CRITERIA FOR RETROFITTING BUILDINGS IN UMBRIA-MARCHE EARTHQUAKE

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SUMMARY

After the seismic events on Umbria and Marche Regions starting September 26th, 1997, two Technical Committees were formed having the duty of establish technical guidelines for repair and retrofit buildings damaged by the earthquake, programs for microzonation operations, criteria for controls of designs and executions. Above all, criteria for repairing and retrofitting have been performed following political choices and technical requirements by new methods with some specific and interesting aspects. Some results have been obtained so far, a large percentage of the total reconstruction being accomplished.

INTRODUCTION

The following are the aspects that guidelines have touched:

1) damage and vulnerability survey

2) assessment of financial funds

3) criteria for quick seismic microzonation

4) criteria for first step of reconstruction (low risk mitigation)

5) criteria for second step of reconstruction (medium risk mitigation)

6) criteria for reconstruction inside historical centers

Damage and vulnerability survey

As a first a general survey was performed overall on areas hit by seismic events (fig. 1) with 3 principal goals: damages, vulnerability and safety in emergency of buildings. Because of different histories of the two Regions (Umbria was hit by an earthquake in 1979 in an area partially coincident with the actual area, instead of Marche had an earthquake just in Ancona, capital of the Region in 1972), two different survey forms were used, so an elaboration of the Umbria data was needed for reaching the Marche survey form on wich software of GNDT [1] has been available. On the other hand a specific form for buildings safety evaluation was used [12]. Public technicians filled up these forms, but, because of large amount of buildings involved (about 80,000 in Umbria and 45,000 in Marche) and because operations of survey were done for 2-3 times (and more) due to aftershocks and successive events (september 27, 1997, october 14, 1997, april 1998), also private technicians were needed. It is interesting comment some problems of the survey of safety in emergency on buildings hit by earthquake.

As a first the goal of operation. It is the goal to evaluate the *level* of safety or just the *difference* between the safety before and after the event ? If the first option is the right one, the knowledge of the hazard related to aftershocks is needed, for allowing an assessment of risk, at least in the emergency. If the second option is the right one, a simple evaluation of the decay of safety is needed, but this type of

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evaluation can be poorly used, due to the fact that a real safety of the buildings is unknown. Of course the first option requires a very accurate survey of the resisting system.

