Analysis of seismic vulnerability of structures and estimating the vulnerability of technological systems of the hospitals in the Molise Region (Italy)

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Seismic classification in the Molise Region

In the Molise region by the 1915 earthquake in Avezzano until 1981 all municipalities in the Isernia province and a large number of those of the Campobasso province have been incorporated gradually in areas subject to seismic risk. The earthquake of 2002 struck some municipalities in the Campobasso province that were not included in the seismic classification of causing severe damage and the collapse of a school in the municipality of San Giuliano di Puglia causing many casualties among students and teachers. As a direct result of this event the Presidency of the Council of Ministers issued the Ordinance no. 3274 of 20 March 2003 "First elements on general criteria for the seismic classification of the national territory and technical standards for construction in seismic areas", where, in addition to the definition of new "Criteria for the identification of seismic zones," has been made mandatory control of the seismic resistance of all strategic buildings and infrastructure works that assume an important function during seismic events for civil protection, including hospitals.

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1. Introduction

Following the entry into force of the new seismic classification and new technical standards for buildings are under the Ministerial Decree of 14 January 2008, the Health Service of the Molise Region has decided to proceed with the implementation of a plan for seismic monitoring of Hospitals regional considered strategic and relevant. To ensure the effectiveness of the action through technical and scientific knowledge in order to achieve the reliability and consistency of the results for an objective evaluation of the risk status of the hospitals the Department of Health of the Region has entrusted the Institute for Construction Technologies the National Research Council of L'Aquila, the task of making the necessary seismic inspections, including surveys and experimental investigations extended to all hospitals and preliminary identification of possible seismic retrofitting required with relative estimate of the costs of intervention. The main objectives were to assess the level of seismic safety of each garrison, and, based on the results of surveys and assessments, identify key structural weaknesses and, therefore, define the possible intervention strategies for the implementation of preventive measures and quantify the economic resources necessary to achieve an adequate level of seismic safety or identify cases where it is appropriate to replace the building.

In addition to the traditional activities such as audit evidence about the structures and investigation of foundation soils was also conducted a qualitative study of the level of vulnerability of the buildings is that of all the non-structural elements and systems that could affect the functionality of hospitals after the seismic event. So also were examined partitions, ceilings, lifts, distribution networks mechanical equipment and medical gases, electrical panels, lighting systems, generators, fuel tanks, gas cylinders, medical equipment and glass walls to a great extent. The analyzes were performed with priority given to services whose functionality is considered to be strategic due to a seismic event. This approach has made it possible to minimize the costs of the checks to the advantage of the funding for the interventions themselves, while taking into account new technical standards for construction in 2008 and to obtain useful results for the regional planning by defining priorities for action and the related cost estimates for assessing the economic viability of a seismic upgrading compared to demolition and reconstruction.

2. Seismic recommendations in hospitals

The hospitals studied were especially prone to seismic risk because of their vulnerability and high exposure lotus (crowding) and also because they were designed and built in seismic areas classified only after their completion. From the regulatory point of view, reference was made to "ATC-51-1 Joint Recommendations United States - Italy for the preparation of emergency plans in hospitals seismic Italian" and "ATC-51-2 Recommendations joint United States - for Italy reinforcement and anchorage of non-structural components in Italian hospitals "and, for each hospital, were given the following information on the non-structural components: general information of a technical nature, including the description of the damage in past earthquakes, specific recommendations for strengthening and the anchoring of 27 different types of components, a guide on the design of devices for the seismic anchor.

The study allowed us to assess the state of the plants and their level of vulnerability and provide the necessary information about the possibility of adapting or replacing structures or facilities. For each hospital has been produced a ranking of vulnerability of the structures and functions of the various non-structural components (from most critical to least critical). E 'was also calculated the cost needed to reduce the vulnerability of the individual components without necessarily proceeding to structural adjustment. From the information gathered it was possible to relate the cost of intervention to the structural and non-structural conditions of the individual hospitals depending on the seismicity of each zone: for hospitals to Isernia, Venafro and Larino will need to act on all the components, Agnone only for a part and Termoli 's intervention may be even more reduced.

For hospitals of Agnone, Isernia, Venafro Larino and for the high structural vulnerability, you should not upgrade facilities without any prior structural adjustment, while the Hospital of Termoli to the low vulnerability of structure and low seismicity of the site it is possible to upgrade the facilities without any preliminary structural adjustment.

