SEISMIC VULNERABILITY AND CONSTRUCTION TYPES IN HISTORICAL BUILDINGS

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Highlights

The seismic vulnerability classes can be identified based on the observation of some constructive-behavioral aspects of buildings, i.e., *indicators of vulnerability*. In la Graziella area of Ortigia, the following seismic vulnerability classes have been identified: 5 Structural Units (from now on US), in the vulnerability class A; 33 Structural Units in class B; 73 Structural Units in class C1; 2 Structural Units in class C2; and 13 Structural Units in class D1. The qualitative assessment of seismic vulnerability identifies the weak points in a global framework of damage in case of an earthquake, which is useful for designers to operate consistently in the historical center of Ortigia.

Abstract

This study is part of a research, aimed at the definition of a new expeditious method, in the pre-seismic phase, for the analysis and assessment of the seismic vulnerability of the historical urban centers. The typological-probabilistic approach adopted for a sample of buildings leads to qualitative assessments of vulnerability through the preparation of thematic maps and the adoption of Damage Probability Matrixes (from now on DPM). The paper reports the results obtained for the historical center of Ortigia.

Keywords

Expeditious Method, Seismic Vulnerability, Urban Centers, Indicators of Vulnerability, Qualitative Evaluation.

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1. INTRODUCTION

The history of earthquakes that occurred in Italy over the centuries shows that the country is among those at highest seismic risk.

This consideration is added to the awareness that most of the Italian building heritage was built with no appropriate regulatory requirements to be met to withstand seismic events.

Certainly, this is the case in the historical centers, often of great artistic and architectural value, in large Italian cities and smaller towns.

The observation of the damage suffered by urban centers following seismic events, as happened, for example in L'Aquila or Amatrice, has dramatically highlighted the need to address the recovery, strengthening, and seismic improvement of the building heritage with reference to both isolated buildings and structurally connected groups of buildings.

By virtue of the extension of historical urban centers on the Italian territory, the methodologies of analysis and assessment of seismic vulnerability should lead to the adoption of simplified models and expeditious analyses, without neglecting the uniqueness and value of each historical center [1].

In this context, this research was launched, aimed at the definition of an expeditious method, which is applicable in pre-seismic conditions, for the analysis and assessment of seismic vulnerability that provides useful indications and criteria for designers to operate consistently within a specific historical center with the extrapolations that similar situations allow [2]. The aim of the research is, therefore, to provide the tools for proper assessment of the seismic behavior of the structural units and structural aggregates that make up the building network of historical centers through understanding their construction system [3].

The first investigation procedures on the historical building masonry were carried out after the earthquakes of Friuli in 1976 and Irpinia in 1980 in order to identify seismic vulnerabilities on a regional scale [4].

In summary, they refer to three methods, i.e., direct type-based approaches, indirect inspection and classification methods, and mechanical analytical methods [5].

These methods are related to the building characteristics (i.e., type, materials, dimensions and shape, construction details, etc.) and may have different degrees of detail, depending on the level of knowledge of the items under investigation.

The third mechanical-analytical method provides a high level of information based on detailed investigations and surveys of individual buildings and leads to a quantitative assessment of vulnerability through mechanical modeling. The high level of detail required is challenging to achieve, both economically and in terms of time, if the analysis is extended to an entire historical center.

For this reason, this research has focused on the so-called “hybrid methods”, originating from the combination of the first two methods (direct type-based approaches and indirect inspection and classification methods). Both of them adopt typological-probabilistic approaches to be applied to a more or less extensive sample of buildings in order to achieve qualitative assessments of vulnerability through the formulation of thematic maps and the adoption of Damage Probability Matrixes (DPM) [6].

In the framework of the Italy-Malta 2007-2013 project, the method has been tested in the areas of Ortigia (Syracuse - Italy), Malta, and Lampedusa (Italy) [7, 8].

In this Italian research framework (FIR 2014), this method was tested in the historical center of Catania, Italy [9, 10, 21].

This article reports the latest results obtained from the implementation of this method, with a specific reference to the historical center of Ortigia.

2. METHODOLOGY

The expeditious method for the analysis and assessment of seismic vulnerability is divided into three successive phases, i.e., knowledge, analysis, and assessment [2].

