International Journal of Design Sciences & Technology

Volume 21 Number 1

Grazia Lombardo and Chiara Cicero (2015) Analysis of seismic vulnerability for urban centres, *International Journal of Design Sciences and Technology*, 21:1 39-58

ISSN 1630 - 7267

europia

ISSN 1630 - 7267

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International Journal of
Design Sciences and Technology

Volume 21 Number 1

ISSN 1630 - 7267

International Journal of ***Design Sciences and Technology***

Analysis of seismic vulnerability for urban centres

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The current scientific community has been interrogated about the need for a single pre-earthquake methodology for the analysis and evaluation of the seismic vulnerability finding it necessary to define a clear and simplified method encoded at a European level. Based on this issue, the present paper shows the first results of a study that has the objective to define, for the urban centre, an expeditious method for the analysis and evaluation of vulnerability at aggregate scale. It should overcome the detected criticalities in the two most widespread methods: the statistical method and the analytical method. Over to define the method of analysis and evaluation of the seismic vulnerability of the urban centres new compilation forms, for structural units (SeiV-US) and aggregates (SeiV-AS) and their manual of compilation have been defined. The new forms have been verified on the test site (Ortigia – Syracuse - Italy) in order to better define the identified "list of indicators of vulnerability". These indicators of vulnerability, contained in the new forms, refer to the entries of the CLE, GNDT and AeDES forms and to their manuals.

Keywords: seismic risk, vulnerability, urban centre, aggregates

1 Introduction

The tragic earthquakes that occurred in Italy, and not only, in the last decades have maintained high attention on a theme that has already been widely discussed by scholars over the past thirty years. Scholars believe that the policy of conservation of the existing buildings must dialectically confront the issue of seismic safety. However, the way in which we deal with these topics has a number of critical issues and is still confused and ineffective.

For new buildings, the achievement of an adequate level of seismic safety is inherent in compliance with earthquake standards. Whereas, for the masonry buildings of historic centres, this guarantee is entrusted to a practice which is far more complex, and it consists in respecting the logic with which they were built.

The present article describes a methodology of reading of urban centres for the comprehension and reduction of their seismic vulnerability. This methodology was applied to a high seismicity case study within the Sicilian territorial context.

1.1 Seismic vulnerability

In the past the "vulnerability" concept referred to building and at urban scale. Seismic vulnerability at building scale was defined as the susceptibility to damage in terms of structural characteristics of the single building at the time of the seismic event. Today, to analyze or evaluate the seismic vulnerability of a single building, several compilation forms are used. Since the Irpinia earthquake (1980) some forms have been defined for damage detection. Then, based on the experience of subsequent earthquakes (Abruzzo 1984, Basilicata 1990, Reggio Emilia 1996) these forms have evolved. Today, the most widespread are GNDT (1st and 2nd level) [1, 2] and AeDES [9] forms.

AeDES form allows you judge the usability of a building in the post-earthquake. Whereas GNDT (2nd level) form allows you to reach a numerical value of seismic vulnerability just as the analytical method. These forms can be filled in accordance with different levels of “quality of information” regarding the structural, morphological and geometrical characteristics of the single building. In particular, to be filled in, these forms need detailed knowledge that requires internal surveys and specific investigations on the building itself.

As well as in Europe, in the US the latest trends in the field of seismic risk leading to operate with mechanical models. These, although simplified, using modern seismic hazard assessments (PGA, spectral ordinates, spectral response). In particular the methodology HAZUS - HAZard in the United State [16] developed by FEMA - Federal Emergency Management Agency, is now the standard in the analysis of seismic risk building for the United States. These types of activity are difficult to apply to an entire urban centre because they requires high effort and long time to conduct the detailed geometric and constructive survey of the studied buildings.

Instead, urban vulnerability was defined as the sum of the vulnerability of the single buildings that make up the city. Thus, this is without taking into account that other complex factors come into play affecting the correlation between the buildings. One of the existing and more widespread methods for the evaluation of urban seismic vulnerability in Italy is the statistical method (based on statistical data and Braga matrices [6]). This is utilized by municipalities to elaborate the scenery of seismic risk as well, and it is exclusively based on data related to the characteristics of the bearing structure, classified according to the EMS ’98 [15], and on the number of residents involved. Over time, the results obtained by this method did not coincide with the real effects that occurred during subsequent earthquakes.

The difficulty of the study related to the seismic issue of the urban centres emerged for the first time in the manual for the compilation of 1st level GNDT forms. It reads [1] “it is therefore necessary to identify, at urban scale, the aggregate, which is constituted by a set of non-homogeneous structural elements and which can interact under a seismic action (or dynamic in general)" … "An aggregate may consist of one or more buildings grouped. It means that there must be a contact, or a link, more or less effective in buildings generally with different design characteristics [...] within aggregates, buildings are identified, these are defined as homogeneous structural units from sky to earth [...]". This definition highlights the character of interdependence of the buildings in their overall configuration [13] and confers the role of analysis module for the study of urban vulnerability to the aggregate. The recent Italian seismic code [17] has also introduced the need for the recognition of aggregates giving them a key role in the planning of measures for the conservation and safety of the city. The aggregate is defined as: “... consisting of a set of parts that are the result of an articulated and not unitary genesis, because of multiple factors ...” [19].

