

2009 Abruzzo Earthquake Reconstruction Plans: a multidisciplinary approach



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SUMMARY:

The present paper describes the activities carried out at Chieti-Pescara University after the 2009 L’Aquila Earthquake. The activities are multidisciplinary and have involved both engineers (structural and industrial) and architects (urban planner and specialist in historical buildings). The goal was to obtain a comprehensive approach to old towns reconstruction. This activity is particularly important to minimize the earthquake consequences.

Two peculiar aspects of the work are selected among other ones and presented within this paper.

The first one is: how reliable are speedy in-situ surveys, in order to evaluate post-earthquake damages and building occupancy? Considering that both people safety and reconstruction funding depend on this judgment, it is important to check the procedure reliability.

The second aspect is the analysis of an old urban center, viewed as a system of fragile components. System components are both material (e.g. a particular building) and immaterial (e.g. availability of the road system), and have been selected to maximize inhabitants safety, above all in terms of first aid to injured people and in terms of efficiency of strategic structures and infrastructures. These considerations are being slowly introduced in the Seismic Italian Code.

Keywords: Reconstruction Plans, Damage Survey, AeDES Classification Method, In-situ Survey

1. GENERALITY

After the 2009 Abruzzo earthquake, structures and infrastructures rehabilitation and reconstruction are in progress. The process, due to the peculiar Abruzzo characteristics, is quite complex. So it is in progress under the supervision of STM team, a technical Department of the Italian Government created to organize and control the reconstruction phases. The Abruzzo municipalities characteristics, with low population density and low property values, but important historical and aesthetic values, were the focus of the STM intervention policy.

The main initial choice was to co-ordinate reconstruction activities among different towns and necessities (economic, urban, artistic, historical, structural) in a geographical and functional coordination. The operational tools are the so-called “Piani di Ricostruzione” (Reconstruction Plans), in order to respond to present and future needs of the population. The Architecture Faculty of Pescara has been involved in Reconstruction Plans of a large part of the so-called “Area Omogenea 5”. This territory is an important area (13.900 inhabitants, 180 square kilometres, 7 historic municipalities, altitude of about 500 m) on the border of Pescara Province. The work consists mainly in preparation of reconstruction plans and in definition of the main guidelines, together with the preparation of pilot retrofitting projects on important structures (mainly public) having an exemplary character.

In the paper, present and future activities are described, highlighting the positive and negative aspects of this work, together with the interaction between structural, urban and economic aspects. With a special view on the current regulations, the attention is focused on the main structural design approaches, in synergy with all the other design specialties (i.e. architectural and urban planning), in order to implement design criteria that are both safe and respectful of history and aesthetics. The principal goals of this activity are to test the reliability of the post-seismic rehabilitation and seismic improvement procedure as defined in the Italian Code; to evaluate the coherence of the damage survey obtained by means of a simple abacus (AeDES chart) with the local earthquake effects (in terms of maximum peak ground acceleration for example); to define a code of practice for the assessment of historical patrimony. In particular considering old existing buildings, generally built with masonry, the original architectonic characteristics have to be preserved. In parallel with such activity, a multi-disciplinary approach has been carried out considering both structural and urban-planning point of view. A procedure, capable to define the most efficient structural improvement strategy within a urban centre, has been set up. The system (a portion of a municipality) is modelled via its cut sets and at each element is assigned a fragility curve specifically computed. An optimization procedure, aiming at maximizing the global system safety and minimizing retrofitting costs, is then set up. Results clearly indicate the best seismic retrofitting strategy.

2. POST-EARTHQUAKE BUILDING SAFETY SURVEY AND OCCUPANCY EVALUATION

After 2009 L'Aquila Earthquake, the President of Abruzzo Region was designed as Special Commissary for Reconstruction. Many objectives were assigned to Special Commissary: not only a simple structural and infrastructural Reconstruction Plan but also a General Master Plan for regional territory. A Master Plan that involves urban form, reconstruction sustainability (in terms both of structural safety and energetic compatibility), economic balance and, over all, an incentive for repopulation of those historical little towns and villages. This is the ratio of every single Reconstruction Plan (i.e. one Plan for each Municipality). Every plan has to be co-ordinated with regional guidelines and connected with the other confining Municipalities too.

From the administrative point of view each Mayor has "... to predispose Reconstruction Plan for the historical perimeter of the town ..." and his power is based on an old Italian Law regarding the reconstruction after Second World War. For these reasons both technical community (engineers, architects, economists) and academic national community were involved at different levels. Architecture Faculty of Pescara (as regional Faculty) was involved immediately in on site surveys [Baldassarri, E. et al. (2010)] and a large area (the so-called "Area Omogenea 5") was assigned for reconstruction planning to this Faculty.

Each Reconstruction Plan provides four different phases:

- I. definition of Plan perimeters in town historical compound
- II. definition of public decisions and private activities
- III. definition of criteria and modality of structural and urban reconstruction
- IV. coordination and control of reconstruction activities

At this time the first three phases have been completed while IV. phase is in progress.

