SEISMIC DAMAGE OF BUILDING STRUCTURES AND THEIR REHABILITATION

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Abstract: *Building's structures were designed and built according to different standards that were valid at the time of construction. Those standards were, more or less, less demanding than the current European, American and other modern standards. Serious earthquakes events cause damage of the elements, with different level, even their collapse. It is very important to save damaged or weakened structures by emergency strengthening, and to perform rehabilitation of their seismic resistance. The method of evaluation of seismic resistance of damaged elements and structures are discussed. After evaluation of the damage degree and determination of required and available seismic resistance of structures, redesign must be performed. Also, method of rehabilitation of the elements and entire damaged building structures are analysed, including both traditional and advanced techniques. The focus of this paper is on reinforced concrete (RC) buildings, and less on masonry and mixed structures. Post-earthquake assessment and analysis of seismic performance are analysed. Review and comparison of international Code provisionsrelated to topic are discussed as well. Criteria for the choice of structural interventions are discussed, as well.*

Key words: *Earthquake damage, assessment, condition, performance, seismic resistance, rehabilitation*

1. Introduction and terms

Depending on structures' condition after earthquake, there is a need for structural upgrading in order to meet design requirements. International Federation for Structural Concrete (*fib*), has placed considerable emphasis on assessment and rehabilitation of existing structures. Document [11] is related to assessment and retrofitting of buildings. In the US, different organizations prepared particular documents for seismic evaluation (FEMA 178), for evaluation of the buildings with the wall structural system (FEMA 306).

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Both groups, of concrete and masonry buildings, are more or less damaged in earthquakes, depending on the strength of the earthquake and the quality of the buildings. Masonry buildings are significantly more vulnerable to seismic effects, so they experience a lot of damage and even collapse. Inspection of buildings after an earthquake allows one to look at failures in design and construction, the state of the structure and the severity of damage, and evaluate the possibilities of retrofitting. It is very complex process because of the unpredictable behaviour of earthquakes. Among them are historical buildings that belong to the architectural heritage and require special treatment to improve seismic performance, because it is imperative to reduce the loss of their historical and architectural value [8]. This requires an adequate methodological approach to the analysis, aligned with the importance of the building's function. The first step is to investigate the material characteristics of the structural elements in situ or in the laboratory. The second step is the simulation of linear and non-linear behaviour, usually using the finite element method (FEM) in order to determine the behaviuor mechanism, i.e. seismic performance. The rehabilitation phase is conditioned by inadequate performance, especially insufficient seismic resistance [52].

Damage is any adverse consequence for the physical state of a structure or structural component caused by earthquake. *Assessment* comprises the process of gathering and evaluating information about the form and current condition of a structure or its components. *Repair* is process of reconstruction and renewal of the existing buildings, either in whole or in part, while *renovation* is substantial repair or alternation that extends a building`s service life. The term *repair* comprises restoration of the initial mechanical characteristics in order to remove the consequences of adverse-seismic events. *Strengthening* includes interventions made to increase the load resistance of a components or to improve overall structural stability and the overall robustness of the structure; or shorter *strengthening* is Interventions to increase the bearing capacity of a structure. *Retrofitting* is an action aimed at modifying the functionality or form of a structure or its components and improving of future performance (minimizing damage during specified earthquake). *Upgrading* is the action undertaken in order to improve the quality of a building, including the increase of capacity to withstand earthquakes. *Replacement* is an action of providing new substitute components for the ones which have experienced deterioration, damage, degradation or mechanical wear[6], [19] and [22].

