Vulnerability of Cultural Heritage to Hazards and Prevention Measures

Nina Avramidou

FederatioN of the International Centers for the Rehabilitation of the Architectural Heritage – CICOP, University of Florence , Faculty of Architecture, Via S. Niccolò 89a, 50125 FIRENZE
e-mail: n_avramidou@cesit1.unifi.it

1. Introduction

Natural and environmental hazards threaten all European countries. Floods, landslides, forest fires and earthquakes repeatedly occur causing thus major disasters. The response and recovery efforts – even if successful – cannot eliminate disaster consequences. Therefore, the importance of preventive measures against natural and environmental risks should be reflected to the disaster protection policy and initiatives at both local and national level.

Earthquakes are only one of numerous causes of degradation and destruction of cultural heritage. In general, it can be said that the constructions having greaten degree of seismic resistance have survived to this day. Other damage causes (i. e. pollution and human activities) might have been more importance for their preservation or disappearance.

Heavy structural damages can take place for the prevailing aspect of the interaction of several causes of damage (even not serious ones, if it is considered separately); already existing pathologies.

Non-structural damages could also be unacceptable from the economic-social point of view, because expose tenants into several kinds of risk and for the eventual “limitation of use.

We distinguish two categories of buildings belonging to architectural heritage: the MONUMENTAL BUILDINGS and the HISTORICAL MASONRY BUILDINGS (A. Giuffrè, C. Gavarini, contribution to EC8, [1]).

Monumental buildings are existing constructions having important cultural values (historical meanings, typological aspects and material aspects within a general architectural interest), namely having valuable testimony of ancient times, which deserve to be preserved.

Historical masonry buildings are buildings which have in themselves a cultural value as a whole (that is, placed in an historical urban area), while the single building cannot be said monument. The interventions on a single building may be more incisive in some aspects than those regarding monumental buildings, if the general urbanistic character is conserved.

Buildings placed in an historical areas, and thus named historical ones, require a systematic study of the whole historical urban area or village, from the different points of view, history (technical and seismic), architecture, evolutions in time, technology, seismic micro zone; this study should offer both the possibility to evaluate the seismic safety and the indication of possible improving measures.

Codes for the monumental buildings actually in Italy do not exist, so, after an intervention for strengthening of seismic retrofitting the monument is rather often something very different from the original state and sometimes it is lost as a cultural value and as a testimony of the past.

2. Seismic risk mitigation in Italy

Italy has paid a heavy toll in terms of life loss and has suffered a serious damage to property and cultural heritage due to earthquakes during the last 25 years (over 70 billions U.S. dollars of monetary losses). The ratio between the damage caused by earthquakes and the energy associated to them, is however much higher in Italy respect to other seismic countries as California or Japan. (e.g. the damage pattern of the recent 1997 Umbria-Marche earthquake is similar to that of the 1989 Loma Prieta earthquake (F. Sabetta, [2], in spite of an energy about 30 times lower).

The reason of the high damage caused in Italy depends of the high housing stock that is composed of buildings made of stone. More over, historical cities have become increasingly vulnerable to natural hazards due to over-concentration of the population and economic activities (e.g. tourism) the complexity of infrastructure and systems, the transformation of life styles and the lack of public awareness. Therefore, it should be recognised that earthquake prevention is one of the most important policy components contributing to sustainable development in seismic areas.

Eventually, this experience has led to forming over the years an earthquake protection policy framework. The main lines of the earthquake protection policy are:

a. to mitigate seismic risk in the built environmental;
b. to update of the seismic zonation and building seismic codes;
c. to aim the seismic risk assessment at a vulnerability reduction of the older buildings and of the historical and monumental heritage through strengthening and retrofit;
d. use of tax incentives and insurance policies to reduce the cost of reconstruction and achieve higher safety standards;
e. to ensure preparedness at central government, regional and local authorities;
f. to upgrade earthquake awareness and to keep the public informed on seismic safety issues;
g. to improve emergency response and aid provision.

The insurance resource in the field of seismic risk is not very developed in Italy (only some big industries and no private homes). However, in the financial act of 1999, it has been proposed that the private building insurance against fire must be extended to natural risk (earthquakes, floods, landslides, volcanic eruptions).

A first example in Italy of a tax incentive policy aimed at the seismic risk mitigation it is proposed according to the law 449 of 1997 as concern 2578 Italian municipalities, corresponding to 36% of the territory and 21% of the population, see fig. 1, F. Sabetta, 1966, [2]. This reduction consists to a 50% reduction of the taxes VAT for strengthening and reclamation building works.

2.1 Seismic risk assessment

The seismotectonic model (Scandone, 1997) subdivides the Italian peninsula in 80 seismogenetic zones (SZ) individuated on the basis of a kinematical modelling of the tectonic units.

Seismic risk assessment is given, as well known, by the convolution product of hazard, vulnerability and exposure. The Seisrisk III computer code (Bender and Perkins 1987) is usually adopted for seismic hazard evaluation; in Fig. 2 it is illustrated the macroseismic intensity (MCS scale) with a 10% probability of exceedance in 50 years (Albarello at al, 2000) using such a computer code. To perform the risk assessment, F. Sabetta et al. (Italian National Seismic Survey) have been calculate the mean annual rate of occurrence of each intensity value for each of the 8100 Italian municipalities (see [2]), on the following basis:

- Adoption of the historical earthquakes catalogue performed by Camassi and Stucchi (1996), specifically conceived for seismic hazard analyses, removing foreshocks and aftershocks, and considering 2488 events, with intensity bigger or equal of V-VI or magnitude bigger or equal to 4, from year 1000 A.D. to 1992.
- Seismic rates were calculated using the classical Gutenberg-Richter relationship and assuming as maximum magnitude/intensity the historical maximum of each SZ.
- A simple least square regression of the cumulated magnitude/intensity values was used
- The hazards analysis has been performed in terms of several ground motion parameters (macroseismic intensity, PGA, PGV, Arias Intensity, reponse spectral values).
- The attenuation relation of macroseismic intensity (Grandori 1991) has been calibrated for each SZ, whereas, for the strong motion parameters, two equally weighted relations have been employed. The first (Sabetta, Pugliese, 1996) is based on 95 Italian strong motion recordings, the second (Ambraseys et al., 1996) on 422 European records.
- Concerning the vulnerability of the residential real estate was estimated (Bramerini et al., 1995) using data derived from the census performed, at national level, by the Institute of Statistics (ISTAT) in 1991.

The evaluation of the mean expected damage, for a given Italian municipality and a given period of time can be estimated and the vulnerability of the residential real estate, according to the follow formula proposed by F. Sabetta [2]:

$$P\,[D_k] = \sum_I \sum_T p[Dk]/I,\, T] * p[I] * p[T] \quad \text{(F. Sabetta, 2000)}$$

Where

p $[D_k]$ is the probability of having a level of damage D_k (k=0,5)

p[I] is the probability of having an earthquake of intensity I in a given municipality, coming from the hazard analysis and equal to the annual frequency of occurrence;

p[T] is the probability that the considered building belongs to the typology T, assumed equal to the frequency of four vulnerability classes (the three classes of vulnerability foreseen by the MSK scale, A, B and C; class C was further split in two subclasses).

p[Dk]/I, T] is the conditional probability of having a damage level k, given the intensity of the earthquake and the typology of the building.

