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AFTER THE EARTHQUAKE: THE POST-SEISMIC INTERVENTION ON CULTURAL PROPERTY IN CAMPANIA AND BASILICATA BETWEEN BALANCE AND PROSPECTS.

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ABSTRACT

The analysis here submitted, which originates from a careful and specific examination of seismic damage, aims at individuating general trends in structural behaviour, from which all information essential to define a universally called for plan of preventive measures on cultural heritage, can be desumed in terms of expected damage and consequent risk.

The study aims to provide indications for a systematic approach to the analysis of the earthquake damage, targeted on assessing the vulnerability of the monumental assets, within a general framework in which the extremely specific typological, formal and constructional nature of the monumental assets is always present.

KEYWORDS

Architectural heritage; seismic damage; vulnerabilty and risk of the monumental assets.

INTRODUCTION

The monumental assets of Campania and Basilicata damaged by the earthquake of 23 November 1980 constitute a truly considerable complex in terms of typological variety, architectural quality, constructional characters and territorial diffusion.

In this context, the clearest aspect of which, also at a first approach, is that of quantity (the restoration measure in the five-year period 1985-1990 concerned an ensemble of 456 monuments), the survey of the seismic damage has been an important part of the process to restore the individual monuments.

The following examination uses part of the data contained in the survey carried out by the Superintendent General's Department for Post-Earthquake Measures, in particular those relating to the description of the seismic damage suffered by the monumental buildings and to their historical, typological and constructive characteristics (Proietti,1994).

Methodological summary

It has been considered possible to make an in-depth analysis of a number of themes connected with the interpretation of the damage suffered by the assets, so as to achieve a clearer understanding of the behaviour of the monumental buildings under seismic action.

It is known, in fact, that the technical-cognitive instrumentation prepared for ordinary buildings, even historical ones, cannot be transferred mechanically to monumental buildings. The study of the behaviour of such buildings calls for specific typological-constructive disciplines enabling a precise analysis to be performed thereof, and for this various types of data-cards of vulnerability analysis, formulated ad hoc, have been proposed (Braga, 1983).

The existence of a considerable body of information on assets that are fairly homogeneous in their history and territory, with the common denominator of a single simultaneous event, i.e. an earthquake, has made it possible to define the lines of analytical instrumentation which, prior to a precise vulnerability analysis (which requires a thorough, parametric knowledge of the individual monument), can enable a methodologically correct screening to be conducted of the characteristics of the damage suffered by the 456 monumental buildings.

The aim is to identify, with an appropriate selection, a "reduced" but significant sample on which to carry out an estimate of the vulnerability, for a more precise check of the assumptions formulated. Associating, in a preliminary phase, the data collected in reference schemes, a verification is proposed of the use and extendability of the observations made for homogeneous classes of aggregation on a parametric basis, formulated with criteria of comparison and analogy.

Aware of the limits involved in referring things to a "scheme", it was decided to draw up a methodology giving a diagnostic orientation to the singular features of the seismic behaviour of a large part of the cultural assets, identifying the most common relations for instance between the real fact (the damage) and a number of constants, pertaining to specialistic typologies, which influence the behaviour thereof (damageability), in search of indicators, even partial ones, of particular conditions of vulnerability.

The availability of instrumentation in the form of a case history at general level can provide useful indications when programming measures, and can in any case act as a grid in which to place and integrate the results of specific experimental investigations and of multidisciplinary derivation, making analytical-experimental assessments of duly defined representative samples.

It can moreover provide an operative guideline to a strategy of conservation seeking a measure (even a preventive one) that is suitable in mechanical efficacy and compatibility with the structural concept of the monumental masonry assets .

The contribution proposes to describe a number of problematic aspects and ones of method, precisely so as to identify said representative samples, supplying some examples of the elaborations carried out, in the light of a number of preliminary considerations underlying the research, relating to:

1) the characteristics of the survey. The basic catalogue of information on the damage refers to a corpus of monuments that has been regarded as homogeneous in numerical consistency and in relation to territorial diffusion (the regions of Campania and Basilicata), to seismic history, as well as to the evolution of artistic and cultural history. The organization of the information on the earthquake damage, achieved by processing the data contained in the reference cards, has been related - making a generalization - to the single constructive elements, subdivided into structures and finishes. In this way it has been possible to identify and to quantify for each construction element the effects caused by the earthquake, classified into seven categories of damage, expressed with a value indicating the occurrence of the damage for each construction element rather than its gravity.