2.1. The "Area Omogenea 5" territory description

The Abruzzo Region was subdivided, after Earthquake, in 9 Homogeneous Areas. Homogeneity was evaluated in terms of both economical and historical characteristics. In each Area only those Municipalities that suffered significant earthquake damages are selected (so-called Earthquake Crater). In Figure 1 L'Aquila municipal large territory is shown (in red). The 5th Homogeneous Area is globally composed by 21 Communes. Due to earthquake damages 9 Communes are considered in the Earthquake Crater (in aquamarine in Figure 1 left). Seven of these Municipalities signed a Convention with Pescara Architecture Faculty for Reconstruction Planning. These 7 Communes are Brittoli, Bussi sul Tirino, Civitella Casanova, Cugnoli, Montebello di Bertona, Ofena and Popoli (Figure 1 right).

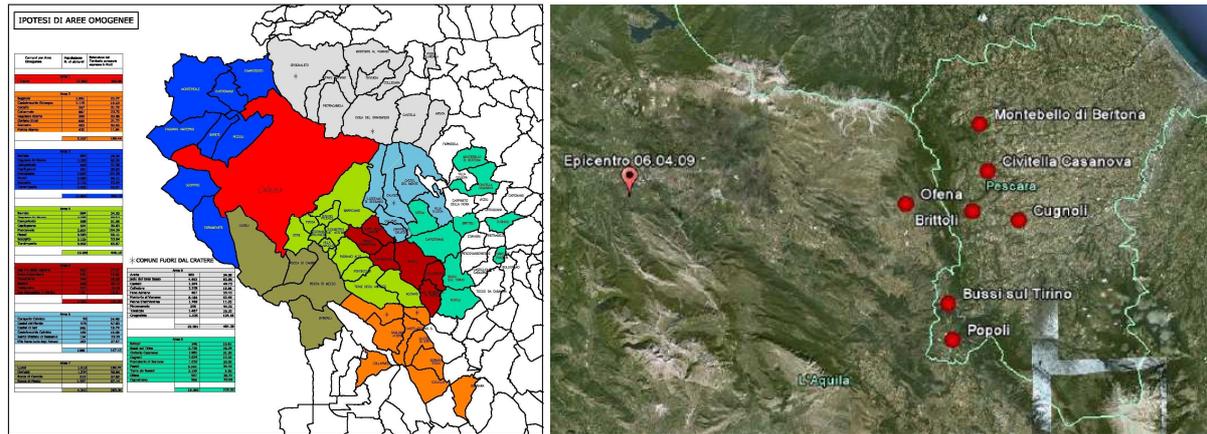


Figure 1. Homogeneous Area subdivision (left) and “Area Omogenea 5” municipality location (right) on respect to L'Aquila Earthquake MainShock Epicenter (01:32:39 UTC 06/Apr/2009 $ML = 5.80$)

Table 2.1. Communes involved in Reconstruction Plans: distance from L'Aquila Earthquake MainShock Epicenter and population at different times are shown

Comune	Geographical coordinates		Distance [km]	Area [square km]	Inhabitants		
	Latitude	Longitude			[1861]	[1951]	[2010]
Brittoli	42°18'59"	13°51'39"	43.40	15.81	1457	1325	346
Bussi sul Tirino	42°12'37"	13°49'38"	42.90	26.29	1429	4089	2739
Civitella Casanova	42°21'53"	13°53'21"	45.80	31.09	3130	4323	1985
Cugnoli	42°18'29"	13°56'00"	49.40	15.32	1772	2737	1624
Montebello di Bertona	42°24'59"	13°52'09"	45.00	20.99	1601	2181	1052
Ofena	42°18'59"	13°51'39"	35.00	36.72	2038	2000	597
Popoli	42°12'37"	13°49'38"	45.00	34.40	6178	8010	5561

Substantially they are positioned on a circle of radius 45 km centred on the position of MainShock Epicenter with the exception of Ofena that is located at 35 km from the epicenter, Table 2.1.. In the same Table 2.1. the population of these municipalities at different times is shown. It is possible to note that all of them had lost population during late 1900's. That aspect is relevant is we consider that the historical building patrimony quantity is linked to historical inhabitants while building patrimony maintenance is linked to actual population. So if, for example, Ofena and Popoli historical extension has a reciprocal ratio 1/4, probably those buildings that actually have a correct maintenance in Ofena are almost one-tenth than in Popoli. This datum has to be considered in a comprehensive approach.