The first phase studies the historical evolution of the urban layout of the historical center through the identification of the areas of expansion and the succession of earthquakes in various eras.

The data collected in this way highlight the significant elements of historical, urban, and technical-constructive nature that characterize the historical center and the behavior of the building network towards an earthquake.

In the second phase, the Structural Aggregates and Structural Units of the area are initially identified.

Mauro Dolce argues that the vulnerability of the Structural Aggregates (from now on AS) and Structural Units (from now on US) can be described through the observation of some behavioral symptoms, which are translated into indicators that contribute to a range to define a global vulnerability value [3, 4].

These indicators consist of a list of structural characteristics a priori considered as significant, based on the experience of seismic events that have already occurred, and a posteriori validated by damage statistics.

In the previous researches, starting from the already existing sheets (AeDES, GNDT, CLE), two lists of vulnerability indicators have been identified, one related to the US sheet and one to the AS sheet [11, 12].

The US sheet consists of 4 sections:

a) Identification Data;

b) General Engineering Characteristics;

c) General Geological and Geophysical Characteristics; and

d) Specific Characteristics.

In particular, the General Engineering Characteristics contain 21 indicators referring to:

- Vertical and Horizontal Structures;
- Geometric-Constructive Characteristics;
- The State of Conservation; and
- Location.

The AS sheet consists of 3 sections:

a) Identification Data;

b) General Engineering Characteristics; and

c) General Geological and Geophysical Characteristics.

In particular, the General Engineering Characteristics contain indicators referring to:

- Geometric-constructive characteristics;
- The state of conservation; and
- Location.

The General Engineering Characteristics contain 21 indicators, 10 of which are specific to the AS, while the other 11 indicators derive from the US that forms the aggregate and they are considered when their presence exceeds 30% of cases.

The data obtained from completing the sheets, and collected in a database, allow the analysis and qualitative assessment of the vulnerability of the historical center at different scales.

An initial qualitative assessment of seismic vulnerability was carried out through the preparation of thematic maps based on the presence of indicators in the US and AS.

To this end, for the Ortigia historical center, as for the other case studies, a score from zero to one was assigned to each vulnerability indicator. A higher score has a more significant influence on harmability.

For each US and AS, the sum of the vulnerability indicators gives, as a result, the vulnerability index I.

Three levels of vulnerability were defined based on the vulnerability index [12].

By assigning a color to each level, it was possible to represent the qualitative maps of seismic vulnerability of

CLASS A						
Intensity	Damage Degree					
	0	1	2	3	4	5
VI	0.188	0.373	0.296	0.117	0.023	0.002
VII	0.064	0.234	0.334	0.252	0.092	0.014
VIII	0.002	0.020	0.108	0.287	0.381	0.202
IX	0.000	0.001	0.017	0.118	0.372	0.498
X	0.000	0.000	0.002	0.030	0.234	0.734

CLASS B						
Intensity	Damage Degree					
	0	1	2	3	4	5
VI	0.360	0.408	0.185	0.042	0.005	0.000
VII	0.188	0.373	0.296	0.117	0.023	0.002
VIII	0.031	0.155	0.312	0.313	0.157	0.032
IX	0.002	0.022	0.114	0.293	0.376	0.193
X	0.000	0.001	0.017	0.111	0.372	0.498

CLASS C						
Intensity	Damage Degree					
	0	1	2	3	4	5
VI	0.715	0.248	0.035	0.002	0.000	0.000
VII	0.401	0.402	0.161	0.032	0.003	0.000
VIII	0.131	0.329	0.330	0.165	0.041	0.004
IX	0.050	0.206	0.337	0.276	0.113	0.018
X	0.005	0.049	0.181	0.336	0.312	0.116

Load-bearing masonry	Damage Degree	Description
	0	No damage
	1	Minor damage: thin cracks and falling of small pieces of plaster
	2	Medium damage: small cracks and falling of small pieces of plaster
	3	Heavy damage: formation of large cracks in the walls, chimney falls
	4	Destruction: detachments between walls, possible collapse of portions of buildings
	5	Total damage: total collapse of the building

Macroseismic intensity levels	
VI	Slightly harmful
VII	Damaging
VIII	Heavily damaging
IX	Destructive
X	Very destructive

Tab. 1. *DPM for classes A, B, and C, (Braga, Dolce, and Liberatore).*

the investigated areas for US (I ≤ 2.5 low level, in yellow; 2.5 < I ≤ 5 medium level, in orange; and I > 5 high level, in red), and for AS (I ≤ 3.5 low level, in yellow; 3.5 < I ≤ 6 medium level, in orange; and I > 6 high level, in red) (Fig.1).

