and distribution of the available parameter are determined for such class.

GENERATION OF THE BUILDING CLASS

The generic building is generated and re-designed adopting an established procedure: firstly the geometric model is defined by a modular grid in the main directions, then the structural system fitting such mesh is located and the elements (beams and columns for a moment resisting frame system) are designed. The fulfillment of such objective is not trivial; in fact, although the geometric model should be compatible with the results of a field survey (global dimensions, building height, plant shape etc.), the exhaustive definition of the structural model and of the dimensions of its elements depend on a number of parameters that are not all easily available at a territorial scale. In order to complete modelling process, then, it is often necessary to rely on engineering judgement, and on a deep knowledge of design codes applying at the time of construction.
Following the logic process that is at the base of building design it is possible to trace its main steps and to select the model input variables that have a discriminative role.
The steps are summarised in Figure 4 and are listed below:

- *Geometric/structural model*. With this model global building dimensions L_x, L_y and L_z together with the geometry associated to the structural system are reproduced. The use of a three-dimensional (3D) module, of linear dimensions a_x, a_y and a_z, allows the definition of a generic plant shape and building height. At the same time, having individuated a 3D mesh in direction x y and z, it is possible to locate the elements that play a role in the horizontal bearing system (columns and beams). In particular, column elements connect two subsequent joints of the structural mesh that are aligned on the same vertical, whether beam elements are located along horizontal joint connections in x or y direction. Elements of discontinuity of the mesh grid, such as the stairs n_s, are explicitly considered.
- *Elements design*. Columns and beams (resisting elements) identified in the previous step are designed (element's transverse section and reinforcement); to this end prescribed code rules (seismic or non seismic code) and design practices related with the construction age, together with common detailing criteria at the territorial scale, are considered.
- *Mechanical model and evaluation of seismic capacity.* Strength and/or deformation capacity of a single element are established depending on material properties and on member mechanical

model. The global seismic capacity, in terms of lateral strength and deformation supply, is determined with non-linear analysis for the building model.

