SEISMIC RISK ASSESSMENT AND MITIGATION OF TWO EXISTING HOSPITALS IN ITALY

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SUMMARY

The paper presents the study carried out to assess the risk that two existing hospitals in Tuscany could loose their functionality due to seismic event. The two hospitals are typical of the Italian situation for these infrastructures. They are composed of various buildings built in different years starting from the end of the fifties. They had been retrofitted for seismic actions but considering the structural part only without any consideration for functionality after the earthquake. Based on the study of the hospital system logic, including structural and non structural components as well as installations and medical utilities, the probability of exceedence of the functional limit state based on system reliability analysis is evaluated. The hospital has been considered out of use when all the operating theatres are out of use. The effect of different retrofitting strategies has been considered and are presented and discussed in the paper. Though the two hospitals are very different in shape and functional logic, the probability of loosing functionality given a seismic event is similar. However different intervention criteria are needed to reach a reasonable safety level in the two hospitals, and it is seen that the adopted method of analysis permits a clear understanding of the possible different choices. It is a matter of fact that bracing of non structural component is essential and proves very effective.

INTRODUCTION

The criteria to upgrade existing hospital in order they can reach a satisfactory safety level with respect to seismic action for what concerns their ability to remain in function can be substantially dependent on the layout of the hospital. These may differ very much from case to case even for hospitals having similar “dimensions”, i.e. the same number of beds, and built in the same period, due to many factors, the most frequent being the creation of new building during the time to face the varying and often increasing functional needs. A rational criterion to detect a seismic upgrading intervention strategy has been found to be the study of the hospital as a system in order to find its seismic safety and detect the “components” whose fragility mostly influence the overall reliability. One can compare the effect of the increase of seismic resistance on some of the components on overall reliability, therefore identifying critical element and optimising the intervention. The feasibility and efficiency of the method has been applied and illustrated in previous cases [Monti G., Nuti, C.,1996]. It seems however especially meaningful to present the case of two different hospitals having the same dimension and placed in zones of equal seismic hazard, in fact due to their different general layout, in both cases a complicate one, intervention needed to reach similar reliability levels differ substantially.

METHOD

The hospital is considered a system which must be to carry out surgical operations after a seismic event (other important functions may be individuated, the one considered been however the most critical, at least after an

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earthquake). The following steps are carried out: structural and non structural and functional description of the hospital; identification of the system logic by ordering components in series and parallel;

reduce the description of the hospital to its minimal cut set: i.e. rearrange the series parallel description into a series of components each composed of parallel elements; identify for each component mean value and variance of the resistance as well as mean and variance of the action (the probability density functions are assumed to be normally distributed, in order to simplify total independence or total correlation are assumed); evaluate system reliability given seismic intensity (except for easy cases a closed form solution is not available, therefore bounds are used. In this manner the most critical cut sets are found. Intervention for upgrading can therefore concentrate on these elements. One should note that if a very fragile elements is part of a cut set which is not critical, being in parallel with other element which are strong enough, than the fragile element need not to be upgraded. Increasing seismic intensity one obtains the relative probability of failure. At different intensities the relative ranking among cut sets may change, therefore the level at which the reliability check is done may determine different choices in the number (which is obvious) but also on the priorities of the elements to be upgraded.

CASE STUDIES

Two hospital have been studied: Castelnovo Garfagnana and Fivizzano. They are placed in the northern part of Tuscany, in zones of moderate seismicity. They are of similar dimensions with a number of beds between 100 and 200, this being the range of the largest number of hospital in Italy. In both case a conventional structural seismic upgrading had been carried out. It essentially consisted in checking that structural strength after upgrading was such to satisfy allowable stresses in steel and concrete for an elastic seismic response of 0.07g, or that in masonry structure an adequate ultimate strength was reached. Scope of non structural upgrading was to attain an accepted risk that the hospital is put out of use for a seismic intensity having a given mean return period, both seismic level of functional upgrading and upgrading strategy: i.e. the choice of component (structural, non structural, installations to be upgraded). The hospital of Fivizzano consists of 9 buildings, as shown in Figure 1 and described in **Table 1**. Buidings are in reinforced cocrete or masonry, dating from 1926 to 1974.

