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SEISMIC ASSESSMENT OF THE MOLISE HOSPITALS AND UPGRADING STRATEGIES

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SUMMARY

The earthquake of October 31st, 2002, struck the region of Molise in southern Italy with moderate intensity and damage. However, it attracted much attention mainly because almost all the victims were children who were involved in the structural failure of their primary school. In this paper attention is focused on a different, but at least equally important, type of structure: hospitals. The October event in the Molise area left them mainly untouched. In the paper we first give a detailed picture of the organization of emergency operations and of the structural damage which occurred. Then we try to give guidance about the most effective retrofitting strategies for the regional hospital system as a whole, following a methodology developed in Nuti and Vanzi, 1998c, and which has been adjusted for this case study. It appears clearly that, depending on the community decision criteria, the hospitals of Campobasso and Bojano should be the first ones to be retrofitted, even though, due to the low seismic intensity of this earthquake, they were left unscathed by the event.

INTRODUCTION

Hospitals with their personnel, equipment and other resources, are central in minimizing inconveniences to population, in case of seismic events. Therefore their strategic role must be considered in any project of seismic risk reduction. Deaths and injuries after earthquakes are due to a variety of factors. Two are the main aspects: the immediate activation of the emergency plans and the vulnerability characteristics of the buildings. Experience has shown that the effectiveness of rescue in the first 24 to 48 hours and especially the immediate response of the medical system can reduce considerably the number of deaths [ATC-51-1, 2002]. The first part of the paper gives a brief representation of the emergency management during the Molise earthquakes.

For what concerns vulnerability, hospitals are complex systems, containing a large quantity of seismically fragile machinery, often more fragile than the structures containing them. Structural types are varied, comprising masonry and r.c. buildings, designed according to the norms of the construction period. As a consequence, the retrofitting of existing hospitals is a crucial problem too. In the second part of the paper

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an application of a procedure already presented by the authors [Nuti et al., 1998, 2001] to evaluate both vulnerability and effectiveness of retrofitting, is given for Molise hospitals.

At regional level, one can observe that the lack of functioning of a single hospital influences the services demanded to the remaining ones, because of transportation to the nearby hospitals. The analysis of the problems related to existing hospitals considered as a regional system, can usefully complement information concerning retrofitting of existing ones.
Application of the procedure to the Molise region in Italy, shows its effectiveness and allows to single out the most critical hospitals, i.e. those ones whose functioning has the largest influence on the system behaviour.

EARTHQUAKE DESCRIPTION

The affected area is part of Molise, a Southern Italy region with a total surface of 4'438 Km^2 and a population of about 330'900. The major centers are: Campobasso which counts 50'941 inhabitants, Termoli with 28'552 inhabitants and Isernia with 20'933 inhabitants.

The earthquake of 31 October 2002 struck at 11:32 am local time. It was a superficial earthquake (10 km focal depth) of magnitude 5.4, corresponding to Mercalli intensity of VIII-IX, with the epicentre approximately 5 km North-West of San Giuliano di Puglia, in the province of Campobasso. The second major event took place on 1 November 2002 at 4:08 pm, with magnitude 5.3 and the epicentre approximately 12 km South-West of the epicentre of the first event (see fig. 1 [INGV, 2002]).

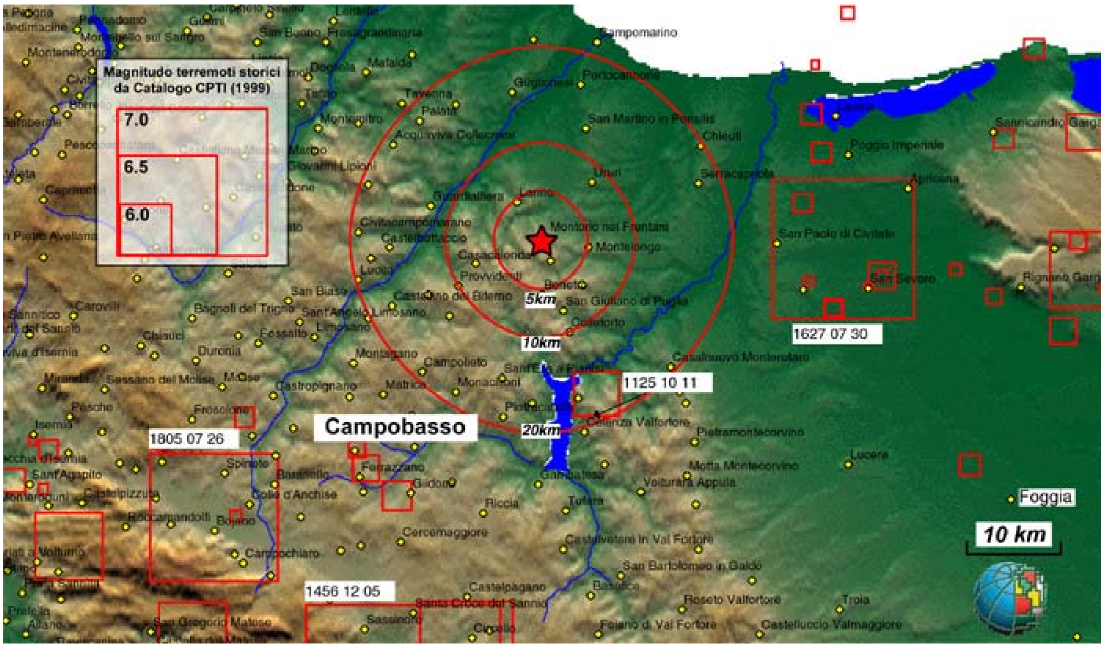


Figure 1. Location of the epicenter of the event of October 31, 2002, in Molise [INGV, 2002]

The earthquake sequence was felt in an area comprising 29 municipalities with a population of about 150.000 inhabitants. The most heavily damaged town was San Giuliano di Puglia, which was entirely evacuated, where the greatest losses were registered. The other towns seriously damaged were Bonefro, also in a 5 km radius from the epicentre, and Ripabottoni, Castellino sul Biferno, Santa Croce di Magliano, all in a 10-12 km radius from the epicentre.

