Vulnerability of Historic Centres and Cultural Heritage

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Introduction

The aim of the research is to set up for historic centres systematic data bases storing the information useful to prepare rescue plans and design interventions on the cultural heritage. This information will deal with: i) the technological and constructive characteristics of the surveyed buildings; ii) the material and structure properties (with particular reference to the constructive techniques and to the materials used for load-bearing masonry); iii) the materials and the techniques used for restoration before the earthquake; iiii) the collapse mechanisms of the buildings and structures due to the earthquake, considering also the ones already retrofitted.

Through the evaluation of the effectiveness of the past safety interventions It will be possible to write some guidelines for restoration and improvement.

During the second year of the research, once the survey carried on the first two centres of Montesanto and Roccanolfi was finished, other surveys on the villages of Campi Alto and Castelluccio di Norcia (PG) continued. On these two historic centres in situ and laboratory investigations were performed with the aim of characterising the masonry texture, the materials and structures.

Subproject Titles

R.U. 1 - Scientific Responsible: arch. Margherita Guccione – Survey on the past safety interventions and their evaluation on the basis of the value of the historic buildings

R.U. 2 - Scientific Responsible: Prof. Luigia Binda – Knowledge of the consistency of the historical patrimony of the four sampled centres; analysis of the seismic risk and evaluation of the vulnerability

R.U. 3 - Scientific Responsible: Prof. Claudio Modena – Evaluation of the effectiveness of past repairs and guidelines for repair and improvement

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R.U. 1 - Scientific Responsible: arch. M. Guccione

A deep historic research has been carried out in the archives and libraries not only on the provincie territory but also in Rome, in order to understand the origin and the evolution of the two historic centres, the history of the seismic events in that area and to explain the presence of some vulnerabilities of the buildings, through the knowledge of their evolution throughout the time.

Campi alto di Norcia: it is a castle perched on a slope surrounded by walls, and whose buildings are arranged in concentric terraces and narrow streets connected by short radial flights (see Fig.1). The buildings follow the orography and are arranged in rows. Campi situated 11 km away from Norcia and 900 mt above the sea level, belongs to the municipality of Norcia. It still preserves the original medieval aspect. Campi is divided in two parts: the old and lower one, "Campi basso", named “La Civitas Campli”, whereas the new one, “Campi alto”, is situated on the top of the hill. When the old part was destroyed the citizens decided to move on the top of the hill and in 1288 they built the Castle of Campi, also called “Campi nuovo” (New Campi). This part is the object of the research. The medieval gateway arch and the tower are still preserved; the characteristics of the buildings show the importance of the castle of Campi, although the damages due to earthquake and the effects of time and lack of maintenance are evident. Twenty-two churches and some monastery were built and 13 churches are still present.

Figure 1. Plan and view of Campi Alto of Norcia.

Castelluccio di Norcia: this little village is situated on top of a hill and is following a helicoidal structure, 1453 metres above sea level. The houses are arranged in concentric half-circling patterns on a slope facing south, whereas the northern side is mainly desert due to the unfavourable climatic and orographic conditions (see Fig.2). The town-planning development of the village is shown in two parts: the first one, gathered around Cassero (the highest part of the village, of which only the planimetric plan and the grid of old streets are still preserved) and the second part at the bottom of the hill where there are still the old stables.

The first written documents on Castelluccio date back in 1276. In the 1442 reform acts and in the banner orders Castelluccio was called Castello de Monte Precino and belonged to the newly born town of Norcia. Until about half of the twentieth century there was only one centre, the one included within the old town walls, whereas outside and down the hill there were the stables.