Sometimes the term *rehabilitation* includes interventions undertaken in order to restore the performances of a structure or its component parts that are in changed to the original level of performance, including all types of repair, retrofitting and strengthening that lead to reduced earthquake vulnerability. *Reconstruction* is a radical intervention, which includes improvements - upgrading/retrofitting, strengthening, replacement of components, and the removal of all or part of a structure, if it necessary to achieve a requested performance. Seismic retrofit comprise: technology of application; experimental data on retrofitted members; engineering models and expressions for the retrofitting design; recommendations for the conceptual and the detailed design of the retrofitting. Retrofitting strategies and instructions for selection of the retrofit technique also included [16]. Besides strengthening, increasing ductility was adopted in order to upgrade seismic performance of the structures and minimise damage during earthquake (retrofit). Sometimes, the criterion on the evaluation of seismic safety of existing RC Buildings, and their aseismic retrofitting is very important.

Architectural Heritage - Buildings and complex of buildings (towns, etc.) of historical value. *Adobe* is bricks made from clay and simply dried in the sun. Some organic materials like straw or animal excrement can be used to improve durability or reduce shrinkage. *Conservation* – Operations which maintain the building as it is today, even if limited interventions are accepted to improve the safety levels. *Diagnosis* n. - The act or process of identifying or determining the nature and cause of damage and decay through, observation, investigation (including mathematical models)and historical analysis, and the opinion derived from such activities. Heritage Value - Architectural, cultural, and/or historic value ascribed to a building or site. *Heritage value* may have varying definitions and importance from culture to culture. *Historical Approach* - Evaluation based upon historical research and past experience. *Holistic* adj. Emphasizing the importance of the whole and the interdependence of its parts. *Structural Typology* - The types of structures interpreted as regards their structural behaviour and their capacity to bear loads. *Safety Evaluation (assessment)* - Evaluation of the safety margins of a structure with regard to heavy damage, partial or total collapse *Restoration*– Process of recovering the form of a building as it appeared at a particular period of time by means of removal of additional work or by replacement of missing later work [22].

This paper provides an overview of the literature, on the behaviour of historic masonry elements and building, as well as publications related to the behaviour of subassemblies and building on earthquake, and some Code related to behaviour and damage in structural element and structure of concrete and masonry buildings. Considered in in-plane shear and simultaneous compression, out-of-plane bending. In doing so, the most frequent damages are analyzed with the indicated causes of their occurrence. The method of evaluating the state of damaged structures, forecasting the remaining service life, and related to that the selection of appropriate interventions aimed at removing damage and/or strengthening the structure was discussed. The frequent construction type, especially historical buildings (built heritage), are obtain in discussion. At the same time, the difference between the intervention of a seismically damaged structure (balance strength, ductility and stiffness) and a structure damaged by some other effects was emphasized. Some of the most common intervention methods were analyzed in order to achieve the desired level of seismic performance, taking into account the state of the construction and the cost-effectiveness of the interventions. The advantages and disadvantages of certain interventions are indicated.

2. Damage and assessment condition of buildings structure

Concrete and masonry building structures behave differently under seismic effects. Their behaviour depends on project solutions and the quality of building construction and maintenance. The evaluation of seismic safety of existing RC buildings is very important before structural redesign for earthquake resistance. In high-seismicity area rehabilitation of buildings must provide ductile instead of brittle behaviour [18]. In design frame structures, damage is likely to occur first in beams then in columns, and columns in frame should be stronger than beams, and foundations should be stronger than columns. It is very important to provided rigid diaphragm action (floor slabs stiff in own plane).

Using the information collected from site observation, performed in order to determine the residual strength, stiffness and ductility of the structure. For estimation the residual strength, stiffness and ductility of a structure, the structural engineer (SE) has to trace the damage in the structural system and non-structural. Crushing of concrete or part of masonry at the top or the bottom of a column or walls accompanied by buckling of the longitudinal reinforcement, X shaped cracks in shear walls with significant axial loading and in short columns are some of damage examples [41].

