ANNALI DI GEOFISICA, VOL. XXXVIII, N. 5-6, November-December 1995

Seismic damage in historic town centres and attenuation criteria

Antonino Giuffrè
Terza Università di Roma, Dipartimento di Progettazione e Scienze dell'Architettura, Roma, Italy

Abstract
The structural significance of the damage scenarios characteristic of VIII and IX degrees on the MKS macroseismic scale is discussed with reference to the seismic behaviour of the buildings which make up the urban fabric of a historic town or city. In an VIII degree scenario, damage is limited to structurally precarious situations, while a IX degree scenario involves seismic damage to external walls. Mechanical interpretation of these scenarios provides the basis for intervention strategies sufficiently well defined as to constitute a guide for seismic damage prevention programmes. VIII degree damage is prevented by identifying precarious situations, while IX degree damage requires systematic action. A proposal is put forward for the clarification of seismic regulations and the usefulness of evaluating future earthquakes in macroseismic terms with reference to the safety requirements of new buildings is discussed.

Key words *Italy – historical towns – assessment of macroseismic intensity – intervention strategies*

1. Some comments on the structure of historic buildings and their seismic vulnerability

Observation of the urban fabric of Italy's historic towns and cities in terms of their construction reveals considerable differences in technical culture according to the geographical location and historical period. These differences are responsible for giving an old building its typical local characteristics and personality and are the reason for preservation work.

However, in spite of these differences, it is nevertheless possible to establish a common matrix, more structural than technological. This consists above all of a number of morphological characteristics: buildings in highly seismic areas are hardly ever more than three storeys high, the wall grid is seldom based on a span of more than five to six metres in either direction and the thickness of the walls is rarely less than 1/7 of the height.

But alongside these widely generalised characteristics common to the structure of most old buildings, another equally general feature must also be mentioned. While there may be considerable variations in the type of stone used and the way it is put together to make the walls, in the arrangement of wooden beams in the floors and in the slope of the roofs, a characteristic feature of all old buildings is the lack of firm connections between the various parts (Giuffrè and Carocci, 1993).

This organic defect makes an old house particularly vulnerable to seismic actions. The horizontal component of the seismic acceleration pushes the perimeter walls outwards while the repetitive acceleration peaks break the fragile links. The dramatic outcome is that the wall topples over.

It is impossible to say which of the dynamic characteristics of the accelerogram produces this phenomenon, whether it is the peak acceleration value or the number of repetitions above a certain threshold or a combination of both these factors. All or nearly all houses in a historic town or city are subject to this danger and since their structure is relatively uniform the phenomenon occurs in all or nearly all of them when the earthquake presents this particular unfavourable combination (Baggio, 1993).

2. Damage scenarios

«A large number of houses so severely damaged as to be uninhabitable» together with some cases of total collapse – this is the scenario which defines IX degree on the MKS macroseismic scale.

This definition suggests the sort of generalised damage which occurs when the resistance threshold of historic buildings is exceeded, the systematic detachment of the façade which certain characteristics of the ground motion cause throughout the urban landscape.

A IX degree scenario can therefore be said to indicate that the stress produced by the earthquake has reached this threshold.

Photographs of damage produced by strong earthquakes in historic towns or cities provide documentary evidence of this inherent and generalised fragility (see the collapses produced by the earthquake of December 28th, 1908 in Messina, reproduced in figs. 1 and 2 and the drawing in fig. 3).

However, the quality of the wall itself and its internal structure play an important role in determining how this mechanism evolves. Well built walls become detached and reveal this detachment through deep lesions, while badly made walls crumble as soon as the toppling motion begins (see the façade of a church in Messina damaged during the same earthquake, fig. 4).

The poor quality of the walls turns what would have been a «badly damaged house» into a collapse and shifts a IX degree scenario towards a X degree.

VIII degree however involves «*some cases of partial collapse*».

It is obvious that in this case the seismic action, either because of the lower acceleration peak, the smaller number of peaks or a combination of these two parameters, is not serious enough to result in detachment of the façades. However fragile the equilibrium of the façades might be, this is not compromised and damage