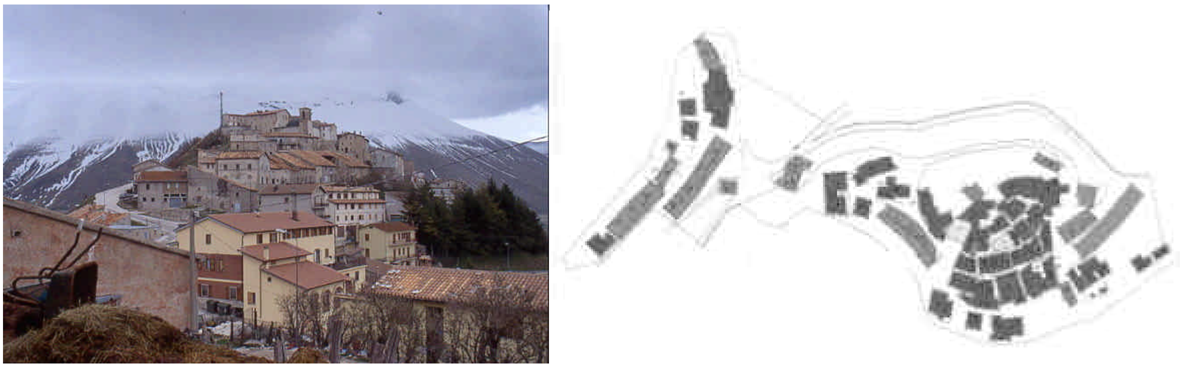


Figure 2. Plan and view of Castelluccio.

Today, due to the decay of the breedings and the neglect of the town, there is a second new part situated in the lower part of the hill, along the provincial road coming from Norcia. Thus Castelluccio has preserved almost entirely its old and original structure. Due to unfavourable climatic conditions, the old house windows, especially those facing the north, were very small and deep in the wall, in order to protect the dwelling from cold and wind. The time of the main development of Castelluccio was in the 16th century, whereas during the first half of the 18th century damages caused by two strong earthquakes (in 1703 and in 1730) were repaired.

During the second year there was also a collection of documents at the Town Hall of Norcia and Soprintendenza regarding the plans and intervention projects that were proposed and accomplished after the earthquake in 1979.

U.R. 2 - Scientific Responsible: Prof. L. Binda

The two centres fit in the preliminary studies aimed to analyse the collapse mechanisms of masonry buildings due to earthquake and to interpret them on the knowledge of the original constructive techniques and of changes following the interventions (also including the recent retrofitting). The aim is to supply useful indication for the rescue plans of the two centres and for their return to usefulness, which choice will be made by the local authority and by the owners. These indications will be useful to prevent and protect from future seismic events.

a) Campi Alto di Norcia:
The only type of building observed in the area is the mono-familiar house with two or more floors, built with a simple technique in stonework and timber roof and floor. Different building typologies are derived only by the different aggregations: isolated buildings, row buildings simple or double, block buildings. Due to the ground slope (more than 100 meters from the base to the top), buildings follow the natural course of the contour curves and develop following a row typology generally with three floors: the first one with an entrance at the lower street (for stables or deposits), one

in the middle and the last with the entrance at the upper street (for living places). The first two are the basement (see Fig.3)
The lowest floor in many cases does not present masonry wall at the bottom but it is excavated directly in the natural rock. These rooms present barrel vaults, that despite the several seismic events are still well preserved even in the collapsed buildings (see Fig.4). A detail observed in almost all buildings, and still to understand, is that the vaults are backward from the facade of about 1 meter.
The numerous past seismic events (1705, 1730, 1859 and more recently in 1979) deeply marked this historic centre together with the state of lack of maintenance throughout the centuries.