Concrete structures (CS) can become deficient due damage caused by earthquakes, especially old buildings which are not design according to contemporary codes. Wide classification of concrete structures and mechanisms of failure was discussed in [18] and in

[17] for different structural systems of building..Data relevant to classification can be classified into following groups:

1. Identification parameters;
2. Structural and quality parameters;
3. Damage and usability parameters.

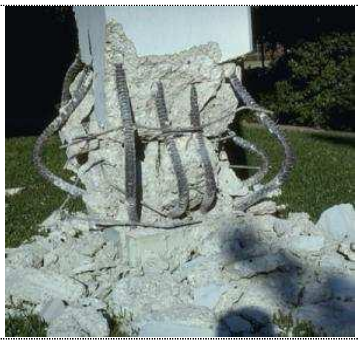	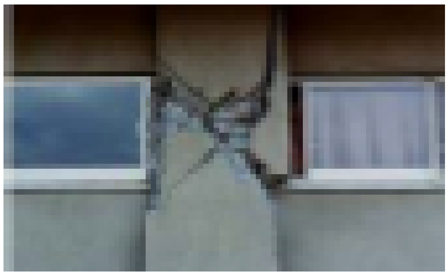
Fig. 1. Poor detail of transversal reinforcement	**Fig. 2.**Shear and axial failure of column du to partial-height infill walls

	
Fig. 3. Collapse with column shear and axial failure. Koceali Eq. 1999.	**Fig. 4.** Column failure due to excessive axial load and insufficient stirrups

	
Fig. 5. Beam-column joint damage, Turkey Koceli, 1999, after [17]	**Fig. 6.** Bursting failure in a column, Northrige, California, 1994, after [5]

According to the influence of damage on the global stability of structures, damage can be classified into: slight, moderate, serious and collapse. Serious damage includes: the occurrence of plastic hinge, strong beam-weak column, pounding of adjacent buildings, short beams and short columns, partial infill walls created short columns and collapse near joints as brittle mechanism. Greater damage accompanied by reinforcement bar buckling (inadequate transverse reinforcement) or breaking and concrete crushing appears in the case of considerable overloading caused by seismic action, poor concrete quality, infill wall damage (diagonal and X mode of damage) etc.[18].

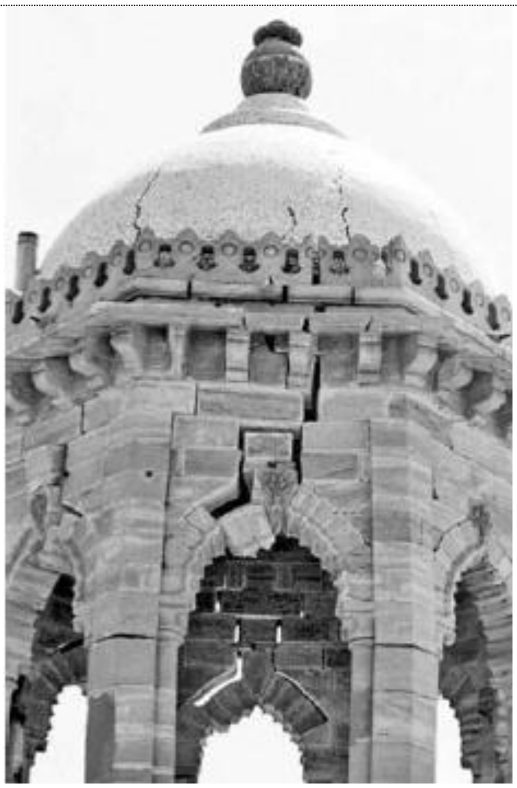

Fig. 7. Damage to a place after the Gujarat, India earthquake of 2001,[5]