The interested area is mostly rural and characterized by a low population density. It has to be noted that the population of Molise is mostly composed of elderly people with 20.6% of the inhabitants older than 65 years, which to a certain extent made it more difficult to cope with the problems posed by the post-emergency interventions.

The earthquake caused 220 casualties and killed 29 people, 27 of whom were children trapped in the collapse of the primary school in San Giuliano di Puglia.

HISTORICAL SEISMICITY

The earthquakes that affected Molise last year took place in an area where no other events of the same energy level have taken place in the last 1000 years. In particular the strongest intensities in the area (of the order of VIII - IX) have been recorded during the sequence of 1456, which represents the most important seismic event of Central-Southern Italy in the last millennium. That event caused great damage in the small town of Casacalenda and some minor damages to the San Giuliano Martire church.

Other relevant earthquakes are: the Gargano sequence of 1627, which caused VII and IX MCS level damage in Termoli and Campomarino, and the Matese earthquake of 1805, causing VI MCS damage in Larino. More recently in 1980 also the Irpinia earthquake seems to have caused damages in the area, in mostly to San Giuliano di Puglia, where local intensity has been estimated around the value of VI MCS.

A list of the registered events in the area that probably caused damages in San Giuliano, is given in table 1 where the MCS intensities I_0 and I_S are respectively the value registered in the epicenter and the one observed in San Giuliano [DPC-SSN, 2002].

Table 1. Intensities of historical earthquakes in the affected area.

Date	epicentral area	Lat. north	Long. east	I_0 (MCS)	I_S (MCS)
5 Dec. 1456	Bojano	41.54	14.47	10	8.5
30 July 1627	Capitanata	41.73	15.35	10	7.5
Jan. 1657	Gargano	41.83	15.33	7	5
5 June 1688	Beneventano	41.24	14.69	11	6.5
20 March 1731	Capitanata	41.27	15.75	9	7
20 Feb. 1743	Canale d’Otranto	39.85	18.78	9.5	4.5
26 July 1805	Area di Bojano	41.50	14.47	10	6.5
22 Nov. 1821	Medio Adriatico	42.17	15.25	7	5
14 Aug. 1851	Monte Vulture	40.95	15.67	9.5	5.5
6 Dec. 1875	Gargano	41.69	15.68	7.5	5
10 Sept. 1881	Chietino	42.23	14.28	8	4
26 Dec. 1885	Monti del Sannio	41.54	14.68	7	4
8 Dec. 1889	Gargano	41.83	15.69	7	5
25 March 1894	Capitanata	41.87	15.32	7	3
9 Oct. 1895	Medio Adriatico	42.15	14.90	6	5
7 June 1910	Irpinia meridionale	40.90	15.42	8.5	5
13 Jan. 1915	Fucino	42.01	13.53	11	5
23 July 1930	Irpinia	41.05	15.37	10	5
26 Sept. 1933	Maiella	42.05	14.18	8.5	4
21 Aug. 1962	Beneventano – Irpinia sett.	41.13	14.97	9	6
23 Nov. 1980	Irpinia meridionale	40.85	15.28	10	6
7 May 1984	Lazio mer. – Molise	41.67	14.05	8	4.5

THE HOSPITAL SYSTEM OF MOLISE

The sanitary system in Molise is organized in four different A.S.L.s (acronym for "Azienda Sanitaria Locale", i.e. Local Health Agency) including a total of eight hospitals.
The four A.S.L.s, delimited according to their geographical position are: ASL1 "Alto Molise" (Agnone), ASL2 "Pentria" (Isernia), ASL3 "Centro Molise" (Campobasso), ASL4 "Basso Molise" (Termoli).

The hospitals are listed in table 2 together with their capacity in terms of available beds and the number of inhabitants of their municipality.

Table 2. Hospitals in Molise

n.	A.S.L.	Hospital	Municipality	capacity	Inhabitants
1	ASL1	Ospedale Civile	Agnone	154	6207
2	ASL3	Ospedale A. Cardarelli	Campobasso	597	50941
3	ASL2	Ospedale F. Veneziane	Isernia	200	20933
4	ASL4	Ospedale Civile G. Vietri	Larino	232	8294
5	ASL4	Ospedale San Timoteo	Termoli	328	28552
6	ASL2	Ospedale di Venafro	Venafro	111	10107
7	ASL3	Ospedale di Bojano	Bojano	90	8426
8	ASL3	Ospedale di Toro	Toro	73	1648

Apart from the major centres, Campobasso (50'941 inhabitants), Termoli (28'552 inhabitants) and Isernia (20'933 inhabitants), the remaining population is rather uniformly distributed on the territory as shown in Figure 2 (municipalities are represented proportionally to inhabitants). Hospital location is given in Figure 3.