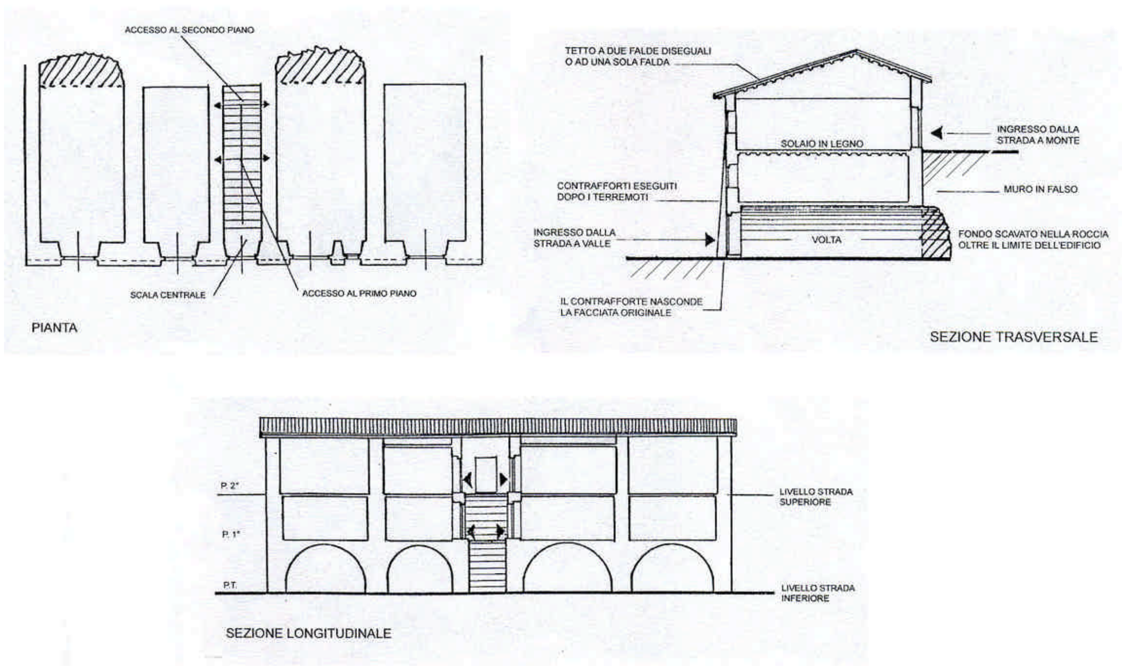
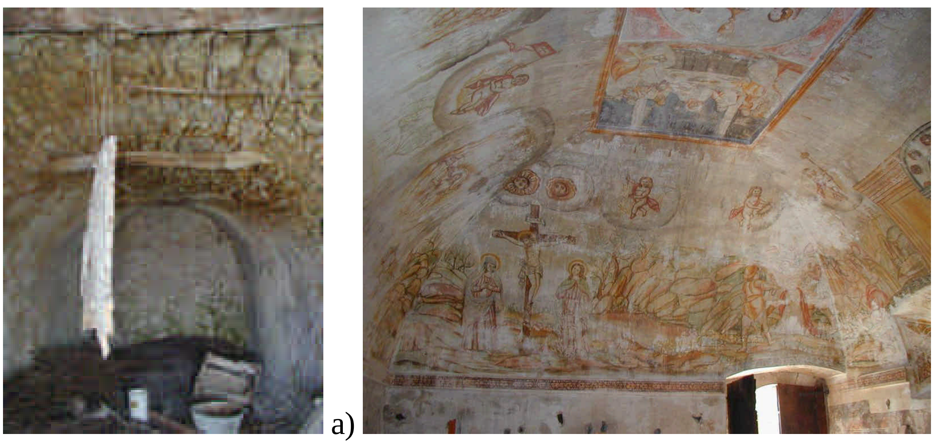


Figure 3. The building typology of Campi Alto.



a) b)

Figure 4. Campi: example of basements with barrel vaults; a) U.I.190 e b) U.I.191.

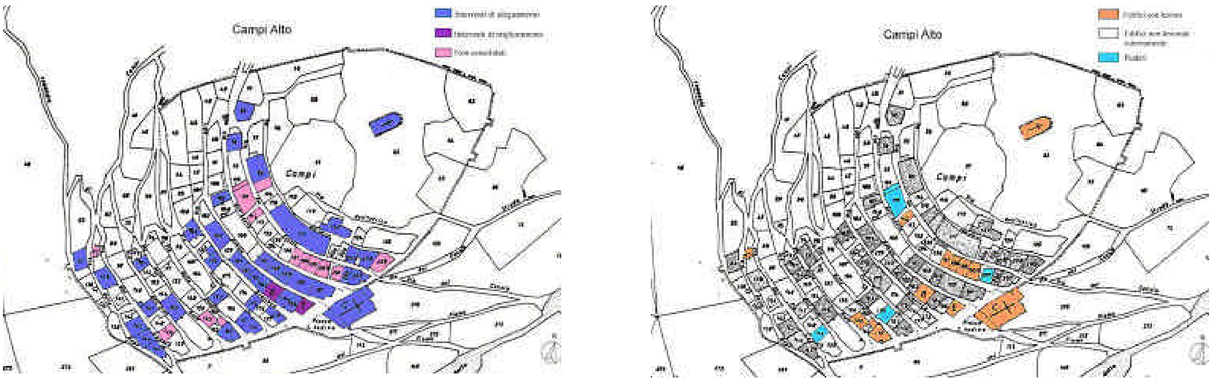
In figure 5 a comparison between the state in 1820-35 and in 1997 is shown.

Edificato
Non edificato

Edificato
Non edificato
Edifici religiosi

Figure 5. Comparison between the state of Campi in 1835 and in 1997.

After the 1979 earthquake that caused many damages to the building structures, the centre of Campi Alto has undergone several interventions of retrofitting that unfortunately changed almost all the original masonry features that now are very hard to study (see Fig.6). Most of the times they were of utmost importance in the preservation of the historic centre after the 1997 earthquake, even if the seismicity in this valley (Castorian Valley) was of minor entity. In fact the damages found in Campi after 1997 were of irrelevant nature, and mainly located in those buildings that were not repaired since a very long time.