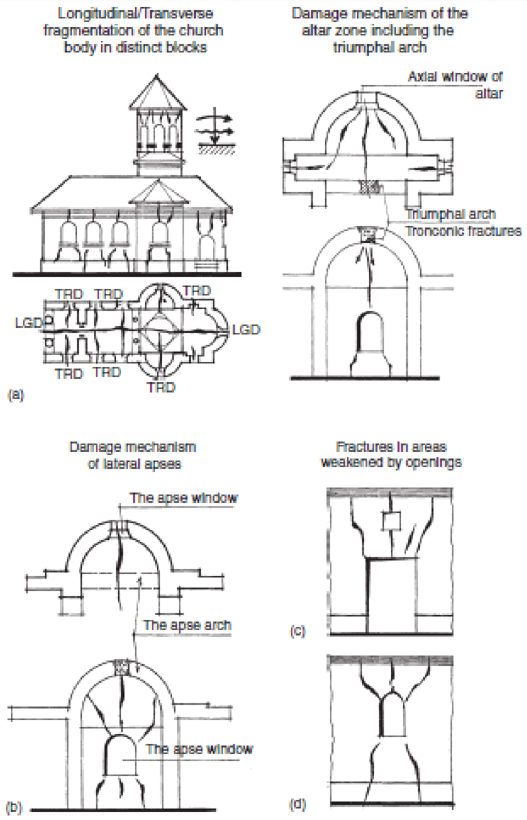

Fig. 8. Typical distribution of Eq. damage to church (Eq. 4 March, 1997. Ro, [36]

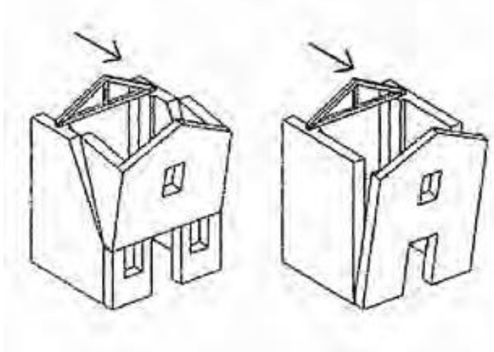

Fig. 9. Overturning of facades, after [7]

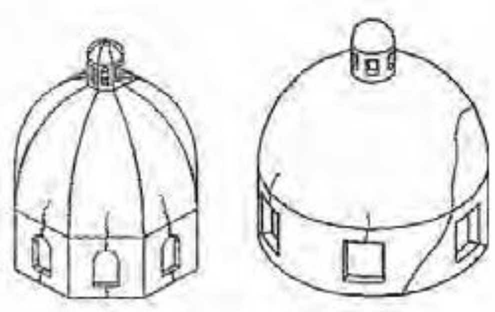

Fig. 10. Domes, after [7]

Weakness to shear and a lack of adequate transverse reinforcement were evident in many examples. This induces the crushing of concrete and the buckling main reinforcement. Weak column – strong beam in frame RC structures caused a failure of the column below the frame joint, i.e. unconvinced mechanism, soft and weak stories. Generally, insufficient detailing of the structural elements is another reason of damages. Short column, hammering, unconfined gable wall and in plane/out-of-plane movement of the walls caused damage [53].Failures of both reinforced and unreinforced masonry in-plane are common. That's why it's significant to evaluate the residual seismic capacity concrete and masonry damaged structures. Experience shows that non-structural items which are suspended, such as ceiling systems and light fittings, perform badly.Appendages such as parapets also suffer high levels of damage.

While complete replacement of a deficient structure is a desirable option, strengthening/repair is often the more economical one and hence the aspect of renewal has received, especially historic buildings, considerable attention over the past few years throughout the world [2].

Fig. 11. Severe damages to shear walls and spandrels 2009 Eq. L'Aquila, Italy, [22]

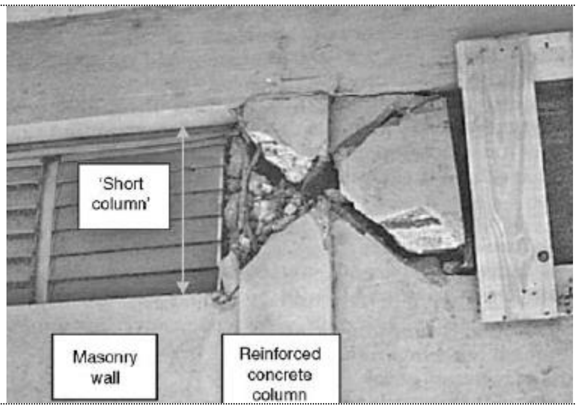

Fig. 12. Shear failure of a lightly reinforced concrete column and the adjacent masonry, opposite a window opening in St Johns, Antigua, 1974, [5]