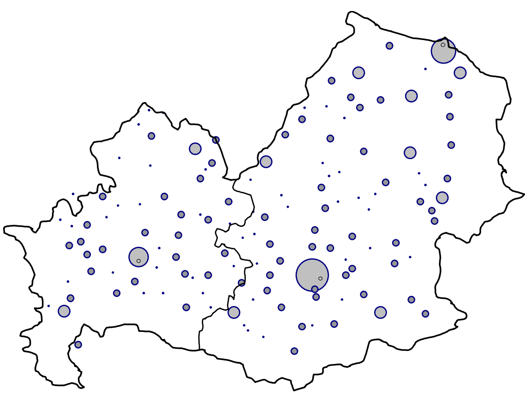


Figure 2. Distribution of population in Molise.

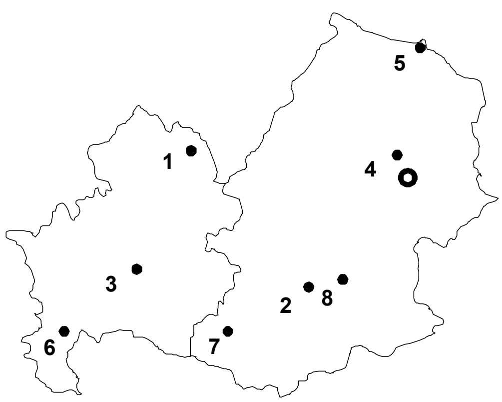


Figure 3. Distribution of hospitals in Molise.

EMERGENCY MANAGEMENT

Within five hours from the earthquake the Italian DPC (Department of Civil Protection) established Mixed Operative Centres (C.O.M.) where the field authorities were concentrated in order to manage the emergency situation. The most important C.O.M., retaining the decisional power and the majority of contacts with the external and governmental institutions, was established soon after the main earthquakes in Larino while two other C.O.M.s were established in Casalnuovo Monterotaro and in San Giuliano di Puglia.

In the main towns, under the authority of the C.O.M., five minor centres were established where local authorities could operate at municipal level. These Communal Operative Centres (C.O.C.) were located in: San Martino in Pensilis, Bonefro, Colletorto, Ripabottoni and Provvidenti.

The emergency functions immediately activated inside the main C.O.M. in Larino, according to the emergency plans, were: assistance to local authorities, safety inspections and damage assessment, transportation and road management, public safety, historical and cultural monuments preservation, information and public relations, urgent technical services and dangerous materials, scientific research and planning, public health, evacuation and logistics, volunteering coordination, telecommunications, general secretariat.

The main operators involved in the emergency functions all over the shaken area were: Fire Brigade (625 people), Italian Red Cross CRI (272), police/military (1250), engineers/technicians (60 ANAS, 70 Telecomunication). More over, about 1500 volunteers provided useful and important help in all the operational tasks [ELSA, 2003].

After the earthquake, two A.S.L.s and three hospitals have been involved in the emergency interventions:

- ASL3 “Centro Molise” in Campobasso, “Cardarelli” Hospital in Campobasso;
- ASL4 “Basso Molise” in Termoli-Larino, “San Timoteo” Hospital in Termoli and “Vietri” Hospital in Larino.

A very important role in the emergency operations has been the one of “118” Call Centre, a service which operates at the territorial level covering all the A.S.L.s in the region. It is a complex operative centre, named Centrale Operativa 118 – servizio di Emergenza Territoriale “Molise Soccorso”, which is organized in 15 decision centres (Unità Operative Territoriali) localised in strategic zones of the region as shown in figure 4. The organisation includes about 100 doctors, 100 nurses, 180 volunteers and 30 transportation means (15 ambulances and 15 cars with basic medical emergency aids).

Nevertheless, even at the peak of the emergency, in this occasion it was not necessary to involve the “Punti di guardia medica” which are spread on the territory, and usually function only during the night and festive days. These are medical centres just for first aid, emergency care or treatment given to injured person before regular medical aid can be obtained. The peak of emergency occurred around the time of the shift of the personnel, therefore the entire medical staff was present in the emergency operations. In particular, nine operating theatres were functional and 13 anesthetists were active in the three involved hospitals.

The Red Cross provided temporary structures for medical care in the zone of Larino, which has been used as recovery for the elderly evacuated from an old folk’s home. Following the earthquake, 22 outdoor emergency shelters (“tendopoli” or camps) were established. The tents were equipped with water supply, generator for lighting and heaters, public phone and sewage disposal. Each camp has been provided with emergency medical supplies. The establishment of temporary relief camps may contribute to the potential risk of epidemics. In order to minimise the spread of contagious diseases, appropriate functions for hygienic-sanitary supervision and batteriological checking have been implemented in every camp. Mass vaccination programmes were adopted especially for elder people and kids.