The DPM adopted in this research derives from the DPM developed by Mauro Dolce et al. following the earthquakes that struck the historical centers in Friuli and Irpinia. In this table, Dolce et al. associate three classes of vulnerability A, B, and C to 13 structural types origi-

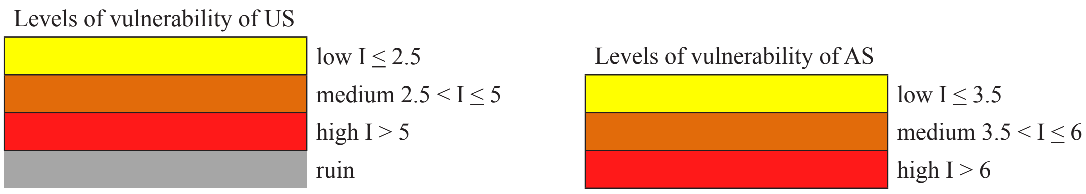

Fig. 1. *Seismic vulnerability levels.*

At this stage, the investigation does not lead to a numerical assessment of the damage to be correlated to a parameter of measurement of earthquake severity, but consists in identifying the particular points of weakness or strength to the earthquake in the aggregate, interpreted in such a way as to form a global picture of the damage to the historical center because of the earthquake, so as to plan the preventive actions for risk mitigation, set the priorities, and allocate financial resources [13].

The second step of qualitative analysis and assessment of vulnerability is based on the experiences of Mauro Dolce et. al., who claim that through the data obtained from filling the US sheets concerning structural vulnerability indicators, it is possible to identify categories of *isovulnerable* buildings [3, 4]. Isovulnerable buildings are those that belong to the same vulnerability class A, B, and C (Table 1) that can be identified through the Damage Probability Matrixes (DPM) [14]. These matrixes express the relationship between a certain degree of damage, for a given type of buildings and a related macroseismic intensity (Table1).

nating from the different combinations between vertical and horizontal structures [15, 16].

The DPM reported in Table 2 was reworked to be adapted to a historical building network of the 18th-19th century, consisting of US built in the absence of an anti-seismic design (classes A, B, and C1), some of which, over time, have undergone structural improvements (class D1) or, albeit rarely, full replacement with reinforced concrete buildings (class C2) (Table 2).

The DPM reported in Table 2 associates the 5 classes of vulnerability to the 25 types defined by the combination of the three structural indicators, i.e., vertical structures, horizontal structures, reinforcement items [17].

The vulnerability analysis at this level allows identifying classes of *isovulnerable* buildings that are identified as representative models of the structural characteristics of the building network examined [20].

For the case study of the historical center of Ortigia, the results related to the phases of knowledge, analysis, and qualitative assessment of vulnerability through thematic maps and the identification of the classes of vulnerability through DPM are described below.

Structural classification	Vertical structures						
	Poor quality masonry		Medium quality masonry		Good quality masonry		Reinforced concrete
Horizontal structures	With no reinforcing items	With reinforcing items	With no reinforcing items	With reinforcing items	With no reinforcing items	With reinforcing items	
Pushers	A	B	A	B	A	B	
Deformable	A	B	A	B	B	C1	
Semirigid	B	C1	B	C1	C1	D1	
Rigid	B	C1	C1	D1	C1	D1	C2

Tab. 2. *Classes of vulnerability associated with 25 structural types.*

3. THE HISTORICAL CENTER OF ORTIGIA

The first cognitive phase defined the evolution of the historical network of Ortigia, identifying the different areas of expansion and construction techniques that have followed in different eras as a prerequisite for a solid cultural and technological basis on which to make the necessary assessments for filling the sheets.

The current appearance of Ortigia is conditioned by the presence of medieval roadways, the 18th-century building reconstruction, which took place after the earthquake of 1693 that destroyed the Val di Noto, and the significant urban development that took place during the 19th century.