Recently, a new pre-earthquake analysis method has been defined (CLE - Boundary Condition for Emergency) [18] to manage the post-earthquake emergency. The CLE was investigated in 2010, along with several possible "boundary conditions" for the urban settlements, as part of the Project Urbisit [4]. This is relative to a "Preparatory study for the development of addressed tools to the application of seismic rules in historical settlements". Mauro Dolce coordinated the workgroup for the development of the CLE forms that, on an experimental basis, have recently been applied to the city of Faenza (Italy).

Five types of forms have been developed related to: ES-Strategic Building, AE-Emergency Area, AC-Infrastructure Accessibility/Connection, AS-Structural Aggregate and US-Structural Unit. In order to manage the post-earthquake emergency at an urban level, intervention strategies are defined through the identification of properly placed buildings, roads and areas in the territory. In particular, the US and AS forms regard just the interfering structural units and aggregates that overlook the emergency areas and the infrastructures of accessibility and/or connection. The buildings and aggregates which interfere with the activities of post-earthquake emergency are characterized by a front, whose height (H), measured to the impost of the coverage, is greater than the distance between the US and the opposite limit of the road (L) or the nearest point of the perimeter of the square (d). The structural unit form (US) is substantially based on the AeDES form. Whereas the aggregate form (AS), being in an intermediate scale of analysis between the single building and the urban centre, is an element of novelty. The form takes into account the factors resulting from contiguity between different structural units in addition to the main morphological, geometric, construction and structural elements of the aggregate.

1.2 Basic ideas for a unified vulnerability inspection method

Based on these issues, the current scientific community has been asked to define a single pre-earthquake methodology for the analysis and evaluation of the seismic vulnerability of urban centres. This methodology must be able to overcome the detected criticalities in the existing methods. Even if the extreme specificity of the urban centres would require a detailed analysis of the individual case, their complexity should lead to the formulation of simplified models.

In 1988 Mauro Dolce [11] expressed the need for a new methodology for analysis and evaluation of vulnerability finding it necessary to define a clear and simplified method, as homogeneous as possible, encoded at a European level. This should allow you to read, interpret and represent the characteristics of the vulnerability of the built environment in order to create a single database. Through this database we can trace "categories of *isovulnerable* buildings defined by a list of structural characteristics already considered significant based on experience and expert judgment and subsequently validated by the statistics of their damage". Based on this view, buildings can be considered organisms whose vulnerability can be described through indicators that contribute to define the global vulnerability qualitatively [12].

For this purpose, Mauro Dolce proposes the creation of a "list of significant structural characteristics from the point of view of their influence on damageability". Today, this need to classify buildings in accordance with their vulnerability has not found significant acceptance and widespread application for minor building of the urban centres. Instead, many applications and experiences have been conducted with the aim of improving the response of the specialist buildings to the earthquake.

1.3 Aim of research

In line with the view expressed by Mauro Dolce, a study was initiated whose objective is to define a simplified pre-earthquake method, for the analysis and evaluation vulnerability of the urban centres. This simplified and expeditious method could be adopted by municipalities to elaborate civil protection plans.

It should overcome the detected criticalities in the two most widespread methods: the statistical method (based on statistical data and Braga matrices) and the analytical method (GNDT and AeDES forms). The structure of the new method is divided into a first phase of analysis and a subsequent phase of evaluation of the seismic vulnerability of the urban centres.

Results reported in the present paper regard the analysis of seismic vulnerability. Within this phase, the objective is the definition of a pre-earthquake methodology to read the urban centres. This methodology is based on more detailed knowledge of the built environment, if compared to the statistical method, and on less detailed knowledge of the built environment, if compared to the analytical method. In fact, the optimum balance should be found between the knowledge of the vulnerability, of structural units and aggregates, and the effort required to obtain it.

2 Method of research

Within this phase of research, analysis of the seismic vulnerability of the urban centres was carried out through the elaboration of new compilation forms, for structural units (called SeiV-US) and aggregates (called SeiV-AS) and their manual of compilation.

The entries related to structural, geometric and constructive indicators contained in the GNDT [1, 2], AeDES [9], US-CLE and AS-CLE [5] forms and in their manuals of compilation, are to be studied and compared. These “indicators of vulnerability” have been revised and updated, for structural units and aggregates, from the point of view of their influence on damageability, based on the experience of the last seismic events in L’Aquila (2009) and Emilia Romagna (2012).

As proposed by Mauro Dolce [11], in this study, structural units and aggregates are considered organisms whose vulnerability can been identified through the observation of behavioural symptoms (indicators of vulnerability) in terms of susceptibility to damage? The new forms for US and AS are structured on the list of these “indicators of vulnerability”.

