Seismic vulnerability assessment and structural improvement proposals for the building typologies of the historic centers of Vittorio Veneto (Italy)

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**Abstract**

This vulnerability study of the historical centres of Vittorio Veneto (TV, Italy) aimed at suggesting compatible solutions of structural improvement in seismic areas. Macro-modelling using kinematics models has been adopted by using a computational procedure set up at the University of Padova in the 1980s (Vulnus) and recently updated in Visual Basic ambient. Several building typologies have been identified in the study and the main characters affecting their vulnerability are discussed here.

**Keywords:** seismic vulnerability, masonry, building typologies, colonnades, macro-modelling, limit analysis, kinematics mechanisms.

**1 Introduction**

Historic structures in seismic areas are characterized by several typologies, especially in minor urban centres, where continuous stratification and superposition occurred during time. Isolated and arrays of buildings, complex aggregates, often located on slopes, can be found. Moreover, existing buildings may have construction features that can induce specific vulnerability problems such as: arcades, loggias and colonnades, large halls. The large variability of the masonry material and the low effectiveness of structural connections among components (walls, floors and roofs), make the assessment of the seismic vulnerability of this class of buildings a particularly hard task. In such a context, common procedures usually adopted for structural evaluations based on the box-
behaviour under seismic actions are not reliable and, when applied, can led to inaccurate results.

Recently, methods for the evaluation of the seismic vulnerability, based on the application of single or combined kinematics models involving the equilibrium of macro-elements, have been validated by direct comparison with the real damage occurred [1] [2]. Macro-elements are defined by single or combined structural components (walls, floors and roof), considering their mutual connections and constraints (e.g. the presence of steel ties or concrete ring-beams), the constructive deficiencies and the characteristics of the constitutive materials [3].

Procedures based on the abovementioned approach have been applied to the two historical centres which compose Vittorio Veneto, namely Serravalle and Ceneda [4] [5]. They consist of about 420 and 690 buildings, respectively, and comprises several typologies, which have been grouped in different categories, following the combination of three classification criteria: (i) dimensions (palaces, buildings, large complexes, annexes), (ii) presence of contiguous constructions (isolated and row buildings), (iii) presence of colonnades at the ground level, considered for all the abovementioned cases. Vulnerability analyses for the whole center and the proposal of improvement interventions are presented and discussed in the paper.

2 The historical centers of Vittorio Veneto

Vittorio Veneto is a small town located along the foothills of the Alps in the Veneto region (Treviso province). It is composed by two historical centers, Serravalle at North and Ceneda southwards, whereas the middle portion comprises now more recent buildings (fig. 1). Its origins go back to the paleo-Veneto period (around 1000 B.C.), but it achieved more importance later, during the Roman Times. Ceneda originally included Serravalle into its defense curtain walls, which was named separately only since the Middle Age. They develop independently until 1866, when they were officially joined under the name Vittorio, which became Vittorio Veneto after in 1923.

Ordinary buildings have mainly 3-4 storeys, made of rubble stone masonry and poor quality mortar, with scarce connections in the thickness and among walls; timber floors and roofs and some tie-rods connecting the main walls are also present. Few cases are in brickwork and better fabrics (cut stones with good mortar and improved connections) are generally recorded for more important constructions (palaces, churches, etc.). Specific vulnerabilities are due to the presence of colonnades at the ground floors and loggias, especially in buildings organized as rows, attics of reduced height at the top, and large halls in the palaces. Alteration of the constructive systems during time led to substitutions of roofs and floors with combined solutions of concrete joists and lightweight tiles or r.c. slabs.

The surrounding area was subjected to relevant earthquakes during the last centuries (up to VIII MCS intensity), that make the region classified into medium-high seismic hazard zones. Therefore, systematic evaluations of the
seismic vulnerability of the buildings are in need, in order to execute provisional analysis aimed at reducing the structural risk and improving the safety conditions.

Figure 1: Orography of the zone of Vittorio Veneto and view of the centre from the Meschio river, which runs through the town.