In the district La Graziella, one of the oldest in Ortigia, already included in previous studies coordinated by Prof. Antonino Giuffrè [18], we note that its triangular layout is defined by three most notable streets: via Dione, via Resalibera, and via Vittorio Veneto, of medieval origin (Fig. 2). Inside there are more ancient road structures that are widely distributed through the "ronchi", which are cul de sac routes that sometimes reach private or semi-public courtyards. At the beginning of the 19th century, the inhabitants of La Graziella district were poor people, such as fishermen and carters. The district consisted mainly of buildings with only one above-ground floor, such as terranean houses, stables, and warehouses. Only along the main roads, it was possible to find larger buildings.

Fig. 2. *The historical center of Ortigia, La Graziella district. (Giuffrè A. 2003).*

Fig. 3. *The historical center of Ortigia, La Graziella district, the structural aggregates.*

In the nineteenth century, there was significant growth in the number of buildings built in horizontal layers by merging adjacent building units, with the consequent changes to the interior partitions and not infrequently accompanied by elevation; on the other hand, there developed phenomena of fractionation by vertical layers of buildings hitherto of a single-family type [18].

The load-bearing walls have a thickness varying between 70 and 45 cm (45 cm only for walls of upper floors), arranged with an average spacing varying between 4.5 and 6 m.

The building stones came from quarries in the Syracuse area and were usually of two types: hard limestone and "giuggiulena" stone.

Only in buildings dating back to the beginning of the twentieth century, it is possible to find the presence of squared soft limestone blocks, which, while allowing greater workability, deteriorate faster over time, under the action of atmospheric agents.

The mortar was composed of lime and sand. Sand could come from rivers, quarries, or cutting stone dust.

The low quality of the materials corresponds to a low technical level of the workers.

By starting from the first half of the twentieth century, the use of wood for the construction of flooring was replaced by the use of metal bars; this construction technique was widespread throughout the first half of the century. The use of reinforced concrete, on the other hand, started in local architecture in the years following the Second World War.

Since those years, a rather common building practice was followed in La Graziella as well as throughout Italy, with the replacement of the original, often deteriorated flooring with brick and concrete flooring made with "breccia" rocks.

Reinforced concrete is sometimes found in the construction of elevations and flat roofs. Buildings with a framed structure are almost completely absent.

With the entry into force of the "Piano Particolareggiato Ortigia" (PPO – Ortigia Detailed Urban Plan) following the 1990 earthquake, improvement work was carried out on the vertical structures with the installation of reinforcements, while the rebuilding of the flooring was oriented towards a recovery of traditional techniques, which involved the use of wooden floors with reinforced concrete slabs.

4. RESULTS

The preliminary historical-urbanistic-constructive study based on consultation of the historical cadastral registers and visits on-site carried out initially in collaboration with Regional Civil Protection experts allowed a direct exchange of information with the local population and

ORTIGIA US INDICATORS		Total	%
13 A	Vertical structures	122	98
13 B	No reinforcement items	107	86
13 C	Horizontal structures	58	47
14	Position in the aggregate	48	39
16	Specialist US	0	0
17	Total number of floors	124	100
18	Basement floors	0	0
19	Floor height	7	6
20	Height of roof base	1	1
21	Single volume	1	1
22	Irregularities of layout	31	25
23	Presence of juxtaposed or poorly connected items	16	13
24	Presence of incongruous opening system	56	45
25	Isolated pillars	0	0
26	Pilotis layout	0	0
27	Presence of elevations	19	15
28	Presence of structural damage	36	29
29	Poor state of maintenance	25	20