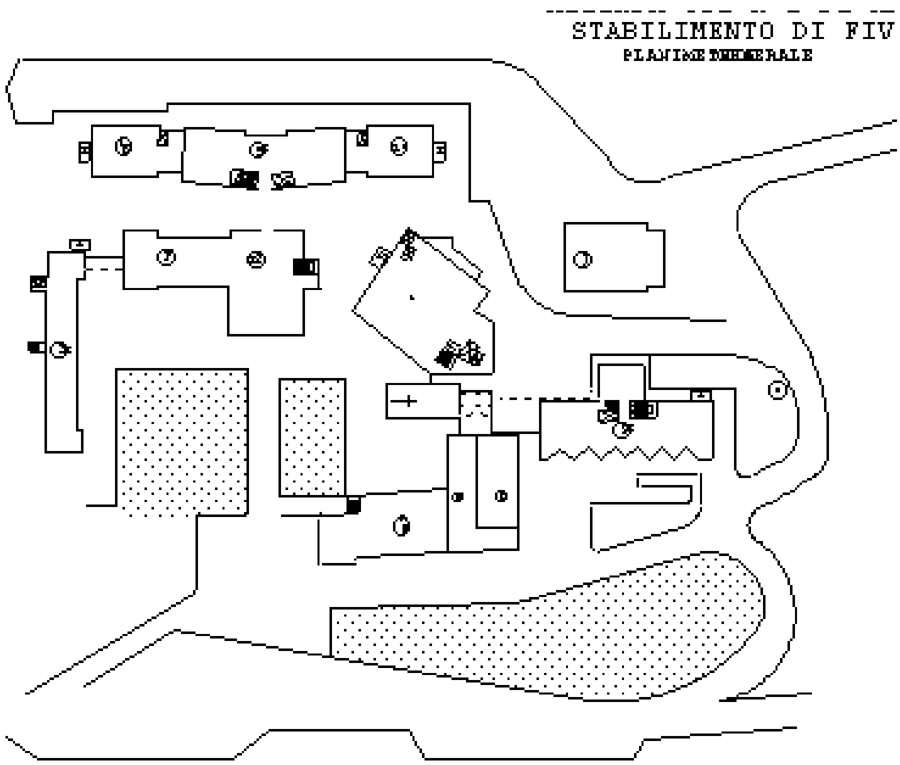

Figure 1-Plant of the Fivizzano Hospital

Table 1.- Buildings and functions in the Fivizzano Hospital

Building	**Material**	**Dimensions**	**Construction date**	**Floor usage**
1	Mixed 1a: masonry 1b: r.c.	1: 18m x 24m x 3 floors @ 3.5m	1a: 1926 1b: 1972	1: |deposit (de)| |blood transfusion (bt)|
2	masonry	9.5m x 22.7m x 3 floors @ 4 m	1926	|Dining room(dr)| |analysis(an)||Operating theaters(ot)+(bt)|
3	masonry	8.4m x 41.2m x 2 floors @ 4m	1926	Not being used
4	r.c.	4 floors	1974	|laundry(la) ||surgery(su)||(su)| gynecology(gy)|
5		3 floors		Not being used
6	r.c.	4 floors	1974	|kitchen (ki)||su| |su| |su|
7		1 floor		|pharmacy (ph)|
8	r.c.	(10.5m x 9.4m)+(12.9m x 19.5m) x 3 floors @ 3.3m	1974	|an||administration(ad)||ad|
9	r.c.	(11.8m x 36.2m)+(9m x 9.75m) x 6 floors @ 3.5 m	1972	|de||an||su| diagnostics(di)||di| di|