It should be borne in mind that brick buildings are significantly more vulnerable especially unreinforced masonry (URM) buildings. Masonry is one of the oldest fundamental materials used in construction exhibit poor performance seismic actions, weak under lateral loads and tension forces. Structural and geometrical typologies, variability of constituent materials, construction methods, connections, intricate configuration, and cultural and artistic specifications are the influential factors in masonry behaviour, particularly under seismic loads [49].

Older buildings also commonly have timber floors with joists that are poorly tied to the supporting walls. Any lack of tying together in a building is quickly exposed by earthquake shaking. In plane, masonry is very stiff, so that the forces transmitted by ground shaking are high; masonry is also brittle so that failure is accompanied by a marked reduction in strength and stiffness. Damage normally comprises either collapse or diagonal cracking in both directions and damage will often be worse around openings.

Characteristic damage are: Cracks between walls and floors; Cracks at corners and wall intersections; Out-of-plane collapse of the perimeter walls; Cracks in spandrels beams and/or parapets; Diagonal cracks in structural walls; Partial disintegration or collapse of structural walls. Evaluation of URM buildings under seismic conditions for both experimental investigation and numerical simulation requires accurate information [51].

Horizontal reinforcement laid in the mortar bed joints substantially increases in plane strength and ductility, as does vertical reinforcement in mortar columns cast into hollow blocks. Introducing masonry tie-beams and columns into masonry walls to form smaller confined panels also substantially improves in-plane resistance. Out-of-plane, free-standing masonry or masonry that has separated from any adjacent structure is liable to toppling failure.

3. Analysis and evaluation conditions of building structure

Depending on structures’ condition after earthquake, there is a need for structural upgrading in order to meet design requirements. International Federation for Structural Concrete (*fib*) has placed considerable emphasis on assessment and rehabilitation of existing structures [15]. An overview of post-earthquake damage and determination the residual capacity for RC buildings in Japan is subject of the paper [33]. Yet, to consider the determination of lateral strength and ductility corresponding to the damage state of each lateral – load resist member. In the damage evaluation Guidelines (JBDPA 2015) the state of damage of each structural member is classified into one of the five classes [33]. Wide post-earthquake evaluation and strength assessment for Balkan Country discussed in book [6]. In USA are used documents ACI [2-3], and FEMA [12] and in Europe [11], and before mention *fib* [15] was used. In Japan, beside [33], [28] and [39] are used. For seismic calcification of structural damage, damage index recommended in [45], and for masonry building [49] and [53].

In U.S. Vision 2000, which gives the numerical definition of four intensity levels in terms of their return period or probability of exceed (*frequent* 50% in 30 years), occasional (50% in 50 years), rare (10% in 50 years), and very rare (5% in 50 years) is still used Fig.13, cited in [19].Performance levels and relative damage are shown in Fig. 14, [16].

Seismic behaviour and resistance deficiencies during a seismic event, the global behaviour of a masonry building are greatly influenced by the type of connection between walls and slabs. A good connection avoids out-of-plane brittle failures and mobilizes the in-plane shear resistance of walls – “box behaviour”. Shear failures may occur in three different types: Rocking, Sliding and Diagonal Cracking. Mixed masonry-concrete buildings (and other masonry structures) generally have insufficient strength for in plane and out-of-plane seismic actions.