2.2. Seismic activity and L'Aquila Earthquake effects on the “Area Omogenea 5”

In order to evaluate the post-earthquake building survey results, seismic activity in the Area as to be evaluated, in terms of both Code provisions and maximum peak ground acceleration due to L'Aquila Earthquake. This area is historically a seismic prone territory. Just in 1962 all of these communes were classified as seismic ones (II category zone) and basic value of seismic acceleration was assumed as $\alpha = a_g/g = 0.070$. This value was confirmed in 1982 Italian territory seismic re-classification. In spite of this, obviously, historic buildings aren't designed for seismic forces while a seismic approach could have been taken into account, eventually, for those building retrofitted after 1962.

After L'Aquila Earthquake, the new Structural Code (Ministero Infrastrutture, 2008) was adopted and seismic input has to be defined considering site location, nominal building life, use category, working building life. Seismic actions for different limit states are shown in Table 2.2. (SLO Functionality Limit State and SLD Damage Limit State for Serviceability Limit States; SLV Life Safety Limit State and SLC Collapse Limit State for Ultimate Limit States) in terms of design peak ground acceleration, $\alpha_d = a_g/g |_{d}$. Each limit state is defined according to a basic return period $T_R = 50$. It is possible to observe that Montebello di Bertona and Civitella Casanova have lower values of design peak ground acceleration; in spite of this those historical centers were damaged by earthquake.

Table 2.2. Design peak ground acceleration according to recent Italian Code

Commune	Code design peak ground acceleration, $a_d = a_g/g_d$			
	SLO	SLD	SLV	SLC
Brittoli	0.068	0.085	0.214	0.276
Bussi sul Tirino	0.075	0.098	0.251	0.321
Civitella Casanova	0.063	0.079	0.193	0.248
Cugnoli	0.063	0.080	0.195	0.251
Montebello di Bertona	0.061	0.077	0.189	0.243
Ofena	0.073	0.094	0.245	0.314
Popoli	0.076	0.100	0.254	0.325



Figure 2. Damaged or partially collapsed buildings in Montebello di Bertona (left) and Civitella Casanova (right)

Some buildings partially collapsed or were so damaged to will be demolished because it has been deemed too dangerous and expensive to rebuild. In Figure 2 this situation is pointed out. It is possible to note that collapsed buildings are old masonry ones with mixed stone and brick masonry, generally without maintenance and steel ties. Again for recently retrofitted ones inadequately approaches are utilized, above all in terms of both horizontal floor (heavy concrete or tile-lintel floors or weak-in-plane steel-brick floors) and lack of masonry improvement (generally not considered notwithstanding dead and live loads increasing due to functional requests).

In the aim to better understand the impact that L'Aquila Earthquake had on this area an evaluation of the peak ground acceleration in each town due to L'Aquila Earthquake sequence was carried out, Biondi, S. and Vanzi, I. (2011). Data of ITACA - ITalian Accelerometric Archive were used (see <http://itaca.mi.ingv.it/ItacaNet/>) and 8 earthquakes were selected starting from L'Aquila Earthquake Mainshock. For each recorded earthquake epicentral location (Latitude N, Longitude E), local magnitude (M_L), hypocentral depth and epicentral distance from study sites were considered. In Figure 3 (left) the selected earthquake epicentres and the considered accelerometric stations are shown; in same figure the L'Aquila near fault accelerometric stations position and geological characteristics [Di Capua, G. et al. (2009)] are pointed out (right).

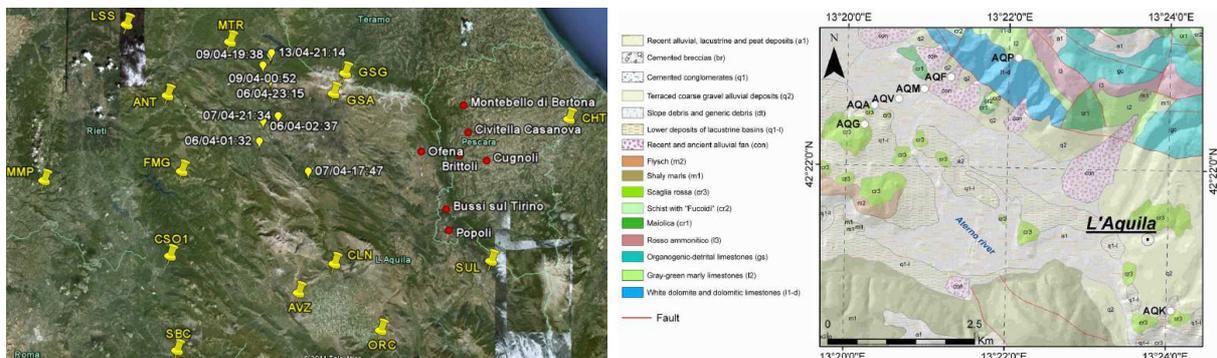


Figure 3. Selected earthquake epicentres and accelerometric stations (left) and L'Aquila near fault permanent accelerometric stations position and geological characteristics (right, [Di Capua, G. et al. (2009)])

