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THE RECONSTRUCTION OF SAN GIULIANO DI PUGLIA AFTER THE OCTOBER 31ST 2002 EARTHQUAKE

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SUMMARY

This paper summarizes the activities in the emergency stages, post-emergency phase and reconstruction planning of San Giuliano di Puglia, struck by the October 31st 2002, earthquake. A brief description of the event, the seismic hazard analysis and the vulnerability evaluation of buildings, are first reported. The main results of the study, carried out by a scientists team ("San Giuliano Technical Scientific Group", SG-TSG), are discussed. These activities concerned participation in the detailed evaluation of damage, draft of the demolition plan, ensuring safe conditions to the buildings to be repaired, actions for allowing residents to safely re-enter their non-damaged houses, and preparation of the reconstruction plan. In agreement with local people, the town will be reconstructed mostly where it was. The seismic safety will be ensured by adequate construction methods and possibly large use of Modern Antiseismic Techniques.

INTRODUCTION

October 31st, 2001, 11:35 local time: a moderate earthquake struck Molise Region (Italy), where the first shock (5.4 magnitude) was followed by another (5.3 magnitude) the day after. Major damage was evident in San Giuliano di Puglia, a small town located about 5 km from the epicenter (Figs. 1-2), completely evacuated after the seismic event, made inaccessible and protected by the police. The images of the primary school collapse, where twenty-seven children and one teacher died, went around the world. Moreover, most buildings, nearby the school and besides the main street, were ruined, causing two further victims. The seismic intensity in San Giuliano was estimated to be at least two MCS degrees higher than in the other epicentral municipalities. In addition, damages were not uniformly distributed also inside the San Giuliano narrow area, characterized by different levels of seismic hazard and structural vulnerability. Due to the above mentioned factors, about 120 buildings were completely demolished. Even the ancient historical center, sited on a rock soil area, suffered spread severe damage in notable structures (Marchesale Castle and San Giuliano Church) and in the majority of the architectonical sectors. ENEA took part in all the activities following the seismic event: a) the emergency stages, under the coordination of the Italian Civil Defense Department, with experts involved in the analysis of the damaged buildings in several towns of Molise (Campobasso, San Martino in Pensilis, Guglionesi, Petacciato, etc.), in order to

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select the usable and not usable ones; b) the post emergency phase, where the authors were members, with other experts, of the San Giuliano Technical Scientific Group (SG-TSG); the group carried out a detailed evaluation of damages in all the buildings, drafted the demolition plan, ensured safe conditions to the buildings to be repaired and operated for allowing residents to safely re-enter their non-damaged houses (about 10% of the 1200 inhabitants of the village); c) the San Giuliano reconstruction planning, with the constitution of a specific working team.

In spite of the high number of demolished buildings, and in agreement with most residents, the town will be reconstructed where it was. Only the buildings in the collapsed school area will be reconstructed in another zone for obvious sentimental reasons. The seismic safety will be ensured by adequate construction methods and possibly large use of Modern Antiseismic Techniques (MATs), such as Seismic Isolation (SI) for new buildings, Passive Energy Dissipation (PED) for retrofitting, Shape Memory Alloy Devices (SMADs) and other non-invasive techniques for Masonry CUltural HEritage Structures (MCUHESs) and historical center [1-2].

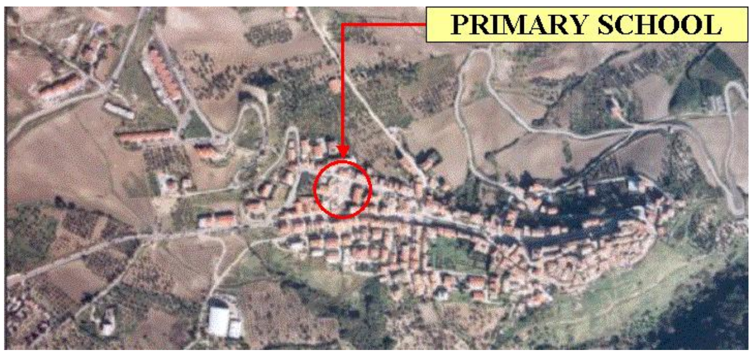


Fig. 1. View of San Giuliano di Puglia

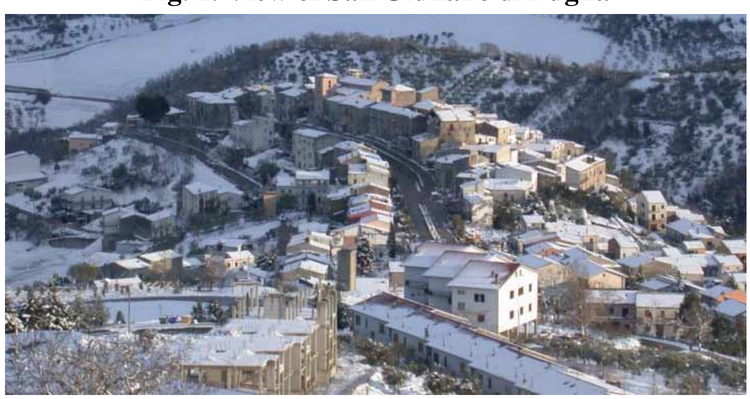
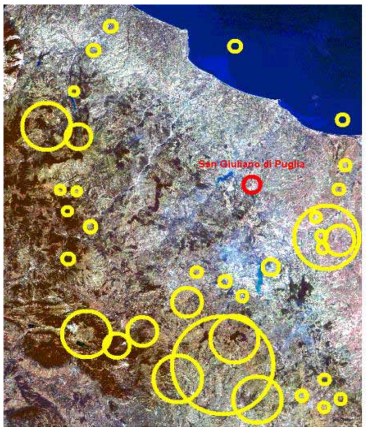