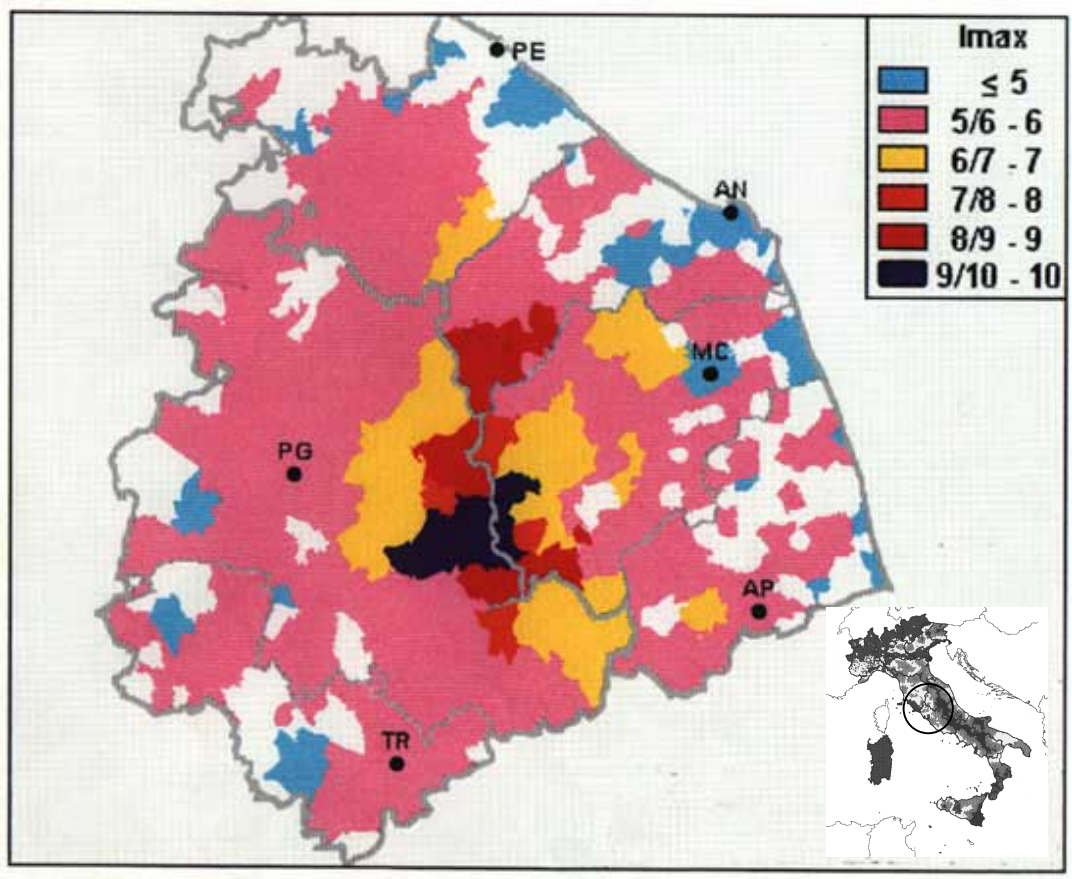

Fig. 1. Areas hit by seismic events from Sept. 28 to Oct. 20, 1997, with MCS Intensities

As second problem, is the responsability of the technical assessment of safety extended just to the period of the emergency (with a probability of occurrence of aftershocks) or more ? And is technicians legally responsible in any case ? Of course the evaluation of vulnerability should be of different accuracy according to the choosen way.

As last problem, technicians in duty for perform this evaluation should have been prepared to, in order to avoid as unsafe assessments (for ignoring the real risk, due to decay of seismic strenght and ductility) as oversafe assessments (for cautious judgements).

Assessment of financial funds

Because of the political choice of partially refunding all damaged buildings, the national gouvernment asked us a quick assessment of the financial funds needed for all operations of repair and retrofitting in both Regions. After the translation of Umbria form in GNDT form, the assessment of the financial funds needed was done in two different manners: a first one obtained by a cost model [2], evaluating the need of unit operations of repair and retrofitting following damages and surveyed vulnerability elements, a second one assuming a cost equal to the maximum public amount available, according to the different levels defined (see par. *Criteria for reconstruction*). Of course the first manner tries to assess the total cost of the reconstruction, while the second one tries to assess the amount of money that gouvernment should supply. The second evaluation is summarized as follows, including just structural aspects and other common parts (however excluding taxes, design expenses, etc.):

Umbria (75877 buildings):18463 billions of lires, i.e. 243 million of lires per building
Marche (45443 buildings):11185 billions of lires, i.e. 246 million of lires per building
Total (121320 buildings): 29648 billions of lires

Evaluating the real cost by GNDT cost model, these values are 15-20% greater (it means that defined levels of public funds are approximately 80-85% of the total cost required, see par. *Criteria for reconstruction*). As a result, because the public funds can be available only under request of private citizens, because over 90% of the buildings are private houses and finally because the total amount of private requests, so far, is about 30-35% of the total of surveyed buildings, the assessment of financial funds has reached, so far, less than 14000 billions of lires instaed of about 30000 billions estimated on the total of *surveyed* buildings. (even if considering that number of public buildings and cultural heritage are unchanged and its average cost is much greater than the average of private houses)

Criteria for quick seismic microzonation

Having noted that in several centers local effects due geomorphological aspects, a quick microzonation based on a groupment of over 2000 small areas in few classes. Because details and analysis related to these operations are described in [13], no more informations are given on this topic.

Criteria for reconstruction

The law no. 61/1998 established to supply public financial funds for the following operations:

- repair of damages
- structural intervents (for low retrofitting)
- other intervents on common parts of buldings
- (just for poor people, percentages increasing as private incomes decrease) any other intervent

Definition and details of all these operations do not need to be explained except the second one, i.e. retrofitting operations, wich depend on the choosen level of seismic protection. For better understanding the problem, it has to be remembered that italian code allows two different types of retrofitting in existing buildings, a global retrofitting, requiring the same level of protection of new buildings, and a low retrofitting, that has not a defined level of protection, characterized by a simple "*increasing safety*". Following the obvious consideration that public funds are available for mitigating risk on buildings just because of suffered damages (and need of repair operations) and not under a general program of mitigation of risk overall on italian seismic areas, politicians choose the *low retrofitting* as a refundable intervent (of course anyone might increases this minimum level by own funds).