To make the method expeditious, the data contained in the new forms is detectable through external inspections, without conducting geometric surveys and/or investigations on buildings. Unlike the AeDES and GNDT forms, for which several levels of compilation can be chosen by the technicians, the accuracy level of the proposed forms is predefined with a unique compilation level. The result is to be the objectification of the vulnerability characteristics in order to have the same quality of information. Moreover, the forms are defined to be filled by non-specialized, but appropriately trained, technicians under the supervision of a coordinator.

The new forms have been verified on the test site (Ortigia – Syracuse - Italy) in order to assess if the identified “list of indicators of vulnerability” are able to describe the damageability of the urban centres in an exhaustive manner. Ortigia is still characterized by some roads of classical structure. Its current appearance is almost entirely determined by the eighteenth century reconstruction, which took place after the earthquake of 1693, and by the significant construction that took place during the nineteenth century. A progressive occupation of open spaces by spontaneous constructions occurred in accordance with a development for clogging. Ortigia is still subject to continuous transformations and variations between adjoining structural units, which are carried out for recasting between buildings or for fractionations [14].

Within this study 7 aggregates and about 160 structural units were identified and considered for the test (Figure 1). These belong to the ancient district of Ortigia called "La Graziella".

Concerning the first phase of research, related to the analysis of urban centres and proposed in this paper, the objectives achieved, through the elaboration of new US and AS compilation forms and the collection data during the site inspections in Ortigia were a prerequisite for the second phase of research related to the evaluation of the seismic vulnerability of urban centres.

Figure 1 Area of experimentation in Ortigia (Siracusa – Italy)

2.1 The indicators of vulnerability

The identified indicators of vulnerability, contained in the new forms, refer to the entries of the CLE, GNDT and AeDES forms and to their manuals. The entries that influence the damageability have been revised based on the last seismic events and on the outcomes obtained by the application in Ortigia. Based on this, some entries have been added or modified as shown below. Table 1 shows the list of identified "indicators of vulnerability" for the **structural unit forms** (SeiV-US) and the entries related to the reference forms.

The entry "The US is a ruin" has been added (Figure 2). The entry "Period of construction and rehabilitation" of the US-CLE, in this case, has been subdivided into two entries "Period of construction" and "Period of intervention" whose ranges are related to the endorsements of the seismic constraint in the studied urban centre. As for the "Bearing vertical structure", the classification of masonry proposed by Di Pasquale, Dolce and Martinelli [10] was considered. This classification takes into account the quality of masonry as follows: good quality, medium quality and poor quality (Figure 3). The levels of masonry quality influence the damageability of the building in different ways.

Moreover, the entry related to the "Bearing horizontal structure", already present in the AeDES form, has been added in accordance with Di Pasquale, Dolce and Martinelli's theory [14], which considers this entry in the classification of vulnerability class in addition to the bearing vertical structure. Four types of bearing horizontal structure have been considered: pushing; deformable; semi-rigid and rigid. For the various types of bearing horizontal structure, the damageability level depends also on the masonry quality. In fact, to understand the influence on damageability we have to observe that, for example, in medium or poor masonry structures, the replacement of the original roof or slab with a new one made with reinforced concrete or steel structure (rigid) is, in most cases, negative in the presence of a seismic event [14, 7, 20] (Figure 4).

Table 1 Indicators of vulnerability for US and the entries related to the reference forms

INDICATORS OF VULNERABILITY	REFERENCE FORMS			
	US CLE	AS CLE	AeDES	GNDT
US is a ruin	-	-	-	-
Period of construction	Section 3	-	Section 2	Section 5
Period of intervention	Section 3	-	Section 2	Section 5
Bearing vertical structure	Section 2	-	Section 3	Section 7
Reinforcing elements	Section 2	-	Section 3	-
Bearing horizontal structure	-	-	Section 3	Section 7
Location of the US in the aggregate	Section 2	-	-	-
Specialist US	Section 2	-	-	-
Number of floors	Section 2	-	Section 2	Section 3
Presence of basements	Section 2	-	Section 2	-
Average height of the plans	Section 2	-	Section 2	Section 3
Total height of US	Section 2	-	-	Section 3
Single volume	Section 2	-	-	-
Regularity of shape	-	-	Section 3	-
Juxtaposed elements or poorly connected	-	Section 2	-	-
System of openings	-	Section 2	-	-
Presence of isolated columns	Section 2	-	-	-
Presence of pilotis plans	Section 2	-	-	-
Superelevations	Section 2	-	-	-
Structural damage	Section 2	-	Section 4 - 5	Section 8
Maintenance status	Section 2	-	-	Section 6
Morphology of the ground	Section 2	-	Section 7	-
Location of the US with respect to the slope	Section 2	-	-	-

Figure 2 Picture of a ruin in Ortigia

Figure 3 poor quality masonry in Ortigia

The “Location of the US in the aggregate” influences the damageability of the building in a different way. In fact, this is reported in “Repertorio dei meccanismi di danno, delle tecniche di intervento e dei relativi costi negli edifici in muratura” in which the calculated vulnerability is corrected, in accordance with the location of the structural unit in the aggregate, applying a multiplicative factor (1 for isolated US, 0,8 for internal US, 1,1 for corner and extremities US) [3].