3. Hospital "Vietri" of Larino example

In the following, by way of example, shows the summary report of the Hospital "Vietri" of Larino. This hospital complex is housed in an imposing structure located in the peripheral area to the urban center of the City of Larino in an area with low slope (about 8%) that produces a difference in elevation of the ground surface from upstream to downstream of about 12 meters. It 'been possible to find the structural design of the reinforced concrete structure and the preliminary draft on the activities of the post-earthquake of 2002. It 'was then reconstructed the history of the hospital complex that was built in 10 lots, between 1971 and 2000 (year of completion), of which only the first three have involved structural work that was completed in the mid-eighty. The building consists of a reinforced concrete frame in large (about 151.50 x 151.50 m in plan) that is spread over 5 levels to a maximum height of the eaves at about 19 m from the plan 'sets of foundations built on plinths isolated and is designed for vertical loads only. Foundations, due to the morphology of the area, have shares tax very variable.

The covering structure, realized with slabs in RC dimensions of 35 +5 cm, lying on a straight staggered in order to ensure a sufficient exposure to light even to the most internal. The floors are made of inter-a.c. with dimensions 25 +5 cm and are not aligned to the entire surface of the structure. The bearing structure is made up of RC walls and pillars that have a regular grid plan of about 7.2 m in two main directions. Some cases have vertical joints made in part to partial height (joints that start at about half pillar) that continue even on the structures and horizontal coverage and end up on the roof with the probable function to allow for thermal expansion without inducing expected compulsions. For some joints have been provided for the works of solidarization of the vertical elements made of steel hoops to the head of the pillars. Beams, for most AC, are generally generous in size but do not guarantee the connections between all the pillars.

According to the documentation recovered, the site investigation, the geometrical surveys and investigations carried out in the campaign it was possible to summarize the structural problems encountered: the existence of a plan to 'stilts' in height up to 14 m; presence of pillars in large slenderness (height up to 14 m); irregularities in the distribution of stiffness in plan due to the presence at the first level of pillars with strong difference in height between the upstream and downstream and of baffles in an eccentric position; presence of joints (for most 'closed' by inclusion of works of solidification) arranged in an irregular manner; presence of overhangs large (up to 3.5 m); deformation of the decks in their plan due to the large size of the building plan; septa equipped with armor of small diameter and large pitch; poor shear strength of the structural elements, in particular the vertical ones; the presence of a long corridor with walls made of reinforced concrete supported by beams.