Criteria for first step of reconstruction (low level of risk mitigation)

As a first step, an easy and short way to retrofit was decided, with the goal of a *fast rehabilitation*, *light structural design* and no *evaluation of level of seismic protection* of several buildings having the two following aspects:

- low damages
- low vulnerability

Both requirements are needed because the case of *few damages, with high vulnerability* simply means that the building was not in epicentral area, but it could be in the future, and the case of *high damage associated with low vulnerability* shows anyway that the building could have suffered a large decay of safety. In both cases retrofitting would not be so easy to do and more accuracy is needed. The threeshold of vulnerability, according to the simple way choosen, is defined simply as a quick evaluation of ratio between the resisting shear force (at each floor) and the permanent loads, by:

$$C = (a_0\tau_k)/(qN)\ \sqrt{\{1+(qN)/[\ 1.5a_0\tau_k(1+\gamma)]\}}$$

with:
a_0 the ratio between minimal resisting area of cross section of masonry walls and total covered surface of the building (in plan)
τ_k the unit design shear strenght of masonry
q the permanent load per unit of covered surface area in plan (including the weight of walls)
N the total of floors above the considered floor
γ the ratio between the maximum and the minimum of resisting areas of cross section of masonry walls (in two orthogonal directions)

This ratio is required to be at minimum, an half of the same ratio required for new buildings. Of course a lot of vulnerability elements are not considered (plan configuration, diaphragms, foundations etc.) but the criterium is simple enough to be managed in a fast manner for low damaged buildings. For masonry buildings passing the test, following technical intervents are compulsory:

- repair of damages
- connections between walls and between walls and diaphragms (prefering rod ties instead r.c. infilled beams)
- reduction of horizontal forces due to arches, roofs, vaults

with a public fund of 0.4 lires per square meter in plan and a maximum of 60 million of lires per dwelling.

For r.c. buildings the only threeshlod is in terms of damages. These buildings have to be retrofitted at minimum by the following intervents:

- repair of damages
- strenghtening, replacing (or creating new) infilled walls

with the same level of public fund.

Criteria for second step of reconstruction (medium level of risk mitigation)

The principal problems to be solved for other buildings (medium or highly damaged or highly vulnerable), are the following:

- which level of seismic protection (and if a defined level should be required)
- which levels of public financial funds for private buildings (depending on needs in terms of damages and vulnerability)
- which strategy for historical heritage

Level of seismic protection

Three ways for the first problem were possible:

1) simply describing goals (in terms of reduction of vulnerability) to be reached without any level of seismic protection
2) defining a level of seismic protection (of course lower than the required one for new buildings)
3) defining a level of ratio cost/benefit to be reached

A long discussion (involving also many experts) was performed leading to a result that the third way *would have been the best one* possible, but the difficulty of perform consequent simple structural designs evaluating the benefit in terms of reduction of seismic risk (also taking account of cost related) and the lack of time and of liable results for properly defining threeshold ratios of cost/benefit, suggested different approaches. For these reasons the two other ways were followed.

The first one has allowed to take into account all learning examples in terms of effects on buildings already retrofitted, according the above mentioned *global retrofitting*. That is why technical guidelines do no suggest intervents like r.c. tie beams infilled in walls (because frequently masonry walls are made by two separate walls without any transversal connection), injections of cement mortar inside walls (because of low probability of infilling, serious controls lacking), strenghtening walls without any connection between walls and between walls and diaphragms. The second way was strongly believed by experts in duty for technical controls and allows to reach a defined level of seismic protection. Of course one of the principal problems was *wich* level and *how to justify* the choice (any referring point lacking). At least, taking also into account the possible increasing factors of amplification for local effects (ranging from 1 to 2.0 and more), a reasonable (by an engineering judgment) level has been choosen as 65% of the required level for new buildings. An interesting point is that (at least) 3 collapse mechanisms are required to be considered (assuming the choosen level of safety):

- global mechanism (collapse for reaching the strength of the wall in its plan)
- actions to be assumed orthogonal to the plan of the wall- connections

Level of financial funds (parametric costs)

In order to avoid that a too high level of safety (with high costs too), a choice has been performed of defining a parametric cost for every possible scenario of damage and vulnerability; i.e. non just a single level of maximum public fund was defined, but 5 levels (the bottom corresponding to the "low level of reduction of risk", the top corresponding to demolition and complete reconstruction of a new buildings). The considered levels of damages are 4 for masonry buildings, from moderate one, passing to high, very high, collapse and 3 levels of vulnerability. For r.c. buildings only 3 states of damages are considered, moderate, high, very high, because of few cases of collapse; there are not vulnerability levels considered for this tipology. Also mixed structures (masonry-r.c.) and precast structures are considered. Corresponding to each state of damage and each state of vulnerability a level of maximum financial contribution can be found.