In some cases, the influence on damageability changes when the indicators are superior to certain values as described below: the “Number of floors” is more than 4, the “Average height of the plans” is more than 3.50 meters and the “Total height of US” is equal or more to 12 meters.

Figure 4 In L'Aquila, the heavy substituted roof caused the crumbling of the walls of the level beneath it [10]

The entry "Regularity of shape" has been added because the presence of asymmetries or no regularity in plan is a frequent cause of failures with consequent activation of torsional motions [20]. At least, the entry "Maintenance status" refers to the US-CLE form, but in accordance with the GNDT (1st level) entry about the presence and the efficiency of windows and plaster [1]. The entry "Maintenance status" does not take into account the status of systems which requires the internal survey to be assessed.

Table 2, instead, shows the list of "indicators of vulnerability" for the **aggregate form** (SeiV-AS) and the reference forms. Unlike CLE, which considers just the interfering structural units and aggregates, the proposed method aims to analyse the entire urban centre. The entry "Coverage ratio" has been added in case of AS with more than 4 US and it represents the occupation of land. Its influence on damageability changes if it is higher than 70%.

The entry "Regularity of shape" was provided just for the structural units. In this case it has been added and adapted to the aggregate. Both for structural units (US) and aggregates (AS), some damage can refer to particular constructive conditions with particular reference to the system of openings, the morphology of the ground and the contiguous buildings.

In fact, buildings with particular constructive characteristics (high walls and great openings), as churches are, have proven to be particularly vulnerable in previous earthquakes [20]. Moreover, during the earthquake which occurred in L'Aquila in 2009 some damage was facilitated also by the presence of openings in critical areas of the buildings and by the morphology of the ground [8].

Table 2 Indicators of vulnerability for AS and the entries related to the reference forms

INDICATORS OF VULNERABILITY	REFERENCE FORMS			
	US CLE	AS CLE	AeDES	GNDT
Presence od US with large spans	-	Section 2	-	-
Average height	-	Section 2	-	-
Coverage ratio	-	-	-	-
Regularity of shape	-	-	Section 3	-
Recasts or clogging	-	Section 2	-	-
Misalignment of total height US	-	Section 2	-	-
Misalignment of floors	-	Section 2	-	-
Misalignment of facade	-	Section 2	-	-
Misalignment of internal space	-	Section 2	-	-
Slender header	-	Section 2	-	-
Juxtaposed elements or poorly connected	-	Section 2	-	-
System of openings	-	Section 2	-	-
Presence of isolated columns or pilotis plans	-	Section 2	-	-
Superelevations	-	Section 2	-	-
Steeples, towers, chimneys	-	Section 2	-	-
Deteriorated or damaged US	-	Section 2	-	-
Reinforcing elements	-	Section 2	-	-
Presence of ruins	-	-	-	-
Morphology of the ground	-	Section 2	-	-
Location of the AS with respect to the slope	-	Section 2	-	-

Through the observation of damage that occurred, Guido Sarà affirmed that a widespread crisis mechanism had been detected because of action ramming caused between adjacent buildings from not aligned floors [20] (Figure 5). In addition, the buildings adjacent to abandoned constructions were damaged because of the lack of the stabilizing contribution of neighbouring cells. This shows that also the state of preservation plays an important role particularly referring to damage caused to the contiguous buildings [8].

Figure 5 damage caused by the adjacent building [20]

3 Results

3.1 The new forms

Two different forms for structural units and aggregates (called SeiV-US and SeiV-AS) and their manuals have been defined. These contain the list of the indicators of vulnerability. These have been defined starting from what is present in the literature about the existing forms, from the application in Ortigia and from the experience of the last seismic events. The forms are structured in order to be compiled on-site through an expeditious visit performed in outdoor spaces without specific surveys or invasive investigations on the built by properly trained unskilled technicians.

Table 3 SeiV-US Form

STRUCTURAL UNIT FORM					
SECTION 1 - IDENTIFICATION DATA					
1	Date of compilation			Cod ISTAT	
2	Region				
3	Province				
4	City				
5	Locality				
6					
7	Number of identification of the Structural Aggregate				
8	Number of identification of the Structural Unit				
9	Address				
SECTION 2 - GENERAL ENGINEERING CHARACTERISTICS					
10	Ruin	YES		NO	
11	Period of construction	Before 1974	After 1974		After 2008
12	Period of intervention	Before 1974	After 1974		After 2008
13	Structural classification				
	A. Bearing vertical structure	Poor quality masonry		Medium quality masonry	
		Good quality masonry		Framed structure	
	B. Reinforcing elements (masonry US)	YES		NO	
	C. Bearing horizontal structure	Pushing	Deformable	Semi-rigid	Rigid
14	Location of the US in the aggregate	Internal	Isolated	Extremities	Corner
15	Interfering structural units	YES		NO	
16	Specialist US	YES		NO	
17	Number of floors	1-4		≥5	
18	Presence of basements (N. of floors > 5)	YES		NO	
19	Average height of the plans	H≤3,50 m	3,50 m <H< 5,00 m		H≥ 5,00 m
20	Total height of US	H≤7 m	7 m<H<12 m		H≥12 m
21	Single volume	YES		NO	
22	Regularity of shape	YES		NO	
23	Juxtaposed elements or poorly connected	YES		NO	
24	System of openings	Congruous	Incongruous		Very incongruous
25	Presence of isolated columns	YES		NO	
26	Presence of pilotis plans	YES		NO	
27	Superelevations	YES		NO	
28	Structural damage	Absent	Mild	Medium-serious	Serious
29	Maintenance status	Good	Sufficient		Poor
30	Morphology of the ground	< 15°	15-30°		>30°
31	Location of the US with respect to the slope	Neither above nor below the slope		Above or below the slope	