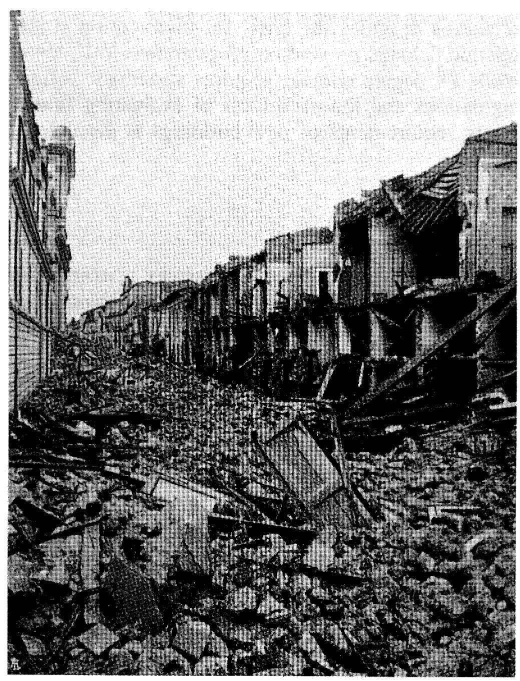

Fig. 1. The overturning of façades along a street of Messina after the earthquake (December 28th, 1908).

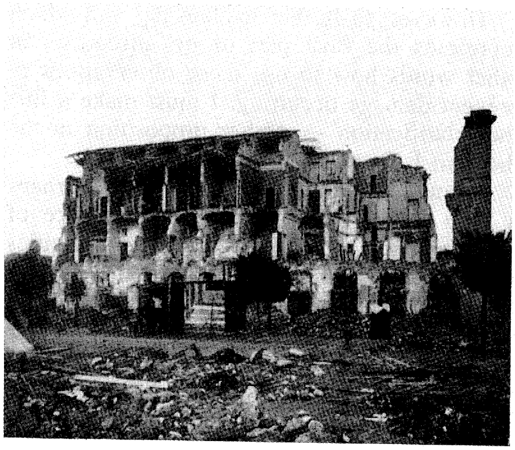

Fig. 2. A house in Messina which suffered the collapse of the façade on December 28th, 1908. The earthquake intensity was higher than IX degree and most of the façades was not only detached but completely overturned as well.

Fig. 4. The front wall of this church was badly built: not well interlocked stones. It was overturned in advance as soon as the horizontal acceleration had concentrated the resultant of the stresses on the edge of the section.

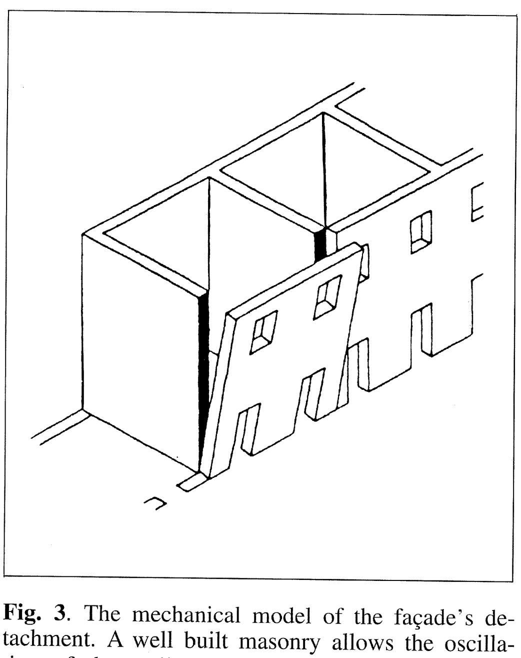

Fig. 3. The mechanical model of the façade's detachment. A well built masonry allows the oscillation of the wall, without collapse, as far as the barycentre arrives at the vertical from the rotation line.

is therefore limited to situations which are even more fragile – «particularly precarious» situations where the equilibrium is even more easily upset than that of the façade of a house in a normal urban fabric.

After having defined the general structural characteristics of an old urban fabric in terms of the number of storeys, the thickness of the walls and the distance between them, it is not difficult to define a «particularly precarious» situation. This is represented by walls which are too thin, bracing walls which are too far apart or buildings which are disproportionately tall, ... In other words, structurally abnormal situations.

The damage which defines VIII degree is significantly different from that which constitutes a IX degree scenario.

Looking at an earthquake damaged town from a structural viewpoint, the differences between damage limited to «particularly precarious» situations and generalised damage extending to the majority of normal houses and consisting of the detachment and sometimes toppling of façades is immediately obvious.

Where «particularly precarious» situations are especially widespread, as is the case today in the decaying centres of many historic towns and cities where the buildings are incongruously tall, where openings have been made in internal walls and where the urban fabric has been interrupted by the demolition of buildings, there may be extensive damage during an earthquake which would have caused only an VIII degree scenario if the buildings had been in better condition. However, it would be clear to the structuralist that in all normal cases the façades have remained intact.

3. Comparison between damage scenarios produced by VIII and IX degrees of MKS

I am now going to put forward the opening proposition on which my conclusions will be based: the damage scenario which defines VIII degree differs from that of IX degree not in terms of the quantity of damage, but of its quality.