Fig. 2. Winter in San Giuliano after the earthquake

THE OCTOBER 31ST 2002 EARTHQUAKE

The main seismic events interesting Molise Region are shown in Fig. 3 [3]. The historical data pointed out that the seismic sources affecting San Giuliano are far from it and localized along the Apennines ridge. The maximum seismic intensity at the site was estimate to be VIII-IX MCS, observed both during the 1456 and 2002 events. The return period has been estimated equal to about 250 years for VII-VIII MCS event and to 500 years for VIII-IX MCS event. San Giuliano had not interested as epicentral area since several centuries, but the 2002 earthquake struck the town with about two degrees more than the closest municipalities (Fig. 4). Probabilistic (Fig. 5, [4]) and deterministic (Fig. 6, [5]) maps, available for Molise, gave similar results. The territory of San Giuliano had already been mentioned among “high seismic risk areas” [6], but only in the last classification [7] it has been included in zone 2 (Fig. 7).

After the earthquake, the Italian Civil Defense Department appointed a technical commission to perform the seismic microzoning in San Giuliano (Figs. 8-9, [8]). From a seismic point of view, three main zones can be individuated: the historical center, classified as A1.2, i.e. rigid soil (A) and amplification factor S=1.2; the saddle area, classified as B1.6 (soil B, S=1.6); the Northern side, including also the West saddle area, classified as B1.4 (soil B, S=1.4). Small areas with lower hazard, at North and West of the historical center, have been classified as A1.0 (soil A, S=1.0).



Epicenter	Year	Month	Day	Hour	Min	Lon	Lat	MCS	M
Molise	1456	December	05			14.711	41.302	XI	6.6
Sannio	1688	June	05	15	30	14.570	41.280	XI	7.1
Molise	1805	July	26	21		14.470	41.500	X	6.6
S. Giuliano	*2002*	*October*	*31*	*10*	*34*	*14.964*	*41.685*	*VIII-IX*	*5.4*

Fig. 3. Historical earthquakes interesting San Giuliano

Municipality	Lon	Lat	MCS
San Giuliano (*)	14.964	41.685	VIII-IX
Bonefro (*)	14.935	41.704	VII
Casalnuovo Monterotaro	15.105	41.620	VII
Castellino del Biferno	14.731	41.701	VII
Ripabottoni (*)	14.808	41.688	VII
Santa Croce di Magliano (*)	14.991	41.711	VII
Colletorto (*)	14.970	41.663	VI-VII
Montelongo (*)	14.950	41.736	VI-VII
Casacalenda (*)	14.848	41.740	VI
Montorio nei Frentani (*)	14.933	41.758	VI
Larino (*)	14.911	41.799	VI
(*) Municipalities not classified as seismic zones before the 2002 earthquake.			

