HISTORIC CARTOGRAPHY OF L'AQUILA CITY AS A SUPPORT TO THE STUDY OF EARTHQUAKE DAMAGED BUILDINGS

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Abstract
The city-center of L'Aquila suffered big damages from the main seismic event (6th April 2009, 3:32 a.m., local time; Ml=5.8, Mw= 6.2) of the seismic sequence that included hundreds of aftershocks (more than 30 of them 3.5<Ml<5.0) (*INGV, 2009*). Causes and modality of the collapse of some buildings are still under investigation.
A 1:2000 map representing the center of L'Aquila city at the beginning of twentieth century was recently found and the comparison of this map with contemporary ones can help the study of the causes of the different response to seismic stress to different aged buildings. This study represents the first step to build a database of historic buildings in L'Aquila to test a potential correlation between the anti-earthquake regulations adopted over the years and the resulting damages. A comparison with post earthquakes damage map and the map of seismic zoning was performer to find all the possible combination of other parameters that together with building age can help to evaluate building vulnerability.

Key Words: *L'Aquila City, damages, seismic event, map.*

1. INTRODUCTION

L'Aquila is a city and "comune" in central Italy, both the capital city of the Abruzzo region and of the Province of L'Aquila. Earthquakes mark the history of L'Aquila, as the city is situated partially on an ancient lake-bed that amplifies seismic activity. On December 3, 1315, the city was struck by an earthquake which seriously damaged the San Francesco Church. Another earthquake struck on January 22, 1349, killing about 800 people. Other earthquakes struck in 1452, then on November 26, 1461, and again in 1501 and 1646. On February 3, 1703 a major earthquake struck the town. More than 3.000 people died and almost all the churches collapsed. Anyway the most serious earthquake in the history of the town struck on July 31, 1786, when more than 6.000 people died. On June 26, 1958 an earthquake of 5.0 magnitude struck another time the town.

On April 6, 2009, at 01:32 GMT (03:32 CEST) an earthquake of 6.3 magnitude struck central Italy with its epicenter near L'Aquila, at 42.4228°N 13.3945°E. The earthquake caused damage to between 3,000 and 11,000 buildings in the medieval city of L'Aquila. Several buildings totally also collapsed, 308 people were killed by the earthquake, and approximately 1,500 people were injured. The April 6 earthquake was felt throughout Abruzzo; as far away as Rome, other parts of Lazio, Marche, Molise, Umbria, and Campania.

To understand how much the city was struck by the earthquake we should know how it was structured. The city before this last earthquake had a historic center, situated on a hill above the surrounding basin, and from ancient time it appeared compact, enclosed by medieval walls.

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A first breach of the perimeter of the city happened with the construction of sports installation of the Gran Sasso, during 40s.

The urban expansion developed deeply since 60s and 70s following the opening of the highway from Rome to Pescara (Adriatic sea), and its subsequent development has occurred since then from the historic center and involved all directions, except for the south-west where is located the Aterno river.

The earthquake of April 6, 2009 caused damage mainly to buildings in the historic center. This is highlighted by the border of the so called “RED AREA” that is the area still forbidden to the citizen (**Fig. 1**).

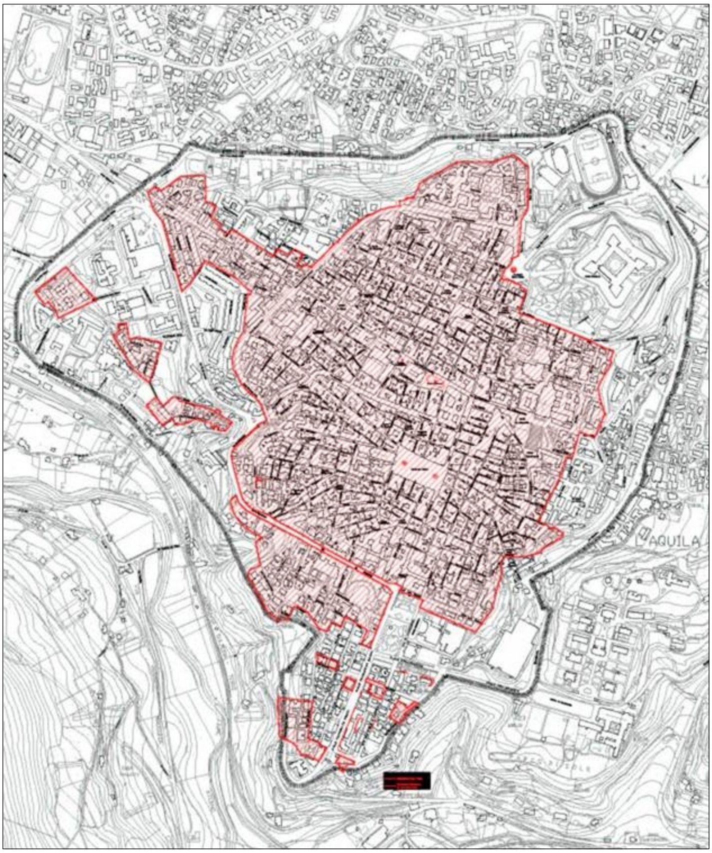

Fig. 1. The “RED AREA” in the center of the city L’Aquila.