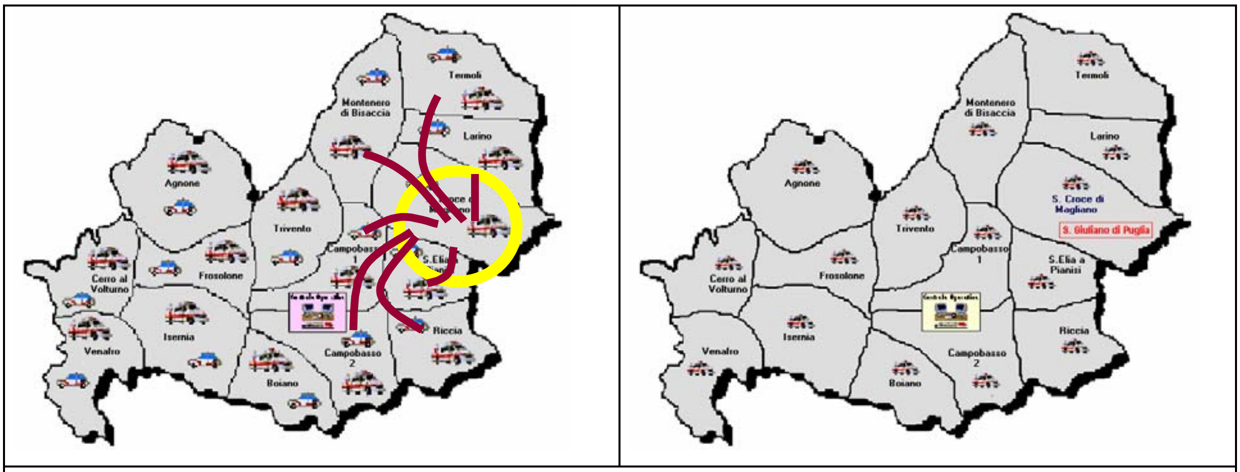


Figure 4. "118" organisation [Director of "118", personal communication]

PERFORMANCE OF HOSPITALS

Firstly, it has to be noted that no significant damage has occurred to lifelines, and consequently no significant interruption of the main services which influence the hospital performance has taken place.

The road system in the area is made of secondary roads. The main axis is the Bifernina, a motorway linking the area of Campobasso with the coastal town of Termoli and with other important towns nearby. The motorway has a number of small-to-medium reinforced concrete viaducts, which did not suffer any significant damage from the earthquakes. The local roads suffered only minor and localized damage during the sequence of seismic events but remained accessible to vehicles. [ELSA, 2003].

No damage and therefore no interruption of the activity of the electric power distribution network, water supply, sewage system and food provisions, has been registered. Instead, partial interruption of telecommunication system has occurred for about half day. This caused some difficulty in the transmission of forms for data collection given to each hospital in order to monitor the sanitary situation. Moreover, the malfunctioning of telecommunication has made hard the interchange of information essential for the coordination of activities in order to minimize any waste of the available resources.

After the earthquake, several teams surveyed the damages in the region and some of them had a close look at the situation of hospitals. No heavy damage was recorded, and in fact all the hospitals in the region were functional after the earthquake. The only exception was the hospital of Larino, figure 5, which will be shown within the context of Molise in the next section, in which some damage was observed.
The hospital was surveyed by two teams, the first one belonging to the Italian Civil Protection, and the second one headed by prof. Mauro Dolce of the University of Basilicata [Dolce, 2002]. Both teams highlighted that existing cracks in some of the beams had widened because of the earthquake, recommending to put in place external reinforcement for shear in beams (e.g. plates). Interior partitions also suffered because of cosmetic cracks (width lower than 1 mm). The hospital however continued to work regularly.

Figure 5. Ospedale Civile of Larino (courtesy of Prof. Mauro Dolce and ing. A. Moroni)

No particular congestion has been observed in the sanitary structures. The affluence of the casualties to the hospitals has been similar to that which occurs every year during high season periods, for example during summer.

To have an idea of the peak situation a brief description of major data has been given in what follows. First of all, for what concerns the amount of people requiring hospitalization, all the incoming casualties have been statistically analyzed considering their distribution in the three involved hospitals (figure 6), the means of transportation used to reach hospital (figure 7) and the distribution of injured people for different age (figure 8). Then, in relation to the capacity and organization of the hospital in giving medical aid, the “Triage factor”, defined below, (figure 9) at the reception and the given type of treatment (figure 10), measured with respect to the total casualties, have been shown. The Triage factor, immediately assigned to the incoming injured at the entrance to hospitals, indicates the degree of urgency. Triage classification is useful to decide the order of the patients treatment, especially in case of finite medical resources as in a mass-casualty situation following earthquakes when it is used in order to concentrate medical resources on those with life-threatening injures who are likely to recover with treatment but who would die without it.

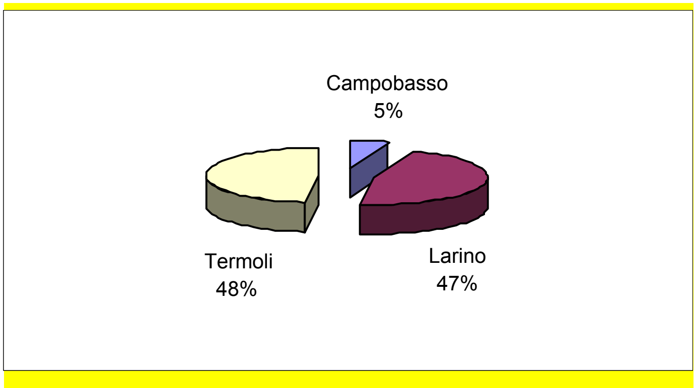


Figure 6. Affluence to hospitals.

