HOSPITALS BEHAVIOR DURING THE SEPTEMBER 1997 EARTHQUAKE IN UMBRIA AND MARCHE (ITALY)

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SUMMARY

Some of the hospitals in the area of the seismic sequence in Umbria and Marche (Italy), started on September 26 1997, have been inspected in order to identify the most frequent malfunctioning causes and the most opportune measures to improve their seismic performance, which is of key importance for emergencies management. A brief description of the structural damages and the functional response of the hospitals short after the earthquake are presented. First hints for the repair of the damaged parts and for the improvement of the system for future events are drawn.

INTRODUCTION

The effects on the hospitals system of the Umbria and Marche seismic sequence started on September 26th 1997 confirmed the low safety of these infrastructures, which in previous earthquakes in Italy and abroad behaved badly both for structural response and for disaster management procedures. The biggest part of the hospitals was evacuated after the second shock of September 26 1997, at 11:00 a.m.; the evacuation was caused both by actual loss of functioning, even in places modestly struck, and by the panic of hospitals patients and employees, justified by the length and intensity of the seismic sequence. Important damages were generally found in the structures and installations of both old hospitals (due to their age and structural complexity) and of recent r.c. ones. These structures were built without specific regard to seismic problems, because most of this area was included in the seismic classification during the years 1982-84. Malfunctioning was similar to that observed during the 1976 Friuli and 1980 Irpinia earthquakes, after consideration of the different intensities. In these regions too, most hospitals were built in old structures, highly vulnerable to earthquakes [3, 7], and many recent structures were not seismically designed since the areas were not classified as seismic ones. In the epicentral areas, where intensity had reached X in Mercalli scale (MCS), some hospitals, like Gemona in Friuli and S. Angelo dei Lombardi in Irpinia, although designed according to the seismic regulations of the building period, had collapsed. Emergency medical interventions had been carried out in both cases via camp hospitals. Less severe damage was observed in sites of lower felt intensity, but hospitals faced however strong difficulties in the emergency operations. Installations showed many severe malfunctioning, e.g., the loss of functioning of elevators with operating theaters made unreachable and the collapse of piping support. Telephone lines were often disconnected so that the organization of rescues was made more difficult. Emergency provisions were only exceptionally sufficient to distribute water, electricity, gasoline and food. Municipalities were difficult to reach because of topography and urbanization. The lack of correct emergency planning both for the employee's preparedness and organization and independence of resources was clearly showed. This paper describes the damages observed in the hospitals of the Umbro-Marchigiano earthquake epicentral area: Camerino, Foligno, Assisi, Treia, Trevi, Gubbio, Gualdo Tadino, Spello and Montefalco. Some hints are further described, gathering simple solutions for some problems observed in the structures. In Italy the problem of the new hospital structures is solved by the seismic norms with an increase equal to 40% of the actions, without an explicit control of the serviceability limit state. Moreover, for regular masonry buildings the computations of the earthquake effects may be disregarded. This implies, in these cases, that the protection coefficient is not being used. The problem of

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the existing structures built without any seismic norm or with the old ones, remains: in Italy more than 50% of the existing hospitals in seismic areas have been built before any classification and therefore without opportune norms [8]. The correct seismic design of a hospital requires an integrated analysis both of the resistance of the structures and of the installations functioning [2, 4, 5]. The National Seismic Survey, in collaboration with the University of Chieti (Italy), is leading a research for the Health Ministry, whose primary objectives are the constitutions of a knowledge base for the civil protection uses and the implementation both of methods for vulnerability and risk evaluation and of specific criteria to reduce the vulnerability of these structures. This project will allow the improvement of the database of the Ministry [1] with the addition of the vulnerability aspects of buildings and of the autonomy of emergency installations. This will allow the emanation of norms to improve the present seismic regulations in the specific field.