To determine the maximum local peak ground accelerations, $\alpha|_i = a_g/g|_i$, the maximum recorded peak (near fault) ground accelerations, $\alpha|_{AQi} = a_g/g|_{AQi}$, are used (considering both permanent than provisory accelerometric stations). In this aim an original attenuation relationship, (B-V), in terms of epicentre distance x (km) is used, [Biondi, S. and Vanzi, I. (2011)]. In order to control this result, in the range of “Area Omogenea 5”, two different attenuation relationships, (S-P) [Sabetta, F. and Pugliese, A. (1987)], and (Z-M) [Zonno, G. and Montaldo, V. (2002)] are considered, based on Italian earthquake data for local magnitude and epicentral distance similar to that of the present paper. These two relationships generally underestimate near fault peak ground accelerations and overestimate far fault peak ground accelerations, [Ameri, G. et al (2009)]. Results for L'Aquila Earthquake Mainshock (06/04/09 01:32) and two successive shocks (07/04/09 17:47 & 09/04/09 00:52) are shown in Table 2.3..

Table 2.3. Maximum local peak ground accelerations estimated via different attenuation relationships for L'Aquila Earthquake Mainshock (06/04/09 01:32) and two successive shocks (07/04/09 17:47 & 09/04/09 00:52)

Commune	maximum local peak ground accelerations $\alpha _i = a_g/g _i$				
	06/04/09 01:32 $\alpha _{AQi} = 0.656 - M_L = 5.8$			07/04/09 17:47 $\alpha _{AQi} = 0.675 - M_L = 5.3$	09/04/09 00:52 $\alpha _{AQi} = 0.181 - M_L = 5.1$
	(B-V)	(S-P)	(Z-M)	(B-V)	(B-V)
Brittoli	0.0551	0.0550	0.0500	0.0478	0.0324
Bussi sul Tirino	0.0564	0.0556	0.0506	0.0552	0.0284
Civitella Casanova	0.0492	0.0522	0.0474	0.0392	0.0319
Cugnoli	0.0415	0.0484	0.0440	0.0344	0.0259
Montebello di Bertona	0.0511	0.0531	0.0482	0.0381	0.0356
Ofena	0.0817	0.0679	0.0620	0.0755	0.0442
Popoli	0.0511	0.0531	0.0482	0.0498	0.0251

It is possible to observe that Montebello di Bertona and Civitella Casanova have lower values of estimated maximum local peak ground accelerations too. For these reasons it is important not to evaluate a single event (a single building collapse as in Figure 2) while to evaluate a global response of a historic compound. This will be the matter of the successive paragraph.

2.3. Post-seismic survey results in “Area Omogenea 5”

After Main-Shock, a lot of professional teams, composed by structural engineers and architects, are created in order to evaluate structural damages and to report occupancy situation in each town. This operation was co-ordinated by the Civil Protection Department. In order to obtain this goal a simple, and speedy, post-seismic survey was carried out for each independent building (where independent means both structural independency and sole property) and an occupancy judgment was delivered. This judgement was obtained by means of a simple abacus (AeDES chart) that considers few parameters in order to evaluate structural damage. After a review of general data (location, construction type, age, height and plan area, occupancy type) a risk evaluation is carried out in terms of structural, non structural, external and geotechnical risks, Figure 4.

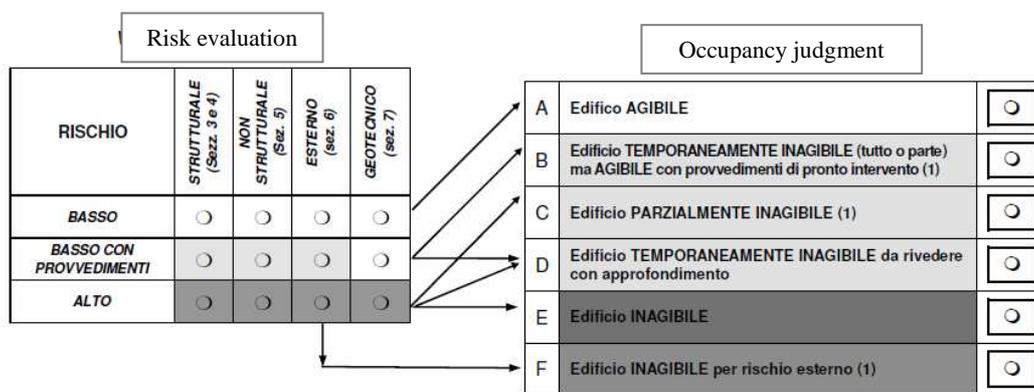


Figure 4. Risk evaluation (left) and occupancy judgment (right) in the AeDES chart (scheda_AEDES.pdf in <http://www.protezionecivile.gov.it>)