Interventi di adeguamento
Interventi di miglioramento
Edifici non consolidati

Edifici con lesioni
Edifici non lesionati estern.
Ruderi

Figure 6. Comparison between the interventions realised before the earthquake of 1997 and the damage verified after the seismic event.

b) Castelluccio di Norcia: the topographic structure of the village is subjected to the soil orography. Thus the main streets wind around the hill dividing the village in four sloping rings. The main streets that in the upper part of the village are almost on level ground, join through short, narrow and steep radial ramps, called BUCI. These are narrow passages whose vaults still bear traces of black old smoke. Unfortunately in the first years of 1980 all the streets of the village were paved with concrete.
There are no isolated houses apart from two new buildings. The village is clustered in a compact building structure. It is to be remembered that in the compact building complexes, the study of the seismic behaviour is much more difficult and in general less clear than those having a regular structure.

c) laboratory and in situ investigations: a diagnostic investigation has been carried out in some private (houses and stables) and religious buildings of Campi and Castelluccio. The Soprintendenza of Regione Umbria has made them available for this survey. The religious buildings are highly valuable but decayed, not only because of the seismic consequences of but also due to the lack of maintenance and presence of moisture in the basements.

Figure 7. Campi: Religious buildings (U.I.C e U.I.B).

The in situ tests consisted in: 1) geometric and material surveys of the single buildings, reported in specific forms and starting points for mathematics models; 2) surveys of the crack patterns; 3) photographic surveys of the details, useful to study the evolution of the building; 4) tests with Flat jacks; 5) sonic surveys; 6) sampling of materials for their chemical-physical-mechanical characteristisation. The sonic tests can be considered as part of the non destructive surveys. They characterize and describe the quality of the masonry. The Flat jack are part of the semi-destructive tests because they detect the state of strain and the tense-deformative behaviour of the masonry. The lab tests have been held on mortars and stones and they led to the definition of physical and mechanical parameters and to the composition of mortars. The results will be very useful in the choice of the intervention materials. The diagnostic phase on the structures and on the materials is important for the interpretation of the behaviour of the structures, for the choice of the right materials

for the structural analysis, and for the choice of the improvement and restoration techniques.
The recommended tests represent the minimum level for the knowledge of masonry, particularly in cases of shortage of funds.
On some buildings of the historic centres some samples of mortar and some of the most recurrent stone materials have been sampled. Mechanical-physical and chemical analysis have been carried out (see Figs. 8,9 and 10).


a)

b)

Figure 8. Sampling of local masonry materials: a) mortar carried out from a religious building (Church of S.Andrea): presence of lime pebbles; b) stones typologies present in the buildings.

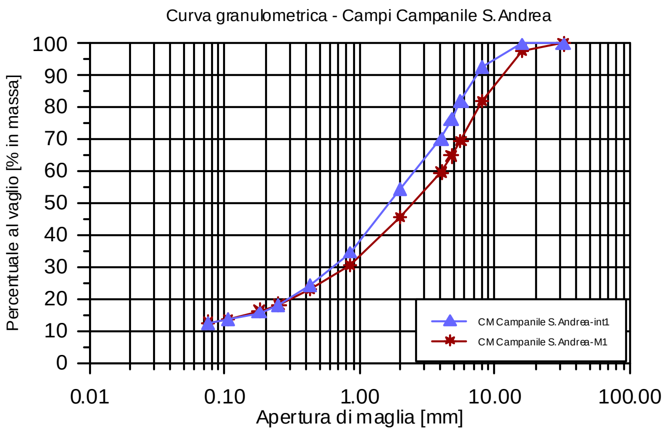


Figure 9. Grain-size distribution of the mortar aggregates sampled from the internal and external masonry of a religious building.

The mortars sampled from private and religious buildings have revealed a high presence of lime pebbles that (as the chemical analysis have confirmed) reveal the putty lime in the binder. The aggregate is mainly calcareous and its ratio with the binder may be stated around 1:2 1:2,5.
On the stone coring of samples have been made in order to get some cylindrical samples to be tested in dry and saturated conditions in two direction. In figure 10 the stress-strain diagrams in compression of some stones are reported.