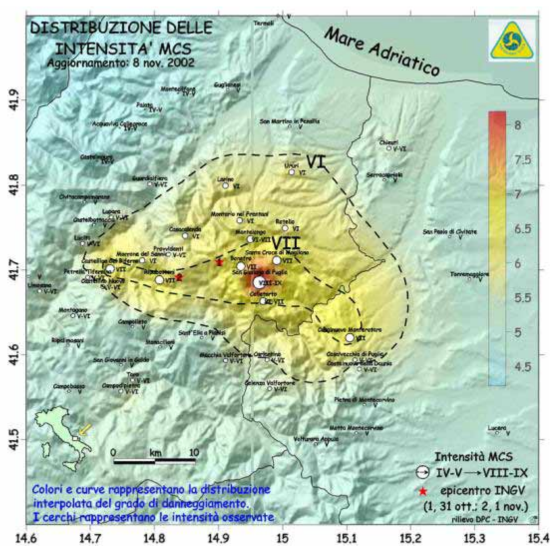


Fig. 4. MCS distribution after the 2002 seismic event

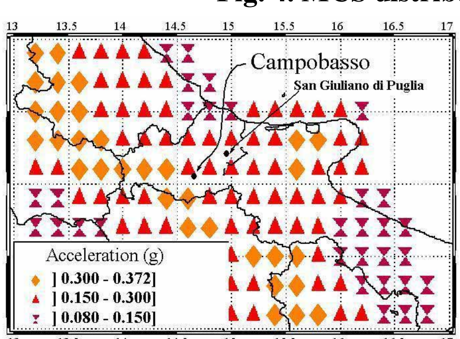


Fig. 5. Probabilistic PGA

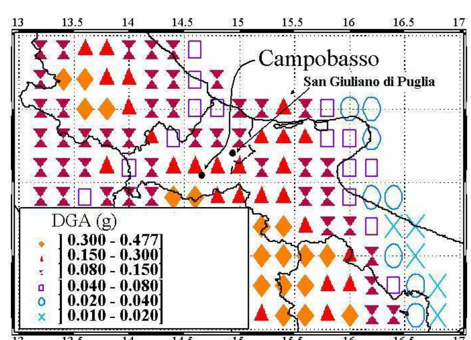
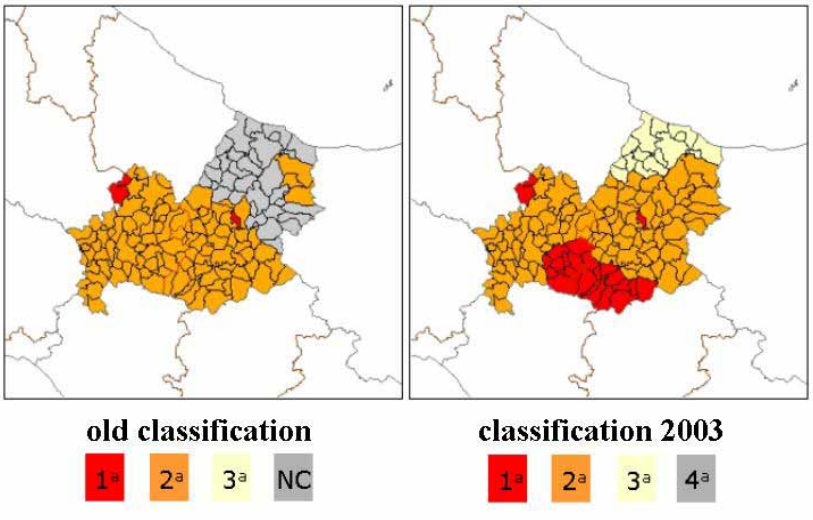


Fig. 6. Deterministic PGA



SEISMIC ZONES	
ZONE	a_g
1	0.35 g
2	0.25 g
3	0.15 g
4	0.05 g

Fig. 7. Molise seismic classification before and after the October 31st earthquake

Fig. 8. The San Giuliano saddle from Western side

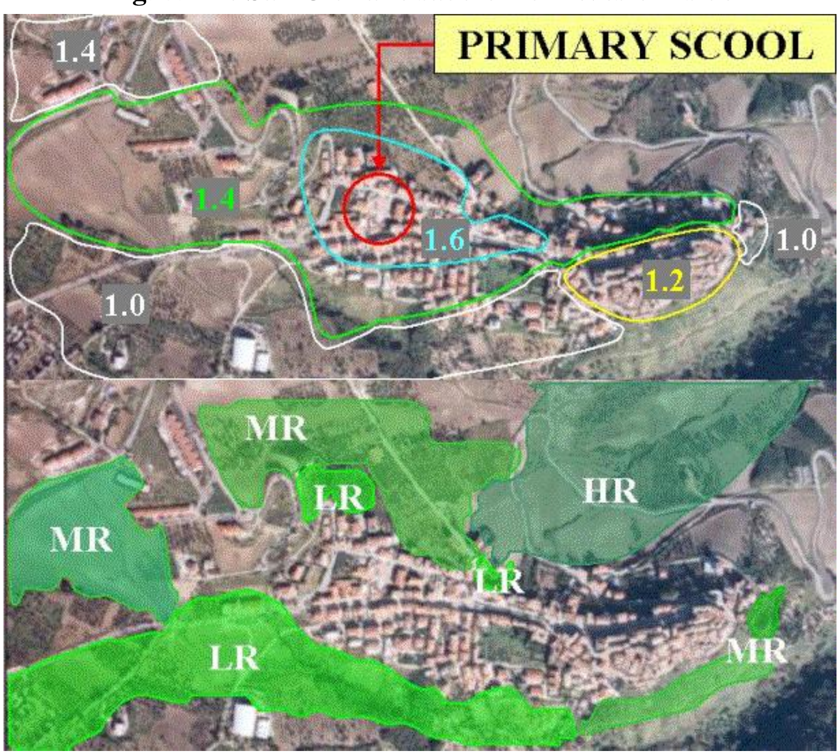


Fig. 9. Microzoning at San Giuliano: amplification factors (top) and slope hazard (bottom)

With reference to slope instability hazard, the urban area has been also divided into three zones, characterized by three different degrees of slope instability hazard: LR, characterized by low risk, with instable soil having thickness t < 1 m; MR, with medium risk, 1 < t < 3 m; HR, having high risk, t > 3 m.

The seismic microzoning reflected the zones with different topography and built in different ages:

i) the ancient center, very interesting from a historical and architectural point of view, located on the top of the Southern hill; it was almost ruined and uninhabited in some internal zones; the most notable MCUHESs are San Giuliano Church and Palazzo Marchesale;

ii) the central area, placed on the saddle, developed around the main street (the "Corso"), with buildings of the first decades of the twentieth century;

iii) the Northern side, formed by buildings of 50s, often with concrete structure.

It is worth noting that the reconstruction of medieval villages destroyed by seismic events, related with amplification problems, was already studied by ENEA after the 1997 Marche-Umbria earthquake [9].