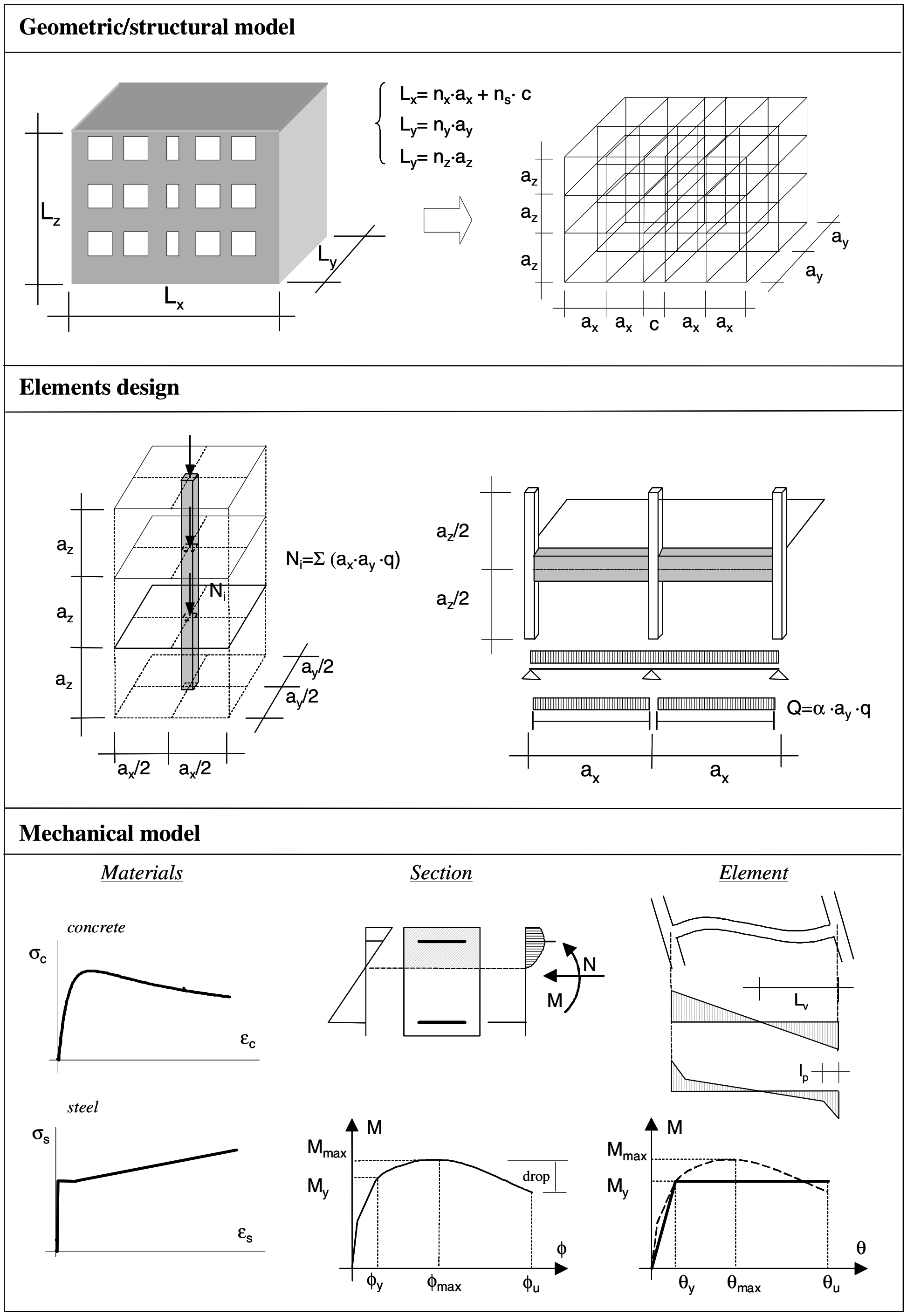

Figure 4: Main steps of the building generation process

In the following sections the three subsequent phases of the generation process are exposed, evidencing the relative modelling parameters.

Geometric/structural model

Structural model identification depends on the choice of a number of parameters that allow the clear definition of dimensions and structural mesh-grid of the building. Adopting a 3D mesh with variable module's linear dimensions a_x , a_y , a_z it is possible to reproduce a geometric model that is globally compatible with surveyed data (global building dimensions L_x and L_y and L_z); at the same time the repetition of x, y and z module, defines a structural mesh of a number of n_x, n_y and n_z modules. The choice of dimensions a_x , a_y , a_z not only depends on geometric/morphologic aspects (eg. inter-storey height for a_z), but most importantly on structural aspects such as minimum or maximum bay length.

Global building dimensions in plant and elevation, then, may be easily expressed as a function of the aforementioned parameters; for a rectangular shaped building:

$$L_x = n_x \cdot a_x + n_s \cdot c \quad \text{with} \quad a_x \in \lfloor a_{x,\min}, a_{x,\max} \rfloor \tag{1}$$

$$L_y = n_y \cdot a_y \quad \text{with} \quad a_y \in \lfloor a_{y,\min}, a_{y,\max} \rfloor \tag{2}$$

$$L_z = n_z \cdot a_z \tag{3}$$

with n_x and n_y bay number in x and y direction and n_z number of storeys. The term $n_s{\cdot}c$ in eq. (1) represents the discontinuity caused by the stair module (n_s is the number and c is the amplitude of stair modules), which is explicitly considered. Limits $a_{i,min}$, $a_{i,max}$, with i= x, y can be determined combining the information on L_i and n_i (first and second section data); when second section is unavailable engineering judgement has to be applied to control the generation process.

Generally, for each geometric model having global dimensions L_x, L_y and L_z it is possible to consider a number of structural models depending on the combinations $a_i{\cdot}n_i$ that respect the (1) (2) and (3). Moreover, for each structural model, it is possible to define a number of sub-models depending on the number and position of its structural elements. Although column number and location is uniquely determined for a structural model, in fact, this is not true for beams because of their different role in the global 3D frame (gravity and/or seismic loads). In the geometric/structural model adopted herein, beam number and position are determined with the aid of the number of plane frames in x and y direction n_{px} and n_{py}; parameter n_{px} and n_{py} define a group of column and deep beams connected at the mesh-grid joints of the planes y=const. and x=const.