2) the limits of the survey, which relates to monumental buildings whose post-earthquake restoration was financed under Law No. 219 of 1981 (in the period between 1985 and 1987). The property surveyed includes 456 monuments, grouped in four typological categories: churches, campaniles and towers, palaces and castles. This is a typological generalization relating to buildings of a diverse nature in terms of size, state of conservation and from the morphological-distributive standpoint. Archaeological monuments were not included because of the specific distinctive features of this category of assets.

3) the qualitative character of the basic information, calibrated by the assumption verified in the field and through historical research, of an initial constructive quality of the monumental assets of the area of Campania and Basilicata (in materials and building techniques), seriously compromised above all by the transformations through the centuries (modifications of the original "facies" are present in over 70 percent of the basic sample), apart from the earthquake damage suffered.

4) the relationship between physical consistency and vulnerability which may be stated schematically as "points of fragility", understood as those intrinsically weak structural situations in relation to seismic action, generally connected with the peculiarities of the monumental typologies (properly verifiable only with the parameters used in the second-level vulnerability analysis); and as "elements of earthquake resistance", understood as intrinsically "safe" structural situations. In both cases the assessment of the damageability is defined independently of the intensity of the earthquake, and the prerogatives of brick buildings (which account for the whole of the sample examined) permit us to refer to the morphological-structural apparatus, broken down into its basic elements (Giuffrè1988).

In the light of the range of the initial information (regarding all the monuments examined), of the survey of the damage depending on a single event and the systematic nature of the elaborations carried out, by means of the study outlining the method, it is intended to develop an investigation that will permit greater adherence to the reality of the monumental building, in keeping with the level of knowledge available at the present time.

ELEMENTS FOR A READING OF THE RELATIONSHIP BETWEEN DAMAGE AND INTENSITY IN MONUMENTAL TYPOLOGIES

First it was deemed advisable to relate the investigation of "elements of fragility" and of "earthquake resistance" to the degree of intensity of the seismic action, preparing a quantitative reading of the damage in relation to the macroscopic intensity referred to the municipality to which the monument belongs, for a twofold purpose:

- to make a rough check on the "behavioural difference" between monumental building and ordinary building, to provide parameters for the macroseismic element.
- to identify comparatively any differences between monumental typologies to be related to the other proposed parameters.

In particular the data referring to collapses and to fracturing were identified as indicators of gravity of the post-earthquake pattern of cracking, relating them to four belts of macroseismic intensity.

By collapse is intended the mechanism of partial or total collapse of the resisting structure, while fracturing is intended as the presence of lesions going through from one side to the other of the resisting structure, such as to divide an originally continuous element into portions.

The choice of damage indicators has been guided by an overall reading aimed at identifying the most significant phenomena. As may be intuitable for collapses, also for fracturing the significance that the phenomenon assumes in the description of the patterns of damage is independent of the typology and of the complexity of the monumental building.

A preliminary reading was then made to extract statistical generalizations from a direct examination of the sample, not claiming to be important in itself, but to give a general picture of the physical dimensions of the damage and suitable for use as a function of the other parameters, which enable regularity or differences of behaviour to be noted, to refine and circumscribe the analysis, increasing its reliability.

The following tables and the graphs propose the distribution of the damage (in the events of greatest gravity) in relation to the degree of intensity of the stocks recorded in the municipality where the monument is situated, and they contribute at purely indicative level and with the margins of uncertainty that derive from the reciprocal influence of many factors, towards outlining the reference seismic scenario (Fig. 1 and 2).