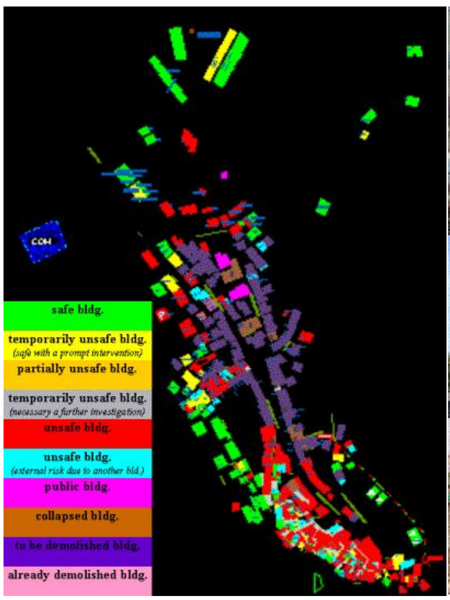


Fig. 10a. Safe (green), unsafe (red) and demolished (violet) houses

Fig. 10b. Demolition works

Fig. 10c. The saddle area after the demolitions

Fig. 11. Recovering of valuable architectonical elements

THE POST-EMERGENCY ACTIVITIES

As in all the municipalities hit by the earthquake, also in San Giuliano teams of experts analyzed all the buildings, under the supervision of the Italian Civil Defense Department, pointing out the damages and declaring them usable or not. This work (about 800 sheets) was also useful for the subsequent post-emergency phase, when the ENEA researchers, in the framework of the SG-TSG activities, carried out a detailed analysis of all the structures. These were classified in (Fig. 10a): severely damaged buildings to be demolished (violet); damaged buildings, which could be repaired and seismically improved (red); buildings that could be used immediately (green). On the basis of this analysis, SG-TSG drafted the demolition plan, approved together with experts of Molise Region, Cultural Heritage Office, Province of Campobasso, National Fire Brigade and San Giuliano Technical Office (in the framework of subsequent and collective investigations). Then, a dedicated team of Firemen performed the work (about 120 structures, Fig. 10b), in presence and in agreement with the owners. Thanks to these and other interventions, it was possible to eliminate the danger and make accessible the principal streets (Fig. 10c), in order to allow the residents to safety re-enter their non-damaged houses (about 10% of the 1200 inhabitants of the village). Recovering, if possible, of personal effects and valuable architectonical elements (above all stone portals and balconies, see Fig. 11) was also performed.

OVERVIEW ON THE SEISMIC VULNERABILITY OF BUILDINGS

About 50% of the San Giuliano constructions were in masonry, made of perforated bricks or stones; 25% of dressed stones masonry with flexible floors; and 25% made of very good masonry or concrete structures. With reference to the damage mechanisms observed (Fig. 12), the urban area can be divided into three zones (Fig. 13): the historical center (medium-severe damage); the saddle zone (maximum damage level); the Northern side (light damage). The San Giuliano medieval center (Fig. 14), laying on the top of an hill and pleasantly integrated in the environment, was deeply investigated by the SG-TSG members during the post-emergency. Only a few houses, sited along the West side of the enclosing walls, were ready for reuse, while the East side (Fig. 15) was declared unsafe. In spite of the absent or low local amplification, the historical center presented partial collapses and a medium-severe damage summary, depending on the position. In fact, some notable MCUHESs (such as Marchesale Castle and San Giuliano Martyr Church, Fig. 16), together with the inner architectonical sectors, partially uninhabited, suffered major damage. Moreover, the historical center was in general unfortunately characterized by high vulnerability (past wrong interventions, scarce maintenance and degraded conditions), which certainly emphasized the damage due to the earthquake (Fig. 17). Most part of the masonry-made constructions (75%) had stones irregularly placed with very poor mortar. Only in a few cases good masonry have been observed. Almost always the typical "muratura a sacco" was used, with low effective thickness and heavy fill, with the two sheets often not linked one each other transversally. (Fig. 18);

The most usual collapse mechanisms were the wall inflexion with the typical cross cracks. In some cases, recent storey additions and restoration works, made without improving the masonry mechanical properties, caused collapse or heavy damage (Fig. 19). Sometimes the pull out of beams and steel ties from the walls was observed (Fig. 20). Most of the horizontal structures (Figs. 21-22) were steel or timber floors (75%), while only 10% vaults (Fig. 23) and 10% concrete. The vaults supported the seismic action well enough when suitable supports were at the springings; in other cases, they felt down (Fig. 24), when not suitable interventions modified geometry and loads. Masonry foundations often lay directly on the rock, and not at the same level. Moreover, the seismic behavior of many Italian historical centers is also influenced by their structural organization. Often composed by a reciprocally dependent chaotic system of bodies (with height and size in plan very different, without respecting the joints criteria and the maximum suggested building size), they resulted in very irregular stiffness. This situation makes quite complex the interpretation of the structural behavior and almost impossible any numerical modelling. The develop of the saddle zone started in the first half of the twentieth century with masonry constructions and continued in the second half with concrete buildings. The saddle area was characterized by two alignments at the sides of the "Corso", each of them called "stecca", composed by different constructions close together (Fig. 25). About 50% of the constructions were poor masonry buildings, 25% good masonry buildings and 25% concrete or mixed (masonry-concrete) buildings. The horizontal structures were steel or timber and the other 50% concrete floors.

a) in-plane shear actions

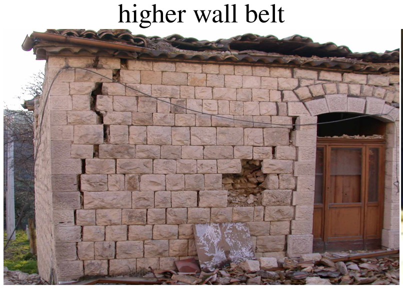
f) wall flexural failure

m) Yielding of architraves

b) in-plane shear actions in the higher wall belt

g) horizontal floor sliding

n) material irregularity, local weakness, etc.