For this reason the centre is now almost desert, moreover, unlike other town in Italy, the historical center of l’Aquila was also the commercial and social center of the city so the earthquake total inverted this trend.

In this work we want, through the use of historical maps, to find the date of construction of individual buildings in the city of l’Aquila , in order to improve dating of those built before the 1930 and those after 1940, because around this years the building methodologies change deeply. We want investigated if there is a correlation between a building methodologies and the damage suffered by the building.

2. DATA

In this work was considered a 1:2000 historical map that rappresente the center of the city (**Fig. 2**).

Fig. 2. Historical map that rappresente the center of the city L'Aquila.

This map defines the area that includes the historical center of L'Aquila. The test area is contained in the historic city walls, with an area of 1.2 km2.This map is undated, and for this reasons we tried to figure out what years it was, considering the buildings in it rapresented. Observing the map's layout, and we can hipotize that the map was drow between 1930-1940, that are approximately the years in which the build metodologies changed deeply.

Another map used in this work is the map of fitness for human habitation (**Fig. 3**) (Comune L'Aquila); on it we can clearly distinguish two different types of territory: an area heavily populated, predominantly characterized by buildings of 1700, and an area of more recent construction where the degree of human activity is lower.

The evaluation of fitness for human habitation executed during the first emergency period following the event of 6th April 2009, is a preliminary estimation whose main goal was to establish if the buildings struck by the earthquake can be used without risking human life (*Baiocchi et al. 2012, Baiocchi et al. 2012*). The surveys were performed using technical form, to make the evaluations of different surveyors as homogeneous as possible to allow an immediate digitalization and statistic treatment of the data. The result of the judgment of fitness for human habitation had to fit in one of the six possible categories specified in the chart, where "usable" intends "building suitable for human habitation":

A. Building usable;
B. Building temporarily unusable (everything or part): but usable after some intervention, which makes it usable in all of its parts, without danger for the residents;
C. Building temporarily unusable, to be investigated further: when building presents characteristics that make the evaluation uncertain;
D. Building partially unusable: the state of certain portions of the building could cause elevated risk for their occupants;
E. Building unusable due to structural, non structural, or geotechnical risks; and
F. Building unusable due to serious external risk, in absence of consistent damage to the building: for example, an undamaged building contiguous to a building that could collapse.

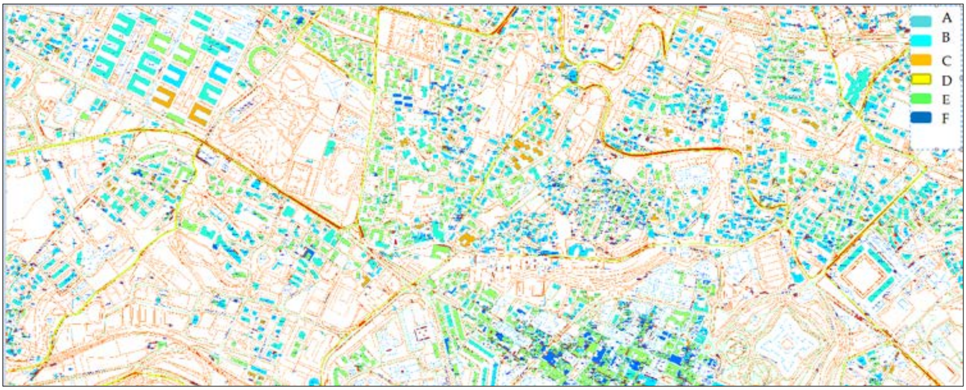

Fig. 3. The map of fitness for human habitation.

On the basis of the results of the surveys carried out by qualified technicians under the coordination of the Civil Protection Department, the maps of fitness for human habitation have been realized as shown in the underlying figure. The original vector maps were not available so mosaic of some pdf file was performed in Q-GIS environment; the map, originally 1:2,000 scale referred to CASSINI-SOLDNER projection, was projected in UTMWGS84- ETRF89.

At this point overlapping the map of fitness for human habitation and the historical map we can distinguish between new buildings and old buildings, so to study if there is a correlation between a building methodologies and the damage suffered by the building.