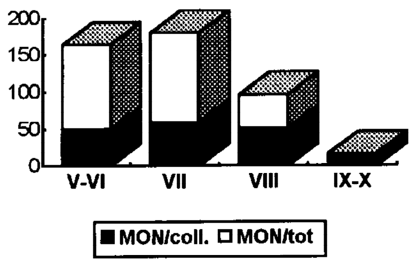
Observing the trend of the data on the collapse, there is a significant preliminary remark to be made on the ensemble of monuments surveyed: in the majority of cases they are partial collapses, seriously compromising the solidity of the building, but hardly ever totally destructive.

In the light of this, the examination of the trend of the collapse shows that the threshold of resistance - which in the average historical building is between the 8th degree (partial ruination of some houses) and the 9th degree (total ruination of some houses and very many houses so gravely damaged as to be uninhabitable) - tends to decrease for the specialistic typologies that present high values relating to the presence of a grave compromise as from the first group considered: ranging from 30.4% of the monuments with collapses of the 5th-6th degree, up to 81.2% of those with collapses in the group of maximum macroseismic intensity (9th-

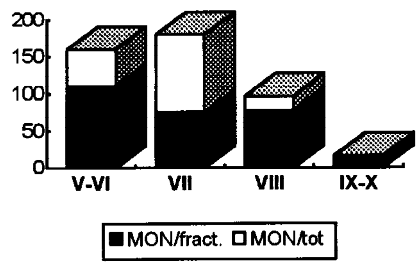
10th) recorded for the area. For this last value it is necessary to introduce reservations due to the smallness of the sample taken (16 monuments).

Another precise indication of the "fragility" of monumental buildings comes from the analysis of the presence of fracturing having an average value considerably higher than those for collapses, especially in the lowest group (5th-6th) in which fracturing concerned 67% of the monuments.

Lastly, an analysis was made of the distribution of the maximum damage in three specialistic categories: churches, palaces and castles. There are variations of a certain importance both in relation to collapses (the highest percentages in the palaces) and in relation to fracturing (which instead is prevalent in the churches), substantially bearing out the behavioural difference between the specialistic typologies and the average values for normal buildings.



COLLAPSES

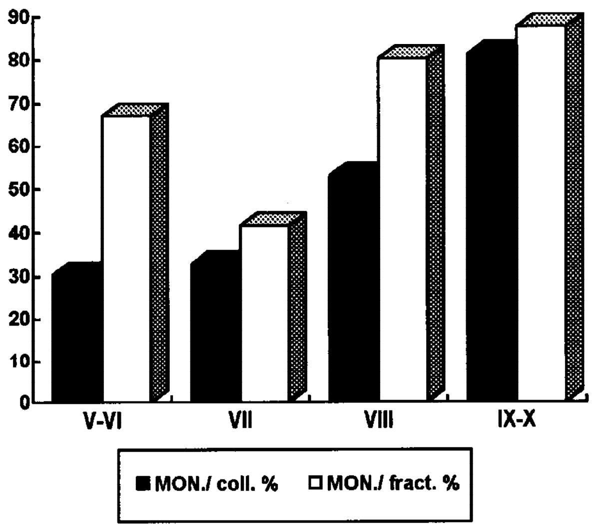


FRACTURING

Number Monum.	V-VI	VII	VIII	IX
TOTAL	164	180	96	16
with collapses	50	59	51	13

Number Monum.	V-VI	VII	VIII	IX-X
TOTAL	164	180	96	16
with fracturing	110	75	77	14

Fig. 1. Distribution of assets inventoried/damaged in relation to macrosismic intensity



	V-VI	VII	VIII	IX-X
% MON with collapses	30,4	32,7	53,1	81,2
% MON with fracturing	67,1	41,6	80,2	87,5

Fig. 2. Percentage distribution of damage in relation to macroseismic intensity collapses - fracturing

WEAKNESS AND STRENGTH

The approach to the problem of the connection between characters of the buildings, damage and earthquake has been more empiric in type than mathematical, preferring a qualitative analysis of the large amount of information collected rather than proposing a mathematical model of the components of the masonry buildings under the action of the earthquake or modelling a survey sheet of the vulnerability. The aim is to contribute towards the identification of "points of weakness" and "points of earthquake resistance" of monumental structures (regarded not only as physical points but more generally as characteristcis), within a framework in which knowledge of those characteristics is deemed fundamental for a correct operative approach to restoration and prevention.