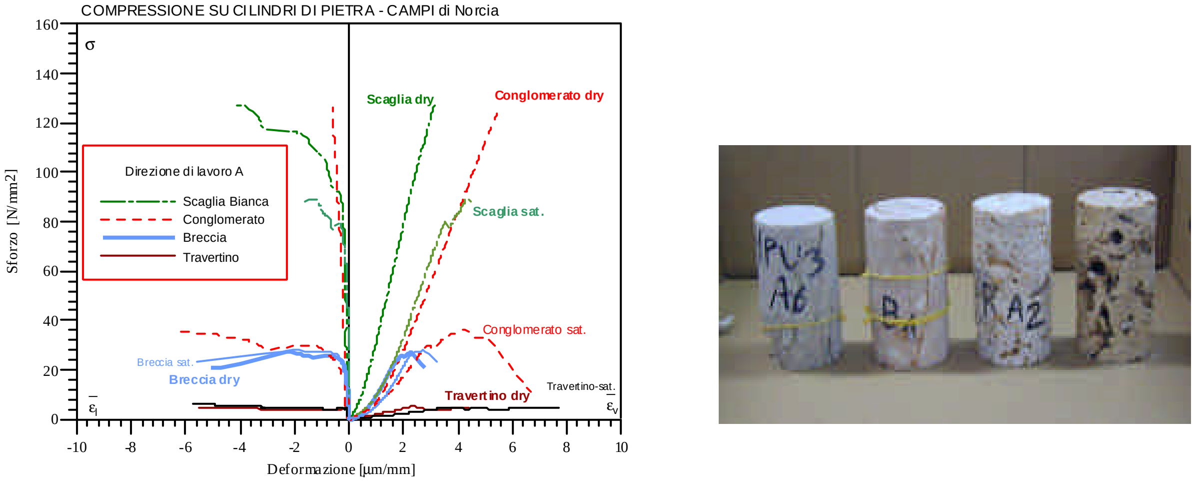
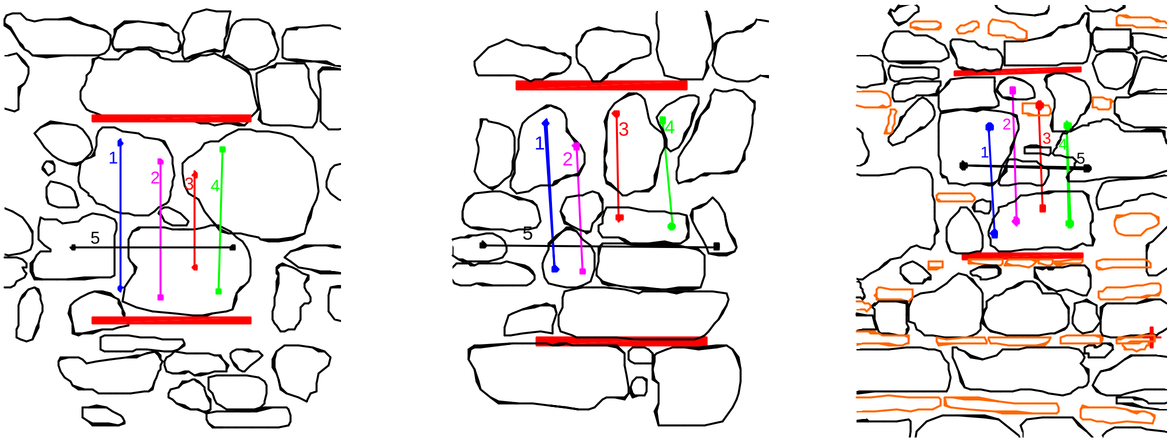


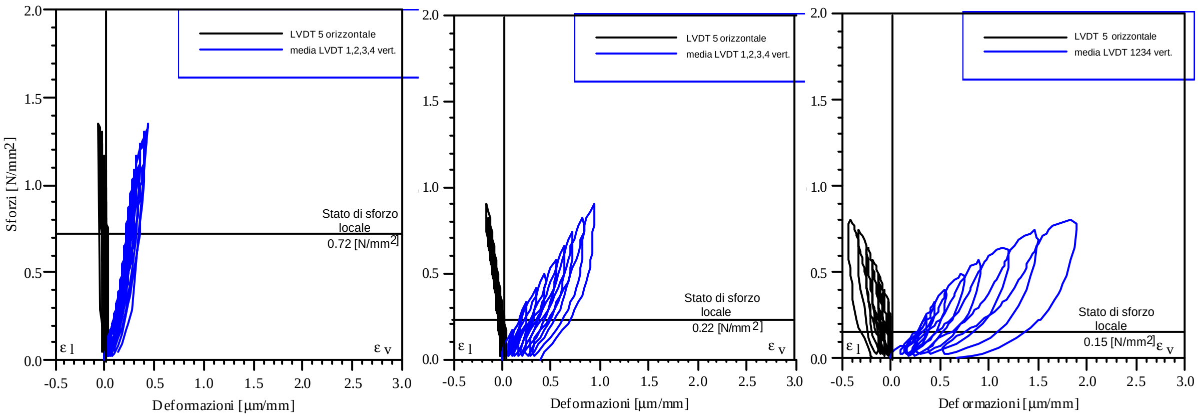
Figure 10. Monotonic compressive tests carried out on cylindrical stone specimens tested in dry and saturated conditions.