Tab. 3. *US Vulnerability Indicators.*

	Ortigia AS Indicators	AS1	AS2	AS3	AS4	AS5	AS6	AS7	Total	%
15	Large spans	0	0	0	0	0	0	0	0	0.00
16	Height of roof base	0	0.5	0.5	0.5	0	0	0.5	2	28.57
17	Coverage index	1	1	1	1	1	0	1	6	85.71
18	Regularity of shape	0	1	1	1	1	0	1	5	71.43
19	Merging or clogging	1	1	1	1	1	1	1	7	100.00
20	Roof base misalignments	1	1	1	1	1	1	1	7	100.00
21	Floor misalignments	1	0	1	0	0	1	0	3	42.86
22	Façade misalignments	1	1	1	0	1	0	1	5	71.43
23	Interior partition misalignments	0	0	1	1	0	0	0	2	28.57
24	Slender head	0	0	0	0	0	0	0	0	0.00
25	Juxtaposed items	0	0	0	0	0	0	0	0	0.00
26	Incongruous wall opening system	1	1	1	1	1	0	1	6	85.71
27	Isolated pillars, porches	0	0	0	0	0	0	0	0	0.00
28	Elevations	0	0	0	0	0	0	0	0	0.00
29	Towers, bell towers	0	0	0	0	0	0	0	0	0.00
30	Degraded US	1	1	0	0	1	1	1	5	71.43
31	Absence of reinforcement item	1	1	1	1	1	1	1	7	100.00
32	Presence of ruins	1	1	1	0	1	0	0	4	57.14
33	Soil morphology	0.5	0	0	0	0	0	0	0.5	7.14
34	Location	0	0	0	0	0	0	0	0	0.00

Tab. 4. *AS Vulnerability Indicators.*

workers. It was crucial to fully understand the merging of adjacent building units, otherwise difficult to deduce from layouts.

Seven structural aggregates and a total of 160 structural units were identified, including 8 buildings in ruins. Therefore, 7 AS sheets and 152 US sheets were filled in, of which 124 buildings in load-bearing masonry, 2 in reinforced concrete, and 24 US not totally surveyed [7, 19].

The data concerning the total number of indicators present and the percentage value on the total of the 152 US that form the 7 structural aggregates are summarized in Table 3. The numbers reported in the 'Total' column show how many times that particular indicator is present in the structural units examined, while the 'Percentage' column shows the ratio between the number in the Total column and the total of the structural units.

The data concerning the total of indicators forming the aggregate are summarized in Table 4. Some indicators are considered when their presence exceeds 30% of the cases, while the others are specific to the aggregate.

The results show that 6 AS (86%) present a high level of vulnerability, while 1 AS (14%) presents a low level of vulnerability. More than 70% of the aggregates have a layout irregularity indicator. This is justified by the fact that after the 1693 earthquake, Syracuse was rebuilt in the same site according to the pre-earthquake urban layout of ancient origins, giving rise to structural aggregates with irregular layouts.

All the buildings analyzed – therefore 100% of the US – have the merging or clogging indicator, as they are mainly extremely poor residential buildings. The rather spontaneous growth mechanisms are regulated by purely existential needs that generate continuous transformations that are still present today.

The coverage index indicator that exceeds 85% shows the clogging due to the progressive occupation of public or semi-public space inside the courtyards, with buildings mainly for residential use.

The massive presence of clogging has led over the years to a growth of the aggregate or even to several aggregates union with the free space occupation that originally separated them.

This is why in La Graziella district, we find AS composed of a very high number of structural units such as AS2 with 45 US and AS4 with 40 US. Moreover, since these are extremely poor buildings, the structural units are mainly made up of tiny courtyard-row houses with no more than two floors, of modest height. Only 6% of the structural units have an average floor height indicator

>3.5 m, and none of the US units analyzed have a coverage height indicator >12 m.

The few larger buildings are located only along the main streets via Dione, via Resalibera, and via Vittorio Veneto.

About 40% of the US buildings examined occupy end or corner positions in the aggregate due to the highly irregular shapes of the aggregates and their spontaneous growth mechanism. In fact, there are no aggregates with a slender head.

In addition, since the ends of the aggregate are the most valuable areas, as they overlook the main streets, they are usually occupied by the most formally and dimensionally important buildings.

In these cases, these buildings are highly vulnerable due to their extreme position in the aggregate and their