c) global wall overturning

h) foundation settlement

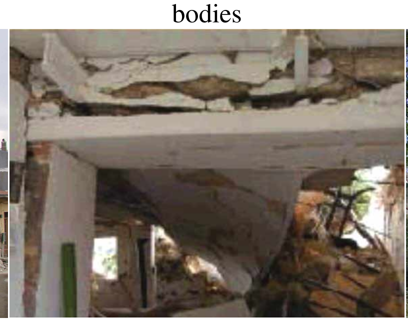
o) out-of-plane tympanum overturning

d) partial wall overturning

i) irregularity between adjacent bodies

p) out-of-plane overturning of the superior angle wall

e) wall vertical instability



l) floor beams pulling out from the vertical wall

q) roof wall belt out-of plane overturning

Fig. 12. Damage mechanisms observed in San Giuliano

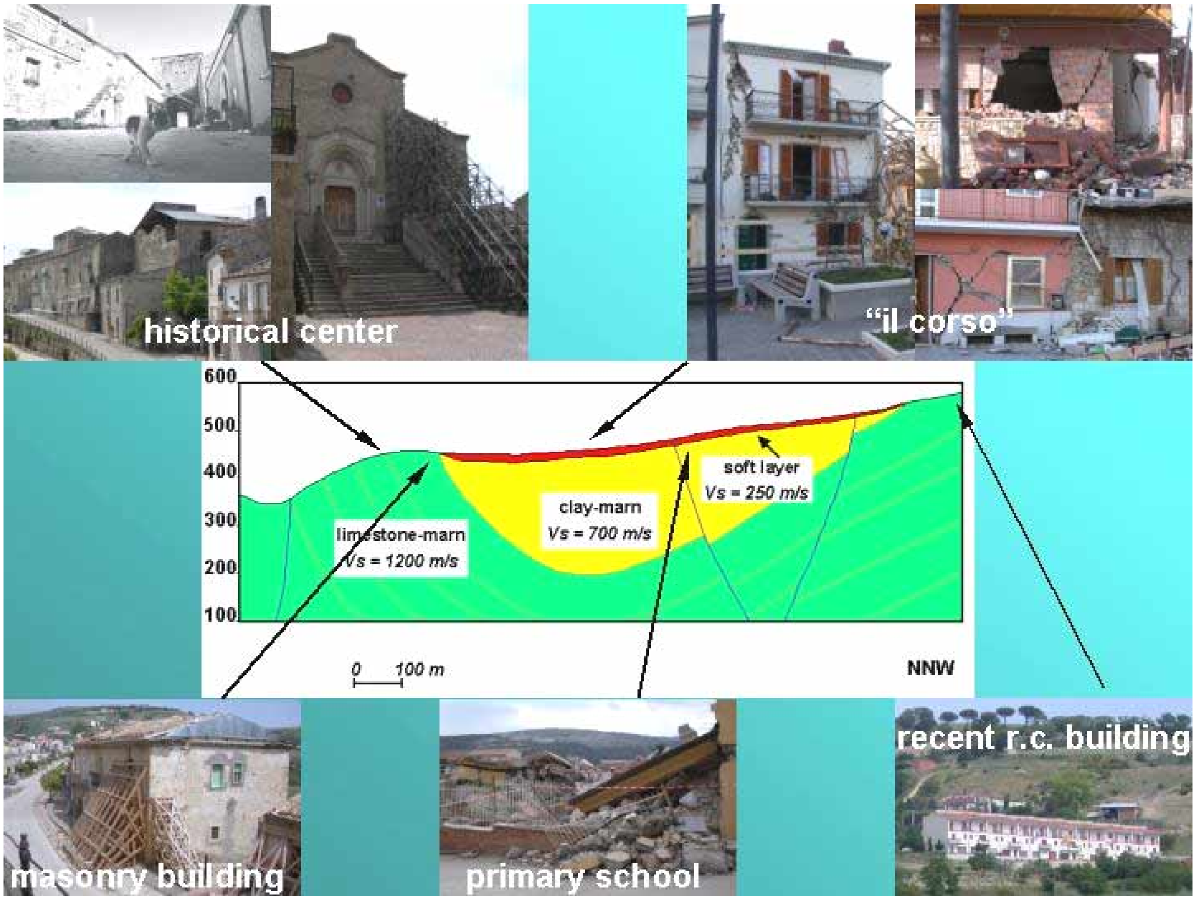


Fig. 13. Soil characteristics and San Giuliano different built areas

Fig. 14. View of the historical center

Fig. 15. External enclosing walls (East side)

The most impressive feature was that lots of houses were made of stone or perforated bricks, certainly suitable to absorb neither vertical nor seismic actions, especially in presence of subsequent storey additions. The most usual collapse mechanism was due to shear actions (see Fig. 12). In fact, typical cross cracks in the walls could be observed, due to their very low strength, related both to very thin thickness and to the presence of many openings (external and internal, see Fig. 12). Recent restoration interventions often increased the vulnerability, because they introduced heavy concrete elements not well connected to the masonry. In this zone, also concrete buildings showed serious damages (Fig. 26).

The Northern area had grown in the 50s and modern concrete buildings were built, containing more than one apartment. In general, damages were very low. It is worth noting that buildings almost undamaged have defects (as the absence of seismic joints, see Fig. 27), requiring an anti-seismic improvement.

Fig. 16. Damages to Marchesale Castle and Tower and to San Giuliano Martyr Church

Fig. 17. Building collapse

Fig. 18. "A sacco" wall with heavy fill

Fig. 19. Storey addition

Fig. 20. Pulling out of a steel tie in unreinforced stone masonry

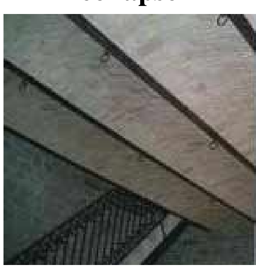


Fig. 21. Steel floor

Fig. 22. Wooden floor

Fig. 23. Masonry vault

Fig. 24. A vault collapse

Fig. 25. The "stecca", West side (top) and East side (bottom) in the saddle area

Fig. 26. Damages to concrete buildings in the saddle area

Fig. 27. Absence of joints

This very hard work (confirmed by other studies [10]) allowed to deduce a huge set of useful information on the seismic vulnerability of structures for engineers and architects and to set up methodologies and techniques of analysis in the post-emergency phase, a valid heritage to let known.