Chiesa S.Andrea – external walls CMSAJD4

Chiesa S.Andrea – Bell tower CMCJD5

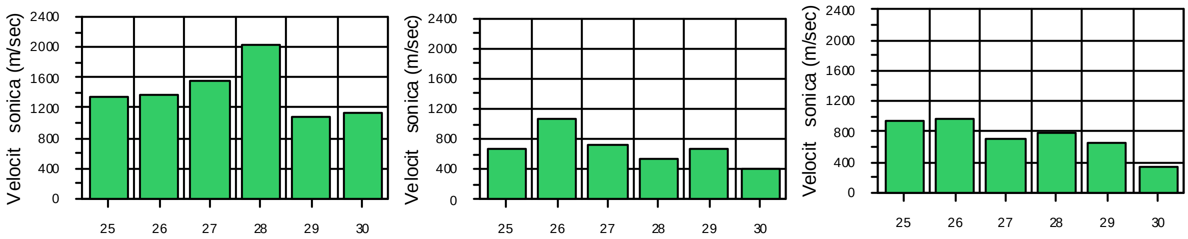
Building UI199 – south façade CM199JD3



	CMSAJD4	CMCJD5	CM199JD3
Local state of stress	0.72 N/mm^2	0.22 N/mm^2	0.15 N/mm^2
Max. reached state of stress	1.35 N/mm^2	0.90 N/mm^2	0.81 N/mm^2
Elastic Modulus (Young)	3116 N/mm^2	902 N/mm^2	435 N/mm^2
Poisson Ratio	0.16	0.18	0.25

Figure 11. Some results obtained through the in situ flat-jack tests.

In figure 11 the results of the tests with simple and double Flat jacks carried out on some sample buildings of Campi di Norcia are reported. The results allow to see the difference of behaviour between the masonry of the important buildings or of complex structures (church or the bell tower) and the private buildings.



Chiesa S.Andrea – mura esterne   Chiesa S.Andrea – campanile   Edificio UI199 – facciata sud

	CMSaSO4	CMCSO5	CM199SO3
Mean value of tot. Velocity	1289.2 m/sec	692 m/sec	737.0 m/sec

Figure 12. Representative results of the surface sonic measurements.

At the same time it is possible to compare the sonic velocity values measured in the same areas where the Flat jack test has been carried out (see Fig.12). Even if to evaluate the differences is not immediate, it is possible to see that the dwelling masonry is the weakest one (UI199) both for flat jack and sonic test. In the next year sonic and Flat jack tests will be proposed as complementary tests to characterise different masonry typologies.

U.R. 3 – Scientific Responsible: Prof. C. Modena

During the second year of research the activity of the R.U. of Padova is focused on the study of the most proper models aimed to the prediction analyses of the vulnerability of the centers that did not show a particular damage after the earthquake occurrence. On the basis of the critical surveys catalogued in collaboration with the R.U. of Milan, the activity has been started on the center of “Campi di Norcia” (PG). The study is founded on the preliminary assessment of the vulnerability of the most damaged centers (Montesanto e Roccanolfi), performed during the first year of the research.

The adopted methodology concerns the application of simply kinematics models able to describe the mechanical behaviour of structural components (macro-models). The analysis is performed at global level by the use of the program Vulnus [1] and, locally, by selecting the most significant elements in the building, by the application of the models describing the single mechanisms of collapse. In such connection, automatic procedures has been implemented in Visual Basic ambient, both concerning Vulnus (Vulnus VB release) [2] and the local application of the single mechanisms (C-Sisma program) [3]; they allow to execute vulnerability analyses in a more large scale, more quickly and easily in comparison to the first applications.