DESCRIPTION OF THE HOSPITALS

In the area struck by the earthquake (MCS intensity more than VI) many hospitals and public care centers are present (Fig. 1). These structures, except Foligno and Tolentino, are small (Tab. 1). The age of the structures varies between tens of years and many centuries, with buildings belonging to different times even in the same care department. Structural characteristics vary within each department: a typical layout is an ancient part in masonry, generally of low quality, with vaults and/or steel and masonry floors, and more modern parts in masonry and r.c. floors or structures completely in r.c.. Joints are always inadequate from a seismic viewpoint. In any case, these buildings have not been designed according to seismic norms since this area has been classified after 1982. Some of the oldest buildings have monumental characteristics and some buildings will probably change use within some years since they will be replaced by structures currently under construction. This circumstance makes difficult to find resources for the seismic retrofitting. As the table shows, seismic intensity has been relatively modest, with a maximum of VII MCS. Buildings, nonetheless, have been evacuated in the most part and later judged usable. The analyses of some of these structures show that new effort will be necessary to make their safety comparable with that of a strategic building.

DAMAGES OBSERVED IN THE HOSPITALS

General summary of damages

In Tab. 1 a summary of the observed damages is shown. Notice that no structure has been built after the seismic classification. One can see that in the most modern structures, even without a seismic design, no structural damage has been observed (except for Assisi, where a landslide caused failure of the foundations). This agrees with the Mercalli intensity of the site. Older masonry buildings, generally of low quality, have instead shown structural damages without total collapse. All the hospitals have shown non structural and/or installations damages, which has caused the loss of immediate functioning for intensities between VI-VII and VII; this intensity level has a return period, in this area, of some tens of years; the probability of a loss of functioning in short times is therefore high. In correspondence of the joints, damages have always been observed because of buildings pounding. Damages to installations have often been started by structural/non structural damages. In some cases also installations have been directly damaged, especially the elevators, due to not adequate details with respect to the seismic actions. A typical case was the misalignment of elevators' counter weights; the main reason of this deluding performance is that many hospitals are located in very old structures, successively enlarged and then linked. The seismic problems have been completely disregarded, because of the absence of seismic classification. The biggest part of hospitals has been evacuated immediately after the seismic event of September 26 in the morning. This has often been caused by emotional reaction and, on other side, inevitable in absence of any preparedness to a seismic event. Few hospitals have offered the service expected in case of seismic emergence, i.e., continuous use of essential functions and fast recovery of secondary functions. The usability judgement generally formulated is concerning the structural and/or non-structural aspects, but does not depend on the factors strictly concerning the hospital's functioning. For instance, the Camerino hospital has been judged partially usable, but its functioning would have required the kitchen and the X-ray department moved to another location.

Assisi

The Assisi hospital is composed of two buildings, the main one and the secondary one, linked by a footbridge. The structure is composed of frames in r.c. with partition walls having the external layer with solid bricks and the internal with hollow bricks. The main building has a rectangular oblong shape and is divided by technical joints. The secondary building has a square cross-section. Three floors are over ground or partially under ground. The hospital is founded on a slope on the same side and downstream with respect to Assisi on an area affected by a landslide. The high heterogeneity of the foundation grounds motivated during the building phase (1996) a detailed study of the foundation system. The foundation ground was also characterized via in site seismic testing. It was finally decided to build the foundation system partly on piles and partly with superficial foundation (Fig. 2). Probably due to the landslide movement, displacement between the two parts of the structures of the main building is evident, localized in a construction joint. The hospital after the earthquake of September 25 has been inspected many times also because of the continuous shaking. The first survey showed the absence of damage to the structures in r.c. besides a column near the joint where the dislocation was evident. Damages were essentially concentrated in the interior walls where some partial collapses were also evident. The first measure concerning the usability has been to forbid the uses of the damaged areas until some retrofitting interventions had had done. Damages have increased with the successive shocks; even the one concerning the structure in r.c., that initially consisted in shear failure in the column at the floor level, has undergone a successive displacement of 1 cm at least. In the last survey of October 7 the hospital has been shortly judged unusable in order to do more accurate analysis concerning both the structural aspects and the soil stability. Also the heating and water installations have shown damages, but their immediate functioning has been possible. The boiler, the conditioning system, the fridge, the electrical installations, the part concerning medical gases, did not show any damage.