The logic of the operating theatres in order they can function is shown in Figure 2 and in 3

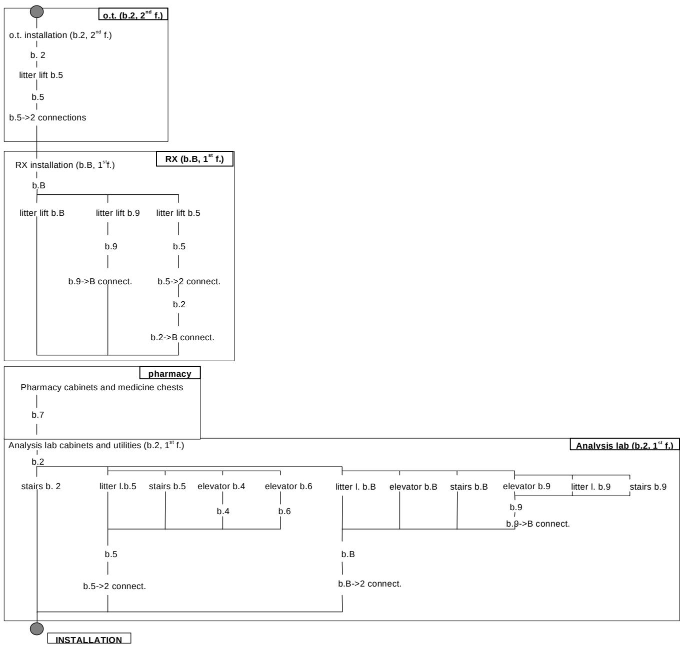

Figure 2 cut sets for the Fivizzano Hospital. The details relative to "installation" are given in

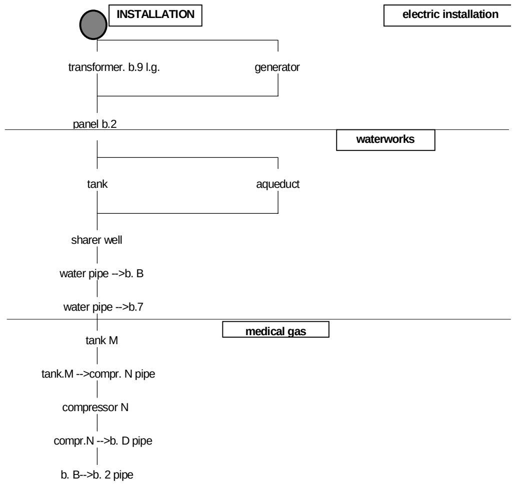

Figure 3 – Detailed Cut sets relative to "installation" in Figure 2

Looking at fig.2 one can see that the system is reduced to five macro element in series: operating theatres, Xray, analysis lab, pharmacy, essential installation and utilities. Each one is detailed at different levels, for example the operating theatre need that some buildings remain structurally functional, that some litter lift works and that some connections between buildings works. One can rearrange the fault tree in the minimal cut set representation, given in **Table 2**, and find for each component element of the minimal cut set its fragility. Many elements of the minimal cut set are composed of a single component. The overall vulnerability, given in Figure 4 (left) is considerably high with respect to local hazard, which is shown in Figure 4(right). There is a considerable number of cut sets having a risk larger than 0.5 for a peak ground acceleration larger than 0.1g, as listed in **Table**

3. Three type of intervention are selected (see **Table 3**): A upgrade installations, this is relatively simple by bracing the nonstructural elements; B upgrade building 2 where operating Theatre and analysis lab are; C upgrade of the other fragile element.