3 Classification of the existing building typologies

Serravalle and Ceneda consist of about 420 and 690 buildings respectively, characterized by different age and historic and architectural value, and belonging to several constructive typologies. By integrating the data of previous database available from the Town Council with the direct survey performed during the research, it has been possible to summarize specific information as follows.

3.1 Dating

The preliminary analyses confirmed that buildings still standing in Ceneda are older than in Serravalle. Serravalle is currently composed by around the 24% of buildings built in 1840-1900, while around 50% is dated before 1800 (14% of this was built in the XV-XVI centuries); Ceneda has more than 50% of buildings built in 1840-1900, and only around the 14% before 1800 (see fig. 2).

3.2 Architectural value

The architectural value was represented, in the preliminary database, by a parameter which resumes information about the architectural quality, age and conservation conditions. Four levels are considered: 0 (no value); 1 (absence of elements having architectural values); 2 (presence of original elements with architectural value even if not extended to the whole construction); 3 (remarkable architectural value extended to the whole construction); 4 (historical and monumental value).

Results showed that Serravalle comprises the 22% of buildings in classes 3 and 4, while in Ceneda only less than the 6% belongs to these categories (fig. 3).
This distribution agrees with dating results, as the correspondence among highest value classes and oldest buildings is confirmed.

Figure 2: Comparison of the dating detected for the two centers.

Figure 3: Comparison of the architectural value detected for the two centers.

3.3 Typology

The two centers include a large variety of buildings, having different morphology and use. The typologies have been classified grouping the different categories following the combination of three criteria:

a) dimensions: palaces, buildings, large complexes and annexes have been distinguished;

b) presence of contiguous constructions: isolated buildings or row buildings;

c) presence of colonnades at the ground level, considered for all the abovementioned cases.

Constructions having specific functions as churches or towers-bastions have been also distinguished from buildings.
Figure 4: Examples of building typologies in Vittorio Veneto: a) isolated palace with colonnades (Palazzo Casoni – Serravalle); b) isolated palace without colonnades (Palazzo Palatini – Ceneda); c) row palace with colonnades (Loggia della Comunità – Serravalle); d) row palace without colonnades (Palazzo Muzzi – Serravalle); e) row building with colonnades (Via Casoni 10,12 – Serravalle); f) row building without colonnades (Via Roma 81 – Serravalle); g) isolated building (Via Tiziano 159 – Ceneda); h) large complexes (Bacologia – Serravalle); i) annexe (to Palazzo Palatini – Ceneda); j) church (Cathedral of Ceneda); k) l) towers-bastions (Torre di S.Martino and Porta di S.Giovanni, both in Serravalle).
Therefore, a total of eleven cases have been selected in the study, as follows (fig. 4): a) isolated palaces with colonnades, b) isolated palaces without colonnades; c) row palaces with colonnades, d) row palaces without colonnades; e) row buildings with colonnades, f) row buildings without colonnades; g) isolated buildings; h) large complexes; i) annexes (mainly used as stores or garages); j) churches; k) towers and bastions.

Results are summarized in fig. 5. They showed that in Serravalle more than 8% of palaces can be found, more than half of which have colonnades at the ground level, while in Ceneda almost all the palaces (7%) are without colonnades. The most diffused typology is the row buildings without colonnades (58% in Serravalle, about 66% in Ceneda). Nevertheless, Serravalle has more than 10% of row buildings with colonnades, whether in Ceneda only the 1% is included in this category. Finally, Serravalle has the highest percentage of large complexes.

The main difference between the two centers concerns the presence of colonnades: Serravalle has the 15% of the whole number of buildings with colonnades, whereas Ceneda has only about the 2% in this category. According to their historic developments during centuries, from a general view Serravalle is composed by long rows of buildings, where oldest ones are located along the main streets, while Ceneda have more spreads constructions, which develops into a intricate streets pattern.

Figure 5: Comparison of the different typologies detected for the two centers.