The catastrophic consequences of an earthquake are limited and foreseen with a plan of national seismic protection, which has a difficult and versatile formulation. In particular way, referring to the architectural heritage, a satisfactory long term plan of seismic prevention is based on an fair compromise between safety and economy, between cost of the construction and remedy of the seismic damages, between degree of safety and human losses, that involve pure political decisions with enormous social responsibilities. The recent earthquakes in Italy and other Mediterranean countries, which caused serious human losses, have evidenced, once again, neglects and weak points, regarding not only the reactivity of the State in applying the post-earthquakes safety plans and the norms concerning the planning and the productions of civil works, but also the attitude of facing the protection of the constructions realized before the last generation of the seismic laws, protection that demands a complex policy of intervention, with economic and social consequences even more serious than those provoked by earthquakes.

Part responsibilities exist, as it often happens in such circumstances, but over all responsibilities for the lack of institutionalisation and legalization of specific technical aspects emphasized from time exists; such as: the completion of the studies of seismic, the adaptation of the urban and architectonic planning laws to the studies of micro-zonization, the periodic formative updating of the technicians working for the public agencies, the elimination of politic orientation to condone illegal situations, the redefinition of the responsibilities in yard procedures, the institutionalisation of the figure of the *"responsible of the maintenance"* and of the *"responsible of the quality guarantee plan"* (according to ISO9000 normative), just to mention some of the most discussed aspects that for years have been expecting a fair consideration by the law.

Focusing the attention on the managerial aspects of the post-earthquake emergency, some important and very precise appraisals can be pointed out, concerning:

a. The lack of a suitable aid plan (lack of suitable passages for means of transport in the great cities), predisposition of equipped acceptance zones, inadequate number of means of aid, etc.);

b. The complexity of coordination among the technicians charged for the first appraisal of the damages, afferent to national, regional or local agencies;

c. The difficulties connected to the necessary coordination in order to have use of the international cooperation that involved the declination of precious collaboration and aid offers.

In the first hours following an earthquake is of primary importance to know the concequences of the event for the emergency management and rescue organization. Such a target can be achieved, for instance, by simulating emergency scenarios based on the focal parameters of the event and on the information related to seismicity and vulnerability of the affected area.

Many social-political decisions in post earthquake emergency conditions are closely connected to technical aspects (attributions of responsibility concerning the structural damages, definition of the damages gravity based on technically and legally incontestable parameters, times of waiting before the interventions tolerable by the buildings, etc.); it is dutiful to inform previously people directly involved, the customers, who usually are the inexpert ones. Whether one adequately informs the political world and the population hit by the earthquakes, about the doubts with which the technicians are forced to operate in seismic zone, it could be possible to avoid the useless and expensive "witch hunt" that get started after every earthquake.

It is necessary to endeavour in order to eliminate the citizens' information lacking, about:

a. the lack of adequate laws concerning the controls of the materials production;

b. the lack of specialized adequate laws about the verification of the specialized operators' technical skills;

c. some specific aspects of the current seismic regulations, that is:

   - the seismic actions can also exceed some legalized probabilistic values
   - the sections' dimensioning is obtained with the internationally accepted safety coefficients, defined by probabilistic way
   - the seismic security is achieved using the legalized criterion of "**damageability**" of some structural elements if subjected to the design earthquake.

More precise information on such aspects would have had the positive effect of appeasing the spirits and of concurring - in some cases – with the participation of the citizens in choices balancing between security and convenience; one of this choices concerns the value of the *social acceptable safety* (that evolves, more or less, like the national gross weight product) and it demands particular cautions in taking hurried social-politic decisions that can lead to unacceptable situations for the current generation, both from the economic point of view and the practical one. More specifically, political decisions involving onerous economic fallen back – such as the decision of choosing the *social acceptable degree of strengthening* some categories of damaged buildings - demands width collaborations and understanding between the scientific world (owner of the necessary competences) and those who has to take such decisions.

In Italy, when earthquake of magnitude 5 or more struck the national territory, the IGN National Institute of Geophysics transmits immediately to the National Seismic Survey the focal parameters of the epicentre (magnitude and coordinates) and then an automatic procedure is immediately activated to produce data, maps, and information concerning the epicentral area. All principal ground motion parameters (macroseismic intensity, PGA, PGV, as well as response spectra values) are calculated for each municipality within a radius of 100 km from the epicentre; then, the elaborated data are used, on aim to evaluate a preliminary expected damage and loss. At the same time data concerning the main features of the stricken area (territory, population, lifelines, hospitals and schools, building vulnerability, seismicity, expected structural damage, expected number of casualties) are transmitted, within one hour, to the Civil Defence Department, see Fig. 3, F. Sabetta, [2], on refer to the expected number of homeless population, realized in occasion of September 26, 1997 Umbria-Marche earthquake; in fig. 4 the values predicted by the scenario are compared with the real values verified on field. Is can be noted that the number of victims are strongly overestimated, whereas the number of homeless, unusable dwellings and monetary loss are closer to the real values, probably because of the fact that the strongest shock (Ms = 5,9) - happened at 11.40 a.m. - was preceded by a weaker event (Ms = 5,5) at 2.33 a.m., giving to the people the possibility of running out of their homes.

A part all uncertainties in hazard and vulnerability, the target of similar as above maps is just to provide the order of magnitude of damages and losses expected in different parts of the Italian territory in order to contribute in the urgency phase management.

2.2 Damage assessment

The architect or the engineer concerned with the problem of seismic vulnerability of existing masonry structures, is facing first of all the problem of the assessment of the present condition of the structure.

This assessment may be based on either a group of informational and experimental data (inspection, measurements, tests, etc.) in conjunction with an analysis based on current design methods, or on overall loading tests (vertical as well horizontal ones). In some cases, these two groups of data may lead to somehow contradictory conclusions; therefore emphasis is given on the need for calibration and good engineering judgment.

Normally, assessment evaluation is based on the data acquired through observation on the degree of damages on building during the strong seismic action, through the testing of materials, elements and structural models and finally, through calculations using computer models.

The diagnosis of the damaged building comprises the following stages (n. 109/1994, Merloni law):

1. *Visual inspection* and estimation of the consequences of the damage in an apposite "inspection report". The inspection report represent a fundamental document, of decision support to the planning phase; it contains, besides the noticeable pathological picture:
    - At sight pathologies, evidencing the most damaged sections; in addition the possible causes and the possible interactions between several causes are postulated;
    - The performance characteristics, that will be the object of direct and normative control;
    - The location, that is, all the possible urbanistic restrictions, specifying the relationship of the building with its context;

- The services available locally or close by; regardless if they are useful, or represent a restriction for the feasibility of the tests (presence of rivers, roads with high density of traffic, channels, railroads, etc.);
- Localization; defining the test environment (accessibility, building typology of the components, volumetric configuration of the building, metric data of the technical elements) and, if useful, enclosing a book of clarifying documentation (drawings, maps, photographs, etc.);
- The environmental conditions: indicating the predominant climatic conditions (eventually enclosing the weather report).

2. In the *preliminary redesign project*:

- Collection of information regarding the previous condition of the building, such as possible previous transformations and repair/strengthening works, the use of the building and the quality controls, if any during construction.
- Sketching (on plans and elevations) of all kinds of damage of load-bearing elements as well as secondary and boundary elements
- (In case of collapse of some structural or secondary building elements, their kinematics is reporter).
- Study of design documents of the building, if any; if the initial design documents are missing new ones must be prepared.
- Finally, it has to be noted that among the above mentioned steps of inspection, an examination of other buildings similar in structural form in the vicinity should also be carried out, for purposes of differential diagnosis, especially in case of damages due to earthquakes, aging-environmental, differential settlements, etc.