Table 2. Minimal Cut set representation of Fivizzano Hospital.

cut-set N.	**Component 1**	**Component 2**	**Component 3**
1	Building 2		
2	Litter lift b.5		
3	Building 5		
4	b.5->2 connection		
5	builgind B		
6	building 7		
7	panel I		
8	well		
9	Water pipe ->B		
10	Water pipe ->7		
11	Tank M		
12	Medical g. pipe->N		
13	Compress. N		
14	Gas pipe N-> D		
15	Gas pipe B->2		
16	Transf. Ed.9	Generator	
17	Tank	Aqueduct	
18	Litter lift b.B	Litter lift b.9	b.2->B connection
19	Litter lift b.B	building 9	b.2->B connection
20	Litter lift b.B	b9->B connection	b.2->B connection
21	o.t. installation		
22	RX installation		
23	Pharmacy utilities		
24	Analysis lab utilit.		

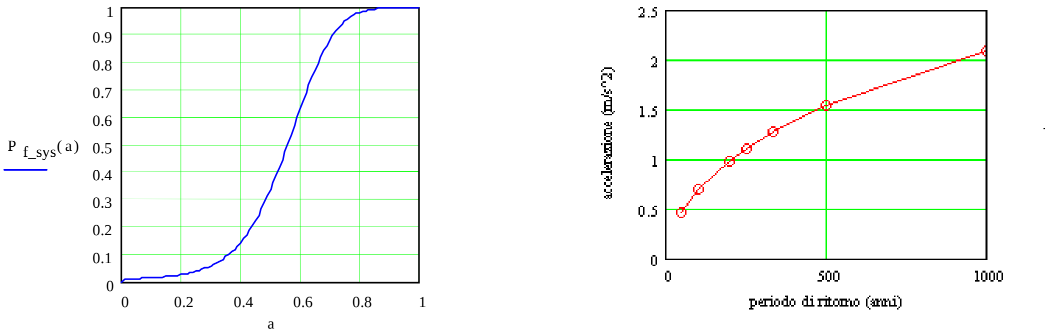

Figure 4. Fivizzano. Overall probability of failure (left). Hazard curve (right)

Table 3 List of the cut sets with probability of failure larger than 0.5 for a pga=0.1g, and upgrading strategies

ranking	Cut set N.	Name.	Damage type	Upgrad. strategy
1	24	Installat. Lab. Analisi	Overturn.	A
2	3	buiding. 5.	Struct. collapse	C
3	4	Link buildng. 5-2	Non struct. collapse	C
4	21	Op. Room installat..	Overturn.	A
5	1	Buildng 2	Struct. collapse	B
6	7	Electr. General rack I	Overturn.	A

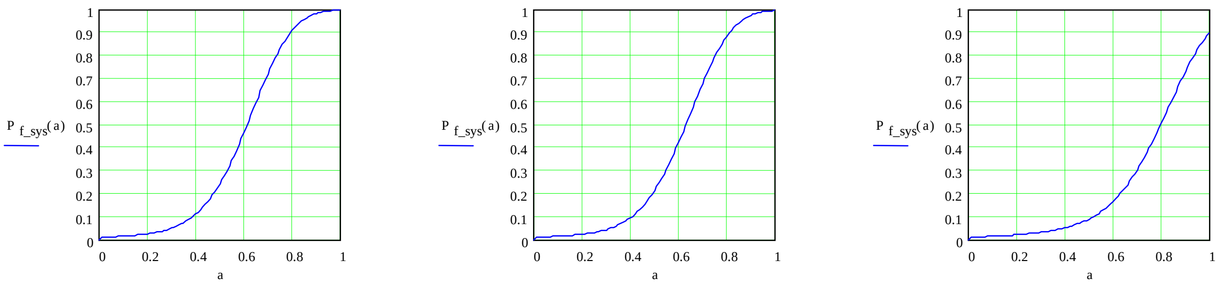

Figure 5. Fivizzano. Risk curves after upgrading type A (left), B (centre), C(right)

There is a significant risk reduction after upgrading A, while if one wants a significant further reduction upgrading C is needed, while upgrading B is quite ineffective with respect to A. In fact with reference to peak ground acceleration 0.47g, having a 50 year mean return period, the probability of failure before upgrading and after cases A, B, C are 0,27, 0.197, 0,172 and 0,078 respectively. The hospital of Castelnuovo Garfagnana consists of 11 buildings built in different dates from 1949 to 1988.