4 Seismic vulnerability of pilot buildings

4.1 Structural macro-modelling analysis

The analysis of about 60 buildings belonging to the two centres has been performed adopting the macro-modelling approach proposed by the VULNUS procedure [6], developed at the University of Padova, and the application of single kinematics models. VULNUS gives three indexes: $I_1$ and $I_2$, which define the seismic coefficient connected to the in-plane shear resistance and out-of
Results showed that the vulnerability level is strongly depending on the presence of the portico at the ground level and of the high dimensions of some constructions. Palaces and large complexes are more vulnerable than others (they often present storey heights higher than 3 m, very long sets and walls), especially regard shear, when colonnades are present, as they reduce the resisting section at the base. Isolated palaces and buildings have generally lower vulnerability than rows. Isolated buildings and annexes present the lowest seismic vulnerability: they have a reduced storey height (often lower than 2.4 m) and often present ties connecting opposite walls at least in one direction.

By simulating different seismic levels ($a/g = 0.16, 0.28$ and $0.40$, where $a$ is the ground acceleration and $g$ the acceleration of gravity) it is possible to say that for high hazards the vulnerability increases for all the buildings except for isolated ones and annexes, which keep low values (fig. 6). The survival probability is comparable for the two centres for different seismic levels: Ceneda has the highest probability of collapse for in-plane shear mechanisms (I1 index), whereas Serravalle has the highest probability for simultaneous shear and flexural collapses (fig. 7). The punctual assessment with the kinematics models confirmed the high vulnerability of the façade sects to global overturning mechanisms, for both whole walls and corners. The global collapse probability is higher for Serravalle than Ceneda for every seismic level, even if values are very close for both centers (tab. 1).

The grouping of the most significant typologies (palaces and buildings, isolates or rows, with or without colonnades) allowed to synthesize the Vulnus results as showed in fig. 8.

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**4.2 Intervention proposals**

Possible applications of strengthening measures have been simulated applying the same macro-element analyses used for the vulnerability assessment.

For the improving of the in-plane behaviour, injections and/or limited rebuilding can be adopted in order to re-establish the mechanical condition of the
masonry. For out-of-plane collapses prevention, tying is the most effective intervention; also the stiffening of floors and roof with compatible materials (dry connection with timber reinforcement, for example) or, where necessary, the thickening of walls, are suggested.

Figure 7: Survival and collapse percentage of buildings for different seismic levels (A=a/g = 0.16, 0.28, 0.40) connected to in-plane and out-of-plane mechanisms for the two centers (their names are shortened).

Table 1: Global percentage of collapse for the two centers for different seismic levels.

<table>
<thead>
<tr>
<th>center</th>
<th>a/g =0.16</th>
<th>a/g =0.28</th>
<th>a/g =0.40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serravalle</td>
<td>55.7</td>
<td>87.9</td>
<td>97.0</td>
</tr>
<tr>
<td>Ceneda</td>
<td>51.0</td>
<td>85.5</td>
<td>96.8</td>
</tr>
</tbody>
</table>

Figure 8: Vulnerability classes associated to different typologies for VULNUS for low (left) and higher (right) seismic level.

A combination of the above-described interventions allows both $I_1$ and, in particular, $I_2$ indexes to be increased, to satisfy the safety requirements (see fig. 9 and 10).
Effect of interventions on $I_1$ index

Figure 9: Comparison of the safety level before and after intervention for in-plane shear strength index.

Effect of interventions on $I_2$ index

Figure 10: Comparison of the safety level before and after intervention for out-of-plane mechanisms.

5 Conclusions

The extensive analysis of the two historical centers which compose Vittorio Veneto in Italy has been presented. Reliable simplified methods, based on kinematic models describing the loss of equilibrium of structural macro-elements
have been used. The presence of colonnades at ground level and the high dimensions of halls in the palace are the parameters that mainly influence the seismic vulnerability of the several building typologies distinguished in the study. Moreover, the lack of ties for the improvement of the scarce connection among walls, floors and roofs, together with the poor conditions of structures and materials and the non-homogeneity of the foundation soil affect the assessment results. Those results allowed some intervention proposals to be suggested, based basically on the application of ties and reinforcement with compatible materials and techniques (both for floors and for walls).

The study will be developed to provide damage scenarios through fragility curves and damage probability matrices on purpose developed. Those evaluations will be used to calibrate macroseismic scale analyses taking into account distributions defined by cumulative percentage of buildings suffering various damage levels for different earthquake intensities.

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References