In terms of structural configuration both masonry buildings and framed (r.c. or steel) buildings are considered in the AeDES chart. Structural (on vertical and horizontal elements) and non-structural damages have to be combined in order to obtain the occupancy judgment finally. Six categories of occupancy judgment can be selected: -A- immediate occupancy without temporary measures, -B- immediate occupancy with temporary measures, -C- partial unoccupancy due to damage, -D- partial unoccupancy due to insufficient structural information, -E- full unoccupancy for building strong damage or collapse, -F- full unoccupancy for external risk. Almost 900 AeDES charts for 900 independent buildings have been considered for the “Area Omogenea 5”. Basing on this data base, damage survey plans have been drawn, Figure 5. In Figure 6 cumulative frequencies of these different occupancy judgments (A-B-C-D-E-F) are shown. These frequencies are collected considering, for every town, the ratio between the number of building having an occupancy judgment to the total of buildings (left side) or the same ratio if the gross area of each building is considered (right side).



Figure 5. Damage survey plan for Montebello di Bertona (left) and Cugnoli (right): red buildings in plan are E buildings (full unoccupancy for building strong damage or collapse)

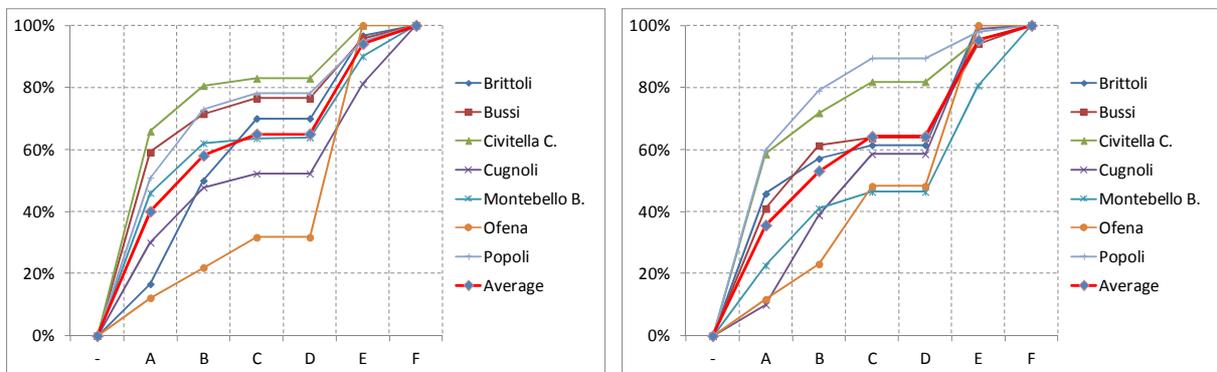


Figure 6. Cumulative frequencies of building number (left) or building gross area (right) for different occupancy judgments (A-B-C-D-E-F)

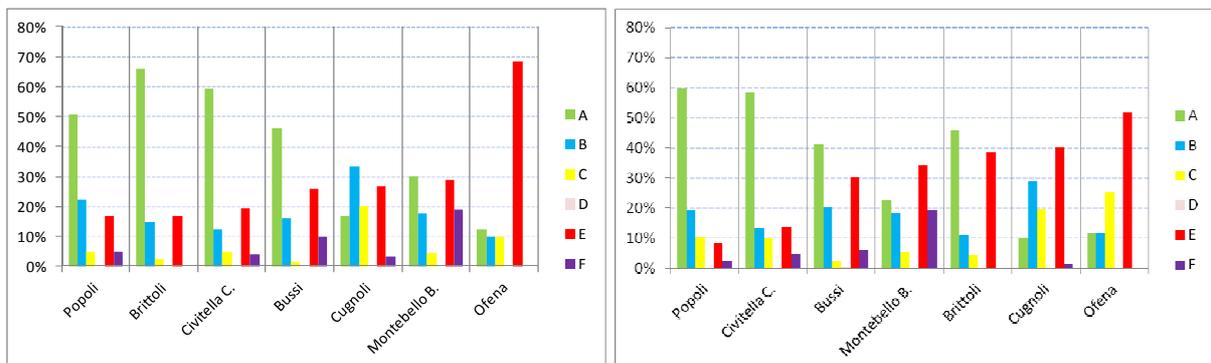


Figure 7. Frequency of building number (left) or building gross area (right) for different occupancy judgments