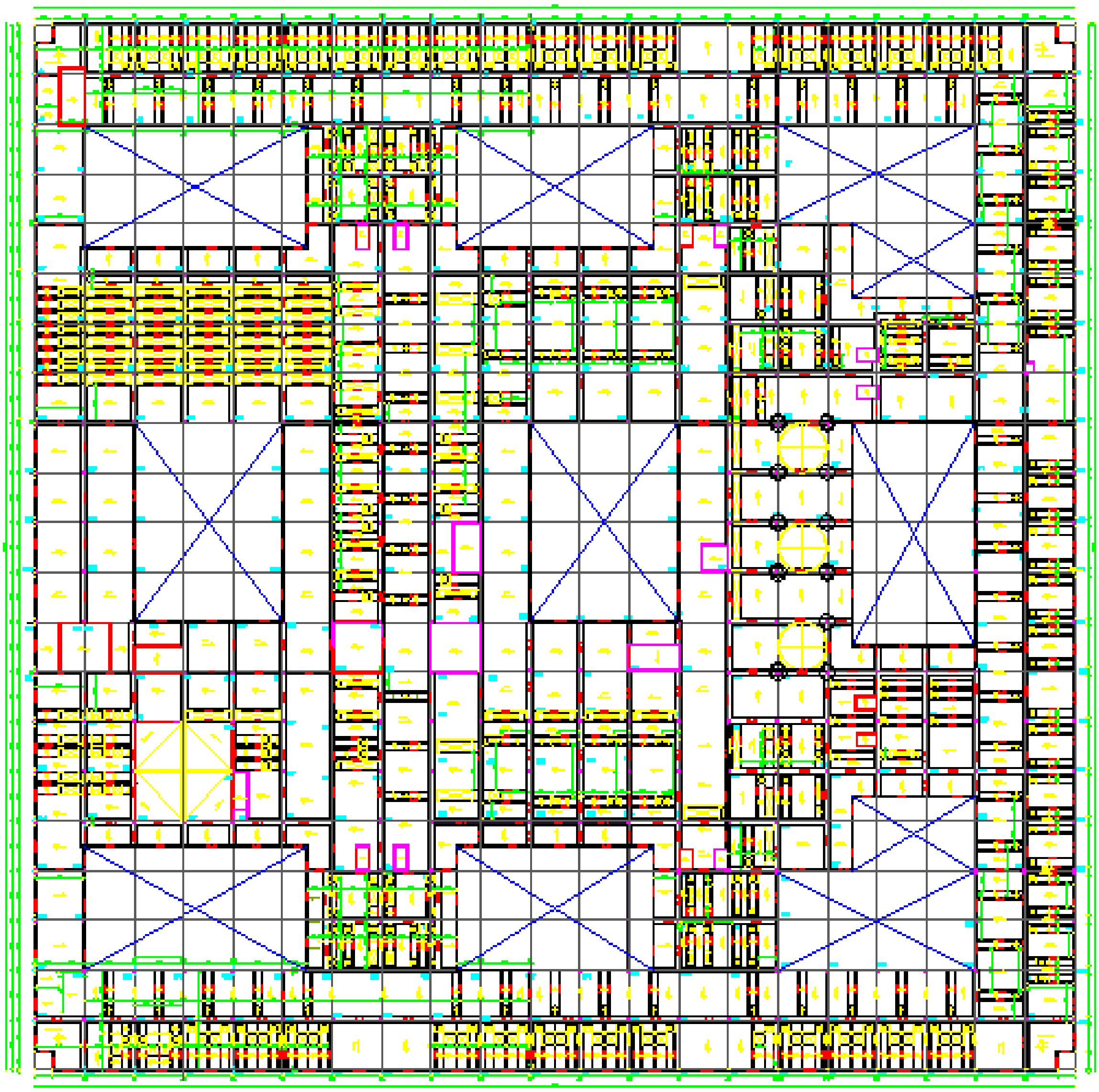

Figure 1: Map of the last level

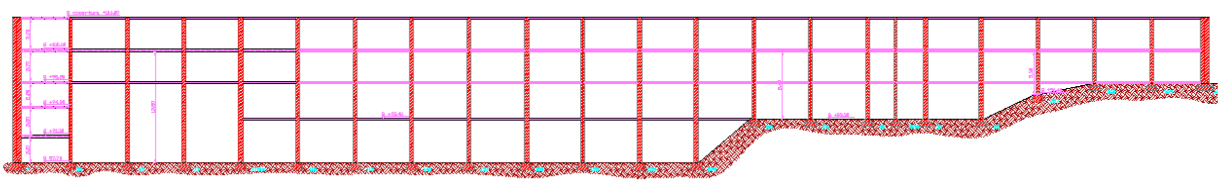

Figure 2: Section

The results of the tests showed the presence of a concrete having average resistance of about 25 MPA N / sq.mm with a value (high) of the depth of carbonation (variable between 40 and 65 mm), little protection of the reinforcement for porosity of the concrete, a high corrosion rate and a presence of corrosion in the pillars and beams.

The brackets of the pillars have variable distance between 20 cm and 30 cm, section 6 and 8 mm while for the beams has the same section with variable pitch between 30 and 40 cm and presence of irons bent. For brackets was used mainly round and smooth and ribbed steel for beams and columns. The fixtures have been sized on the basis of seismic activity related to the second category referred to seismic classification of DM 03/03/75 ag which corresponds to a reference about 0.18.

An intervention strategy for 'seismic retrofit of structures is very closely related to the configuration planimetric and altimetric and weaknesses of the body construction of the building. The survey results showed the presence of a structure not adapted to current seismic code.

To achieve the objective of adaptation interventions are planned consolidation of structures with steel plates, bandages and bracing elements in FRP reinforced concrete or steel. To eliminate the above-mentioned drawbacks construction is expected to reduce the height of the pillars and stabilize the structure with technical joints in places where they had originally planned. To reduce the height of the pillars is possible to provide for the realization of one or two decks intermediate stiffening horizontal or systems that interrupt the height of the pillars.