3. *Definitive and re-construction project*

Instrumental measures and tests may be needed, both in order to quantify the level and the character of damage and to complete the information regarding the condition of the building before any repair and/or strengthening work. Also special tests and measurements may be carried out in order to complete the information regarding:

- General arrangement of the load-bearing and secondary elements dimensions of cross-sections, uncovering and localization of reinforcements.
- Soil investigations (inspection pits, geotechnical borings, sampling, testing)
- Effects of aging-environmental actions or fire, such as: physical-chemical analysis of the materials (stone, mortar, etc.), detection and determination of external agents, etc.

Investigation procedures and guidelines for in situ and laboratory surveys must be defined so that all the data collected can be used for damage assessment and as input data for structural analysis and control models. Nevertheless it is very often difficult to elaborate and interpret the results of the investigation; this situation is especially frequent when the designer is not skilled enough. In those cases could happen that dozens of data are practically never processed reducing the results of all the expensive operation to a pure collection of numbers and diagrams.

It must be marked that, in the recent years, several investigation techniques have been implemented and adopted to evaluate masonry materials and structures. Most of them were previously applied in other scientific fields (e. e. medicine) or to other types of materials like steel and concrete. All these investigation techniques are framed principally in two categories: destructive and not destructive tests. Due to the cost sampling, to the difficulty of evaluating laboratory results on large samples and to the unacceptable damage caused by sampling from historic buildings, non destructive in situ tests are preferred for assessment surveys.

The necessity to establish the remaining (actual) structural capacities of a building (or a building element) after a seismic damage depends from several causes as, i) assessment of the safety coefficient of the structure in a seismic area (before or after an earthquake, or following accidental events like fire, landslides, floods, etc.), ii) change in use or extension of the building, iii) assessment of the effectiveness of the repair/strengthening techniques previously adopted, iv) long-term monitoring of materials and structural performances.

If the way of evaluating or at least understanding the results obtained from any of the tests is not well known, then it is better to avoid the tests. It must be marked that in many cases different tests should be complementary, therefore the schema of the experimental survey must be prepared very carefully in order to avoid expensive and useless operations and tests.

Actually there is a great need to carry out scientific research characterized by the close studies in different sectors (chemical-physical aspects regarding the primary and compound materials, their resistance and mechanic behaviour, the behaviour of constructive elements and of the buildings as a whole, conception of the security, critical survey of the traditional and innovating techniques, historical studies, etc.) as well as, once more, by opportune interdisciplinary studies with operative character.

It is necessary to give up the useful but not always valid securities given by the formal controls, whose use is reasonable only as to the new buildings and that have, moreover, the great defect of giving the ignorant and the incompetents the illusion to “know how”. Instead it occurs to adopt an approach based:

- on the sure ability of the operators;
- on the interdisciplinary collaboration and on the evaluations and choices made by decision of a team;
- on the close study of the present situation and the history of the building in question;
- on the respect both for the materials and for the cultural reality of the building.

The basic ideas of the “National Committee for the Seismic Protection of Monumental Buildings and Italian Cultural Heritage” (which have been gathered in two consecutive texts written by the National Committee and issued as official documents by the Ministry of Cultural and Environmental Heritage) are the following (C. Gavarini, [1]):

- Seismic history is of paramount importance: if we know that the monument supported the “maximum” expected earthquake in the zone without big damages, then we can say that is known its seismic safety.
- If there are different situations concerning the mechanical safety of the construction itself and the safety for people, the needs of the safety for people may involve interventions that are against conservation principles; in this case, we can adopt two different solutions: *change in use* or *limitation of use* (until forbid the use of the building). In the case the question of safety for people is solved by the control of occupancy, all costs/benefits decisions are not established by an algorithm but through an interdisciplinary job which involve seismic engineers, experts involved in conservation, architectural historians and others.
- As the problem of safety for people is solved by the control of occupancy, the acceptable level of building safety becomes again a matter of cost/benefit analysis, where the benefit is an increase on seismic safety of the construction, while the cost is a possible loss in conservation following a strengthening. As a consequence, the main approach to getting the “right” seismic safety for a monumental building is a technique said “improvement” different from the well known retrofitting generally adopted for ordinary buildings. Such a concept is present in the Italian Seismic Code

and consists in the “execution of one or more works to the single structural elements of the building, with the purpose of attaining a higher degree of security without anyhow modifying substantially the global behaviour”

The consequences of such a choice (improvement) could be summarize as follows, (C. Gavarini, [1]):

- One accepts the safety level given to the building by the original constructors, after that the decay has been eliminated:
- While analysing the present situation a special attention is given to the above mentioned historical approach;
- The possible calculations are elements of evaluation among others (of qualitative, comparative, heuristic nature) and they do not exclude these latter;
- Every intervention must prefer the original materials and master ships; in every case the interventions must be compatible with the existing tissues, with the great suspicion towards the utilization of different materials;
- The use of whatsoever innovating technology, up to now considered as “indispensable” is not excluded a priori, but it must be subjected to the triple verification of the compatibility, of the durability and of the reversibility. Moreiver, one must add still another condition, that if the mechanic efficiency, too often considered to be obvious without a scientific verification;
- All the evaluation and choices must be a result of interdisciplinary contributions and of collegial decisions.

Also in terms of intervention technologies the document gives, in the Commentary, quite significant indications, that contest resolutely the modern critical adoption, often generalized, of certain solutions.

The reconstruction (repairing/strengthening) of built heritage involves a risk that we must reduce at the minimum acceptable for the society and the surest way to reach it is to guarantee the diagnosis, redesign and execution quality.

In order to develop economical and effective retrofit standards for buildings, as well as performance criteria for optimised retrofit interventions, and to choose from among various alternate upgrade solutions, there is the need for considering the “Overall Performance” of a building within the re-design process framework of a building as a system. At the same time, the re-design specifications should be capable of considering problems for any detail, time of event, and for any actor involved including public administrators, designers, contractors, managing or monitoring agents, and users.

Due to the peculiarity of monumental and historical constructions, as well as to the lack of diagnostic protocol standardisation, several problems may be faced during diagnostic phase:

- Higher probability of possible survey of damage errors
- Low accessibility in some buildings sectors or subelements
- Difficulties in implementing appropriate field quality controls.

For this reason the need of careful and extensive assessment of the effectiveness of some specific pathologies presence cannot be over emphasised. This assessment is carried out during the recognition operations (testing of materials, testing of the effectiveness of operations, etc.) as well as after the completion of the interventions (mainly by means of aver all loading tests – vibration tests, etc.). Re-evaluation of performance characteristics of building-elements may be carried out:

1. by calculation: this way may be the case when all basic data are available or may be estimated with an acceptable accuracy. To be compatible with the reliability level

induced by Codes, similar procedures (conventional as they may be) should be applied as foreseen by Codes in verification of ultimate and serviceability limit-states.

2. by testing: Some times, this way may be a complementary procedure, e. g. the maximum width of shear or flexural cracks or even the bearing capacity of the building-element may be found or estimated by means of appropriate load tests. However, due care should be given in achieving the same overall reliability as imposed by the philosophy of Codes in designing by calculations.

2.3 Urgency of interventions

There is always a problem of timing for repairs or strengthening of a monument; that is, how long we can wait before any structural intervention is made? This is a complex socio-economic and engineering problem, which has treated i.e. to Euro code 8, part 1.4. where an algorithm has developed to this purpose.