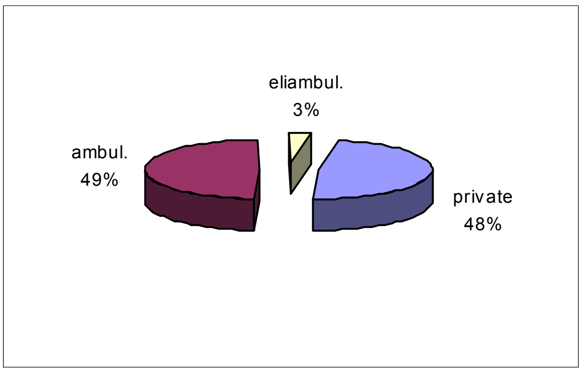


Figure 7. Transportation to hospitals.

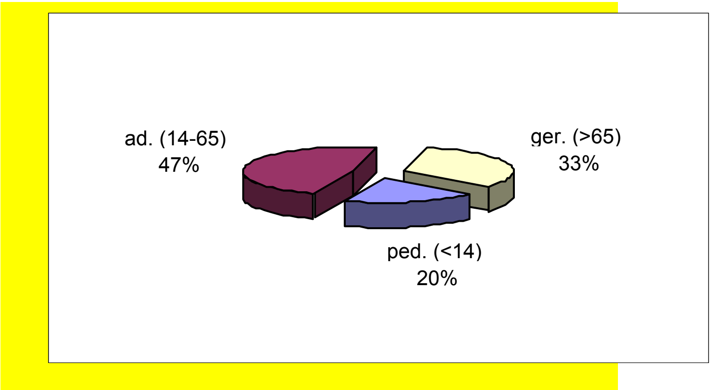


Figure 8. Age of injured people. Children less than 14 years need *pediatric* assistance, people between 14 and 65 are considered *adults* and people older than 65 need *geriatric* assistance.

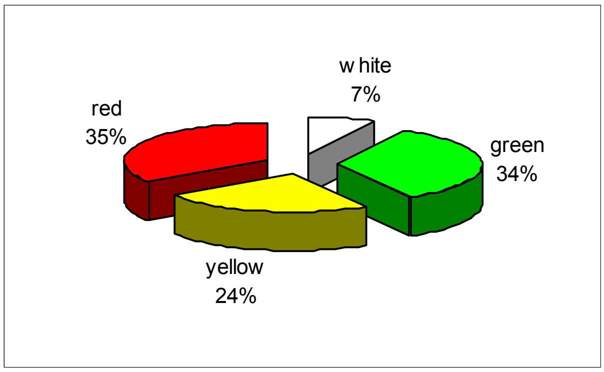
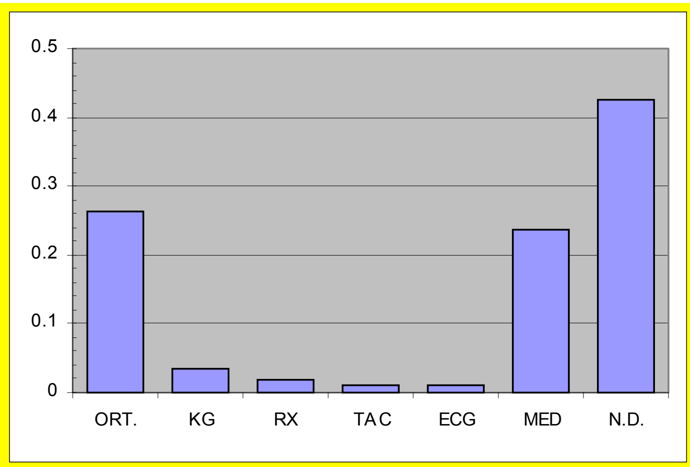


Figure 9. "Triage". RED involving risk to life indicates *immediate care*, YELLOW *delayed care*, GREEN *ambulatory or walking wounded* and WHITE *no care*.



ORT. Orthopedics

KG Surgery

RX Radiology, X Ray

TAC Radiology, Computerized Axial Tomography

ECG Cardiology, electrocardiogram

MED Medical care

N.D. others, (non defined care)

Figure 10. Type of treatment.

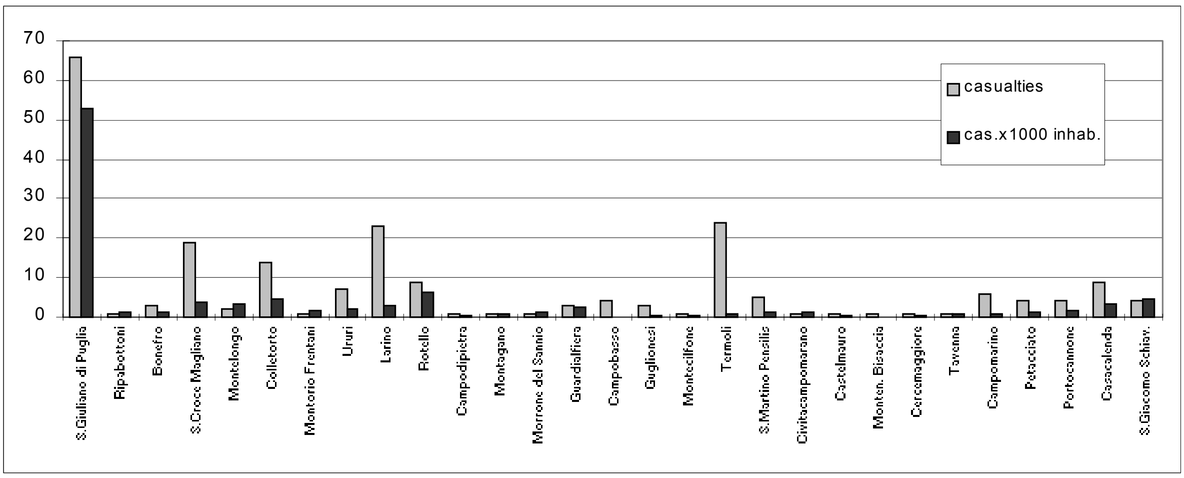


Figure 11. Distribution of casualties in the municipalities.