Finally, another significant parameter for the definition of the structural model is the main column orientation. When seismic design rules are applied it is hypothesized that half percent of the columns is oriented in x and y direction respectively; on the other hand, this rule can't be applied for non seismic design. In the latter case, considering that column orientation follows architectural rules, it is assumed that perimeter columns and those adjacent to stair module are oriented so to lay inside the infill thickness. For the "other" columns of a gravity load designed frame, orientation can be assigned randomly. Thus, in order to evaluate main orientation effect, two limit schemes are adopted for the "other" columns, considering for each direction x and y the extreme situations (OR=1) strong column (OR=0) weak column orientation. Main column orientation effect may be significant for tall buildings, where transversal sections of the bottom floor columns may be very deep.

Elements design

In order to proceed with elements design, i.e. to determine elements transverse section and steel reinforcement, a number of rules affecting the entire design process have to be established.

They may be summarised in :

- definition of external loads
- definition of analysis model
- material design characteristics

External loads are assigned depending on if seismic or non seismic design is performed; because the entire design process is affected by this choice it is necessary to have an a priori clear distinction. By the knowledge of building location and year of construction it is possible to establish seismic zoning of the area at the time of construction and to attribute the correct code (seismic or non seismic) for design.
Definition of analysis models is strongly influenced by common practice rules and manuals adopted at the age of construction. For non seismic design it can be stated that generally the design of columns and beams was decoupled; columns are then designed for centred axial load, whether for beams both extreme clamped model or continuous models are adopted.
Material properties selected for design derive from prescribed codes and considering steel and concrete types commonly used at the age of construction. Moreover, code principles and manual's rules help in the establishment of minima transverse section dimensions and prescribed reinforcement percentage.

Evaluation of seismic capacity

Lumped plasticity model for the elements is considered; in particular, because only flexural behaviour is accounted for (brittle element's failure is not considered at the present stage), a moment rotation M-θ law, depending on geometric and mechanical characteristics of the element's end sections, has to be found. Existing mechanical and/or experimental capacity models [6], [7], [8] allow to define yielding and ultimate deformation capacity for the elements; the latter is conventionally determined for a prefixed drop (15%-20%) of the maximum flexural strength of the element. These mechanical model are fully characterized by concrete compressive strength f_c and steel yielding strength f_{sy}. In our model, beam and column's flexural behaviour is represented by an elastic-plastic M-θ law, as shown in Figure 4. The M - θ relation is determined by yielding moment M_y and by yielding θ_y and ultimate θ_u rotations evaluated following the Panagiotakos et al. proposal [9].
Building capacity is determined in the hypothesis that plastic mechanism forms for the structure. Assuming a number i of pre-defined collapse mechanisms (Fig. 5) for each structural model [10] the base shear $V_{b,i}$ are evaluated by equilibrium relations, and ultimate roof displacement $\Delta_{u,i}$ are determined as a function of minimum ultimate rotation θ_u for the structural elements; linear distribution of the horizontal seismic forces is assumed.

$$V_{b,1} = \frac{\sum M_c^k + \sum_{i=k+1}^{n} \sum M_b}{\sum_{i=k+1}^{n} H_i \cdot (H_i - H_k)} \sum_{i=1}^{n} H_i \,; \quad V_{b,2} = \frac{\sum M_c^1 + \sum M_c^k + \sum_{i=2}^{k-1} \sum M_b}{\sum_{i=1}^{k-1} H_i^2 + \sum_{i=k}^{n} H_k H_i} \sum_{i=1}^{n} H_i \,; \quad V_{b,3} = \frac{2 \cdot \sum M_c^k}{\sum_{i=k}^{n} H_i \cdot (H_k - H_{k-1})} \sum_{i=1}^{n} H_i \tag{4}$$

In the (4) indices 1, 2 and 3 refer to the considered plastic mechanism, M_c^k $(= M_{c,y}^k)$ represent the generic yielding moment at the base section of k[th] floor columns, M_b $(= M_{b,y})$ is the generic yielding moment for beam's ends and H_i is the i[th] storey height to foundation level.

$$\Delta_{u,1} = \theta_u \cdot (H_n - H_k); \quad \Delta_{u,2} = \theta_u \cdot H_k\,; \quad \Delta_{u,3} = \theta_u \cdot (H_k - H_{k-1}) \tag{5}$$