Following a damaging natural hazard (i.e. earthquake), many buildings may be closed pending determination of safety and necessary repairs. A lack of repair standards criteria for reoccupancy creates controversy and denied owners use of their buildings. This is particular truth in the case of small Italian historic centres. On the other hand, conservative standards may delay the economic recovery of the community. So, in order to develop technical standards that will solve this problem, the acceptable levels of safety for occupancy first must be set. Development of rational standards is also hindered by limited ability to estimate lateral load capacity of buildings of various materials and in various damage states. Once a safety criteria is set, however, technical guidelines could be developed which would improve the current situation.

Considerable effort has been expended in developing in Italy appropriate systems for emergency situations, especially post-earthquake ones [3]. These procedures essentially divide buildings into two categories: 1) Those judged essentially undamaged ("blue tagged") and 2) Those judged damaged to the extent that some limitation of building use is warranted ("red tagged"). Although plagued with issues of appropriate evaluating criteria and of consistency, these procedures are necessary and useful to protect life safety immediately after a damaging earthquake.

There are other important issues associated with natural disasters damaged buildings that lack procedures and standards including temporary shoring, emergency demolition, removal of personal belongings, and protection of historic buildings. However, the most difficult and also the most significant problem is the lack of standards for repair or strengthening of damaged buildings that is sufficient to allow reoccupancy.

Quantitative data regarding available margins of safety after a damage, may serve as a guide in making the necessary decisions on repair and/or strengthening of the system (building or building-element.

If R' denotes the load bearing capacity of a system (or an element) and S' the action-effect this system (or element) would be required to resist according to the actual national Code, the notion of the "capacity ratio"

$V = R' / S'$ can be introduced. Based on these capacity ratio values, residual stiffness may be roughly estimated, to be used for the redistribution of action-effects to each structural component after damage of some sub-elements (i. e. after elimination of some walls connected by rigid horizontal diaphragm).

The maximum time tolerated before implementation of remedial measure, is understandably a function of the capacity ratio "V". Capacity ratio values lower than about 0.7 require immediate repair action; higher values may leave time up to 1 to 2 years, whereas V-values approaching unity indicate longer tolerated periods before intervention (of the order of magnitude of 20 to 30 years). As a mayor of fact, social, historical and economical parameters may considerably influence decisions on urgency of repair and/or strengthening. It has also be noted that if the existing national Codes do not account for the "importance" of the building, then this factor should be taken into consideration in re-evaluating the estimated capacity ratio $V_I = V/I$, where I denotes the importance factor. Guidance in selecting I-values is indicated the Italian seismic Codes, as well as in CEB Seismic-Annex and Euro codes.

Finally, in case of in-time evolution of actions and/or damages, decisions on urgency may be considerably influenced by the estimated “rate of evolution”.

The guide-rule above exposed are not intended for general use; in every case, specific expert’s decision is needed making use of the maximum informational and experimental data available and all the possible trial calculations. The actual state of knowledge does not yet allow for scientific solutions of general validity.

The repair versus strengthening problem was recognized in Italy after recent earthquakes. Methods were suggested to determine appropriate reoccupancy repair that either measured level of damage or required buildings to meet some absolute criteria; the reocupancy repair was a step beyond emergency evaluation, but grouped repair and strengthening together without any suggestions as to how to determine what is appropriate.

Buildings posted “red” or “blue” should not be used before they are repaired and strengthened to standards set by authorities. Depending of the importance of a building, its useful life and other factors, these standards may be lower, equal or higher than those applicable to new construction. A detailed analysis of the damage and a repair-strengthening design by a licensed professional engineer or architect and the approval by an appropriate authority should be required to repair and / or strengthen any building posted red, before it can be used again.

State and local government lack minimum standards for the repair of earthquake damaged buildings in historical centres; so, the public has been exposed to the following in past earthquakes:

- unacceptable risks from hazards of existing damaged buildings
- delays in earthquake recovery and repair efforts
- demolition of existing buildings without adequate due process or adequate damage evaluations
- cosmetic repairs to buildings that should be required to have hazards significantly reduced to meet minimum seismic safety standards for future earthquakes
- lack of consensus about appropriate procedures and minimum safety standards.
- Inaccurate damage cost estimates by damage assessment teams unfamiliar with the methods and costs of repairs (only recently it is introduced in the Italian universities specific courses on the theme of diagnosis and repairing/strengthening: methods, technologies, materials, etc.)

Since local repair will be needed in any reoccupancy repair scheme, continued research into acceptable methods is needed. A compilation of existing methods with a commentary on expected performance would be extremely useful. Insurance companies and emergency aid organizations (e.g. Italian National Seismic Survey) should clarify and simplify the scope of their coverage to avoid dependence on current nonexistent reoccupancy standards; when such standards have consensus acceptance, they could incorporated into contractual agreements and regulations.

Finally, it is necessary to continue to research properties of ancient materials and systems so that they can be more accurately modelled in non-linear computer analysis, as well as develop a method of measuring a structure’s capacity to undergo shaking by considering its global hysteretic behaviour for the damage estimation; if such a method could be developed, it would be useful also in determining residual structural performances of undamaged buildings.

3. Redesign

Measures necessary for improving the seismic resistance are proposed on the basis of the data acquired through observation of the degree of damages on buildings after seismic action (pre-diagnosis), and through calculations using computer methods (diagnosis).

Quantitative data regarding available margins of safety after damage, may serve as guide in making the necessary decisions on repair and/or strengthening of the building.

Depending on estimated capacity ratio values, on emergency needs, on cost-benefit considerations, etc. several means of interventions may be adopted in order to restore, at least, the capacity ratio value of a building element or of a whole building as close to unity as possible; in some cases, it is required to increase the previous seismic resistance (i.e. for public use buildings: schools, hospitals, museums, etc.).

3.1 Optimisation

In addition to all general and technical criteria previously exposed (safety, economy, reoccuoancy, etc:), decision making in the case of monumental and historical buildings has to consider a third set of criteria, which are more specifically related to the intrinsic values of such a buildings (aesthetic appearance, historic importance, etc.); all these values are antagonist among them, and must be contemporary considered during trial optimisation:

In order to assist decision-makers to place their deliberations in such a consciously interdisciplinary space, a formal technique was developed by T. Tassios, 1985, for the selection of an "optimum" structural intervention among several (equally safe) solutions, [4]:

1st step

Estimate the needed "miimum resistance" $R_{dmin}= S_d (L_t, P_f)$ versus external actions (e.g. earthquake) where

- L_t (years) + intended conventional Life-time
- P_f+ socially acceptable probability of exceedence ("failure")

Respective recurring period of destructive quake:

$T_m= - L_t : \ln (1-P_f)$

Corresponding peak ground acceleration [cm/s^2]

$a_{gr} = e^{(\beta \log10 Tm+\delta)}$

2nd step

(a) Formulate the minimum requirements for the other performances "P_i":

- Durability $D_{r\ eq.}$
- Arch. Integrity $I_{r\ eq.}$
- Reversibility $RV_{r\ eq.}$

(a) Estimate the "relative importance" of each of the above performances, by means of relevant weighing factors "f_i"

such that $f_D + f_I + f_{RV} = 1$

3d step

- Consider several alternative interventions, (techniques, materials, methods, extent of intervention);
- Proceed to the preliminary designs of all these “candidate solutions”, observing the same basic requirements of $R_d min$;
- Estimate the respective global costs

  C_1, C_2, C_3, …. For each of these “solutions”.

  (“Global” means: costs of: credits, design, education of personnel, construction, quality assurance, social costs during the intervention, maintenance.