The new form SeiV-US (Table 3) for the seismic vulnerability analysis of the structural unit consists of 3 sections:

1 identification data
2 general engineering characteristics
3 specific characteristics

Table 4 SeiV-AS Form

STRUCTURAL AGGREGATE FORM					
SECTION 1 - IDENTIFICATION DATA					
1	Date of compilation				Cod ISTAT
2	Region				
3	Province				
4	City				
5	Locality				
6	Cadastral section				
7	Number of identification of the Structural Aggregate				
SECTION 2 - GENERAL ENGINEERING CHARACTERISTICS					
8	Total number of US				
9		Number of masonry US			
10		Presence of adjacent masonry US	YES	NO	
11		Number of reinforced concrete US			
12		Number of other US			
13	Total number of overlooking US				
14		Interfering structural aggregate (≥ 30%)	YES	NO	
15	Presence of US with large spans		YES	NO	
16	Average height		H≤7 m	7 m<H<12 m	H≥12 m
17	Coverage ratio (> 4 US)		< 70%	≥ 70%	
18	Regularity of shape		YES	NO	
19	Recasts or clogging		YES	NO	
20	Misalignment	total height US (masonry US)	YES	NO	
21	Misalignment	floors (masonry US)	YES	NO	
22	Misalignment	facade (masonry US)	YES	NO	
23	Misalignment	internal space (masonry US)	YES	NO	
24	Slender header		YES	NO	
25	Juxtaposed elements or poorly connected		YES	NO	
26	System of openings		YES	NO	
27	Presence of isolated columns or pilotis plans		YES	NO	
28	Superelevations		YES	NO	
29	Steeples, towers, chimneys		YES	NO	
30	Deteriorated or damaged US (no ruin)		YES	NO	
31	Reinforcing elements (masonry building)		YES	NO	
32	Presence of ruins		YES	NO	
33	Morphology of the ground		< 15°	15-30°	>30°
34	Location of the AS with respect to the slope		Neither above nor below the slope	Above or below the slope	

Even the new form SeiV-AS (Tab. 4) for the seismic vulnerability analysis of the aggregate consists of 3 sections:

1 identification data;
2 general engineering characteristics;
3 general geological and geophysical characteristics.

In the new proposed forms (SeiV-US and SeiV-AS) the second section related to the “General engineering characteristics” contains the indicators regarding:

- vertical and horizontal structures;
- geometric and constructive characteristics;
- state of conservation;
- location.

The cataloging stage, after the compilation of such forms in an urban centre, will lead to the establishment of a consistent database that can be used in various activities by municipalities.

3.2 The manual compilation

When the new entries coincide with the ones in the CLE or AeDES form [9, 5], their definitions have not been changed in the new manual. Whereas in some cases new definitions have been drafted.

For the **structural unit**, the entry “The US is a ruin” has been added. The manual reads: “*a US is defined ruin if it has suffered meltdowns, even partial, such as to affect the box-like behavior of the structure (total collapse of coverage and/or intermediate floors). This state corresponds to the D5 level as provided by the scale of damage EMS '98”*.

The entry “Bearing vertical structure” is so defined: “*The vertical structures consist of two main categories:- Masonry structures;- Framed structures (still or reinforced concrete) or other structure in reinforced concrete. …”*. Then the manual proposes a description and a classification for the masonry structures: good quality masonry, medium quality masonry and poor quality masonry.

Relating to the entry “Regularity of shape”, the manual requires the technician to “*Evaluate presence of:*

- *Shape irregularities in the plant; plants not equipped with two perpendicular axes of symmetry , for example, plants made in L, T, U, E, P, etc;*

- *Shape irregularities in elevation; macroscopic surface variations (± 30%) with the height that create obvious protrusions or indentations”*. Unlike the AeDES form [9], the present manual considers just elements of irregularity that can be detected by means of external inspections.