Global seismic behaviour, then, is represented by base shear coefficient $C_{b,i}$ (base shear $V_{b,i}$ versus seismic weight W) and the corresponding lateral $(drift_u)_i$ (roof displacement versus building height):

$$C_{b,i} = \frac{V_{b,i}}{W} \tag{6}$$

$$(\text{drift}_u)_i = \frac{\Delta_{u,i}}{H_n} \tag{7}$$

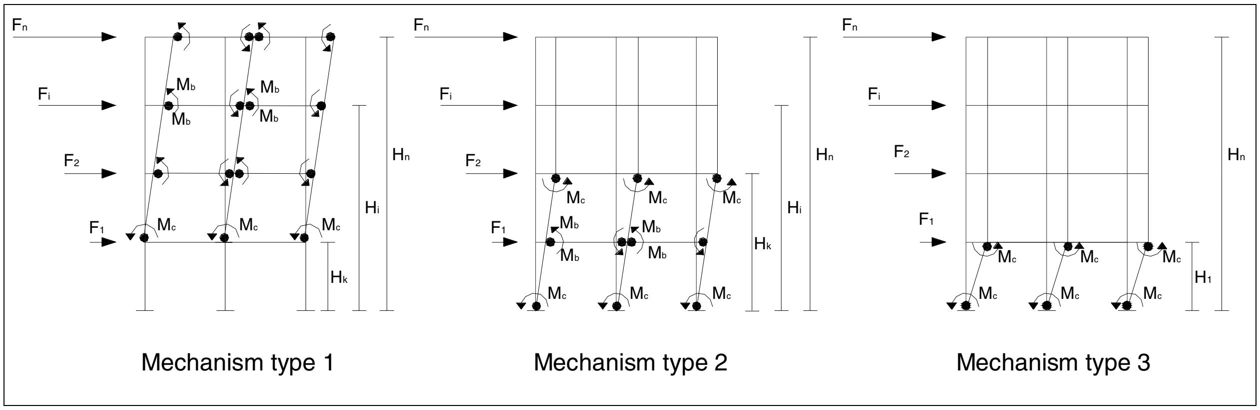

Figure 5: Collapse mechanisms

Such way, a number of $3 \cdot n_z$ mechanisms is analysed, with 3 number of pre-fixed mechanisms and n_z number of storeys; conservatively, building capacity is assumed as the minimum C_b among the evaluated ones, and by the corresponding $drift_u$. In Table 1 adopted model parameters are resumed.

MODEL PARAMETERS			AVAILABILITY
Geometric	Plant dimensions	L_x , L_y	ISTAT data
	Elevation data:		
	height	L_z	Plan-volumetric survey
	number of storeys	n_z	*(Survey form – first section)*
	inter-story high	a_z	
Structural	Bay length in x, y direction	a_x , a_y	Engineering judgment
	Number of stairs	n_s	
	Number of x and y plane frames	n_{px} , n_{py}	Field survey
	Column orientation	OR	*(Survey form – second section)*
Mechanical	Steel reinforcement (%)	ρ_s	Codes Manuals Database
	Material properties		
	concrete	f_c	
	steel	f_{sy}	

Table 1: Model parameters with relative availability

SEISMIC CAPACITY OF A BUILDING CLASS AT A TERRITORIAL SCALE

The generation process and the evaluation of seismic capacity described in the previous sections allow to reproduce a generic single building model and to determine its seismic supply in terms of lateral strength and drift. Obviously, when the vulnerability analysis is performed at a territorial scale, the variability of morphologic/geometric/structural configurations within the building stock is very large and it is necessary to suitably account for it in the assessment procedure. A number of building models reproducing the building stock, then, have to be generated and their response investigated; in this process the grouping of buildings in suitable defined classes helps to reduce the indiscriminate variation of some parameters and to guide the analysis towards more useful results. First of all, in order to reduce parameters dispersion, the entire building stock is subdivided in macro-classes. In the present work we refer to the sole rectangular morphologic shape and to the 3D frame structural type; this choice doesn't reduce the theoretical validity of the method for other morphologic and/or structural configurations. Within this typology building class is defined in terms of construction age (i.e. code class) and number of storeys. Referring to a building class, then, it is possible to determine the variation (distribution) of the relative model parameters in the investigated territorial area. To this end, it is necessary to rely on building inventory as made disposable from (partially or totally filled) survey forms. In particular geometric data are necessary; without this knowledge level it is not possible to proceed in the analysis. Information on the structural system, as contained in the second section of the form, allows to have a better definition of parameters distribution; when these data are missing engineering judgement has to be applied, but the variability of the second section parameters becomes consequently larger. In order to complete building model characterization, finally, material properties (f_c and f_{sy}) with the relative distribution and percentage of reinforcing steel for the elements have to be assigned; these parameters are obviously not collectable in survey forms, thus the relative distribution need to be chosen based on the knowledge level of construction materials and design code rules and regional databases.