4th step

- Evaluate the performance levels achieved by each of the above “solutions”:
  Solution 1 → D_1, I_1, RV_1,

  Solution 2 → D_2, I_2, RV_2,

  Solution 3 → D_3, I_3, RV_3,

  “ …. → … … …
- To this end, if quantitative methods are not available, convene a Group of Experts. They will assess (be it qualitatvely) each of these solutions from their performance point of view (e.g. → classes A, B, C …).

5th step

- Discard those solutions which do not fulfil the minimal Performance requirements you had formulated in Step 2:

  Step 4 → $P \leq Preq$ ← Step 2
- Calculate the PERFORMANCE MARGINS INDEX of each remaining solution:

$$(PMI)_i = f_D(D_i-D_{req}) + f_i\,(I_i-I_{req}) + f_{RV}(RV_i-RV_{req})$$

6th step

By comparison of each one redesign solution in terms of their “total costs(C)” and their Performance Margin Index (PMI)”, it is select the solution that ensures the maximum benefits versus its costs.

3.2 Quality assurance of interventions

Concerning quality assurance, it does not exist an ideal Quality Assurance System, which can be recommended for all redesign cases. On the contrary, there are different models, which could be adopted according to the circumstances, and within each model, different levels of assurance may be established, [5], [6],[7].

For widespread or weak intervention, which affect the resistance and stability of the structure, or which involve a redistribution of action effects beyond a certain limit, the Quality Assurance level must provide systematic and documented actions, of an imperative character in all the redesign process phases (diagnose-project, design-project, supplies and construction).

In what follows the instruments used in the managing the quality of the interventions, according to ISO9000 2000 (E) are considered. In particular, it is considered the Quality Assurance Plan of some specific stages of interventions to ensemble of all the practices established and implanted in order to ensure the attainment of the quality in planning, redesign, construction and exploitation of it, with the required grade of quality and level assurance.

Norm UNI EN ISO 8402 (1995) defines Quality Plan as the "Document that specifies the particular operating modalities, the resources and the sequences of the relative activities to the quality of determinate product, service, contract or plan"; its function is to explore the operating and organizational details of the job, defining the phases and the specific performance, as well as the requirements to respect, the plans and the controlling modalities.

The specific function of the quality plan is to break into in the operations and organizational plans of the project; to define, from the decomposition in phases and the times performance (job plan), requirements to respect, the quality plan actions and the control modalities, based on a written procedure established by the company, that contains modalities and contents of the quality plan in function of the specific objectives described by the quality system.

All the actions relative to the Quality Plans must be documented and must answer to the general requirements of the Quality System adopted. In addition, the diagnostical tests company would have to guarantee that the Quality Plans are prepared and maintained active.

Fig. 5 illustrates the articulation of the Quality plan, following the guidelines of norm UNI EN ISO 9004-5 and applying what is required by norm UNI EN ISO 9001.

- The quality plan of a non destructive test

  Used as detectors of a specific parameter (physic-chemical or mechanical), no destructive techniques of surveying, lead to the appraisal of technical performances, leaving the original values of the object nearly unchanged.

  The critical reading of the numerical data obtained by the tests (outcomes of the tests), is carried out in a meaningful "number" of points (nodes), linked to the intrinsic characteristics of the object and its context, allowing to clearly characterize the entity of the deterioration. The reading of the degradation as a complex phenomenon, whose factors are attributable to pathologies often interacting, depends in many ways from the outcomes of the diagnostic tests.

In order that such outcomes can turn out as close as possible to the effective state of conservation of the object, it is necessary that the tests respect the following principles:

- Conservation of integrity of the examined object;
- Global examination of information;
- Ability to supply qualitative and quantitative data;
- Simplicity of restitution and graphical processing of data.

The contingent conditions during the conduction of the tests assume particular importance. It is necessary to evidence all those factors (environmental, meteorological, etc.) that turn out to be unfavourable to the operability of the tests, during the execution of the tests.

Fig. 4 illustrates the procedure methodology for the attainment of the Quality Assurance, and evidences the factors that can negatively affect the reliability of surveying.

“Test contextualization" means that the transfer of the instrument details to the physical and environmental context is carried out; it is necessary to identify all interrelated factors of the "Environment System" and of the "Building System" which influence the outcome of surveying and the interpretation of the results. In order to reduce the degree of uncertainty of the results, it is necessary to accurately define the zero setting of the instrument configuration, before executing the tests, thus proceeding to instrument calibration on site.

In the practice it is often necessary to limit as much as possible the number of instrumental surveys. It is possible to take advantage, for analogy, of the results obtained with other surveys carried out on the same building. In the case this was not possible, information can be found by consulting specific databases (data coming from analogous tests of laboratory or on site tests on similar objects). It is important therefore to proceed to the systematic cataloguing of tests, contributing to the realization of databases, as well as to the decodification, interpretation and localization of the obtained data.

Fig. 5 illustrates the distinction in phases of one job for NDT tests, to proceed to definition of levels of requirement.

- Redesign of the contract and the plan

  Re-examination of the contract precedes the acceptance of the job and follows precise procedures for rechecks both of the diagnostic plan actions and the contract, later communicated to the inside of the organization. Norm UNI ISO EN 9004-2, in the procedure of contract and design documents re-examination shows the means with which a company (in this case an SD: diagnostic tests society) assures that:

- The planning requirements have been completely defined and comprised within the organization, to be able to execute the test in compliance with the requirements;
- It has the ability to satisfy contractual requirement in technical, economic and timing terms;
- Resolve eventual divergences in respect to those indicated in the offer.

The flow diagram of Fig. 6, illustrates the procedural flow of a job for a cognitive surveying (from the offer to the contract), excluding the managerial activities within the company. It is up to the Production manager, responsible of surveying, to carry out and/or to forecast procedures of re-examination of the contract and the design to formulate an offer and also to plan the entire diagnostic process in a way coherent to the offer.

It is fundamental an accurate analysis and an optimised management of the information of the documents of the offer and eventual drawings (which often show general indications on the execution of the tests).

The analysis begins generally with the preliminary examination of the job and the pre-diagnostic plan, and includes the processing of the necessary data to the execution of surveying, and the systematic appraisal of the possible implications.

- Contractual precognitive phase

In case the job received is not supported by documentation, it is preferred, after an inspection on site, to write up a "technical and economic report of inspection", which indicates in detail all the useful elements for an appraisal of the technical, economic and logistic aspects. This document has the twofold scope to constitute an informative support for a better formulation of the diagnostic plan and, above all, to supply the fundamental data for localization of instrumental surveying and the tests to carry out. Therefore, is a control of use and maintenance (or in some cases control of accidental damages) of the building in which the quality control is not formalized.

Once prepared the inspection report, it is possible to control the reliability of such performance, which depends on five parameters:

The actions and products relative to this cognitive-contractual phase, will have to be included within the contract document, that contains:

- All the administrative actions, the permissions, the correspondence, etc;
- The "inspection report";
- The eventual "modification report";
- The description of the necessary activity to be accomplished for surveying;

- The technical characteristics of the instruments, the methodologies of surveying, the limits of application, executive details;
- The location (position, extension, etc.) of instrumental surveying;
- The list of the supplied documents;
- The cost of instrumental surveying;
- The beginning date activity;
- The eventual requirements for supplies and services (special scaffolds, equipments, etc.);
- The validity of the offer.