Based on the definition reported by the CLE manual for the AS form, the present manual provides two classifications for the entry “System of openings” that are incongruous and very incongruous: “*the system of openings is defined "incongruous" when it is characterized by one of the conditions listed … the system of openings is defined "very incongruous" when it is characterized by at least two of the conditions listed* …”. While the entry related to the “Maintenance status” provides a “*Summary judgment on the conditions* *of maintenance of the building, referring to the state of functionality of the following indicators: plaster and window frames. Each indicator has three classifications: Z=non-existent; N=not efficient; E=efficiently. To each classification is assigned a value: Z=0; N=1; E=2. These values are added for the indicators considered. The classification of the overall state of repair will be: Poor (0-2); Sufficient (3); good (4)".*

Relating to the **aggregate**, in the proposed manual, the entry "Coverage ratio" has been added and it is defined as: "*the ratio between the total area occupied by the US and the total area of the AS. Indicate whether this value is greater or less than 70%. This field must be completed only when the total number of US is greater than or equal to 5"*. A chart pattern is reported in the manual as shown in Figure 6.

Figure 6 Chart pattern for the entry "Coverage ratio" for AS

As mentioned, the entry "Regularity of shape" has been adapted to the aggregate requests. The manual defines: "*regular form of AS when: the main dimensions (length L and width B) are in the ratio L <4B or if the AS is provided with two orthogonal axes of symmetry"*. A chart pattern is reported in the manual as shown in Figure 7.

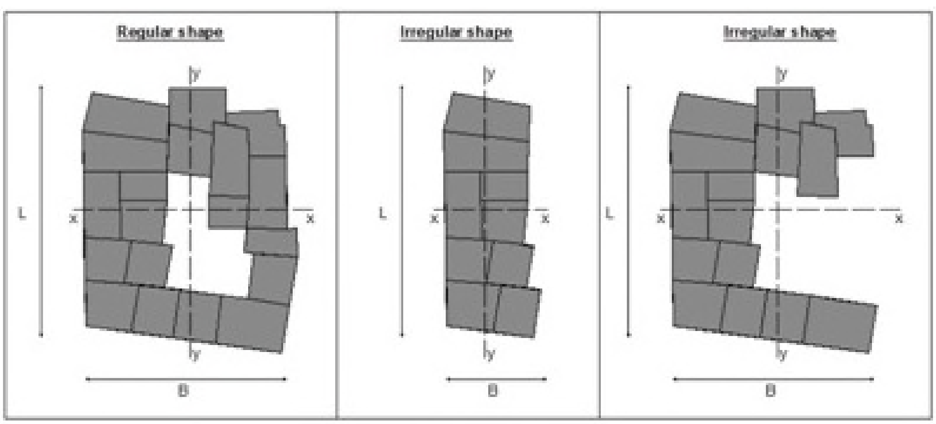


Figure 7 Chart pattern for the entry "Regularity of shape" for AS

4 Discussions

The proposed forms for structural units and aggregates (SeiV-US and SeiV-AS) have several elements of novelty as reported in Table 5. In fact, they allow technicians to overcome the detected criticalities compared with the existing forms. Their application is in pre-earthquake. They analyse the aggregate taking into account all the factors resulting from contiguity between different structural units. They analyse the entire urban centre in structural aggregates contrary to CLE, which considers just the aggregates that interfere with the post-earthquake activities of emergency. Moreover, unlike the existing ones, they are not based on an internal survey like AeDES and GNDT (2nd level). They are not based on specific investigations as GNDT (2nd level) and they provide a single level of compilation.

Table 5 Comparison between the new forms (SeiV-US and SeiV-AS) and the existing ones

	SeiV-US and SeiV-AS	CLE forms	GNDT	AeDES
Application in pre-earthquake	YES	YES	YES	NO
Analysis of the aggregate	YES	YES	NO	NO
Analysis the entire urban center	YES	NO	NO	NO
Based on an internal survey	NO	NO	YES	YES
Based on specific investigations	NO	NO	YES	YES
Single level of compilation	YES	YES	NO	NO

Table 6 Percentage of presence of indicators of vulnerability for US

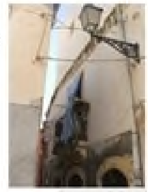
ORTIGIA	
STRUCTURAL INDICATORS	
Poor/medium quality bearing vertical structure	98%
No reinforcing elements	87%
Rigid/pushing bearing horizontal structure	70%
OTHER INDICATORS OF VULNERABILITY	
Incongruous system of openings	45%
Corner/extremities location of the US in the aggregate	39%
Presence of structural damage	29%
Irregularity of shape	25%
Poor maintenance status	20%
Superelevations	15%
Juxtaposed elements or poorly connected	13%
Average height of the plans higher than 3,5 m	6%

Table 7 Identified typological classes in Ortigia

TYPOLOGICAL CLASS	Bearing vertical structure	Reinforcing elements	Bearing horizontal structure	Presence in the urban tissue
A	Poor/medium quality	NO	Rigid / pushing	57%
B	Poor/medium quality	NO	Deformable / Semirigid	30%
C	Poor/medium quality	YES	Rigid / pushing	13%