While badly made or decayed walls may aggravate detachment of the façade and, by increasing the scale of the damage, create confusion between a IX and X degree scenario, this confusion does not occur between an VIII and IX degree scenario. Indeed, the poor quality of the wall does not anticipate the onset of the mechanism. At worst it accelerates its evolution towards collapse.

Before going on, I would like to apologise for my perhaps excessive simplification. The effort of generalising and identifying trends in phenomena which can well be defined as fleeting and uncontrollable cannot be accomplished without a certain amount of forcing.

The observations I have made so far are not aimed at the person who monitors seismic damage so as to provide a means of distinguishing between VIII and IX degrees. I know very well how belated that would be. My aim is different, as I hope will shortly become clear and is addressed to all those who want to preserve historic towns and cities and avoid these distressing scenarios from appearing in the first place.

However, to further explain my aim which represents the final part of my discourse, in other words how to use these observations to prevent damage occurring, I must make a further clarification – another proposition in the theorem I am about to expound.

It could be said (although this too is perhaps a little forced) that before the experience of modern living, when historic towns and cities were inhabited with a propriety that today we try hard to recover, they were not in a seriously precarious structural condition.

Before Le Corbusier turned the idea of «open plan» into a myth, people were happy to live in apartments divided up according to a 5×5 grid as intended by the builder. They did not presume to knock down walls, build garrets, open up an entrance for the car, ... or at least these demands were not as numerous as they are today.

It can be assumed that the precarious situations introduced by tampering (as would happen today) did not lead to the effects of an earthquake being multiplied to such an extent as to confuse the non-structuralist observer and make him interpret an VIII degree scenario as a IX degree scenario.

In short, my second opening proposition is as follows: given the critical skill required to interpret the documentation and an understanding of the historical context, archive information usually allows one to distinguish between an VIII and IX degree scenario, in other words, between earthquakes which have affected only the precarious situations existing in the building fabric and those which have exceeded the resistance threshold.

If this second proposition is true, then historical information on events affecting the urban site in question gives us a reliable means of deciding whether we need to fear an VIII or IX degree event.

This is extremely important for the validity of my theory. I can accept confusion between VII and VIII degrees and between IX and X degrees, but not between VIII and IX degrees. This would eliminate a discriminating factor which, as I will now explain, plays a fundamental role in seismic risk protection programmes.

4. Intervention strategies

So here is the theorem: depending on whether the historic town or city has to be protected against an VIII or IX degree seismic event, there are two well defined strategies which can be followed to prevent potential damage (Giuffrè, 1993a).

Indeed, the definition of seismic intensity in terms of *damage scenario* can be matched by a prevention programme in terms of *intervention strategy*:

– if VIII degree damage is expected, in other words collapse of «particularly precarious» situations, the strategy consists of identifying these situations and eliminating them or returning them to normality;

– if IX degree damage is expected, not only do these precarious situations have to be eliminated, but the façades also have to be prevented from toppling by joining all external walls to those at right angles to them.

As soon as you decide the macroseismic intensity against which you require protection, the outline of the «recovery plan» is immediately established in terms of strategy.

In short, I maintain that in a seismic regulation aimed at safeguarding our historic towns and cities, it is more effective and appropriate to specify that a certain site must be protected from an VIII degree (or IX degree) event than it is to assign an acceleration peak and an elastic response spectrum.

The damage that can be produced by an VIII degree (or IX) earthquake is inherent in the terms of the theorem and the decision on what can be done to prevent it is immediate, while the absence of sufficiently versatile algorithms means that no-one is yet in a position to predict the effects of a certain acceleration peak associated with an elastic response spectrum on a rigid structure lacking connections and it is therefore impossible to determine the appropriate course of action.

Use of the macroseismic definition as the objective of the protection plan has yet another implication. Damage is expressed in terms of the construction of the original structure and the intervention to limit this damage is naturally conceived in the same terms: bringing an abnormal situation back to normality involves action which falls within the norm for the building.

If on the other hand reference is made to elastic definitions, this encourages one to wrench the original structure away from its rigid normality to bring it in line with the theory on which the regulation is based. And rather than being preserved, it may be destroyed.

5. Codes of practice

As a codicil to this conclusion, I would like to make it clear that while supporting the idea of defining the level of protection required in macroseismic terms (obviously only in the case of historic towns and cities and not when designing modern structures), I do not want to hide the fact that this definition involves making a difficult choice. The selection of VIII or IX degree as the objective for the protection plan is inevitably made on the basis of the quantity of historical information available covering the area concerned, information which up till now has been macroseismic in nature. This is why I made the second of my opening observations on the reliability of historical data, providing it is correctly interpreted. It also follows logically that major cities with no shortage of historical background are in a privileged position with respect to other sites where extrapolations are derived from uncertain attenuation curves.