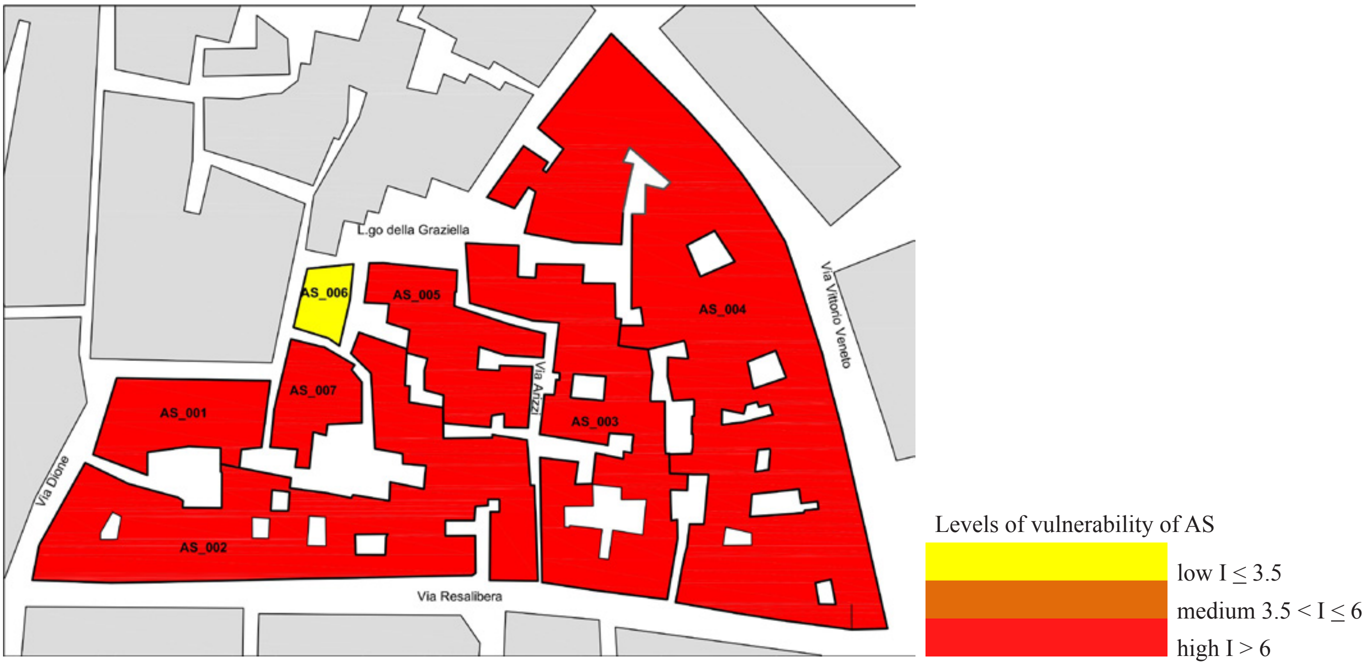

Fig. 4. *AS Vulnerability Map.*

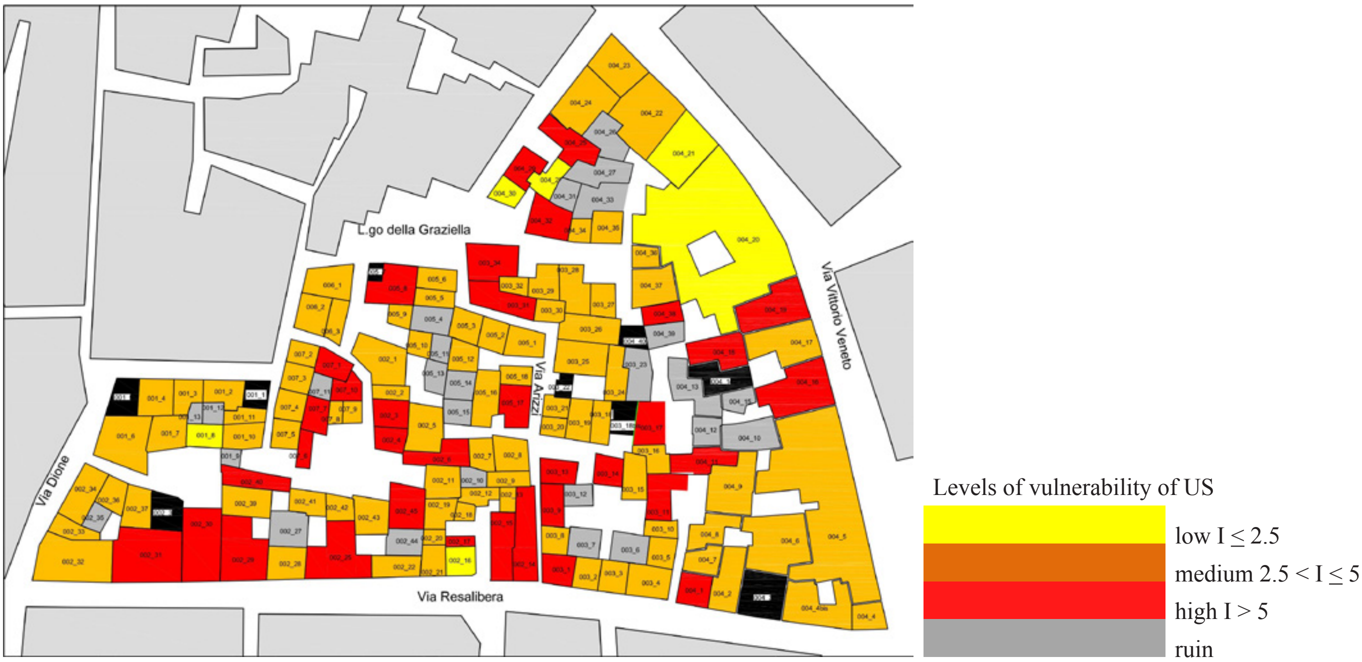

Fig. 5. *US Vulnerability Map.*

larger size. The internal US, of minor importance, frequently present a medium-low vulnerability.

About 70% of the aggregates have the misalignment indicator in the façade.

This is due to the fact that only the US facing the main streets create continuity on the outer fronts ensuring, in principle, the alignment of elevations on the street fronts, while on the inner front, they occupy spaces more or less spontaneously, creating misalignments on the inner fronts.

The presence in the same aggregate of spontaneous buildings formed by US with different formal and dimensional characteristics causes a greater vulnerability due to the misalignments of roof bases (100%) and ceilings (42.86%).

The Incongruous Wall Opening System indicator at 45% also shows that the building network of La Graziella in Ortigia has been remodeled over the centuries to adapt to the new needs that gradually appeared.

Other indicators, albeit with lower percentages, such as the presence of elevations (15%) and the presence of juxtaposed items (13%), also confirm the transformations suffered by the building network over time.

The vulnerability of the US in aggregate is also due to 98% medium-low quality load-bearing masonry (respectively 90% medium and 8% poor quality) and, at the same time, to the widespread lack of reinforcement systems (86%).

In almost half of the US there is no horizontal structure indicator because in recent times, the original ceilings have been replaced by rigid or semi-rigid ceilings.

Only 20% of the units have not undergone any recent interventions and are in a poor state of maintenance.

Finally, 29% of the US units analyzed showed structural damage.