With the established (determined and/or assigned) parameters distribution for a class at a territorial scale, then, a number of building models are generated for such class, that constitute the base for capacity analysis. The sample building stock artificially reproduced is analysed and seismic capacity in terms of base shear coefficient and ultimate lateral drift is determined. The relation of the model generation parameters with building class capacity, next, is evaluated through the response surface method. In particular, for both C_b and $drift_u$ (dependent variable Y_i with i= 1, 2), response surface in the form:

$$Y_i = b_{o,i} + \sum b_{j,i} \cdot x_j \tag{8}$$

is built as a function of the independent input variables x_j.

This analytical representation is very useful to determine the influence of single parameters on seismic capacity for a class. The evaluation of response surface and the definition of parameters distribution allows to determine vulnerability curves for a building class. The latter expresses, for each value of capacity, the probability that the building class have a capacity lower of an assigned one. To this end, a crude Montecarlo simulation is applied; territorial parameter distribution are the input for the simulation, whether response surface gives capacity for each combination of the input variables considered in the simulation. This way it is possible to explicitly evaluate the effect of parameter dispersion (major or minor knowledge level) on capacity at a territorial level. In the next section, an illustrative example will be presented.

EXAMPLE

It is shown the vulnerability assessment for the building stock of a small town, in Campania region (southern Italy). The buildings are all constructed in the age '60, before seismic zoning of the area, thus they are gravity load designed. Two building classes of 3 and 6 storeys are considered; only rectangular shaped, moment resisting type frames are evaluated. Adopting the generation process described in the previous sections the building stock is artificially reproduced; it is supposed that horizontal slabs resist mainly in the y (transverse) direction. Hence results presented refer to the sole y direction.

In order to illustrate the influence of a major or minor knowledge of the built environment characteristics, different hypothesis on the level of knowledge on model parameters are considered. The distribution of global geometric parameters L_x, L_y and a_z for each class are known by the field survey (section one of the form); material properties distributions (f_c, f_{sy}) are assigned considering available databases at the regional scale. Information on other parameters (bay length a_x, a_y, number of stairs n_s, number of plane frames n_{py}, column orientation OR) varies following two hypothesis:

(a) distribution and range of variation assigned by engineering judgement (no data on second section of the survey form);
(b) distribution and range of variation derived from survey (second section of the survey form).

Parameters		distribution	mean	C.O.V.
L_x	[m]	normal	36.00	30%
L_y	[m]	normal	13.50	30%
a_z	[m]	-	3.00	-
a_x,a_y	[m]	uniform	4.00	12.5%
n_s		uniform	-	[1, 2]
n_{py}		uniform	-	[2, n_x]
OR		uniform	-	[0, 1]
f_c	[N/mm^2]	normal	24.32	31%
f_{sy}	[N/mm^2]	normal	370	14%

Table 2: Geometric, structural and mechanical properties

Combining these two hypotheses (low and high knowledge levels) for each of the structural parameters, it is possible to evaluate the influence of the single input variable on seismic capacity.
In Table 2 the distribution of geometric and mechanical parameters and the distribution of the structural parameters relative to the first hypothesis are shown. With this first assumption, applying the procedure presented in the previous section, the vulnerability curves in terms of C_b and $drift_u$ for 3 and 6 storey classes are derived; in Figure 6 results are shown. As it can be seen the influence of n_z on capacity is significant; this confirms the choice of n_z as a discriminative parameter to define a building class. The results of this first analysis are referred to as case 1.