I have not talked about intensities greater than IX degree, since where these events have occurred recently, the historic town or city in fact no longer exists, for example Messina, Reggio Calabria, Avezzano... It is difficult, although not impossible, to protect a masonry-built town as we would like from such serious damage.

Finally, for all those operating in the preservation sector, to avoid misunderstandings I would like to make it clear that the strict correlation I have drawn between the level of protection in macroseismic terms and the intervention strategy does not detract from the fact that strategy must be developed into a plan and that this calls for numerical analyses and controls which can and must be made clear in the regulation.

This is why I believe it would be helpful to these historic towns and cities if a *Code of Practice* were to be drawn up for each (examples of such applications are to be found in the studies carried out at Castelvetere sul Calore and of the damage to the historic centre of Syracuse (Ortigia), see Giuffrè *et al.*, 1991 and Giuffrè, 1993b). These codes would contain all available information on local seismic activity, original construction techniques and the most widespread forms of precarious situation, suggest methods of verification and help orient those planning the intervention towards choosing the right techniques to use in respect of the culture which created the town or city and of efficient modern damage limitation methods which we can now specify a little more effectively than in past centuries.

6. A look at the future of macroseismic scales

I would like to take this opportunity to add some outline remarks made on the future of macroseismic scales during a seminar organised in Macerata by the «Seismicity» Working Group of the GNDT (Giuffrè and Carocci, 1994). It is generally recognised that macroseismic information, although highly condensed, can be extremely important in protecting a historic town or city. However, the situation is different when it comes to constructing new buildings where the macroseismic viewpoint seems less useful to the designer.

The text of the newly proposed «European Macroseismic Scale 1992» (1993) shows that this is mainly concerned with offering a typological definition of modern buildings and the relative damage. This is evidence of an attempt to codify a way of observing damage as far as possible in terms of parameters, enabling macroseismic research to continue in relation to modern earthquakes and in the presence of new buildings. This is certainly not the place to debate this orientation, but perhaps it would be helpful to express a little puzzlement at the idea of macroseismic research aimed strictly at the design of new buildings.

The images included in Annex A of the text by Grünthal (in the European Macroseismic Scale, 1992) provide eloquent evidence of the usefulness of damage observation, provided that the immediacy of the direct evidence is not lost. Those who had the opportunity of hearing the remarks Professor W. Bertero of California University (Berkeley) used to make during international seismic engineering conferences up until a few years ago will recall the insistence with which he urged designers of new buildings to avoid not weaknesses calculated by algorithms or specified in technical regulations, but those revealed through actual earthquake experience. In short, he invited his listeners to take advantage of history when making operational choices. Here a quotation made by Alberti during the second half of the 15th century seems appropriate: «*We learn less from studying the philosophers than we do from observing historic buildings*».

Placed in this context, observation of what has happened in the past (gathering of damage data during post-earthquake inspections constitutes embryonic historical research) becomes the direct cultural baggage of the designer without first being summarised or reduced to parameters (and perhaps it then leaves the sphere of interest of seismologists to fall in that of engineers and architects).

Thus we have a preliminary direct way of using historical investigation in common with all other cultural sectors. However, it should be noted that even when its use is so immediate, historical research (the gathering of damage data) is anything but exempt from the demands of critical control. Coherence between the description of the damage and an understanding of the damaged structure affects the significance of the observations. To be useful to the civil engineer, the damage must be recorded by someone with structural expertise.

If we want to go beyond the usefulness of direct observations of the behaviour of materials and structures, construction techniques and the organisation of the site, we must also bear in mind the importance that the physical parameters of the seismic activity have now taken on. Indeed, current design criteria cover seismic activity in terms of ground acceleration and a further observation with great importance in design terms is that based on instrumental monitoring of ground motion. Only this can add something to an intelligent examination of the damage.

In short, the designer can learn little from a seismic scenario translated into percentages of buildings in such a class subject to such a level of damage and then concentrated into a single numerical value of macroseismic intensity. All the richness of the information is lost in the averaging operation. It is, however, useful for the designer to have a critical description of the damage and a knowledge of the ground motion which has caused this damage. Statistical interpretation of the damage and an assessment of macroseismic intensity may be useful for other purposes, for example, in comparing the severity of seismic activity in different locations, although for this it is more efficient to base the comparison on instrumental parameters.

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