The technical joints can be achieved through the construction of new piers at a short distance from existing ones. Such intervention to be very invasive and substantially change the appearance and configuration of the structural complex. The realization of the horizontal stiffeners could encourage the creation of new surfaces at the service building. To reduce the costs of intervention was also examined the possibility of realizing an insulation at the base of the pillars with elastomeric isolators.

This project involves the installation of insulators below the altitude of the ground floor, the implementation of a plan to drive this share over tightening intermediate in the light of the pillars with excessive costs.

Alternatively was hypothesis intervention which allows a significant improvement with no high costs is that of providing local works which would improve the response of the structure. They are related primarily to the strengthening of the external nodes, with technical notes that provide confinement with composite material (intervention aimed also to a strict compliance with the instructions given in the regulations), and the introduction of a system of bracing steel posts also in correspondence of the structures to pilotis that would have the dual function of bracing the building and suspend large free spans of inflection of the pillars that constitute a structural inadequacy that evidently has a negative impact on the whole structure.

The level of security achieved with assistance of local reinforcement is equal to 45% of a capacity equal to 0.10 g. To estimate the costs of intervention are referred to the costs incurred for seismic upgrading of public facilities in Molise following the earthquake of 2002 and the estimated cost for the reconstruction of private hospitals in Abruzzo.

Given oh the seismic action hospital complexes and the additional cost due to the presence of complex systems has been assumed an average cost of 800 euro / sqm for the adaptation of structures and 300 euro / sqm for plants for a total of 1100 € / sqm. Were computed in addition to the interventions of high technology for the mitigation of seismic risk as base isolation, the dissipative braces.

The estimated cost for seismic upgrading is approximately € 34,185,046.50 as shown in the table below. The cost of seismic improvement was estimated at about 4 million euro.

4. Summary of costs of intervention and assessment of vulnerability

The table shows the estimated costs of intervention for seismic upgrading of structures and facilities. In addition, it was considered the cost for the recovery of medical implants variable between 20% and 40% of the cost of technological systems in the invasiveness of structural function.

HO	square	techonoligical implants	medical implants	Costs
Agnone	7,393.20	2,217,960.00	40%	887,184.00
Larino	52,062.77	7,809,415.50	30%	2,342,824.65
Isernia	19,350.60	7,840,240.00	40%	3,136,096.00
Isernia	11,517.34	4,606,936.00	40%	1,842,774.40
Termoli	31,046.71	4,657,006.26	20%	931,401.25
Venafro	22,037.00	6,611,100.00	40%	2,644,440.00
Totale	**143,407.62**	**33,742,657.76**		**11,784,720.30**

Table 3: Summary cost recovery medical implants

HO	sup	structures	implants	medical implants	costs	costs mq
Agnone	7,393.20	5,914,560.00	2,217,960.00	887,184.00	9,019,704.00	1,220.00
Larino	52,062.77	26,375,631.00	7,809,415.50	2,342,824.65	36,527,871.15	701.61
Isernia	19,350.60	20,550,600.00	7,840,240.00	3,136,096.00	31,526,936.00	1,629.25
Isernia Dea	11,517.34	11,517,340.00	4,606,936.00	1,842,774.40	17,967,050.40	1,560.00
Termoli	31,046.71	9,314,012.51	4,657,006.26	931,401.25	14,902,420.02	480.00
Venafro	22,037.00	13,222,200.00	6,611,100.00	2,644,440.00	22,477,740.00	1,020.00
Totale	**143,407.62**	**86,894,343.51**	**33,742,657.76**	**11,784,720.30**	**132,421,721.57**	**923.39**

Table 4: Summary cost of seismic improvement

Buildings	**Structural vulnerability**	**Implants e non structural components vulnerability**
Francesco Caracciolo Agnone	***HIGH***	***MEDIUM-LAW***
G.Vietri Larino	***HIGH***	***HIGH***
F.Veneziale –Isernia	***HIGH***	***MEDIUM-HIGHT***
F.Veneziale – DEA – Isernia	***MEDIUM-HIGHT***	***MEDIUM***
SS. Rosario - Venafro	***MEDIUM-HIGHT***	***HIGH***
San Timoteo di Termoli	***MEDIUM-LAW***	***LOW***

Table 5: Synthetic evaluation of structural and implants vulnerability