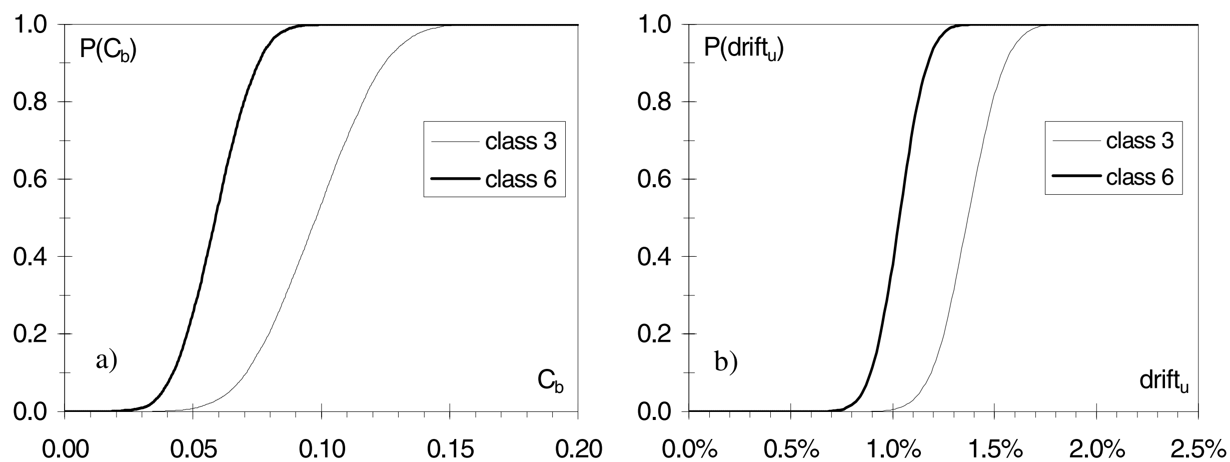

Figure 6: Vulnerability curves for 3 and 6 storey building class: a) vulnerability curves in terms of C_b; b) vulnerability curves in terms of $drift_u$

In order to emphasize hypothesis (b), starting from distribution of Table 2 for each structural parameter, the same distribution is considered minimizing the range of variation of the parameters.
This way, applying the hypothesis (b) to the number of plane frames n_{py}, two other cases are derived: case 2 considers n_{py} equal to the number of n_x bays (maximum number) and case 3 considers the minimum n_{py}, corresponding to the sole two perimeter frames; case 1 is evaluated in the hypothesis of uniform distribution of plane frames in the range [case3, case2].
As it can be seen (Figure 7) the influence of plane frames is significant both for 3 and 6 storey class; in fact, the C_b vulnerability curves shift sensibly (~30%) from case 3 to 1 and from 1 to 2.

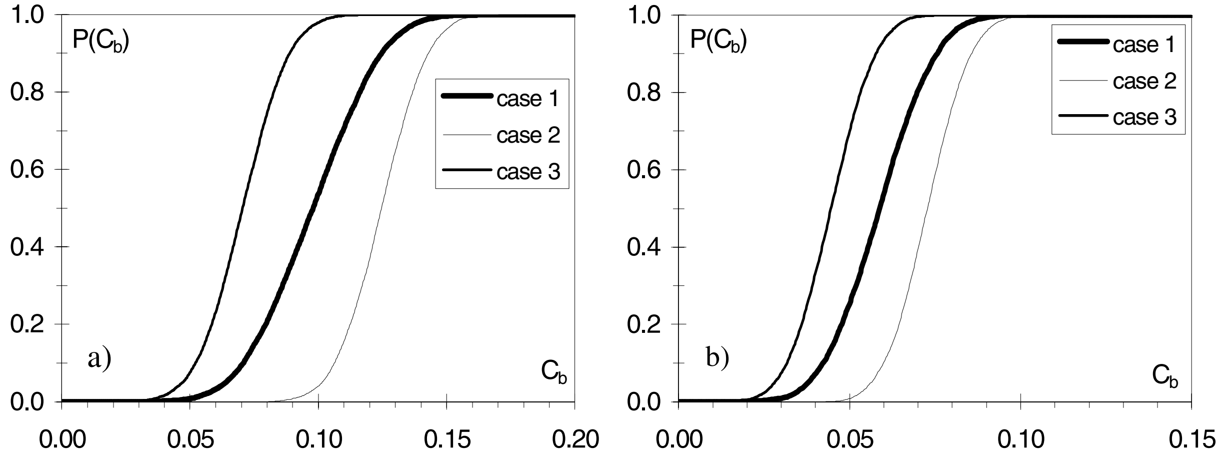

Figure 7: Vulnerability curves in terms of C_b for hypothesis (b) applied to the number of plane frames; case 2 maximum number, case 3 minimum number: a) 3 storey class; b) 6 storey class