THE RECONSTRUCTION OF SAN GIULIANO DI PUGLIA

General information

In the last months, a group of experts and technicians (with the participation of ENEA researchers) worked at the reconstruction plan and faced the most important questions, which were mainly: hydro-geological problems; town planning, road system and lifelines layout; restoration of the historical center; reconstruction of the demolished buildings; retrofitting of the structures to be repaired; reconstruction of the multipurpose center, including social services and the new school; definition of energetic, social and economical aspects. It is worth noting that ENEA (with other subjects) organized immediately a public conference (January 29th, 2003) at San Giuliano, in order to present the population the possibility to rebuild the town mostly in the original place, taking into advantage of MATs. ENEA also performed, a few months later, a sociological analysis [11], in which San Giuliano people confirmed the will to live in their town, hoping in a safer reconstruction with innovative techniques. The reconstruction plan foresaw the following preliminary steps: analysis of the microzoning study; identification of the buildings to be reconstructed in site and those to be reconstructed in other sites and choice of the expansion areas; design of the main street and public buildings; choice of the architectural and structural types.

Microzoning

As already said, the microzoning study (Fig. 9) pointed out the presence of a slope instability at the East side of the saddle. Therefore, this place was cancelled from the possible expansion zones. In addition, high amplification factors (S=1.6) were detected in the saddle area (including the site of the unlucky school), and in the Northern side (S=1.4). It is worth observing that the maximum spectral amplitude expected at San Giuliano in zone B1.6 (soil B, S=1.6) is lower than the amplitude suggested by the Italian Code for the same soil type in zone 2 (soil B, S=1.25). This occurrence is mainly due to the fact that the actual amplitude on the bedrock at San Giuliano site is a_g=0.165g, very close to the minimum value for zone 2, equal to 0.15g. For these reasons, ENEA experts suggested that all the saddle area could be included in the reconstruction plan.

In site and not-in-site reconstruction
In the urban development plan preceding the earthquake, the Northern side was already chosen as an expansion area. The reasons for that were the good exposition to sun and the soil stability. The seismic event encouraged that choice. Nevertheless, the technical group involved in the reconstruction plan avoided the reconstruction in the area surrounding the collapsed school. This was not related to the microzoning results, but to the wish of the municipality government to dedicate a wide memorial place to the victims of the earthquake, reminding for ever what happened on October 31st 2002 in San Giuliano (Fig. 28). The buildings here erected before the event and then demolished will be reconstructed in the Northern side.

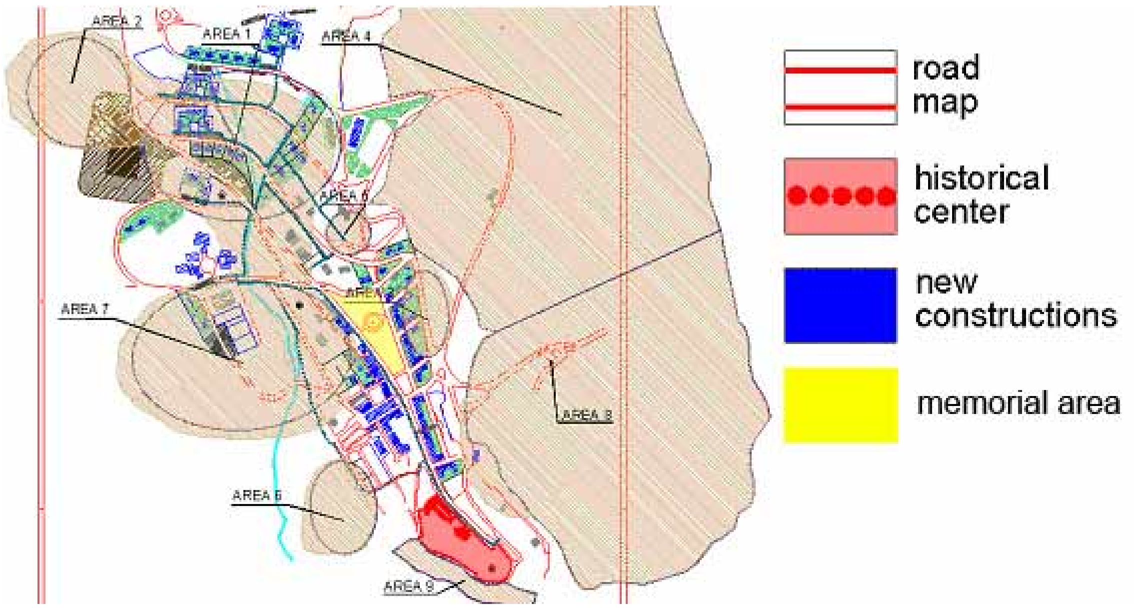


Fig. 28. Map of the reconstruction plan

Street, roads and public buildings
The new town center was identified in the central square, settling it along the old "Corso", to be designed with the typical characteristics of the local constructions. Road and street planning, following more or less the same previous routes, was rationalized, connection with external roads improved, with respect of the modern urban development requirements. Since the beginning, the reconstruction of the school became a topic question in the reconstruction of the entire town. The new school settlement was put just at the North side of the Sports Stadium, including the school and buildings for social activity, such as the old age center.