4. Planning process of project of not destructive surveying

In the planning phase that starts with receiving the documents of job award the SD establishes the procedures for the improvements of every single test of the project, finalized to the analysis of all the technical and procedural aspects. It is necessary, therefore, to deepen the study of the diagnostic plan, analysing all the aspects and translating the requirements expressed from the customer in technical specifications, concerning the diagnostic instrumentation.

The aim of this study is to obtain the predetermined level of quality of the tests. Thus, tests specifications and programs would have to be such to assure that they are realizable, verifiable and controllable during the entire executive phase.

Management should take responsibility for the quality planning of the in diagnostical tests society (SD), according to ISO 90004:2000 (E). This planning should focus on defining the processes needed to meet effectively and efficiently the SD quality objectives and requirements consistent with the diagnostic plan.

Inputs for effective and efficient planning include:

- Strategies of the SD
- Defined needs and expectations of all interested parties
- Evaluation of statutory and regulatory requirements
- Evaluation of performance data processes
- Comparison with previous experience of similar conditions
- Related risk assessment and mitigation data.

Outputs of quality planning for the SD should define the tests realization and support processes needed in terms such as:

- Skills and knowledge by the SD and sub-contractors
- Responsibility and authority for implementation of process improvement plans
- Resources needed, such as financial and infrastructure
- Needs for improvement including methods and tools
- Need for documentation, including records.

A furthermore advantage of the process approach herein adopted consist to the ongoing control that the individual processes within the system of processes, as well as their combination and interaction.

Management should define the infrastructure necessary for the realization of tests while considering the needs and expectations of interested parties. The infrastructure includes resources such as plant, tools and equipment support services, information and communication technologies, and transport facilities.

According to ISO9000: 2000, the process to define the infrastructure necessary for achieving efficient in situ tests realization should include the following:

- Provision of instruments infrastructure, defined in terms such as objectives, function, performance, availability, cost, safety, security and renewal;
- Development and implementation of maintenance methods to ensure that the entire infrastructure continues to meet the SD needs; these methods should consider the type and frequency of maintenance of instruments used for testing, based on its criticality and usage;
- Consideration of environmental issues associated with infrastructure (such as conservation, pollution, etc.).

5. NEEDS

The variety of technical situations in repair cultural heritage is endless and the lack of consensus in each case may be due to inadequate research, ignorance of research, or simply the absence of an appropriate method or funds to gain engineering consensus.

Some arguments to be exploiting in the occasion of **ARIADNE meeting** could be the followings:

1. **M**ETHODS AND EFFECTIVENESS OF REPAIRING ELEMENTS TO ORIGINAL CONDITION
2. **C**ONDITIONS UNDER WHICH A DAMAGED ELEMENT CAN BE REPAIRED OR REPLACED WITHOUT CONSIDERATION OF THE BALANCE OF THE STRUCTURE.
3. **M**ETHODS OF MEASURING THE SIGNIFICANCE OF DAMAGE FOR THE PURPOSE OF TRIGGERING OVERALL BUILDING STRENGTHENING.
4. **R**ESEARCH FOR PREVENTION
5. **R**ESEARCH ON FORECAST OF POSSIBLE EARTHQUAKES CONSEQUENCES IN SMALL HISRORIC CENTERS
6. **N**ETWORK IMPLEMENTATION BETWEEN RISK MANAGERS TO ASSIST WITH THE DECISION-MAKING AND FOSTER CO-OPERATION IN THE FIELD OF RISK MANAGER
7. **F**ULL CO-OPERATION, TRASPARENCY, INFORMATION BETWEEN ALL EUROPEAN COUNTRIES IN ORDER TO REACH AN EFFICIENT AND USER FRIENDLY SYSTEM.

[1] Proceedings of Joint USA/Italy Workshop “Learning from Practice, A review of Architectural Design and Construction Experience After Recent Earthquakes”, Orvieto, Italy, 1992, organized by C. Comerio, N. Avramidou and L.Binda.

[2] S. Sabetta, “Prevention and mitigation of seismic risk in Italy”, Italian National Sesmic Survey, proc. “Mitigation of Sesmic Risk Support to Recently Affected

European Countries, Belgirate (IT), Nov. 2000, organized by DG - Joint Research Centre, ISIS - Safety in structural Mechanics Unit, DG – Environment and Civil Protection Unit.

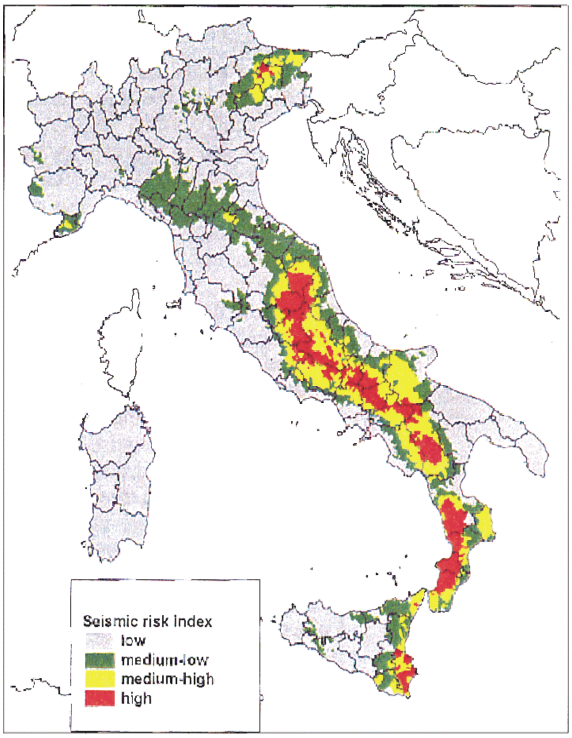
[3] N. Avramidou, “The earthquake of Athens on 7th September 1999. Urgency and recostruction measures”, proc. “Mitigation of Sesmic Risk Support to Recently Affected European Countries, Belgirate (IT), Nov. 2000, organized by DG - Joint Research Centre, ISIS - Safety in structural Mechanics Unit, DG – Environment and Civil Protection Unit.

[4] T.Tassios, “Formal Techniques in decision making related to Monuments strengthening”, National Technical University of Athens, proc. of International Workshop on Seismic Performance of Built Heritage in Small Historic Centers, organized by International Center for the Rehabilitation of the Architectural Heritage, CICOP-Italy.

[5] Avramidou, N., “Analisi sistemica-prestazionale di edifici monumentali in regime di Assicurazione Qualità” atti del 5° Congresso Internazionale CICOP sul "Restauro del Patrimonio Architettonico”, Firenze, 2000, organized by International Center for the Rehabilitation of the Architectural Heritage, CICOP-Italy.

[6] Avramidou, N. “Application of Quality Assurance Systems in the Rehabilitation of the Architectural Heritage”, proc. of Inspection, Appraisal repairs & Maintenance of Building & Structures, Special Session on “Repairing and strengthening : architectural design and construction experience” organized by CICOP-Italy), Nottingham (UK), Sept. 2001, organized by Dep. Of Civil & Structural Engineering of the Nottingham Trent University.

[7] Avramidou, N. , “Applicazione dei Sistemi Qualità nella Diagnostica degli Edifici”, Alinea editor, Firenze 2001.