3. RESULTS

The experiment was conducted on an historic 1:2000 scale map on the center of the city of L'Aquila. Historical maps often suffered geometric deformations during their conservation and other deformation are caused by acquisition (scanning) (*Baiocchi et al. 2000*). To make a georeferencing, usually known points are collimated on the resulting raster file; in this case a GPS survey campaign was performed because there was no modern map with an accuracy comparable to the one of historical map. Georeferencing precision can be estimated considering residuals on Ground Control Points, accuracy can be evaluated considering residuals on Check Points (points independent from parameter estimation). In QGIS we can choose the algorithm for the georeferencing and we choose the 3rd order polynomial, because we think that this transformation surely manages the deformation due to the eventually different projection.

Obviously the number and spatial distribution of GCPs influences the final result of georeferencing of a map; for this reason at first, we identified a set of GCPs found on the ground trying to keep a planimetric distribution as uniform as possible. This was not easy for two reasons; first of all full GPS signal coverage in the historical center does not reach all points, secondly the 75% of the historical center is still inaccessible.

The extension of the area implies the need of a fast survey, technically permissible, relative to the precision and accuracy to be achieved, and economically convenient.

For this reason a Real Time Cinematic (RTK) GPS/GNSS differential mode was used; this mode allowed acquisition of collimable points points on the ground with centimeter accuracy, without being too demanding in terms of time and costs. As it's well known, the GPS-RTK differential technique makes use of a single reference station, fixed on a vertex of known coordinates, located close to the receiver user; measurements of phase, in fact, are faster if calculated in real time referring to a near station because the integer solutions of the phase ambiguity is reached earlier. In this case 27 points distributed on the map (**Fig. 4**) were measured referring to the permanent station of Monticchio (AQ02).

Fig. 4. Distribution of points on the historical map.

Obtained the 27 points, several test have been carried out varying the number of GCP, the first test was made with 12 GCP and increasing two points at time. Obtained results are here represented (**Fig. 5**).

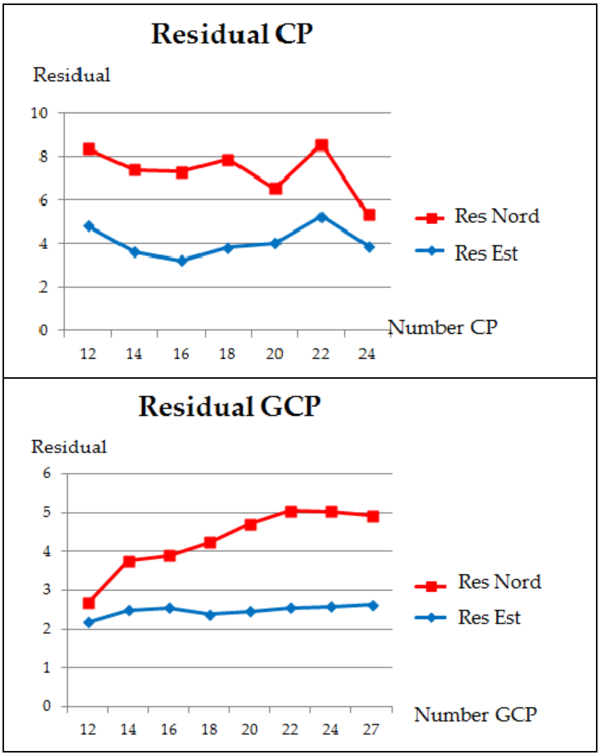

Fig. 5. Trends in residues of GCPs and CPs.

We can observe that, as it was expected, that residuals of GCPs increase till a stabilization while for CPs is just the opposite. It has to observe that N and E residuals don't stabilize at the same value so there is an anisotropy.

We observed a peak that we can't explain and so we investigated if there was an error on that specific points.

We checked GPS coordinates and collimation on the image but we couldn't find anything of wrong, so we checked if the 1:5000 map is more near to GCP point than the georeferenced raster map (**Fig. 6**).

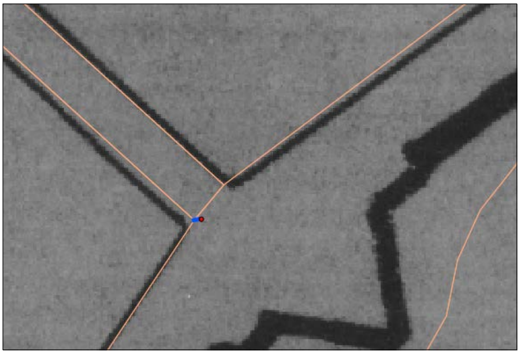

Fig. 6. Overlapping of the historical map with 1:5000 cartography.

This is true on all investigated points, and so we concluded that no gross miscalculation of the coordinate of the point was made but still there is no certain explanation of the causes of the peak.

In QGIS we can choose the algorithm for the georeferencing and we choose the 3rd order polynomial because we think that this transformation surely manages the deformation due to the eventually different projection.

Obtained the georeferenced map, this has been overlapped with the map of fitness for human habitation (**Fig. 7**).