Therefore, referring to the layouts and related vulnerability levels I (Fig. 4, 5), we can say that 23% of the structural units have a high vulnerability level, 72% medium vulnerability, and only 5% low vulnerability [19].

Eighteenth and nineteenth-century structural aggregates are mainly highly vulnerable, especially if they are large and irregular. The highest vulnerability is found near the heads.

The data collected through the AS and US sheets, besides forming a database used to define a qualitative vulnerability map, can be used to trace categories of *isovulnerable* buildings.

Isovulnerable buildings are those that belong to the same vulnerability class.

Considering the vulnerability classes defined and reported in Table 2, for the US of La Graziella district of Ortigia, we find the vulnerability classes A, B, C1, C2, and D1 distributed in each aggregate as reported in Table 5. In particular, we find respectively, 5 US in vulnerability class A, 33 US in class B, 73 US in class C1, 2 US in class C2, and 13 US in class D1.

It appears evident that the most numerous class is class C1, consisting of 73 US composed by the masonry of medium quality combined with rigid horizontal structures and medium quality masonry with reinforcements combined with semi-rigid horizontal structures.

Next is class B with 33 US, represented by structural units with medium quality masonry combined with semi-rigid horizontal structures, the masonry of poor quality combined with semi-rigid and rigid horizontal structures, and structural units with poor and medium quality masonry and reinforcement items, combined with deformable horizontal structures.

Only 5 US belong to vulnerability class A. They consist of poor and medium quality masonry combined with

	AS1	AS 2	AS 3	AS 4	AS 5	AS 6	AS 7
A	1	0	2	2	0	0	0
B	4	7	6	8	4	0	4
C1	3	25	17	16	8	0	4
C2	0	1	0	0	1	0	0
D1	0	5	3	0		3	2

Tab. 5. *DPM for La Graziella district in Ortigia (Syracuse).*

pushing or deformable horizontal structures, with no reinforcement items.