US TYPOLOGICAL CLASS A		
Structural indicators of vulnerability	**Common indicators for the typological class**	**Variable indicators of vulnerability**
Poor/medium quality bearing vertical structure	US is not a ruin	Incongruous system of openings
No reinforcing elements	Period of construction before 1974	Corner/extremities location of the US in the aggregate
Rigid/pushing bearing horizontal structure	No specialist US	Presence of structural damage
	Number of floors between 1 and 4	Irregularity of shape
	Average height of the plans lower then 3,5 m	Poor maintenance status
	Total height of US lower then 7 m	Superelevation
	No single volume	Juxtaposed elements or poorly connected
	No presence of isolated columns	
	No presence of pilotis plans	
	No structural damage	
	Morphology of the ground plain	
	Good location of the US with respect to the slope	


A5002_US07


A5002_US03


A5003 US34


A5003 US11

Figure 8 Typological class A

The test in Ortigia highlighted that the compilation of the forms satisfy the request to be expeditious. In fact, they allow you to reach the optimum balance between knowledge of the vulnerability and the effort required to obtain it. The application in Ortigia provided further contributions to the definition of the indicators of vulnerability contained in the section “General engineering characteristics”. This enabled us to reach an exhaustive analysis of the damageability for structural units and aggregates. The computerization of the collected data allowed us to elaborate a database for every analysed structural unit and aggregate. Starting from the analysis of the data contained in the database, it is also possible to identify typological classes constituted by categories of “isovulnerable” buildings characterized by the same indicators of vulnerability as described by Mauro Dolce.

A typological study was conducted in Ortigia and the results are reported below. In the first phase, the diffusion of indicators of vulnerability was analysed for the structural units. Table 6 shows the percentage of presence of the indicators of vulnerability in the studied area of Ortigia. This table highlights that the most widely observed indicators of vulnerability are the ones that describe the structural characteristics of the units: bearing vertical structure, reinforcing elements and bearing horizontal structure. For the district “La Graziella” in Ortigia, based on the combination of these structural indicators, three typological classes have been identified as shown in Table 7.

The typological classes are characterized by a list of non-structural indicators that are common to every structural unit belonging to the class and by a list of variable indicators that are not common to every structural unit. The indicators that characterize the typological classes of Ortigia are reported in Figures 8-10. In particular, for typological class A (v. Figure 8) the variable indicators of vulnerability are:

- Incongruous system of openings (36%);
- Corner/extremities location of the US in the aggregate (31%);
- Irregularity of shape (24%);
- Superelevation (19%);

- Juxtaposed elements or poorly connected (17%);
- Presence of structural damage (11%);
- Poor maintenance status (4%).

US TYPOLOGICAL CLASS B		
Structural indicators of vulnerability	**Recurrent US characteristics**	**Variable indicators of vulnerability**
Poor/medium quality bearing vertical structure	US is not a ruin	Incongruous system of openings
No reinforcing elements	Period of construction before 1974	Corner/extremities location of the US in the aggregate
Deformable/semirigid bearing horizontal structure	No specialist US	Presence of structural damage
	Number of floors between 1 and 4	Irregularity of shape
	Total height of US lower then 7 m	Poor maintenance status
	No single volume	Superelevation
	No presence of isolated columns	Juxtaposed elements or poorly connected
	No presence of pilotis plans	Average height of the plans higher then 3,5 m
	Morphology of the ground plain	
	Good location of the US with respect to the slope	

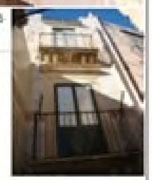




Figure 9 Typological class B

US TYPOLOGICAL CLASS C		
Structural indicators of vulnerability	**Recurrent US characteristics**	**Variable indicators of vulnerability**
Poor/medium quality bearing vertical structure	US is not a ruin	Incongruous system of openings
Reinforcing elements	Period of construction before 1974	Corner/extremities location of the US in the aggregate
Rigid/pushing bearing horizontal structure	No specialist US	Presence of structural damage
	Number of floors between 1 and 4	Irregularity of shape
	Total height of US lower then 7 m	Average height of the plans higher then 3,5 m
	No single volume	
	No juxtaposed elements or poorly connected	
	No presence of isolated columns	
	No presence of pilotis plans	
	No superelevation	
	Good maintenance status	
	Morphology of the ground plain	
	Good location of the US with respect to the slope	

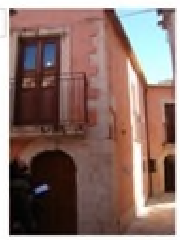


Figure 10 Typological class C

For typological class B (v. Figure 9) the variable indicators of vulnerability are:

- Presence of structural damage (73%)
- Incongruous system of openings (65%)
- Poor maintenance status (59%)
- Corner/extremities location of the US in the aggregate (35%)
- Irregularity of shape (30%)

- Superelevation (16%)
- Juxtaposed elements or poorly connected (8%)
- Average height of the plans higher than 3.5 m (5%)

For typological class C (v. Figure 10) the variable indicators of vulnerability are:

- Corner/extremities location of the US in the aggregate (75%)
- Incongruous system of openings (44%)
- Average height of the plans higher than 3.5 m (31%)
- Irregularity of shape (19%)
- Presence of structural damage (6%)