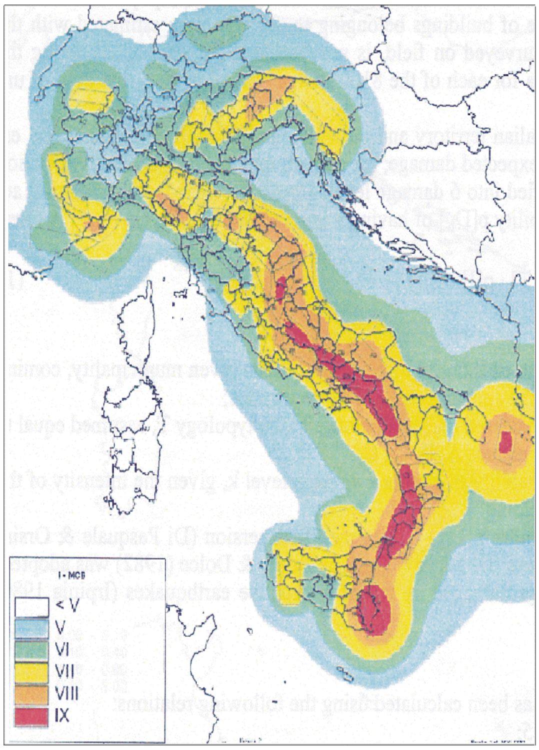


Fig. 1 seismic risk index

Fig. 2 Percentage of the damaged surface of the residential real estate espected per year in each municipality (from Working Group SSN-ING-GNDT of the Civil Protection Department, 1996)

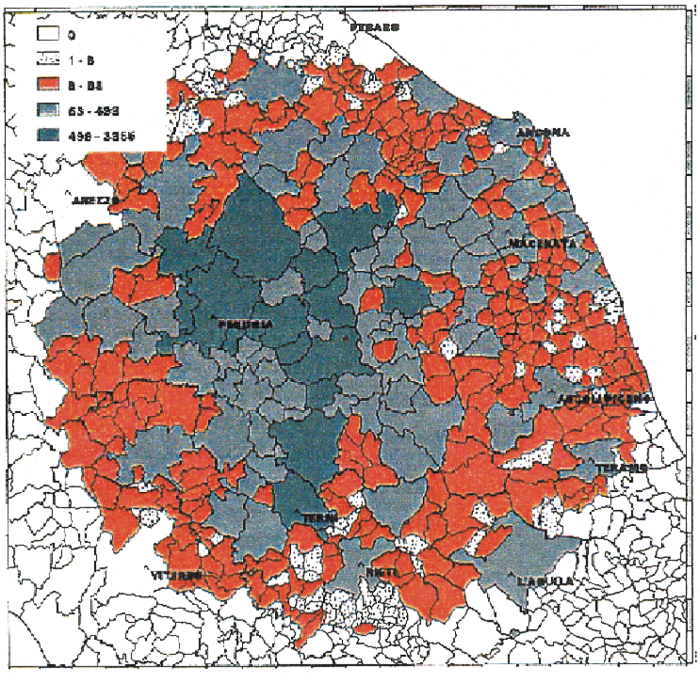


Fig. 3 Number of expected homeless population in the simulation scenario of the Umbria-Marche 1997 earthquake

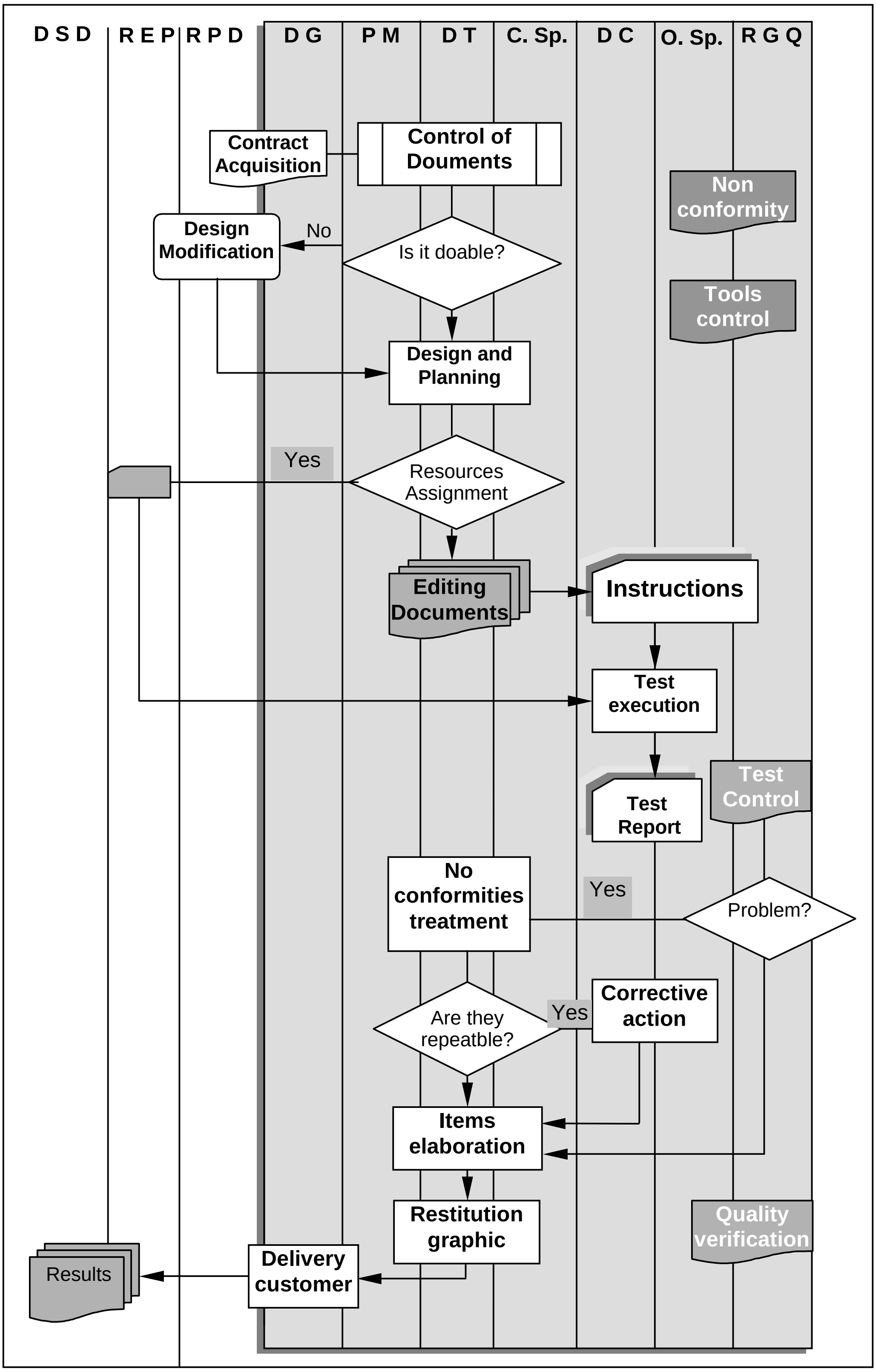


Fig. 4 Procedural iter of order in a DS, of not destructive testes (NDT)