Tab. 1: Summary of the observed damages

Hospital (beds)	**Structural type**	**MCS intensity**	**Usability**	**Building period**	**Structural damages**	**Non structural damages**	**Damages to installations**
Assisi (129)	R.c.	VI-VII	No	1966	R.c.: only a column near the constr. joint	Interior walls, partial collapses	Heating, water, damaged but working
Foligno, S. Giovanni Battista (576)	Mixed, r.c. masonry	VII	Masonry: no R.c.: yes, after repair		Masonry: X cracks, beams cracks, start of facade separation, reopening of old cracks	Cracks in interior walls (r.c. part)	Elevator, batteries fell
Gualdo Tadino, Calai (151)	Mixed, r.c. masonry	VI-VII	Yes	1900-1960	Masonry: shear cracks R.c.: floor cracks	Interior walls (r.c. part)	Derailment of counterweight
Gubbio (200)	Masonry	VI	Yes		Modest		
Montefalco	Masonry	VI	Yes, after repair		Modest, in arches and masonry bearing parts	Plaster fall	
Spello	Masonry	VI-VII	Yes		Modest		
Trevi	Masonry	VI	Yes, partially		Heavy		
Treia (78)	Mixed, r.c. masonry	VI-VII	Masonry: yes, partially R.c.: yes	1820-1862	Slipping of floor beams, modest cracks, joint between new and old	Tiles displacement	
Camerino (221)	Mixed, r.c. masonry	VI-VII	Masonry: yes, partially r.c.: yes	1400-1950	Masonry: poundings, cracks in walls and floors, facade separation, chains, chimney	Masonry: cracks in the walls R.c.: ceiling partially fell	Piping, elevator (worked shortly afterwards), lights supports
Cingoli	Masonry	VI-VII	Yes, after repair				
Tolentino	R.c.	VI	Yes				
Fabriano		VI-VII	Yes, partially				

Fig 1: Location of the surveyed hospitals

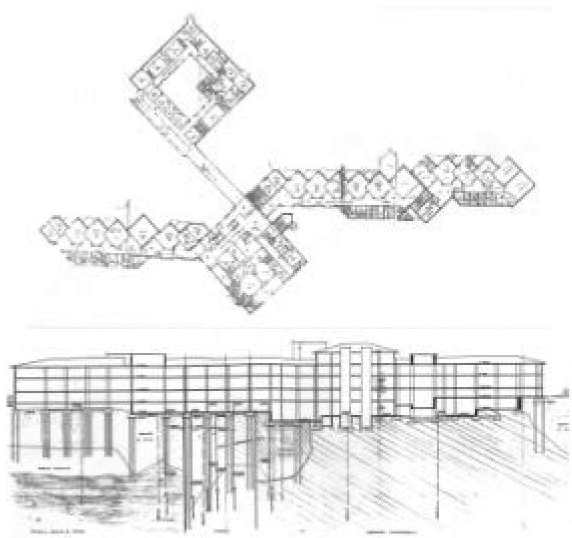

Fig 2: Assisi – typical floor plan and longit. section

Treia

The hospital is located in the historical center of the municipality near the town walls and schematically consists in two buildings linked by a footbridge: the new hospital in r.c. (no damages) and the older one, in masonry, built in 1820 with enlargements in 1947, retrofitted in 1962. The old hospital is E shaped with the backside parallel to the walls and three arms orthogonal toward the valley. The external dimensions are about 39 x 25 m and each floor has an average surface of about 750 sq. meters. Four floors are present with three completely over ground, while the first is partially underground towards the valley. The maximum height of the building is about 18 m and the total volume is of 13'000 cubic meters. The vertical structures are for the most part in masonry, except for the transversal central arm built in 1947 in r.c. (building D in Fig. 3). Besides the external walls, two longitudinal walls parallel to the longer side of building B are present. The parts built in 1820 are of masonry similar to that of the adjacent historical buildings, with irregularities and cracks. Floors are generally borne by cross and cylindrical vaults in masonry. In some case r.c. floors are present. The roof floor is in wood. The roof of the B building is carried by trusses in the central part and simple beams for the remaining. The ceiling of the rooms at the last level is connected to the walls with false vaults in plaster on canes. Damages due to the last earthquake are concentrated at the last level. The wooden roof has shown some discontinuities along the tiles but no damages were found in the bearing structure or in the supports. The floor at the last level has undergone the most evident damages, i.e., falls of some plaster from the roof and starting of slipping of the wooden beams from the masonry. These damages were not dangerous immediately. Some small cracks visible from the outside in the masonry near the doors and the windows have been found. Cracks were present in correspondence of the joints between the older part and the newer one. The last level has been immediately judged unusable whereas the lower ones remained in working order. No damage to the plants was found.