RETROFITTING STRATEGIES FOR THE HOSPITAL SYSTEM

The description of the October 2002 event makes clear that no big damage was observed and the hospital system worked normally. But what should be best done to improve the structural behavior of the hospitals in the region? In this section it will be shown that, in order to upgrade the hospitals and improve the overall system behavior in the region, reliability analyses are a powerful tool and allow to identify in which hospital, and at which retrofitting level, resources would be best used in structural upgrading.

The model used, already presented by the authors, aims at minimizing the distance, as the crow flies, covered by each casualty to reach hospitals. The minimization is done with respect to the possible retrofitting strategies. The distance to reach a hospital is, in fact, under the assumption of uniform distribution of the transportation links, acceptable in a developed region at a large scale, is proportional to the time elapsed before a casualty is cured and its reduction lowers the mortality rate.

Figure 12 CDF of distances to reach hospitals in Molise.

The increase of this value due to earthquakes will synthetically define the system performance. Average values will be compared with those computed in case of a seismic event, and with various retrofitting schemes.

In normal conditions, the CDF of distances among Molise inhabitants and the nearest hospitals, weighted on the population, has been computed with the census data [Colozza & De Marco 1988, ISTAT 1991]. The curve is given in Figure 12. It indicates a mean value of the distance equal to 6.826 km.

Model for the casualties, fragility of hospitals and earthquakes

The relationship between earthquake intensity and mean number of casualties as a percentage of the population, $\bar{C}(I)$, has been presented and discussed in [Nuti and Vanzi, 1998c] and reads:

$$\bar{C}(I) = (I - I_{min})^4 \cdot 0.00048 \qquad (1)$$

where Imin=7 MM. (Eq. 1) is plotted in Figure 13.

In figure 13 we have also shown the "experimental" data that have been recorded for the October 2002 event. One can notice that the point relative to San Giuliano, the municipality where most victims were caught, is much higher that the predicted value from the model. However, considering that the victims were all in one building, with all the other buildings basically unscathed, this point is likely to be a very unfortunate outlier.

As for the hospitals' fragility, while building types and years of construction for hospitals are normally extremely variable, in this case the fragility curves are actually the same for all the hospitals. The fragility curves have been estimated using the procedure and data in [Nuti and Vanzi, 1998b,c] and are shown in figure 14, together with the "experimental data" recorded with this earthquake.

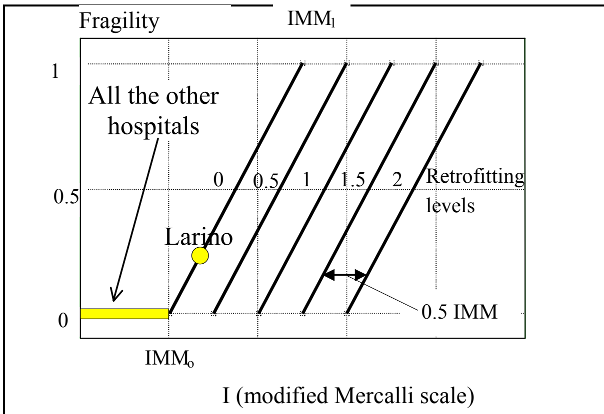


Figure 13. Casualties as a percentage of population

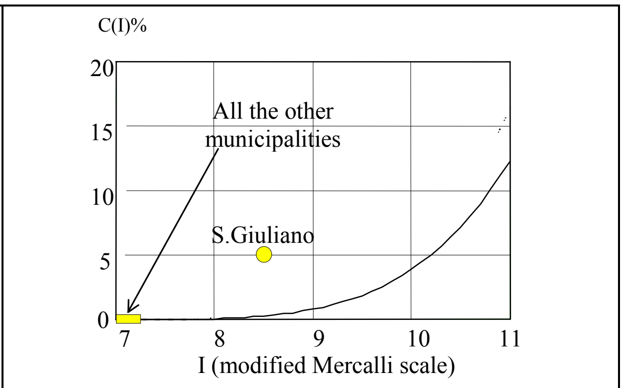


Figure 14. Damage indicator as a function of the intensity

The values of IMM0 and IMM1 for the Molise hospitals are respectively 5.5 and 7.85. The assumed fragility curves are further in good agreement with the observed damages. In Larino, the hospital closest to the epicentre, a Mercalli intensity equal to 6 was recorded and actually some minor damages, as noted above, were noticed. The damages were not so serious as to impair the correct functioning of the hospital.
From the fragility curves of figure 14, the deterministic part of the damage to the hospital would have been estimated equal to 20%, and the probability of observing a minor damage, e.g. lower or equal to 10%, would have been equal to 0.1. This is more or less consistent with what has been observed, considering that the fragility curves represent average situations. For the other hospitals were intensities have been recorded, Toro, Campobasso and Termoli, the fragility curves predict no damage, consistently with the field observations.