GUIDELINES FOR HISTORICAL HERITAGE

Of course a specific attention has been considered for historical buildings, wich were in large number and importance struck by this earthquake. Due to the nature of retrofitting intervents, as compulsory, as simply suggested, they have been requested (or simply suggested) also for historical buildings, but, because the strategy is a low retrofitting and because on historical buildings many intervents are quite impossible or not recommended (i.e. r.c. structures, reinforced cement mortar on walls etc.), some more suggestions, referring also to [14], have been written like:

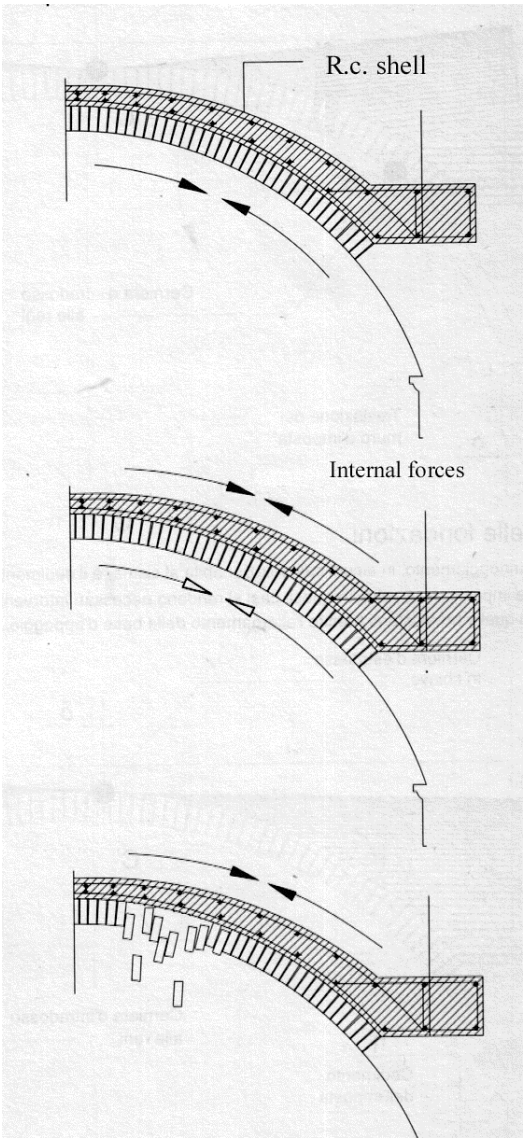

Fig.2. Example of *not recommended* retrofit on historical vaults

- avoid strong reinforcements of vaults

- use traditional materials (bricks, stones, wood, steel)

- avoid substitution of floors and roof by r.c. slabs, too stiff and to heavy

In fig. 2 a scheme of a *not recommended* intervent on vaults is shown, according [11].

Criteria for reconstruction inside historical centers

Due to the fact that many small historical centers were damaged (fig 3), the law allows the possibility of planning the reconstruction passing trough urban programs, wich would propose conditions for obtaining homogeneous intervents inside the center, as in terms of *structural intervents*, as in terms of *architectonical aspects*, as in terms of the *urban system*. Inside these centers, some of wich are constituted of a continous buildings in plan, many more suggestions have been proposed like:

- homogeneous intervents on adjacent buildings
- warning for partial intervents (limited to some buildings inside the blocks) in order to avoid decreasing safety in connected buildings
- suggestions on global (i.e. extended to the block and not limited each building) analysis
- taking account of amplification, at minimum as recommended by guidelines

Fig. 3. Example of a small damaged center subjected to urban program

CONCLUSIONS

The reconstruction in Umbria and Marche are still in progress, with the prevision of a large amount of the total of buildings quite completed during 2001(i.e. 3-4 years after the principal event, while the fastest large reconstruction in Italy –Friuli 1976- was completed at 90% in 10 years). The choice of *low retrofitting*, for the strong reduction of vulnerability available by *low-cost* and *low-impact* intervents, especially on masonry buildings, seems to be a good choice also as base of a program of reduction of seismic risk in an area, like Italy, suffering victims and damages by earthquakes, *not for high hazard*, but for *high vulnerability*.

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