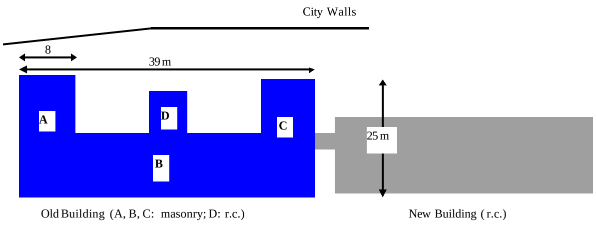

Fig 3: Treia – hospital layout

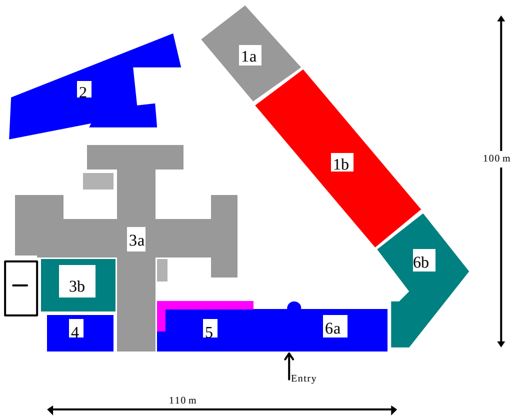

Fig 4: Foligno – hospital layout

Foligno

The hospital has been ideally decomposed in structural unites homogeneous as far as possible with respect to the building period, the materials, the relationships with the other buildings (Fig. 4). Structural joints have been found only in the newer r.c. buildings; in the other cases the quake itself caused the formation of joints (Fig. 5). Buildings 1a and 1b are in r.c., adjacently built in different periods. Building 1b is divided in two parts, structurally independent through an intermediate joint 2 cm wide where columns are doubled. Both buildings have been built before the seismic classification of the municipality of Foligno. These are the least damaged with small cracks in interior walls (Fig. 6) and an increase of 1-2 mm of the width of the joints with the masonry buildings 6b. Building 2 has a mixed structure (masonry and r.c. frames). Building 3a and 3b are the older ones in masonry. These showed a clear degradation in external masonry at the last level. The less frequent damages found are X shaped cracks in the interior walls, cracks near the windows, incipient separation of the facade; the worst damages are some walls heavily cracked and the collapse of a beam (Fig. 8). In the cloister some vertical cracks in the columns have been noticed, probably preexisting but to be carefully checked. Building 4 in masonry might be an appendix built in successive periods near the cloister. The removal of the cracked plaster showed that the whole stair wall is built with parts of different nature, one on top of the other and almost never connected each other. Cracks on the bearing walls, beams, arches have also been noticed. The interaction with the roof of the adjacent church is probable (Fig. 7). Building 5, in masonry, looks similar to the 6a but is actually different, because part of it has been expanded through a r.c. structure. In the area of the operating rooms at the 2nd and 3rd level no cracks have been noticed. The elevator to the operating rooms was put out of order during the main shock because of the excessive displacements. At the higher levels important oscillations must have taken place; this caused, beyond the derailing of the elevator, the fall of the light batteries from the racks (Fig.9). This has been confirmed also by the readings taken by the accelerometers installed in building 1 by the Servizio Sismico. During the earthquakes after September 26, at the second level an acceleration peak more than three times the PGA was recorded. Some losses of oxygen from the pipelines were also observed.

Fig 5: Foligno - formation of joints

Fig 6: Foligno - small cracks in interior wall

Fig 7: Foligno - interaction with the adjacent roof

Fig 8: Foligno - collapse of a beam

Camerino

The hospital is located inside the historical center of the city (Fig. 10). It consists of three buildings. The oldest one dates back to 1400 and is in masonry with square cross section. The elevation is of three very high floors. The second dates back to the period 1935-50 and is built with a mixed structure of masonry and r.c. The 3rd building, built during the sixties next to the second building, is built with a mixed structure with big central columns and r.c. beams. This last building contains a first level partially over ground and five more levels. The whole structure looks toward a small road descending from E to S-W. On the opposite side the complex is founded on the slopes of the town itself with about 20 meters of difference of level. The 14th century building in the S-W corner extends up to the base of the town slopes. No structure is designed according to the seismic regulations because the area was seismically classified only in 1983. The hospital beds number is 221.