DSD: Direction of diagnostic society — *DT: Tecnical manager*

REP: Responsible testes execution — *C.Sp.: Specialized tester*

RPD: Responsible of diagnostic project — *DC: Yard's manager*

DG: General manager — *O.Sp: Specialized operator*

PM: Project Manager — *RAQ: Responsible warranty of quality*

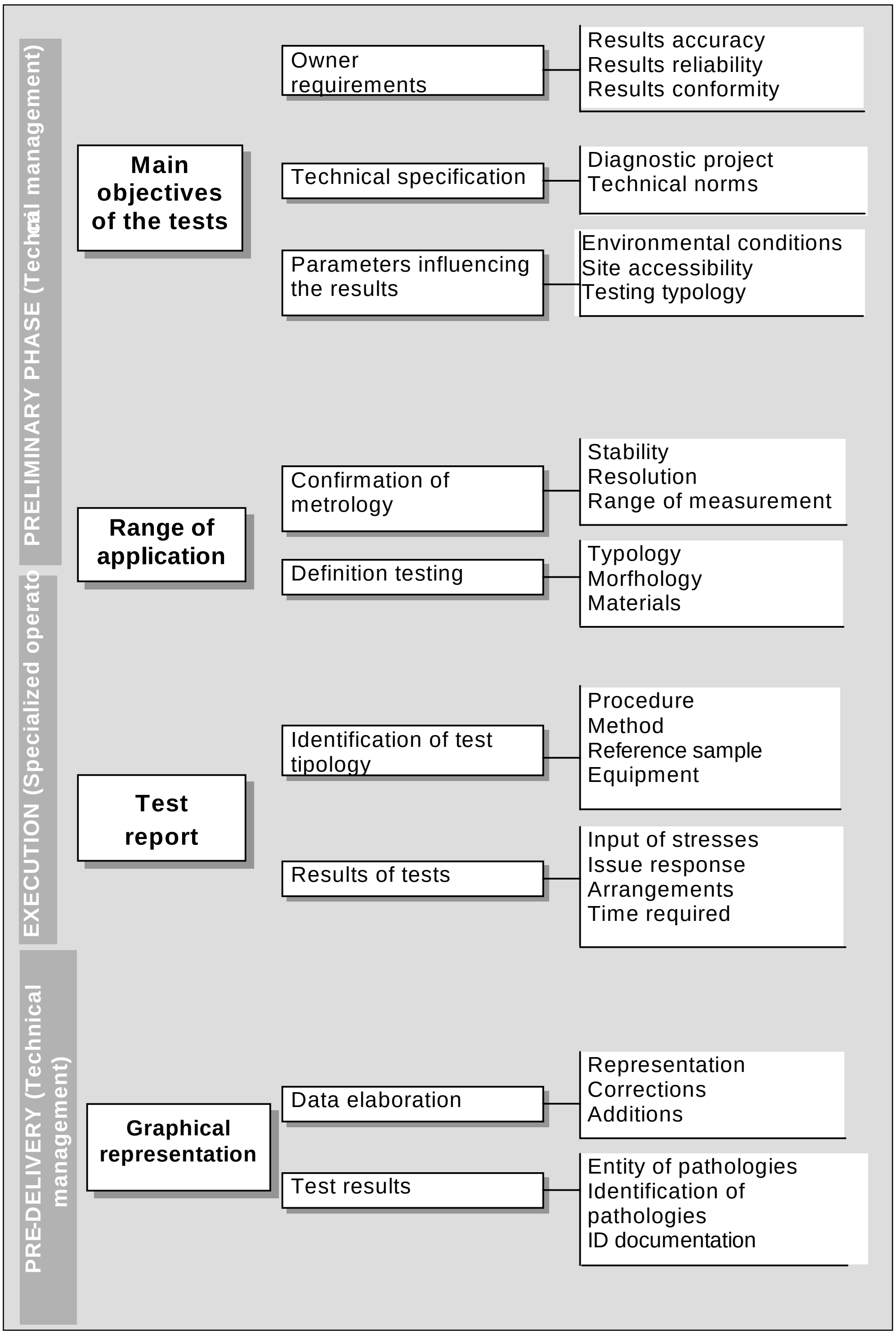


Fig. 5 Workforce definig the requiriments of instrumental tests.

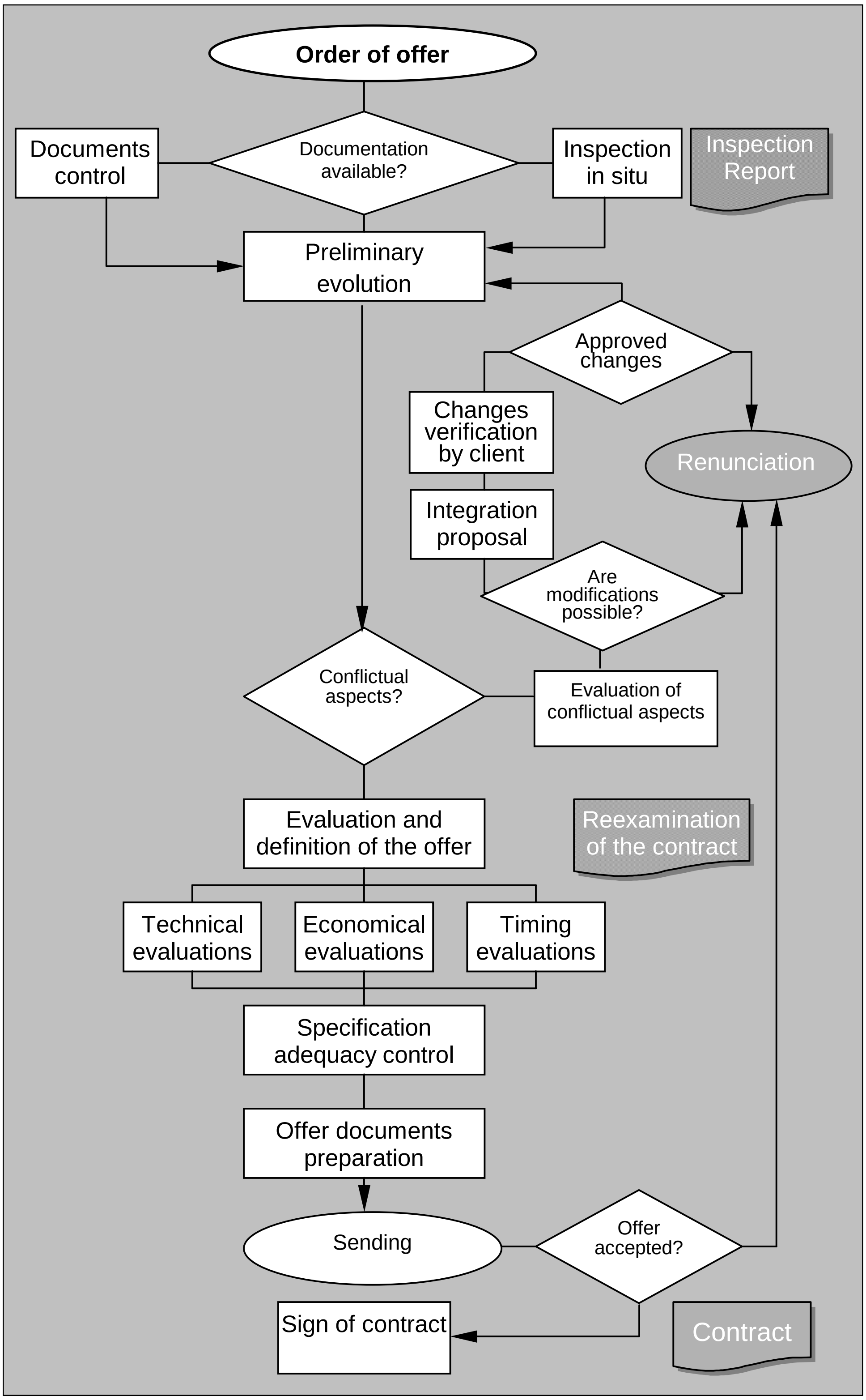


Fig. 6 Procedural path of a diagnostic job in a diagnostic company.