Parameters for seismic-structural analysis

The parameters used in this phase of seismic-structural analysis are basically of qualitative type, and are all those that define the building's spatial and structural "configuration" (Arnold, Reitherman,1985).

- relationship with the context
- dimensional scale
- geometry and morphology
- general state of degradation
- structural transformations and deterioration

The analysis of these aspects is extended to all the monuments on which restoration has been carried out, even if in the first phase preference was given to buildings of worship, which differ more than convents, palaces and even castles in their "earthquake behaviour" from ordinary buildings.

The relationship with the context has been viewed as the ensemble of the ways in which a building relates both to the site, and hence its geomorphological characteristics, and to the surrounds, and hence possible connections with other buildings.

Without going into the merit of the site characteristics, on which there is sometimes insufficient information, it results from a first examination of the monuments that a large part of them are contained in vasdter structural complexes. They are in fact historical buildings, almost always dating from some centuries ago, situated in urban centres. In this connection it has to be considered however that 62.6 percent of the monuments examined are buildings for the purpose of worship, and the majority of them are of a size out of scale with respect to the built-up context. It can therefore be assumed (and the initial processing of the relevant data would appear to bear out this assumption) that the connection with other buildings has only a moderate effect on the seismic behaviour of the monument itself.

The out-of-scale relationship with the adjoining buildings characterizes also the other typologies present, and in particular the palaces.

Regarding the monastic complexes, on the other hand, these are almost always whole blocks, in which there are structural relations between the convent proper and the church, but which are separate from the remaining urban fabric.

The dimensional scale is a parameter of great interest, above all if referred to buildings for worship. It is indeed clear that there is a difference of behaviour between a church of a certain size, i.e. of considerable height and with large covered spans, and a small chapel, whose absolute values, both horizontal and vertical, are very similar to those of ordinary buildings. This fact, which has been assessed with an indicator of large/small type (not knowing the precise metric dimensions of all the buildings), has to be mediated by the consideration that often for small buildings the construction process has been rather summary, regarding both the techniques adopted and the materials used, especially in the case of small rural churches built by very poor communities. For large churches, on the other hand, whether these be the mother churches of even modest urban centres or the imposing constructions of provincial capitals, and Naples in particular, which all presupposed conspicuous funds available to the client, the constructive difficulties linked with the size and with the typology itself (think for example of the great vaulted or domed structures) made it necessary to turn to specialized workers, usually heedful of the good rules of building and using good quality materials. It is also true that at times, when great expense has been lavished on internal decorations (paintings, statues, furnishings in general), comparable funds have not been spent on the structural aspect, above all in cases where the building work has taken the form of a predominant remaking of existing structures. In such cases, apart from using materials already used, the rules of good and workmanlike construction have very frequently been waived, particularly in making angular connections and with the balance between the openings and the solid parts of the masonry.

The geometry and the morphology have a basic influence on the behaviour of buildings under seismic influence. It is by now clear that the morphological-spatial regularity and homogeneousness and structural isotropy contribute towards increasing a structure's earthquake resistance. It was therefore thought extremely interesting to seek to assess the grade of divergence from a regular, homogeneous and isotropic model, of buildinhs which, by the fact of being "monumental", are all more or less without such characteristics. As far as churches are concerned, the sole element of "regularity" is their longitudinal symmetry, present however only when the building is isolated, without other buildings against it (convents, sacristies, etc.). The almost always irregular and complex layout is matched vertically by the presence of anomalous volumes: apses, domes, campaniles, which preclude all and any possibility of an "isotropic" behaviour by the structures.

A particularly anomalous structural element is represented by the façades, due both to the presence of numerous voids at various elevations, and to the presence of such an element as the triangular tympanum which is practically detached at the top. The concentration of symbolic and representative values in the façades has always made the structure very complex, with the presence of many architectural elements which in aggregate define a three-dimensional character.