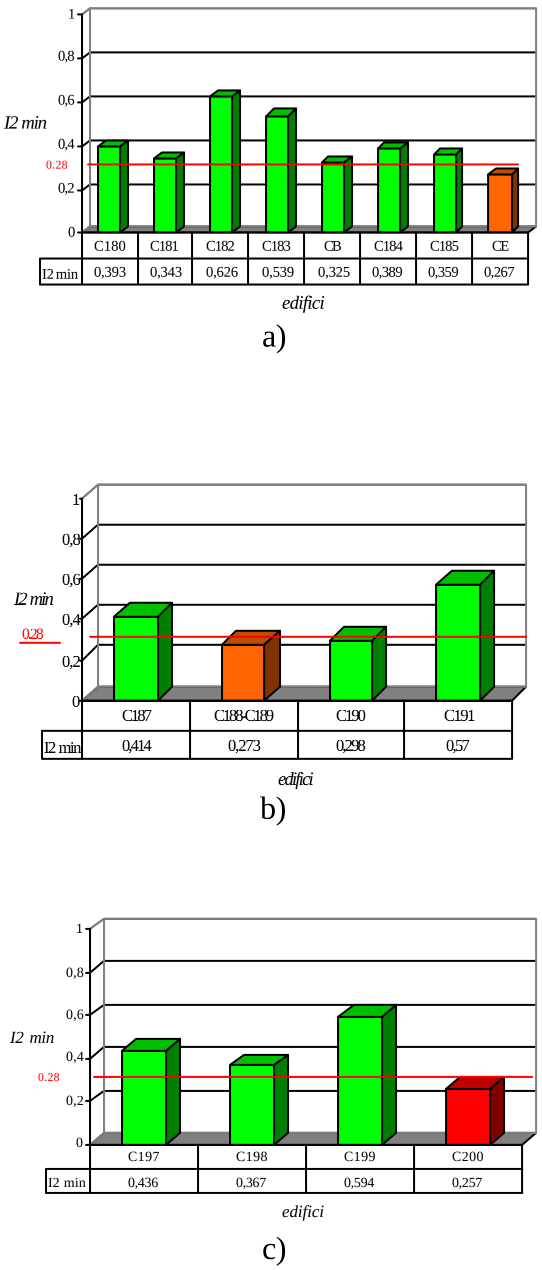


Figure 13. Resuts obtained with Vulnus for the row buildings of "via Graziosa" (a), "via Entedia" (b) and "via dell'Aquila" (c).