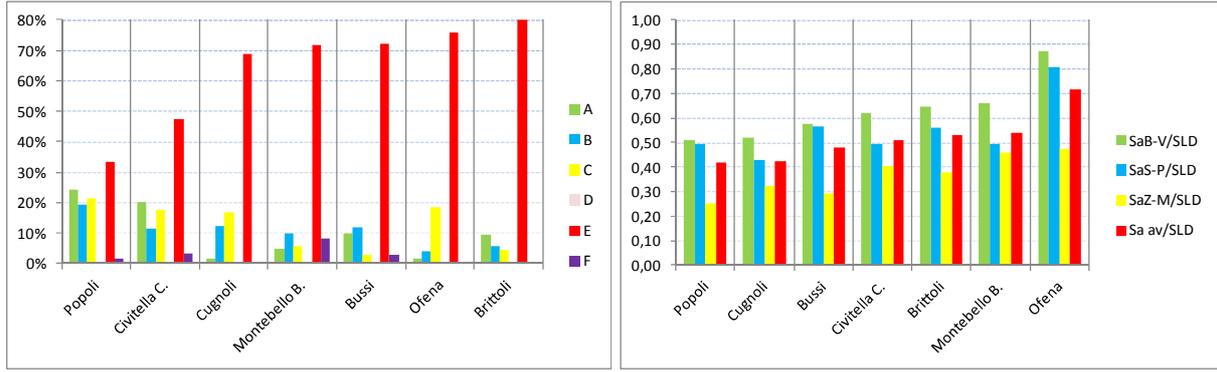


Figure 8. Frequency of admissible fund request (left) for different occupancy judgments. Ratio between maximum local peak ground accelerations estimated via different attenuation relationships to design peak ground acceleration at SLD limit state (right)

In Figure 7 frequencies of these different occupancy judgments (A-B-C-D-E-F) are shown: building number ratio (left) or building gross area ratio (right); finally in left side of Figure 8 the frequency of admissible fund request for different occupancy judgments is shown. In fact as previously discussed [Biondi, S. and Vanzi, I. (2011)] each building owner (both private and public one) has the possibility to request a money amount to the Special Commissary for Reconstruction that is proportional to AeDES Chart results in terms of occupancy judgment. For these reasons the AeDES Chart availability is a crucial topic. In order to evaluate this availability the spectral ratio of (2.1) is considered, $S_{aB-V/SLD}$ is thus the ratio between the maximum local peak ground acceleration estimated via the original Biondi-Vanzi attenuation relationship, $\alpha|_{B-V} = a_g/g|_{B-V}$, and the design peak ground acceleration at SLD limit state as determined for each site in Table 2.2., $\alpha|_{dSLD} = a_g/g|_{dSLD}$. The same ratio can be calculated for two other different attenuation relationships, (S-P) and (Z-M), and for the average value of three different attenuation relationships, $S_{a av/SLD}$. It is to note that all graphs in Figure 7 & Figure 8 are ordered in terms of increasing E frequency. So it is possible to note a good fitting between AeDES Chart responses in terms of building number and the spectral ratio defined in (2.1); while a better fitting is for AeDES Chart responses in terms of building gross area and the admissible fund request. In conclusion we can say that the AeDES Chart approach is a good operative procedure in post-earthquake activity. This conclusion is particularly important if the peculiarity of that part of Abruzzo region is considered: little towns in decentralized position with evident depopulation phenomena.

$$S_{aB-V/SLD} = \frac{a_g/g|_{B-V}}{a_g/g|_{d(SLD)}} \quad (2.1)$$

3. A PROCEDURE FOR URBAN RISK ASSESSMENT AND REDUCTION

A particular relevance assumes the analysis of urban seismic vulnerability; such kind of analysis has been developed in the past by the Authors. In particular a procedure for safety evaluation was improved for network systems like electric power, road, water, hospital regional systems or for hospitals, bridges or strategic buildings as a single structure, Nuti, C., Rasulo, A. and Vanzi, I. (2010). In the specific case of Reconstruction Plan a new system is considered: the so-called Urban Minimum System (SUM) i.e. an urban system composed of buildings, open spaces and public ways [Biondi, S. and Vanzi, I. (2011), Biondi, S., Fabietti, V. and Vanzi, I. (2011)]. If this system is composed with infrastructural networks and external risks (environmental and geological risks) it is possible to analyze a complex system.

From a mathematical point of view, considering that aleatory quantities are involved, as structural strength, the approach has to be probabilistic; on the other hand if a Reconstruction Plan has to be approved, practical and operational decisions have to be assumed.

Generally when a seismic safety evaluation is carried out a procedure to maximize safety of selected nodes and minimize economic expenses has to be constructed, allowing identification of which components, within each part of the system, have to be upgraded to obtain the maximum economic convenience. In the case of a urban system the approach has to be revisited in order to take into account functional, and social, role of the different part of a city. So the evaluation of urban vulnerability doesn't only depend on the constructive characters of each structure but it is strictly connected with city identity. So, for example, in a historical towns, as those of this paper, isn't only important that inhabitants will be safe during an earthquake but it's important that they will remain in the historical center, that shops and public offices will be re-open, that schools will guarantee their lessons, that monumental buildings will not damaged and touristic activity will continue.