Architectural and structural types
In the framework of the reconstruction plan, the town has been divided into three zones: the historical center, which will be entirely rehabilitated by means of appropriate repairing and seismic improving works; the saddle zone, still representing the meeting point of the town, where the demolished buildings will be rebuilt and damaged structures improved, possibly applying respectively SI and PED; the Northern side, future residential area, with new conception structures provided by MATs systems.

New buildings in the saddle area and Northern zone
Most of the collapsed or demolished buildings are in the saddle zone. The adoption of SI, greatly developed in the last 25 years and now fully matured technology, offers a great opportunity, reliable and cost-effective. SI is based upon the idea of reducing the energy transmitted from the earthquake to the

structure by changing the structure's dynamic characteristics, i.e. increasing its natural period, in order to make it farther from the period of the main harmonic components of the seismic actions. This change is usually achieved through the use of special devices ("isolators"), with very low horizontal stiffness and appropriate damping, which separate the structure from the ground motion induced by the earthquake.
At the moment, in the framework of the agreement signed by the San Giuliano authorities and the Public Works Superintendent of Molise Region (in which ENEA is also involved), the preliminary design of two important pilot reconstructions is underway; it regards the new school and one of the most populated sectors of the demolished "corso". On the basis of several applications in Italy, in both cases ENEA researchers suggested the adoption of SI (see Fig. 29 [12-15]).

Repairing and seismic improving
SI can also be used for existing buildings to be repaired or at least seismically improved, because designed without anti-seismic criteria. Relevant examples are the structures in Fabriano and Naples, Italy, which needed a seismic improvement, achieved by means of SI (see Fig. 29, [16]). Alternatively, PED devices can be used: they have also a great potential for reducing the seismic risk. In particular, great interest arose in the research activities for the development and optimization of PED systems of various types: viscous, elastic-plastic, viscous-elastic and electromagnetic systems. The strategy consists in dissipating a part of the seismic energy in specified zones of the structure, expected to experience important relative displacements during an earthquake. PED devices concentrate in themselves most of the energy to be dissipated, preserving other structural elements from major damage. PED devices are sometimes used in parallel with SI devices, with the main aim of reducing base displacements. Relevant experiences have been carried out on devices at ENEA Casaccia Research Center by means of shaking table tests, while an interesting example of PED application is the seismic reinforcement of the Gentile Fermi school in Fabriano (see Fig. 29, [17]).

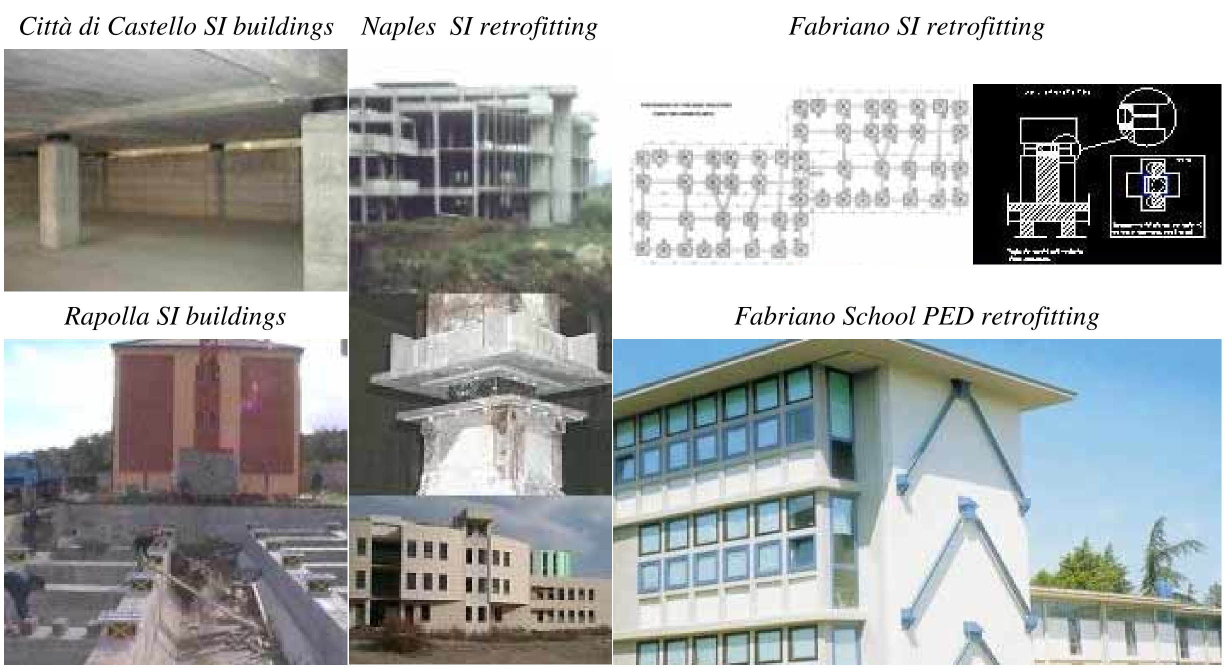
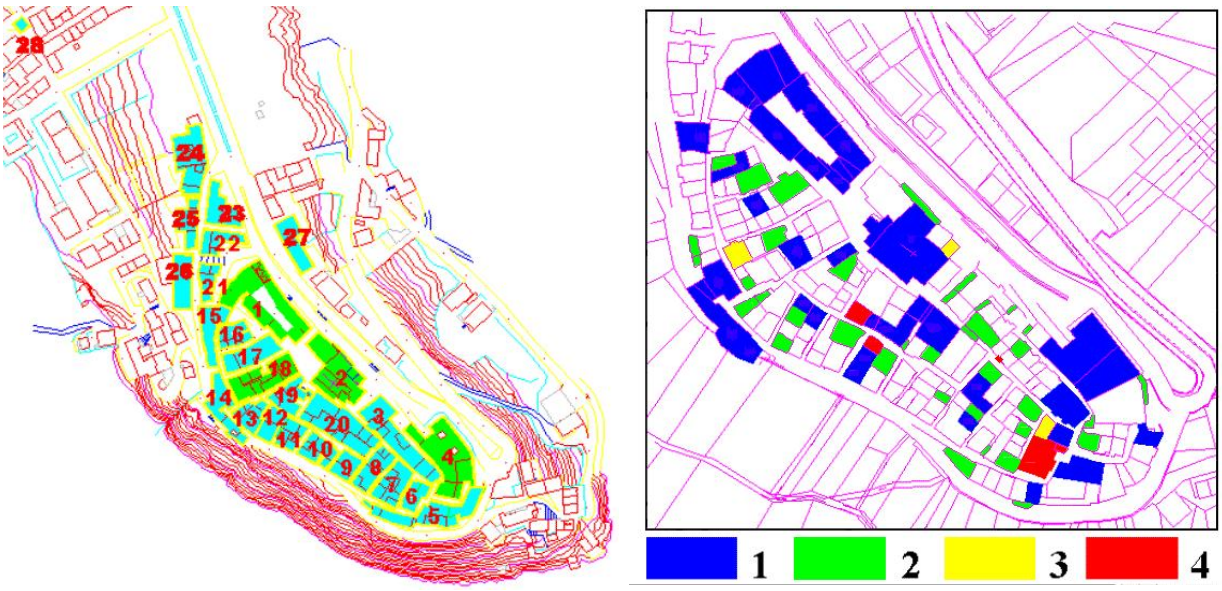