The assessment of these characteristics has been made with a qualitative indicator: simple/complex layout, presence or otherwise of abnormal elements. Apart from campaniles, apses and domes, also crypts and chapels have been regarded as abnormal elements.

The general state of degradation is obviously one of the basic parameters for pinpointing the points of vulnerability of buildings. While it is true, as has been authoritatively asserted (Giuffrè, 1993) that a well-constructed building possesses such levels of structural safety as to enable it to resist environmental actions, including earthquakes, provided said levels are adequately maintained, it is likewise true that failure to maintain these levels of safety is the norm in the history of monumental buildings, and that their punctual, constant maintenance is unfortunately the exception. Interest has always been shown in the conservation and restoration of decorative elements rather than structural components, and this not only for buildings forming part of "poor" environmental contexts, but also for monuments of greater historical and artistic significance.

The centuries of life of monumental buildings has multiplied the opportunities for their degradation. It is also true however that in general various restoration operations have been carried out on these buildings in the course of time, to concerve at least the possibility of using them, if not their static integrity. When instead they have been abandoned, then the degradation curve has become even steeper.

In the analysis made of the monuments, it is thought that a close relations can be made out between the period of dususe and level of degradation.

Three levels of degradation have been identified:

1 - Abandonment for some centuries is matched by a maximum state of degradation, so that the building may be likened to a ruin: collapse of all the floors and the upper part of the vertical structures, and instability of the elements themselves; for buildings abandoned for more than fifty years before the last world war (a period which in this sense represents a sort of watershed) the state of degradation is high, with the collapse or in any case the loss of functionality of the roof elements, loosening of connections with cracks and parts becoming detached, deterioration of the mortar and of the wooden elements of roofs and ceilings, but the substantial stability of the vertical structures.

2 - In buildings whose routine maintenance has been interrupted for a few decades, a medium level of degradation has been found, taking the form of damage to the roofs, loss of tightness in connections, small areas of collapse in nonstructural external elements, particularly those which protrude such as cornices and bell gables, and the deterioration of installations and finishes.

3 - Lastly, even for buildings still in use a minimum level of degradation has been identified, but this has not been tabulated, consisting above all in the imperfect control of the runoff of rainwaters.

Structural transformations and deterioration of monumental buildings constitute an extremely broad field of investigation, including as it does all the very numerous measures carried out in past centuries and up to our own times. For the churches in the sample examined it can be stated that only in rare cases has the original structure been conserved. Indeed the concentration on such monuments of conspicuous works, linked with their representative nature, which occurs in all socio-economic contexts, has facilitated the carrying out of numerous extensions, transformations and restructuring measures, never adequately controlled from the static point of view, and these represent veritable Achilles' heels for the relevant structures.

The most common sort of deterioration are to the roofing (replacements of vaults with slabs, the construction of vaults and domes on masonry that previously supported simple trusses, replacement of vaults and slabs with suspended false ceilings, etc.), but there are also numerous cases of transformation of the actual layout, with elongations of the nave, the addition of side aisles (and the consequent raising of the level of the central nave), the addition of transepts, apses and chapels, the linking of bell towers or bell gables, and so forth.

A very frequent transformation has taken place in the façades, because any measure whatsoever inside the building has been accompanied by a redefinition of the outer image, concentrated above all in the façade, which in a great many cases has been heavily reorganized, if not actually reconstructed.

Negative consequences of these measures have been the imbalances in the distribution of loads, with overloads located on sections that had not foreseen them, but above all the summary or inexpert way in which the wall connections between old and new structures were made. A particular type of deterioration is represented by the presence of consolidation works after earthquakes in the past, consisting in "chain" buttresses. Unfortunately this is an element about which the survey is incomplete

Added to these "historical" violations we have also "modern" measures, especially reinforced concrete link beams and slabs, and metal roofing structures.

In the first phase of the research the indicator used is of the Yes/No type, repeated for both historical recent transformations. A further level of infomation foresees the indication of the deteriorated structure (roof, nave, apse, façade, etc.).