As for earthquake generation, the classical Cornell model, with diffused seismicity, has been assumed. The reader is referred to [Nuti and Vanzi, 1998c] for the description of the model. The adopted attenuation law is circular and reads

$$\Delta I_s(R) = a + b\cdot(R+R_o) + c\cdot\log(R+R_o) + \varepsilon \qquad (2)$$

fitted with a maximum likelihood method has been adopted. In Eq. 2, log is the natural logarithm. Its parameters $R_0 = 3$ Km; $a = -4.44$; b=0.0056; c=1.88 , ε =N(0;$\sigma_\varepsilon = 1.037$) have been calibrated using registration of events in central Italy. It should be noted that the macro seismic intensities recorded after the Molise event of 31.10.2002 show that the attenuation from the epicenter to the sites was not *circular*, i.e. that sites at the same distance from the epicentre experienced different intensities, and that also local soil effects were important.

Table 3. [INGV, 2002], shows the seismic intensities recorded after the earthquake at the municipalities where some of the hospitals are located and at a few more selected sites.

Municipalità	Longitude	Latitude	I (MCS)
San Giuliano di Puglia	14,964	41,685	8/9
Montorio nei Frentani	14.933	41.758	6
Larino	14.911	41.799	6
Toro	14.766	41.570	5/6
Campobasso	14.667	41.557	5
Termoli	14.993	41.999	5

San Giuliano di Puglia is more distant from the epicentre than both Larino and Montorio nei Frentani but is the municipality where the highest intensity was felt. Furthermore, directional effects have also been evident [Mola et al., 2003] with sites east of the epicentre showing higher damages.

For the above reasons, a direct comparison of the adopted attenuation law with the macro seismic data is not feasible, for the attenuation law is representative of the situation averaged over a number of earthquakes. However, if one considers the sites farther from the epicentre, where local effects have been less important (e.g. the municipalities with intensity equal to about 5 MCS and distance from the epicentre of about 30 km, figure 9, [INGV, 2002]) the attenuation from the epicentre, which is located at about halfway between Larino and San Giuliano di Puglia and where MCS 7 is the most frequent value, is of about two degrees MCS, which is in agreement with what predicted by eq. 2.

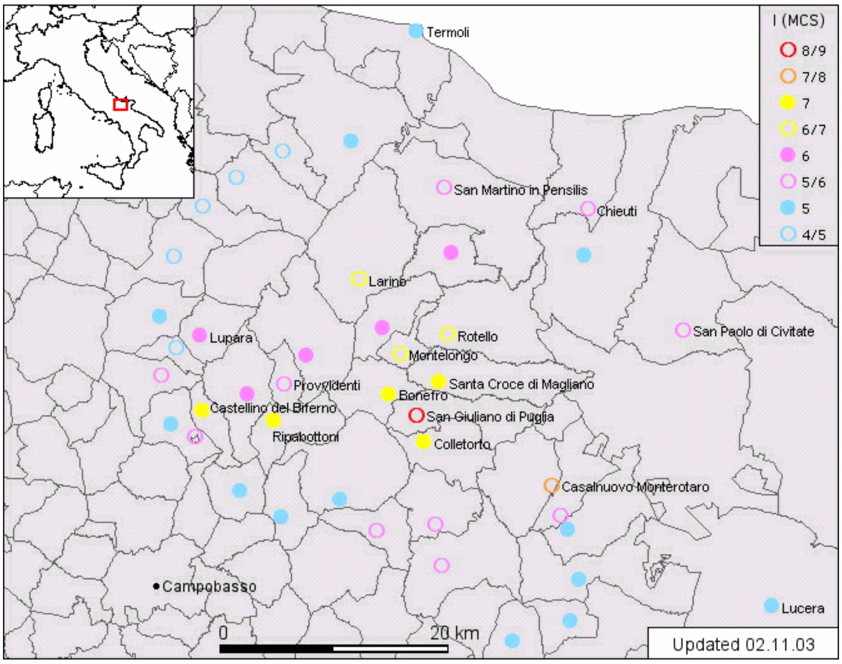


Figure 15. Macroseismic intensities for the event of 31.10.2002 [INGV, 2002]

Results
The analyses carried on in the following aim at finding which hospital, in a network, should be chosen to be first retrofitted.

The analyses have been conditioned to one seismic event in one of seismogenic areas and have been done via a Montecarlo simulation with the computer program Ghost [Nuti, C., Vanzi, I., 1999]. Via repeated sampling of earthquake intensity, local intensities, number of casualties at municipalities and state of the hospitals, we have computed the statistics of the casualties's movements to reach a hospital.

To identify the retrofitted hospitals to which the maximum benefit is associated, we have considered the fragility of a single hospital at level higher than 0 (one of the levels 0.5, 1, 1.5, 2, 2.5, 3), while maintaining the fragilities of the remaining hospitals at level 0 (see figure 14).

Retrofitting of a single hospital, at a level higher than 0, brings about some decrease in the value of the distance that each casualty has to cover; the maximum obtainable improvement is that associated with a hospital network in which hospitals are not fragile. We have expressed the improvements associated with retrofitting of a single hospital normalised to the maximum possible improvement i.e.:

$$i1a(H, F) = \frac{r(0) - r(H, F)}{r(0) - r(\infty)} \quad (4)$$

where r(H,F) is the mean value of the distance per casualty after retrofitting of hospital H at level F, r(0) and $r(\infty)$ indicate the same quantity with the hospitals respectively in the current state and in the state such that all of them are not fragile, ∞ level.
The above quantity, when divided by the number of beds in hospital H, gives the improvement by unit cost (assuming that retrofitting costs are proportional to the size of the hospital, i.e. the number of beds). The improvement by unit cost are not shown here for the sake of conciseness but some of the information that can be gained will be recalled later on in the discussion.