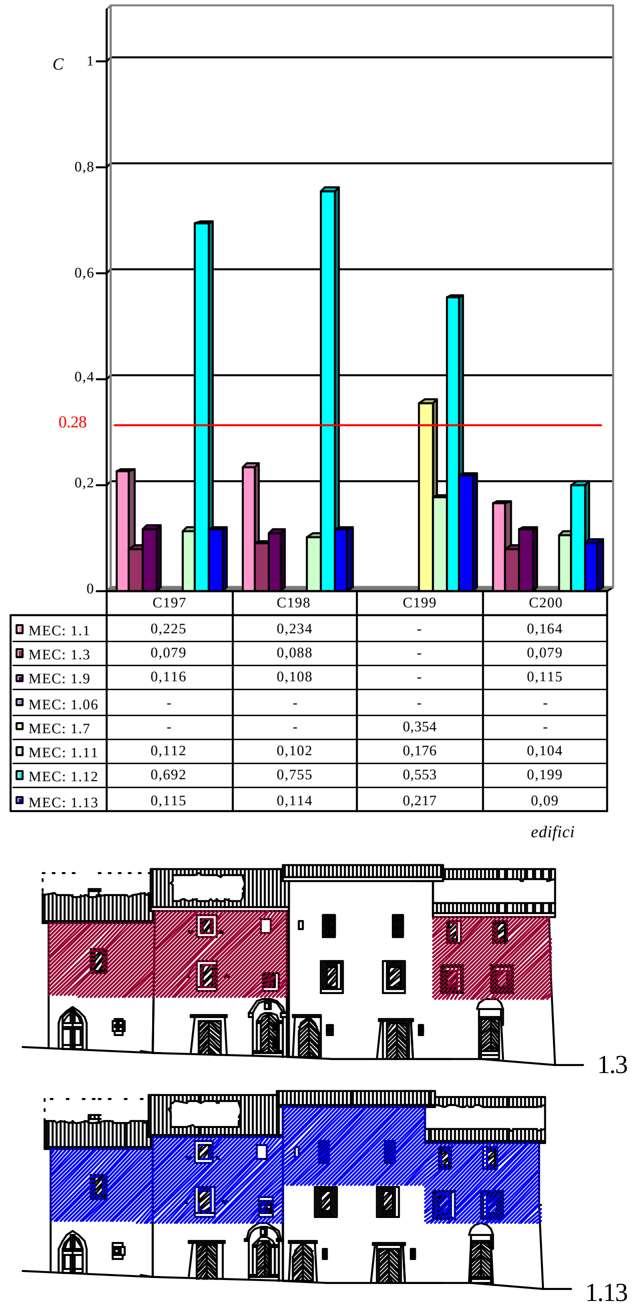


Figure 14. Resuts obtained with C-Sisma for the row buildings of "via dell'Aquila", with mark of the sects more sensible to the weakest collapse mechanisms.

The Vulnus methodology is able to define two indexes, I1 and I2, concerning the in-plane and out-of-plane collapse mechanisms, respectively. The significant parameter, both for the above-mentioned indexes and for the application of the single mechanisms is the collapse coefficient c=a/g, which corresponds to the seismic masses multiplier characterizing the limit of the equilibrium conditions for the considered element. Preliminarily, if the seismic degree of the zone is given (e.g. S=9 for the Campi site, according to the Italian classification standards), it is possible to compare the current vulnerability of the buildings to the limit required from the standards (e.g. c=0.28 for the zone with S=9).

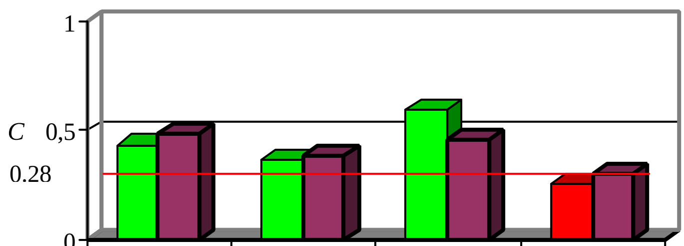
As for the historic center of “Campi Alto”, three row buildings has been analysed; they are composed by 8 units located in “via Graziosa”, 5 units located in “via Entedia” and 4 units located in “via dell’Aquila”.

For all the analysed buildings the lowest collapse coefficients are referred to out-of-plane mechanisms (I2 index). The global “survival” percentage for the buildings is around the 81%. Results denote a particular sensitivity of the most brittle mechanisms (overturning) for the head buildings of the rows.

Fig. 13 shows the results obtained appling the Vulnus procedure; in the graphs, the units which do not satisfy the standard requirements are marked. As an example, Fig. 14 shows the results of the application of the single collapse mechanisms, for the most vulnerable façade of the “via dell’Aquila” row building.

Finally, again for the buildings of the “via dell’Aquila” row, the simulation of several intervention as the strengthening of the masonry walls with injections (where applicable), the possible filling of the openings too close to the corners of load bearing walls, and the rehabilitation of wooden floors and roofs with stiffening compatible techniques [4], can induce a significant improvement. This is quantifiable with a proper reduction of the specific vulnerability (see Fig.15).

In order to complete the general view of the vulnerability conditions of the sites considered in the research, the analysis procedure adopted on the center of “Campi” will be successively applied to the site of “Castelluccio di Norcia” (PG). The main final target is to provide a useful contribution for the draft of a series of recommendations for the design, execution and effectiveness evaluations of the repair and strengthening interventions.



	C197	C198	C199	C200
c prima	0,436	0,367	0,594	0,257
c dopo	0,486	0,389	0,462	0,3

edifici

Figure 15. Row buildings of “via dell’Aquila”: Vulnus simulation of the possibile restoration interventions.

Conclusion

The survey carried out by the 3 U.R., well co-ordinated, thanks to collaboration active of Attilio D'Annibale of Department of Civil Protection, has allowed to gather a great amount of data on:

1. history and evolution of the buildings and of the centres taken into consideration;
2. characteristics of the type of buildings, of structures and of the materials;
3. damages and interventions after the 1979 and 1997 earthquakes;
4. efficacy of the restorations after 1979;
5. possible damage mechanisms of the restored and non restored buildings in the future.

The data have been used to carry on some assesment of the buildings through the Vulnus program, to define their vulnerability and to foresee the necessary intervention techniques.

In the third year the data and the results will be transferred in a database that will deal with the four centres of Montesanto, Roccanolfi, Campi and Castelluccio. Furthermore some guidelines for the diagnosis and for the improvement interventions will be drawn.

References

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