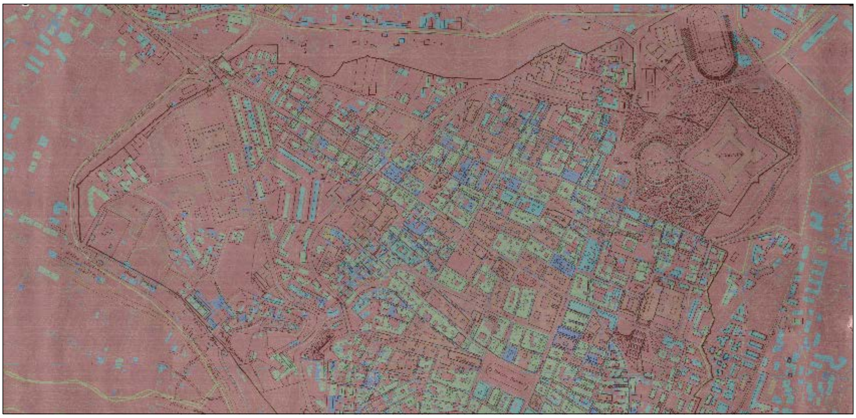

Fig. 7. Overlapping of the historical map with the map of fitness for human habitation.

Within Qgis was then possible to vectorize the polygons according to the classification (**Fig. 8**).

Fig. 8. Vectorization of the buildings according to the classification within QGIS.

Representing the results obtained, we can observe that between the “new” buildings there is a predominance of class “A” that means little or no damage after the earthquake, while for “old” buildings most of them were classified as ”E” or “”, indicating hard damages (**Fig. 9**).

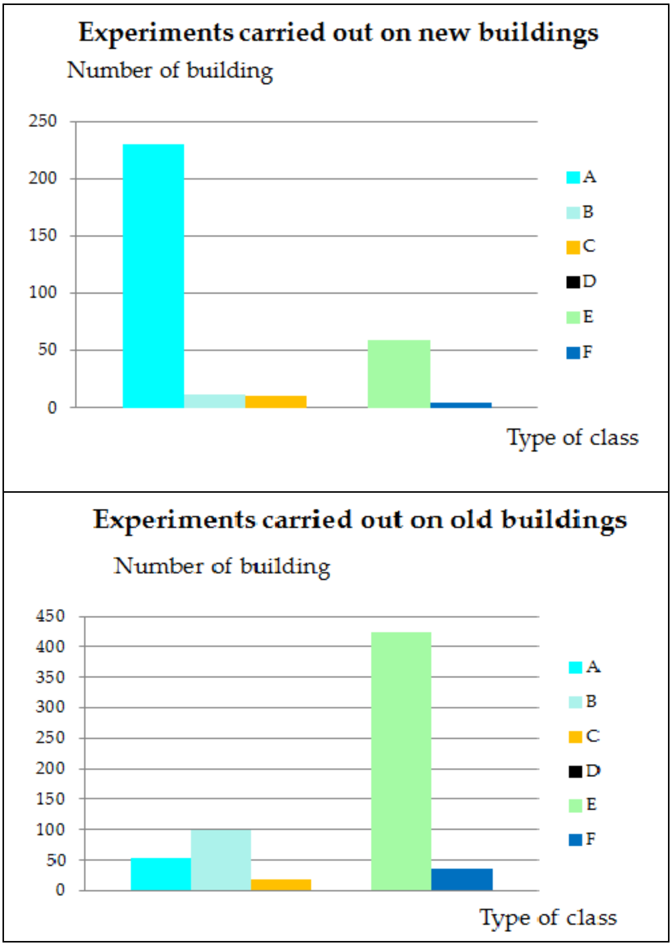

Fig. 9. Graphs showing the distribution in the different classes of new buildings and old buildings.

4. CONCLUSIONS

From the obtained results in this first experimentation we can say that it seems there is a correlation between the age of a building and the damage it suffer after an earthquake. Surely the age is not the only parameter needed to forecast the potential damage of a building but, with GIS and photointerpretation techniques, the age can be detected and mapped very fastly and cheaply. Having a series of large scale maps and aerial images on a city is very easy to create a database of the years of construction every building.

In Italy there are many historic city centers in earthquake risk areas: a detailed survey of the characteristics of each building implies time and costs that probably are not affordable for the Civil Protection Department. Instead we propose a model with no ground survey, therefore much less expensive, with data quickly available and consultable by the different users interested.

Moreover. known the date of construction of the single building, we can go back to the relative regulations and prescriptions at the time of construction. Thus this will help to evaluate, if exist, a correlation between the application of the different legislation in force at the time of construction of buildings and the damage suffered by the buildings themselves.

So this work represents only a first test, but using more large scale maps, it will be easy to realize fastly and cheaply detailed database that can be of support in estimating the possible response of the building to a seismic event and project security plans.

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