The average distance per casualty in normal conditions is 6.826 Km (see figure 12); this value increases to r(0)=19.7 Km (after an earthquake); the maximum obtainable improvement, if retrofitting was made at such a level that hospitals were not fragile, is at the value of $r(\infty)$=11.7 Km. Improvement, for each hospital and retrofitting level, has been computed according to Eq. 4 and is shown in figure 16.

The most important hospitals are numbers 2, 3 and 6 and 7. Hospital 2, the one in Campobasso, is the larger in the region, with 597 beds. The fact that it is the most important among the ones in Molise is not surprising and, on the other hand, one could also have expected that it would have ranked lower if we consider improvements by unit cost. For hospital 7, the one in Bojano, the opposite is true: it is one of the important hospitals with the *i1a* index and, since it is a small one with just 90 beds, it is the one on which the benefit per unit cost is maximum.

Another important feature of these results is that the ranking of important hospitals, like those listed above, changes little whether absolute (*i1a*) or by bed unit improvements are considered. This differs from what found in [Nuti and Vanzi, 1998c] where different retrofitting choices would be made looking at the two indexes.

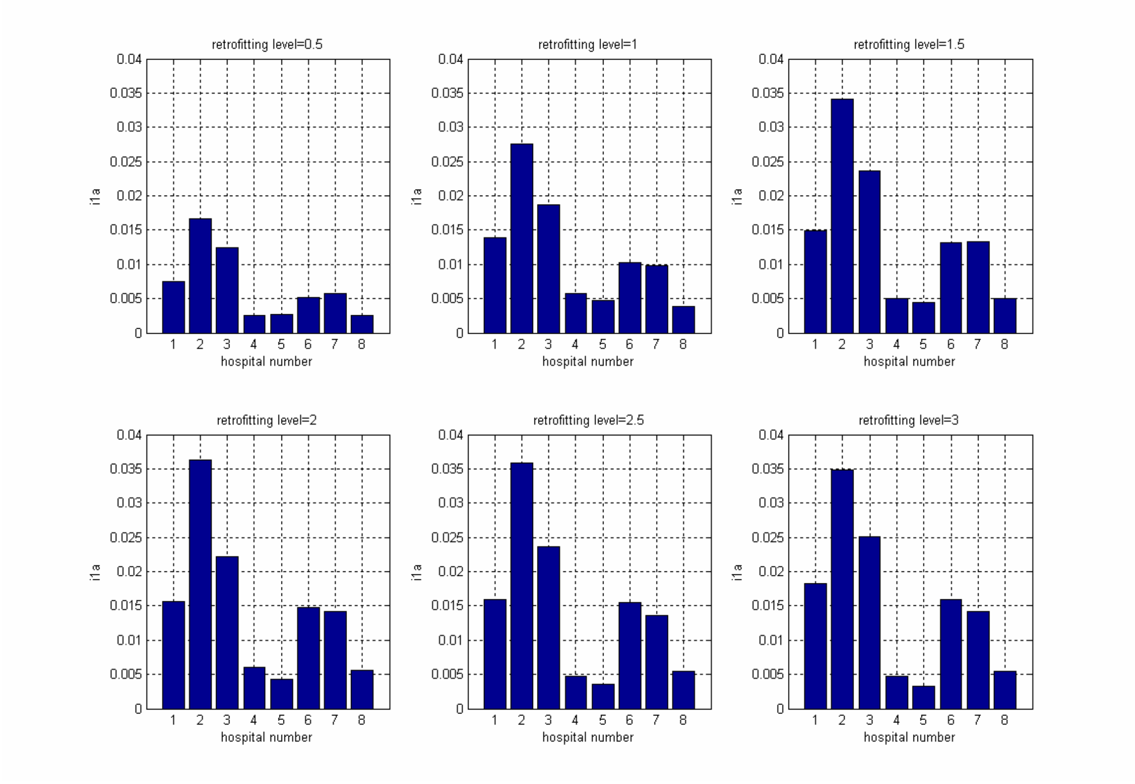


Figure 16 *i1a* as a function of the hospital retrofitted and the level of retrofitting

CONCLUSIONS

The October 2002 event in Molise has been a low intensity one and caused very few important damages with a single, very unfortunate exception: 27 primary school children, caught in the failure of their school.

The emergency management has overall worked well, showing also important redundancies, e.g. hospitals working together with independent small immediate care points.

Hospitals have shown nearly no damage and have regularly kept working. Should all this mean that the regional system is well suited to resist violent earthquakes?

As for hospitals are concerned our answer is that something should be done, from a system viewpoint, since the expected distance to reach a hospital in Molise, given an earthquake and the current hospitals' fragilities, doubles with respect to the normal situation. This in turn means that the time should more (maybe much more) than double.

Depending on the community preference, the hospitals of Campobasso or Bojano should be the first ones to upgrade and this should significantly contribute to the overall regional system safety. In this way the negative consequences of this earthquake could, at least, have the positive effect of motivating safety responsible officials towards a constructive approach.

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