Fig. 29. Italian SI and PED applications for new buildings and retrofitting

This technique can be very useful at San Giuliano in case of retrofitting of many damaged houses which were not demolished, and also for the constructions declared safe but necessitating seismic improvement.

Historical center

The historical center has been divided (Fig. 30) into 28 sectors (20 within the enclosure walls and 8 outside remarkable masonry buildings), respecting the structural continuity and the architectonical features. A detailed analysis has been carried out: complete survey of four reference sectors (nr. 1 Marchesale Castle, nr. 2 San Giuliano Church, nr. 4 of the enclosure walls and nr. 18 of the inner parts), distribution of residents and number of the occupied houses, damage distribution, maintenance, abacus of the original elements, interventions on MCUHESs, demolitions and reconstruction of buildings (or parts), demolitions of buildings (or parts) due to public safety and health.



1: rehabilitation of historical MCUHESs | *2: removal of added parts and other unaesthetic elements* | *3: eventual demolition and reconstruction* | *4: eventual demolition due to public safety and health*

Fig. 30. Architectonical sectors and rehabilitation proposal

Fig. 31. Examples of SMADs applications to Italian MCUHESs damaged by earthquakes

In the framework of the above mentioned agreement, two main pilot interventions have been identified: the retrofitting of the Marchesale Castle (sector nr. 1), which could become the new seat of the municipality office and other public services; the restoration of the sector nr. 4, on which diagnostic campaigns have been performed (elaboration of the results is still in progress). The work will continue on the remaining sectors in the next months.

ENEA has been providing technical-scientific advice to the designers, in order to individuate the most suitable interventions (merging together anti-seismic requirements and conservation criteria) and suggest the application of MATs, as, among others, SMADs and SI (Fig. 31, [18-21]).

CONCLUSIONS

The area of San Giuliano, strongly hit by the October 31st 2002 earthquake, is characterized by high amplification factors, due to the presence of a significant soft layer above the bedrock, especially in the saddle area. Anyway, taking into account the amplification values estimated by the seismic microzoning study, the maximum acceleration at the surface is not higher than that suggested by the Italian Seismic Code for zone 2. The collapses of the buildings are also to be related to their vulnerability, due to material poor quality and structural type. Because of about 120 demolitions, a great part of the buildings have to be reconstructed or retrofitted and the entire historical center restored. ENEA experts, after about one-year hard work living together with the suffering population in the frame of the post-emergency activities and the reconstruction plan elaboration, are now involved in some pilot projects regarding the historical center, the new school and a portion of the "Corso" to be reconstructed. We are making every possible effort in order to reward these people for their bad luck by realizing a new anti-seismic safe town.

ACKNOWLEDGEMENTS

The tragic event of October 31st, 2002, gave us the opportunity to meet lots of people and to appreciate their courage. We are grateful to all the people met in this period that let us believe in our work: the Mayor of San Giuliano, A. Borrelli, the Municipality Committee and Government, the Technical Office of San Giuliano and the School Victims Committee. The activities here described were carried out with the contribution of local and national institutions, such as the Italian Civil Defense Department, the Public Work Director of Molise, Molise Region, Campobasso Province, Campobasso Town Hall, Molise Cultural Heritage Superintendence. A special thanks is due to the other members of the San Giuliano Technical Scientific Group (L. D'Alesio, M. Dolce, A. Dusi, G. Mancinelli, M. Mucciarella) and to the other several members of the technical group for the reconstruction plan of San Giuliano.

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