Macroseismic intensity in Camerino was judged between VI and VII. The complex was visited on Sept. 27. The hospital had already been evacuated.

Fig 9: Foligno - fall of the batteries from the racks

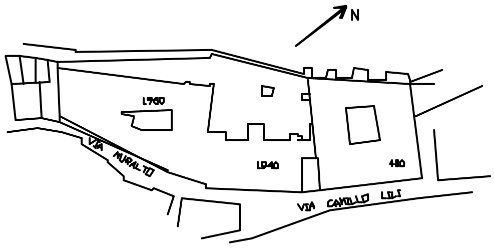

Fig 10: Camerino – location of the hospital

Fig 11: Camerino - cracks in the S-W corner wall

Fig 12: Camerino – pounding

Structural damages

The facility was externally in good state, particularly the newer two buildings, where a light pounding in correspondence of the joints was only visible. The situation, due to the localization of the complex, was different and heavier with many dangerous stone falls on the narrow street, which gets at the hospitals. The 14^{th} century building showed cracks also externally particularly in the S-W corner and in the N facade (Fig. 11). The former namely is the point of higher fragility of the complex whereas the two modern buildings showed damages only in correspondence of the joints because of the pounding (Fig. 12). In the E side important damages are present in the whole 14^{th} century building. Cracks on the walls and on the floor are visible. The whole area, which looks toward the Camerino town, particularly the areas in the S-W corner, was particularly damaged. The whole W facade looked separated from the floors; some E-W chains looked damaged; one of the S facade chains was broken and partially expelled by the walls, whereas the chimney that goes beyond the roof showed a clear fracture in correspondence of the last level, with a displacement of some centimeters. The particular plan distribution of the different buildings and the abrupt stiffness variation due to the interruption of the building showed clearly the seismic sensitivity of the S-W part.

Non structural damages

In the 14^{th} century building, non-structural damages were considerable. Many interior walls showed cracks. In the labor room the lamp was inclined with respect to the vertical direction. At the last floor in the S-W corner some piping inside the walls was damaged. Only one elevator, the one in the intermediate building near the 14^{th} century building, was momentarily out of order. The problem of the lamps was found also in two of the five operating rooms, in the newer buildings, those ones hung in eccentric positions. In the 1960 building, a small part of the ceiling in the intensive care area collapsed. Many drugs fell at the higher level in the 14th century building whereas in the newer ones nothing similar was noticed. All the non-structural hung components showed high earthquake sensitivity. The effectiveness of the anchoring system is essential to guarantee the functionality and to reduce the risk for the building occupants. The X-ray, the labor room, the kitchen and the offices were located in the not usable 1400 building.

Gualdo Tadino

The facility consists of three adjacent buildings. The original building was realized in masonry at the beginning of the century and has four levels, one of, which is partially underground. Two r.c. buildings of the fifties, with dimensions similar to the original towards S and smaller towards N, are present. The hospital is not designed to cope with the seismic action. Plants generally are not well anchored. The complex was visited on September 27. The hospital had been evacuated.

Structural damages

At the external the building looked in good state; some small cracks in the older building were visible. In the main masonry building at the roof level noticeable structural damages were found, with some shear crack in the interior walls in the two directions; similar cracks in the corresponding walls at the upper level were also noticed. Cracks in the bearing walls at the perimeter both at the first level and second level, particularly at the N corner where the intense care department is located, have been observed. These damages are probably due to the interventions done at the upper level. At the 3rd level, besides some floor cracking in correspondence of the operating rooms, no damage was visible. This part of the building is in r.c. and the below level has no interior walls, so a displacement could concentration takes place.

Non structural damages

In the two older buildings (one masonry and one r.c.) damages to non-structural masonry are visible, particularly in correspondence of the 1st, 2nd and last level. The elevator in the r.c. building experienced the misalignment of its counterweight. The hospital not showed other important problems and was considered usable.