Earthquake damage

The damage produced by the earthquake on monumental structures, in the analysis of which a scheme with seven typologies has been used (collapse, yielding, detachment, deformation, cracking (fracturing), widespread lesions and disconnection), has been considered in relation to the construction elements. Starting from the description possessed, a first general reconnaissance was carried out, showing that among the elements most damaged are the vertical structures (94% of the monuments, 96% of the churches), followed by the horizontal structures (75% of the monuments, 76% of the churches) and the roof structures (66% of the monuments, 76% of the churches).

The first generic indication as to the great predisposition (greater than in ordinary masonry buildings) that monumental buildings, and churches in particular, manifest in suffering damage to their vertical structures (the vast walls, the piers, the columns) has to be compared with the gravity of the damage, from which the most interesting considerations on vulnerability may be deduced.

The first correlation made between structural elements and damage consisted in studying the location of the maximum damage to the monument, in particular the location of the maximum possible damage, i.e. the collapse. It is considered in fact that the location of the maximum damage with respect to the structure is a very important qualitative element for specialistic building typologies, with spatial configurations generally fairly important, in which it is uncommon for the damage to be evenly distributed, precisely due to the accentuated structural anisotropy characterizing them. Indeed, in all the monuments examined there were only very few cases of total collapse, whereas there were very many cases of localized collapses in the various structural elements.

Although processing of the data has not yet been completed, it is considered useful to give a first result, namely that the roof is the element in which the maximum damage (in particular collapse) is most frequently localized. Moreover, while the total collapse of a vertical structure has proved extremely rare, that is, extended to the entire planimetric area of a wall, instead the total collapse of the roof, with the obvious consequences in terms of harm to persons, was very frequent.

Linked with this information regarding the roof is that regarding the horizontal structures, which at parity of overall volume in churches have a far more reduced development that in other building typologies. The maximum damage is commonly located in these.

A further correlation emerges between maximum damage and presence of anomalous masses in which the maximum damage is almost always located, in particular in the case of collapse. In cases where the level of damage is low, it seems that the presence of centres of stiffness or of anomalous masses has had little influence on the distribution of the damage. The behaviour of arches and vaults seems to be the opposite: they are always damaged, even if not seriously, but are not always the location of the maximum damage.

CONCLUSIONS

From the first correlations made it is confirmed that points in which the non-box type behaviour of brick buildings, and hence for example the joints and angle elements, is most evident, are ones of earthquake fragility. This does not refer only to the very common phenomenon of the opening of the outside walls of churches, due to the lack of a connection in elevation, but also to the opening of connections at intermediate levels, including those between two floors: the consequences are always ruinous (collapse).

Vertical brackets are one element of extreme fragility, including therefore tympani and, further down the scale, bell gables.

Heavy juxtaposed façades are earthquake-fragile elements; they always come loose from the outside walling.

Campaniles display a singular type of behaviour. They have a certain overall resistance when they have been built separately from the churches, although their spires, where the maximum damage is often (but not always) located, obviously present points of fragility. Instead they have proved extremely fragile when constructed against the churches or, worse still, in elevated positions on church structures. Typical phenomena range from detachment (always present) to major vertical lesions and collapses of the upper orders.

Great fragility is shown by heavy roofs placed over the structures during the course of restoration measures prior to the earthquake.

The characteristics of earthquake resistance evident at a first examination seem to be well-made vertical connections (angle elements made with interconnected quoins of large size, etc.), light roofs well scarfed to the outside walls (an important role in this sense is played by the wooden beams of the floors and by the chains of trusses, showing the need to inspect the deterioration of the headpieces), and previous measures such as chains, buttresses and reinforced concrete link beams (not reinforced concrete floor slabs). One characteristic that seems positive is the "lightness" of the structures, especially the upper ones.

The aim of this study as indicated at the outset is that of gaining fuller knowledge of the behaviour of monumental buildings. And also to provide some indications on the most suitable action methods to achieve mechanical efficacy and compatibility with what already exists, and in particular:

- identifying the most fragile elements on which to take action with greater precision with respect to the generic nature of the typological treatment
- indicating the resistance and strength resources of monumental structures, in order to optimize the possibilities of their use, for a significant improvement of safety requisites.

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