When a Urban Minimum System (SUM) is analyzed, it has to be clear that it generally plays a fundamental role not only in municipal range but also in territorial range. For example if some public or private services are located in every municipality (as town office, postal service, primary school, Pharmacia or food store), other services are territorial (as hospitals, police stations, fire departments, superior schools). This territorial approach was deeply discussed in previous papers. In this paper attention is paid on a smaller portion of territory: a historic centre of a little town or of a small village with its social life and its necessity of safety. In this centre often buildings have low maintenance, inhabitants are generally older and poor and, in some cases, the building owners are unknown and a large part of estate patrimony is abandoned. For these reasons fragility assumptions have to be more conservative than for similar building that have a regular and continuative maintenance; i.e. when a fragility curve is selected for these buildings, a more probable lack of capacity has to be assumed.

3.1. Urban Minimum System: the case of Montebello di Bertona

The case study is that of Montebello di Bertona; this small village has about 1000 inhabitants and it suffered a peak ground acceleration for L'Aquila Earthquake that is almost a half of SLD design peak ground acceleration, Figure 8. On the contrary it is "rich" in potential risk sources, Figure 9.

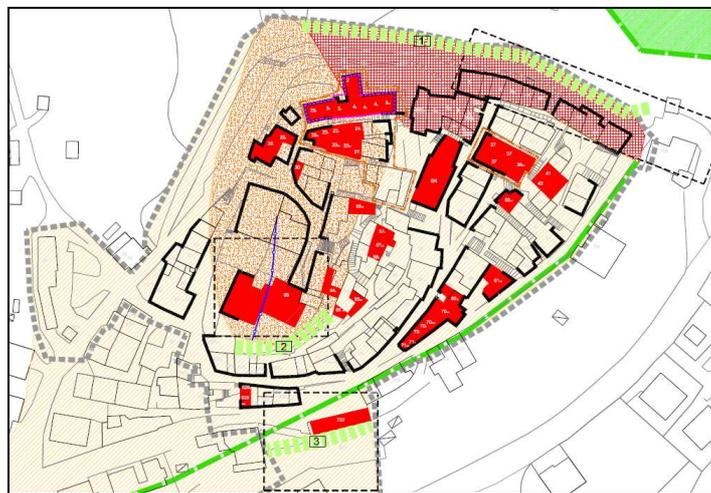


Figure 9. Potential risk sources map in Montebello di Bertona historic centre

These risks are structural (red buildings are those with E occupancy judgments, black thick lines are those building fronts that can collapse on public ways or open spaces), functional (brown dotted lines are those buildings that are abandoned or without clear property situation), geological (green portions are sliding ground, green dashed tick lines are those for potential sliding fault, black dotted lines are those ground portions with insufficient geological information, purple dotted lines are those for potential differential settlements due to ground discontinuity). The logical scheme for Montebello di Bertona Urban Minimum System is shown in Figure 10. This scheme is composed of four sub-systems (strategic buildings, open spaces, external risks, public ways) arranged in series; each of these

sub-system is arranged in series too. When a system is arranged in series it means that each element has to be safe if global safety has to be preserved. So if a strategic building is considered, for example a primary school, it is safe if open spaces near the school are accessible, if electric power is at disposal, if water network is operative, if eventual ground sliding remains in a quiescent stage, if public ways preserve their accessibility to the entire community and, above all, by ambulances or civil protection and fire trucks.

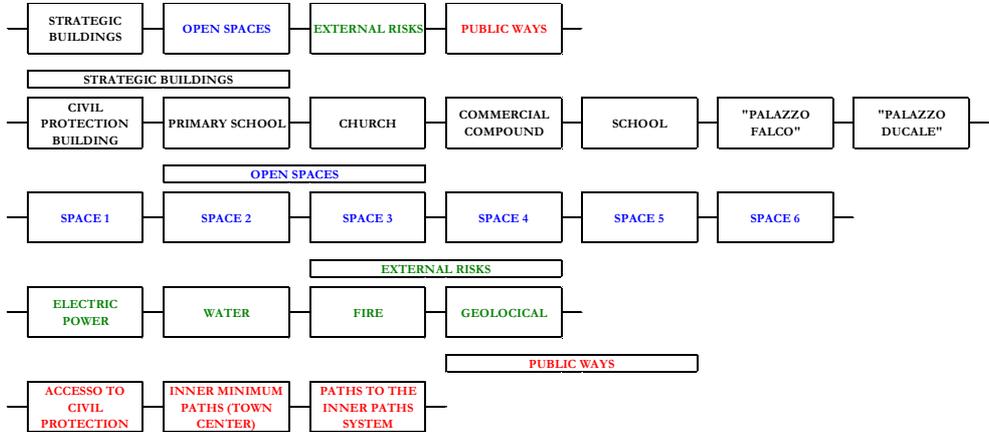


Figure 10. Logical scheme for Montebello di Bertona Urban Minimum System

On the other hand when an element class shows some redundancy, the component can be assumed as arranged in parallel. So if the same primary school can be reached by means of two different road ways, these two ways are in parallel and one of these can collapse if the other remains full efficient. In order to guarantee this equilibrium a probabilistic approach has to be carried out. Fragility curves of each component have to be selected, fragility behavior of the system has to be defined via Montecarlo and target safety level has to be selected. That it is with drastic decisions too: if a building can collapse on an important way, it would be better if the building could be demolished.