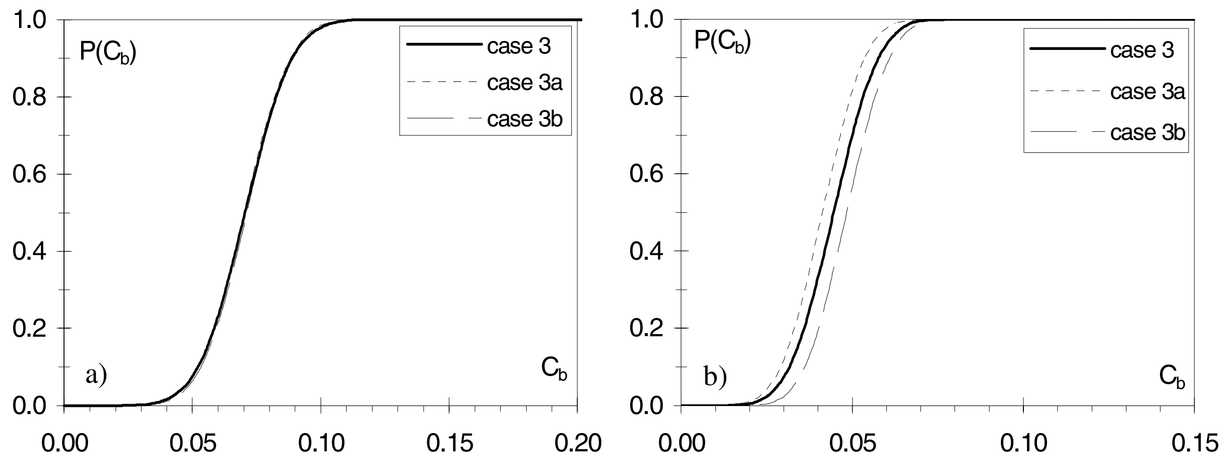

Figure 8: Vulnerability curves in terms of C_b for hypothesis (b) applied to the bay length; case 3a minimum bay length, case 3b maximum bay length: a) 3 storey class; b) 6 storey class

The maximum number of plane frames (case 2) corresponds to modern seismic design of buildings, whether case 3 is representative of gravity load design rules; the latter, then, is more significant for the chosen building stock. Hence, the effect of the remaining parameters is investigated starting from this case.

In particular two other cases regarding the variation on mean bay length parameter are investigated: case 3a considers the range [3, 4] and 3b the range [4, 5] . As it can be seen in Figure 8a the reduction of the range of variation for bay length, a_x, a_y, doesn't influence significantly on the lateral strength for the 3 storey class, whether it is more important for 6 storey class.

This effect is confirmed also for the two limit hypotheses (OR=0 and OR=1) adopted for column orientation, as shown in Figure 9 and 10. Column orientation influence is evident especially when transversal sections of the bottom floor columns are very deep; this depends from mean bay length but most of all from the number of storeys (building height). In fact, for 3 storey class the orientation effect is negligible, whether for 6 storey class (high building) this parameter plays a fundamental role. The knowledge of main column orientation, then, is important especially for tall buildings.

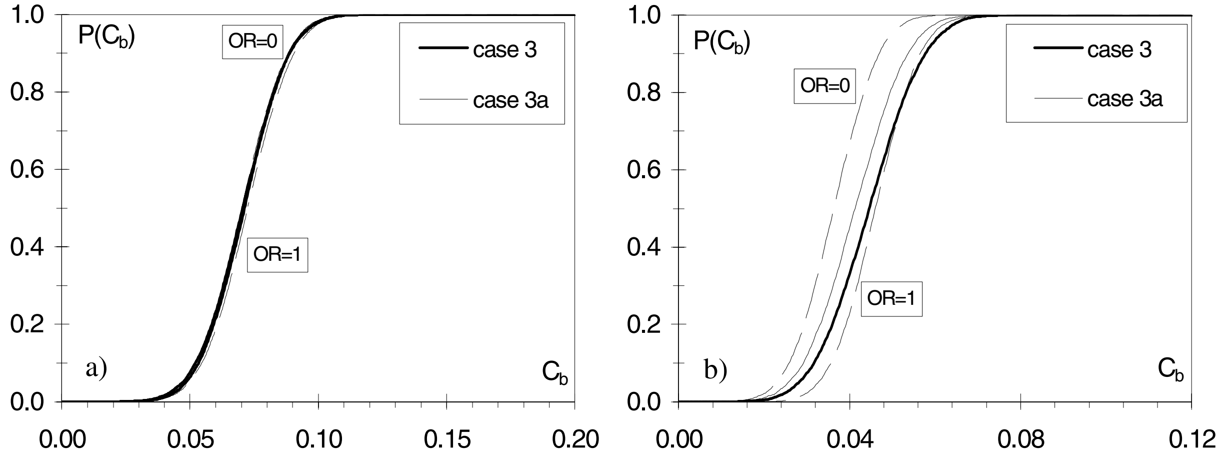

Figure 9: Vulnerability curves in terms of C_b for hypothesis (b) applied case 3a for OR=0 and OR=1: a) 3 storey class; b) 6 storey class