Table 4 Castelnuovo Hospital. Buildings and functions.

building	material	n. levels	Construction date	Floor usage
1a	masonry	3	1949	
1b	masonry	3	1949	
1c	masonry	3	1949	
1d	masonry	1	1949	
2a	r.c.	3	1960	Emodialysis
2b	r.c.	3	1960	Emodialysis
2c	r.c.	3	1960	Emodialysis
3	r.c.	4	1981	RX
4a	r.c.	4	1972	RX
4b	r.c.	1	1972	RX
5a	r.c.	3	1972	Emergency
5b	r.c.	1	1976	Emergency
5c	r.c.	1	1976	Emergency
6	r.c.	2	1982	Operating theatres
7a	r.c.	2	1977	Paediatrics
7b	r.c.	2	1977	Paediatrics
8	r.c.			Ambulatory
9	r.c.			Ambulatory
10	r.c.	2	1988	Gynecology
11	r.c.	2	1988	Gynecology

Table 5 Castelnuovo Hospital System logic. Components 2 and 3 are in parallel as 10 and 11.

Component	Strength	c.o.v	Series / Parallel
1 medical gases	1	0.25	S
2 generator	1.5	0.25	P
3 electric feeding	0.5	0.15	P
4 lift in building 1c	1.2	0.25	S
5 X rays	1.2 (2.0*)	0.25	S
6 X rays building	0.6 (1.1*)	0.25	S
7 analysis laboratory	0.8 (1.2*)	0.25	S
8 pharmacy	1.32	0.25	S
9 lift in building 10	1.3	0.25	S
10 operating theaters 1	1.2	0.25	P
11 operating theaters 2	1.2	0.25	P