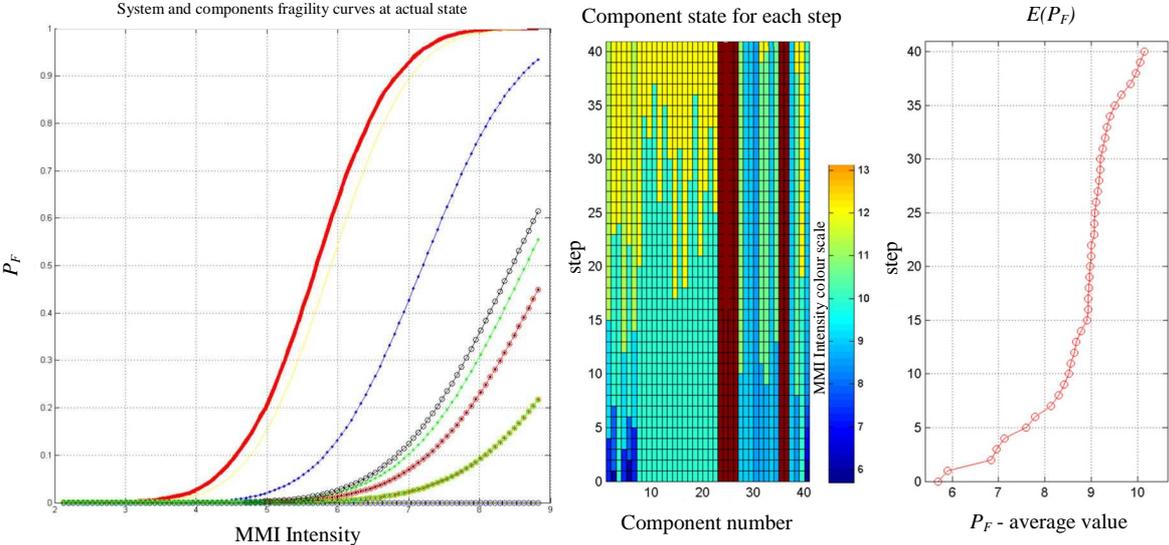


Figure 11. Actual fragility curves for Montebello di Bertona Urban Minimum System (left) and step procedure to minimize failure probability P_F in terms of MMI index (right)

In Figure 11 fragility curves for the study Urban Minimum System are shown (left). Almost 40 elements are considered and red thick line is the actual fragility curve of the system. It is possible to note that system fragility depends mostly on a single component fragility and that actual failure probability is $P_F = 50\%$ for $MMI \approx 5.7$. If the retrofitting procedure is carried out, it is possible obtain that, in about 40 steps of a single element independent improvements, the average failure probability ($P_F = 50\%$) can be observed for $MMI \approx 10.2$. A real and important safety gain for the Urban System.

4. CONCLUSIONS

A complex and important post-earthquake activity is discussed in this paper. In particular the attention is paid on 2009 L'Aquila Earthquake effects on Abruzzo Region in Central Italy. A task group of Architecture Faculty of Pescara was involved both in post-earthquake immediate in-site surveys and, afterwards, in reconstruction activity. This second activity consists in the planning of reconstruction. A Reconstruction Plan, (in Italian: *piano di ricostruzione*), is an original tool that tends to program and co-ordinate structural rehabilitation, urban planning, funding procedures, economical decisions and so on. This tool is controlled by a technical Department of the Italian Government (STM team), and it is co-ordinated by the President of Abruzzo Region, acting as the operative leader for rebuilding activities. It is approved by each Municipality in the epicentre vicinity (a newly coined, self describing Italian word was coined to identify the area, *cratere del terremoto*, i.e. Earthquake Crater). This Plan is compulsory for both public and private reconstruction activities, above all if public funds are used. Two peculiar aspects of the work are selected among other ones and presented within this paper. The first one is: how reliable are speedy in-situ surveys, in order to evaluate post-earthquake damages and building occupancy? This evaluation is carried out considering the AeDES chart that is an abacus used for survey according to Italian Code. The second aspect is the analysis of an old urban center, viewed as a system of fragile components. System components are both material (e.g. a particular building) and immaterial (e.g. availability of the road system), and have been selected to maximize inhabitants safety, above all in terms of first aid to injured people and in terms of efficiency of strategic structures and infrastructures. These considerations are being slowly introduced in the Seismic Italian Code. This system is called Urban Minimum System (SUM) and it is analyzed as a complex network system. Both AeDES chart procedure and Urban Minimum System (SUM) approach proved efficient tools for post-earthquake activities. However, while the AeDES is already contained within the current post earthquake relief procedure, use of the SUM (or equivalent) approach should be further promoted to allow for its use in the Seismic Italian code.

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