Thirteen US belong to vulnerability class D1 characterized by medium quality masonry with reinforcement items combined with rigid horizontal structures.

Two reinforced concrete buildings belong to vulnerability class C2.

With reference to Table 1, we can say that, if a heavy earthquake (8^{th} level) occurs in the 73 buildings belonging to class C1, 9 buildings will suffer damage of grade 0 (no damage), 24 buildings will suffer damage of grade 1 (light damage), 24 buildings will suffer damage of grade 2 (medium damage), 12 buildings will suffer damage of grade 3 (heavy damage), and 3 buildings will suffer damage of grade 4 (destruction, i.e., detachments between walls and possible collapse of portions of buildings).

5. CONCLUSIONS

The expeditious method of seismic vulnerability assessment applied to La Graziella district in the historical center of Ortigia has given positive results as it highlights the real historical-constructive characteristics of the buildings on an aggregate and structural unit scale.

The formulation of the maps based on the presence of structural and geometric indicators of the US and AS showed that the majority of the US (72%) have a medium vulnerability level and only 23% have a high vulnerability level; this is partly due to the structural improvements carried out on the individual US following the 1990 earthquake.

Despite the fact that the US mainly have a medium vulnerability level, the maps show the high vulnerability of the aggregates (86%), due not so much to the characteristics of the individual US but to the specific indicators of the aggregation mechanisms, that is generated by the spontaneous growth of the building network of the past centuries. This phenomenon has given rise to irregular shape aggregates with a very high number of US without alignments on the fronts, except along the main streets and without alignments on all ceilings.

It is therefore believed that this method, extended to the entire historical center of Syracuse, may be valid in identifying specific weakness or strength points to earthquakes in the aggregates, to be interpreted in such a way as to form a global picture of damage to the earthquake in the historical center, in order to plan preventive actions for risk mitigation, establish priorities, and allocate financial resources.

The second level of qualitative assessment of vulnerability, on a structural unit scale, was obtained through the use of DPM. For La Graziella of Ortigia, associating the structural types to the vulnerability classes, the results shown in Table 6 were obtained, respectively 5 US in vulnerability class A, 33 US in class B, 73 US in class C1, 2 US in class C2, and 13 US in class D1.

The most numerous class is C1. Isovulnerable buildings of class C1 are US consisting of medium quality masonry combined with rigid horizontal structures and medium quality masonry with reinforcement items combined with semi-rigid horizontal structures.

Table 1 developed by Dolce et. al. for the data collected shows that in the event of a heavy seismic event (8^{th} level) most of the class C1 US will suffer from mild to severe damage with cracks in the masonry and detachment of parts of plaster; only a small number of them will suffer heavy structural damage with collapsing portions of buildings. These data record the beneficial effects of the actions carried out following the 1990 earthquake with improvements mainly due to the replacement of the original floors and, in a few cases, to the installation of reinforcement items.

However, at the aggregate level, the map showed a high degree of widespread vulnerability due to the fact that the improvements were carried out only on a US scale, and did not affect the specific indicators of the aggregation mechanisms, as there are aggregates with irregular shapes and with a very high number of US, with no alignments on the fronts, except for the main streets, and with no alignments on ceilings.

At present, the small number of samples analyzed has made it possible to carry out a first verification of the methodology of analysis and assessment of seismic vulnerability for historical centers, rather than reaching results that can be extended to the whole historical center.

The results obtained at this stage of the research encourage us to continue in this direction.

The research will be extended to other areas of the historical center in order to have a larger and, therefore, more representative sample of US and AS of the building network.

Further methodological development of the research in the future consists in assessing the effects caused by the set of geometric indicators present in the US to *isovulnerable* buildings (Table 5).

The vulnerability analysis at this level allows identifying subclasses of *isovulnerable* buildings that are identified as representative models of all the structural and geometric characteristics of the building network examined.

On these models, being limited in number, it is possible to apply the analytic mechanical methods that, through structural verifications, provide the quantitative assessment of seismic vulnerability. The results obtained, extended to the entire building network, will provide useful indications and criteria for designers to operate consistently within that particular historical center with the possible extrapolations for similar situations.

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