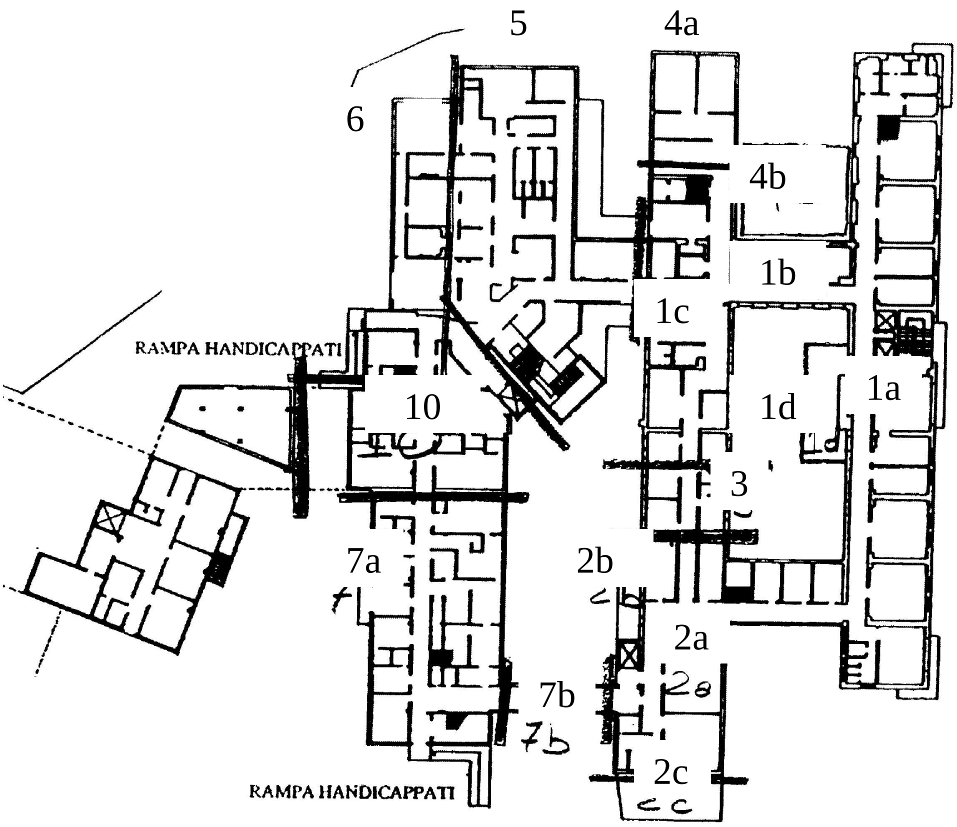

Figure 6 Plant of Castelnuovo Hospital

Building are one adjacent to the other subdivided by structural joints. The two operating theatres are in building 6 at ground floor. The logic of the operating theatre system is given in **Error! Reference source not found.**. It is much simpler than Fivizzano case. The vulnerabilty of the system is shown in Figure 7. At 0.047g (return period 50 years), Pf=0.27 before upgrading and about 0.09 after retrofitting as for case C in Fivizzano. One should observe that upgrading consists only in bracing of X ray and analysis Lab installations, and in a light upgrading of the Xray building to reduce damageability of the infill wall.

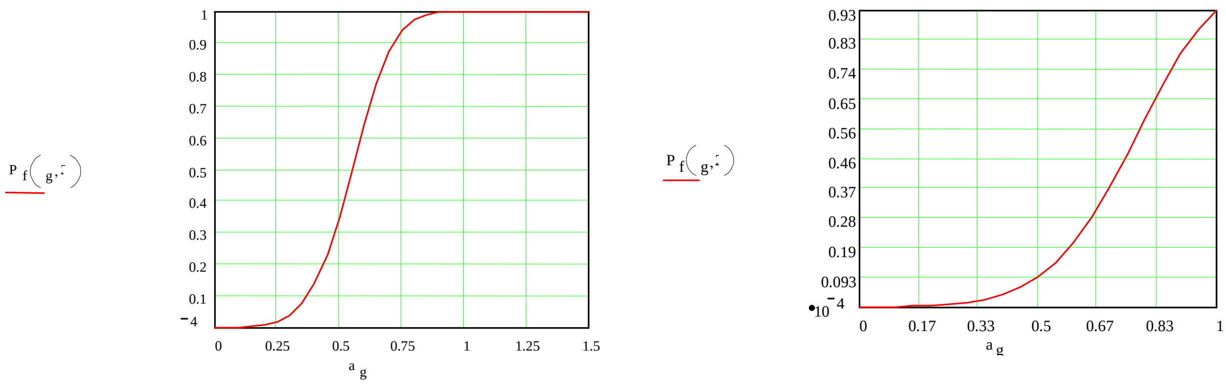

Figure 7 Castelnuovo. Functional vulnerability before retrofitting(left) and after retrofitting (right)

CONCLUSIONS

Two examples of functional retrofitting of existing hospitals have been illustrated. It has been shown that the simple structural retrofitting leaves the hospital extremely vulnerable from functional point of view. System analysis is a very rational tool to detect critical element to upgrade to reach an acceptable functional reliability. It has been shown that depending to the layout of the hospital different strategies may be needed, while a generalised upgrading may result in a very expensive and sometime unfeasible operation. It is a matter of fact however that in one of the two cases, Castelnuovo, the functional upgrading to the desired level is very simple and quite inexpensive being essentially restricted to simple non structural bracing, while for the case of Fivizzano it is more complicated and expensive. It is opinion of the authors however that hospital should be upgraded to higher seismic intensities than here considered. In this case however the structural retrofitting had already been done and was one of the data of the problem. When one decides to retrofit an hospital he should consider both structural and non structural aspects having in mind that such strategic building should maintain intact their capability to operate after intense seismic events.

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