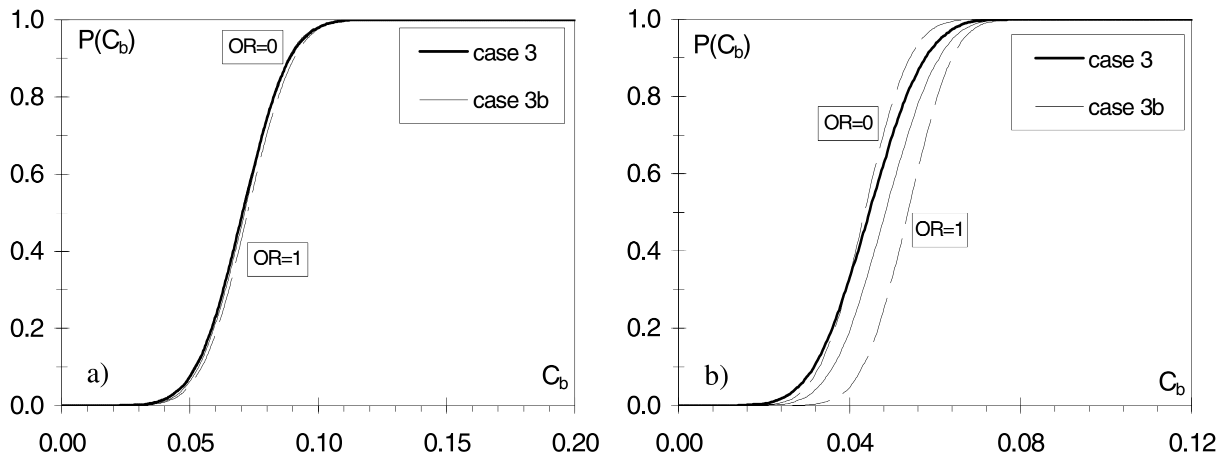

Figure 10: Vulnerability curves in terms of C_b for hypothesis (b) applied case 3b for OR=0 and OR=1: a) 3 storey class; b) 6 storey class

CONCLUSIONS

In the present work a new procedure to evaluate seismic capacity for a building class is proposed that enables to reduce dispersion on results depending on the knowledge level of the built environment. Building classes are defined by construction age (i.e. code class) and number of storeys, and their capacity is determined in terms of base shear coefficient and global drift. Adopting the generation procedure presented in the paper, it is possible to artificially reproduce a building stock accounting for the real distributions of building (model) parameters at the territorial scale.

Building capacity for the sample buildings of a class is evaluated and vulnerability curves are derived in terms of lateral strength, C_b and global ultimate, $drift_u$. Vulnerability curves represent the percentage of buildings in a class that undergo prefixed capacity thresholds; they are very useful in a preliminary vulnerability study at a territorial scale in order to have a measure of seismic damage potential in an area and/or to plan investments for building upgrading. Moreover, vulnerability curves help to highlight the influence of single model parameters and on the relative knowledge level on building response, as it is shown in the illustrative example presented in the previous paragraph. Results of our analysis evidenced

the importance of some structural parameters on global seismic response: given a building class the number of plane frames is a fundamental indicator for lateral strength, followed by the mean amplitude of the bay length and the main column orientation; latter parameter is significant for tall buildings.
When the knowledge level of the built environment is high (for example when the building inventory based on the proposed survey forms is complete) it is possible to reduce uncertainties on model parameters and therefore to limit dispersion on results. On the other hand, when only first section data are available from survey form, the definition of structural model has to rely on engineering judgement and more “possible” configurations of structural parameters defining the building models are considered; as a consequence, results dispersion increases. The knowledge level of the building stock for the investigated area, then, is very important and has a significant influence on the evaluation of seismic capacity for a building class.

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