Montefalco

It is an old masonry building with two levels on one side and three on the other side, with a wooden roof. The structure suffered some small cracks in the vaults and arches. One part of the building, already in bad conditions because of previous interventions, showed some crack and was judged unusable. From a functional viewpoint there was no noticeable problem. The likely separation of the plaster from the corridor ceiling made unsafe the way to reach the elevators.

Trevi

It is a two level masonry building with highly flexible steel and masonry floor slabs. The complex may be considered as a supporting structure to a bigger hospital since it has no operating rooms. Important damages at the S side and at the floor level in the bearing masonry part were visible. Masonry was of low quality with bad mortar and poorly connected bricks. The building was unusable at the S side, where the elevator is located; the other side was judged usable after minor interventions. The building was recently enlarged with a r.c. part which showed no damage; the elevator supporting steel structure, under construction, needs a careful seismic re-verification.

Gubbio

It is an old masonry building with three levels, wooden roof and r.c. floor slab. It showed little damages and was judged usable.

Spello

It is an old masonry building with four levels, the first one being under ground, in bad state. Floors are of different types: wooden, r.c., steel, vaults, in variable conditions between average and bad; the roof is wooden. The macroseismic intensity was VI. Damages were modest, essentially due to the bad quality of the building, with some cracks in the masonry bearing part and a small separation of the ceiling from the masonry-supporting wall. The structure was judged usable.

CONCLUSIONS

The impact of the Umbro-Marchigiano seismic event on the hospital system has been noticeable, although its intensity was low; this circumstance generally confirms the high vulnerability of these structures, such as that of similar structures subjected to some past earthquakes in various regions of the country. Also the vulnerability of the plants was confirmed, i.e., elevators, batteries and medical equipment (lights, etc.) were inadequately anchored. A very important aspect is the absence of preparedness to the seismic emergency of the hospitals employees: many hospitals which were later judged usable, at first were evacuated. A seismic event with higher intensity might have produced disastrous consequences both in terms of human lives and of economical losses. Both the event and the characteristics of these structures were of high interest because they are representative of the Italian situation [2, 8, 9] and of many foreign countries where the seismically level is modest and the constructions are similar to those here interested [7]. Some preliminary indications in terms of minor immediate interventions for the existing hospitals in seismic areas, which will continue to operate for a long time, can be proposed, with the aim to improve their performances.

(1) The anchorages of the equipments and cabinets having stability problems should be improved, particularly at the higher levels, where an amplification of the ground motion up to 3 in terms of accelerations was recorded. This meant for a VII local macroseismic intensity that the acceleration exceeded 0.5 g.

(2) The performance of the interior partitions should be checked: interior walls are often constructed in hollow 8 cm thick bricks with extensions of 20 square meters and more, with important piping inside: the stiffness and fragility of such kind of partitions are high, thus implying the formation of extended cracks and of subsequent damages to the plants. For the future hospitals the use of interior walls with higher resistance and external piping must be recommended. For the existing ones, measures to prevent fragile collapses and plaster fall (especially in the rooms where some essential functions are located like operating rooms, acute care departments, labor rooms and analysis laboratories) should be adopted.

(3) A retrofitting of the elevators, in particular to avoid the derailment of the counterweights, should be planned: in fact, if the elevators are out of order having the operating rooms often located at the upper levels, the use of such essential functions could be interdicted for some days.

(4) Sectioning and interception systems on the medical gases piping should be mounted: such devices allow a quick identification and isolation of dispersions. The hospital layout should be improved in order to relocate strategic departments like operating rooms, emergency care etc., with the aim to avoid the possibility that the loss of operation of one equipment or the unusability of one part leads to the total failure of the system.

(5) The preparedness to the emergency of the hospital employees is of key importance. Each hospital should have an emergency plan with precise tasks for the emergency managers clearly defined; the ability shown by the hospitals employees, even in dramatic situations, has allowed the solution of many problems, that in the future must be foreseen and planned.

A first step in one of the above mentioned direction is the prescription of the maximum allowed interstory drift enforced by the new seismic regulation. It is well known that the seismic design of a hospital facility needs an integrated analysis both of the resistance of the structures and of the functionality of the plants. Certainly the retrofitting of the old systems is a complex problem and rational intervention criteria must be implemented as soon as possible [7].

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