The combination of the variable indicators produces the categories of “isovulnerable” buildings belonging to that typological class. In order to define a category, groups of “isovulnerable” buildings must consist of at least three structural units. For Ortigia, 13 categories were identified overall. Table 8 shows the variable indicators that characterize each identified category of “isovulnerable” US. These are distributed in such a manner:

- 8 categories for typological class A
- categories for typological class B
- 2 categories for typological class C

Table 8 identified categories of “isovulnerable” structural units in Ortigia

"ISOVULNERABLE" STRUCTURAL UNITS	TYPOLOGICAL CLASS												
VARIABLE INDICATORS	A	A	A	A	A	A	B	C	C	A	A	B	B
Incongruous system of openings		X			X			X			X	X	X
Corner/extremities location of the US in the aggregate			X				X	X	X	X			
Presence of structural damage							X					X	
Irregularity of shape				X						X	X		
Poor maintenance status							X					X	
Superelevations						X							
Juxtaposed elements or poorly connected					X								
Average height of the plans higher than 3,5 m													
Number of US	12	8	7	5	5	4	4	4	4	3	3	3	3

5 The future of this study

In the future of this study, the analysis procedure will be tested on other two test sites besides Ortigia: Lampedusa (Italy) and Xemxjia (Malta). The new test sites have different characteristics. The urban tissue of Lampedusa has been realized since 1800 and its original core is characterized by a chessboard scheme, while Xemxjia is characterized by loadbearing masonry buildings constructed during the past 40 years. Instead, from a regulatory point of view, Malta has not an anti-seismic rule while Lampedusa has been classified as seismic zone in 2004 (OPCM 3274/03 and D.R. 15.01.2004) and then affected by the last Italian rule (NTC 2008).

The applications in the test sites will allow us to test the new forms (SeiV-US and SeiV-AS) and to understand if the identified indicators of vulnerability are able to describe damageability of urban centres that are different between them. From the point of view of an application at a European level, the outcomes are to be evaluated in cases of different historical, technical, urban and regulatory contexts.

Results obtained in the first phase of research are a prerequisite for the second phase. This has the objective of the qualitative and quantitative evaluation of seismic vulnerability. During this phase of research more detailed investigations and appropriate structural tests are conducted, on “isovulnerable” structural units, reaching a quantitative evaluation of the seismic vulnerability. Within the entire urban centre, results obtained in this way are exported to the structural units belonging to the same category.

Compilation and cataloguing of the two proposed forms (SeiV-US and SeiV-AS), lead to the creation of a database of indicators of the vulnerability of the built environment. Reading, interpretation and representation of these data allow us to identify the distribution of the indicators of vulnerability in the settlement.

The evaluation of seismic vulnerability, along with exposure and hazard, is necessary to define the civil protection plans. At last, the results obtained are essential premises for the definition of guidelines. Moreover, they allow for the identification, in the aggregate, of particular points of weakness or strength after the earthquake, interpreted so as to constitute a comprehensive picture of earthquake damage to the urban centre. The impact on the territory, of the proposed expeditious method, regards concrete actions, finalized to the mitigation of the seismic risk, to be implemented before a seismic event. This type of evaluation is able to allow municipalities to define priority measures and to develop guidelines for seismic improvement interventions, taking into account the specific features of the urban centres.

6 Conclusions

The present paper regards the first phase of research that aims to define an expeditious pre-earthquake method for the analysis and evaluation of the seismic vulnerability for aggregates and structural units of urban centres. Results obtained in the analysis phase regard the definition of two new pre-earthquake forms for structural units and aggregates (SeiV-US and SeiV-AS), containing the indicators of vulnerability, and their manual. The proposed analysis method is implemented in an intermediate scale of analysis between the building vulnerability and the urban vulnerability, thanks to the definition of the aggregate form (SeiV-AS). In fact, this form takes into account the factors resulting from the contiguity between different structural units. The implementation of the method, through the compilation of the new proposed forms, may prove to be a very useful database for municipalities.

The completion of the first phase is a prerequisite to start the second phase. This has the objective to reach the evaluation of the seismic vulnerability of aggregates (AS) and buildings (US) of the urban centre. The application of the proposed method in Ortigia has highlighted that the new compilation forms (SeiV-US and SeiV-AS) have achieved the objectives. This is owing to the fact that they are expeditious and overcome the criticalities in the existing forms. The experience in Ortigia has highlighted the reaching of the optimum balance between knowledge of the vulnerability and the effort required to obtain it by the technicians that have conducted the surveys. This will facilitate the municipalities in the adoption of the new forms in order to analyse the seismic vulnerability of their urban centres. Thanks to this analysis, municipalities can take action in order to safeguard and protect the territory against seismic events.

However, the new forms, which are still under experimentation, are scheduled to be verified in other test sites, besides Ortigia, which are characterized by different historical, technical, urban and regulatory contexts. This could provide an instrument for the analysis of seismic vulnerability of urban centres to be applied in all the seismic areas at a European level and beyond.

Acknowledgements

The present study was funded within the SIMIT Project regarding an “Integrated System for Transboundary Italo-Maltese Civil Protection” (Operational Programme - European Territorial Cooperation 2007-2013).

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