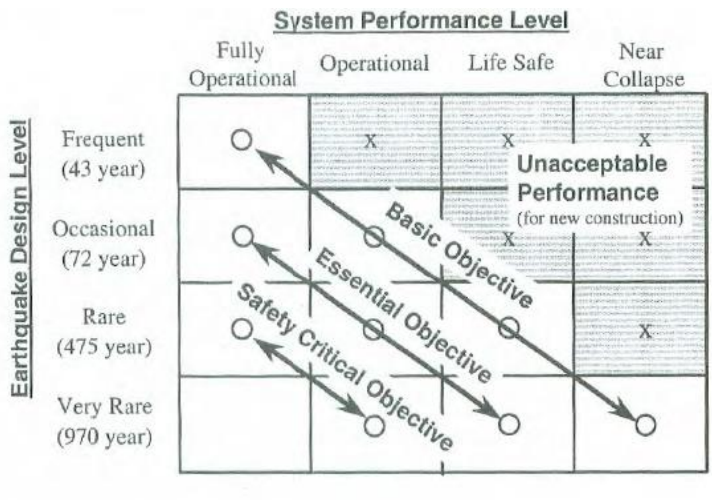

Fig. 13 Performance matrix 2000 vision

For historical buildings, the methodology proposed by ICOMOS is generally used, which shown in Fig. 15.In beginning Data acquisition(content historical investigation, field and monitoring); after structural behaviour, follow diagnosis and safety with explanatory report, and remedial measures with execution documents.

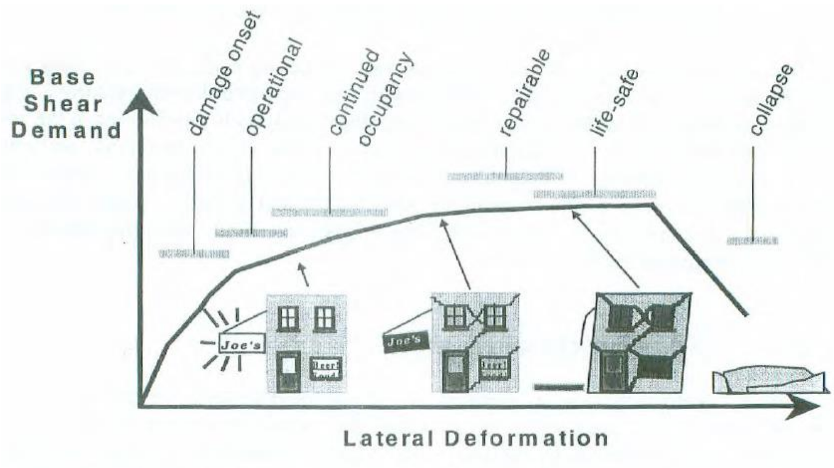

Fig. 14. Performance levels and relative damage, after [16]

Due to the great variety of structural configurations and materials used, rational approaches for the assessment of the seismic safety levels of such buildings are needed. A three-storey masonry building was considered with aspect of applicability of two contemporary seismic strengthening measures: the use of fibre-reinforced polymer (FRP) composites and the implementation of base-isolation to achieve the seismic protection levels. Non-linear static analyses (NSA) for different levels of seismic intensities were conducted on a model of the fixed-base [31]. Also microelement modelling technique for URM structures can use. The techniques, materials and design procedures in use for the structural restoration of historical buildings and monuments, damaged by earthquakes were outline in [42].

During the structural restoration, the original documents from earlier periods of construction are respected. At some time the use of traditional techniques and materials is clearly preferable. Stressed that modern techniques and materials are admissible where adequate capacity cannot be ensured by traditional techniques. Measures are necessary to protect and safeguard fresco and mosaic decoration excluded the use of some strengthening techniques that may cause damage. Analysis by means of FEM with microelements for mortar and bricks are used. The behaviour factor necessary for a quasi-static or dynamic–elastic analysis of the structure cannot be taken from the codes of practice for masonry structures. Bending combined with shear deformation has to be taken into account [21].

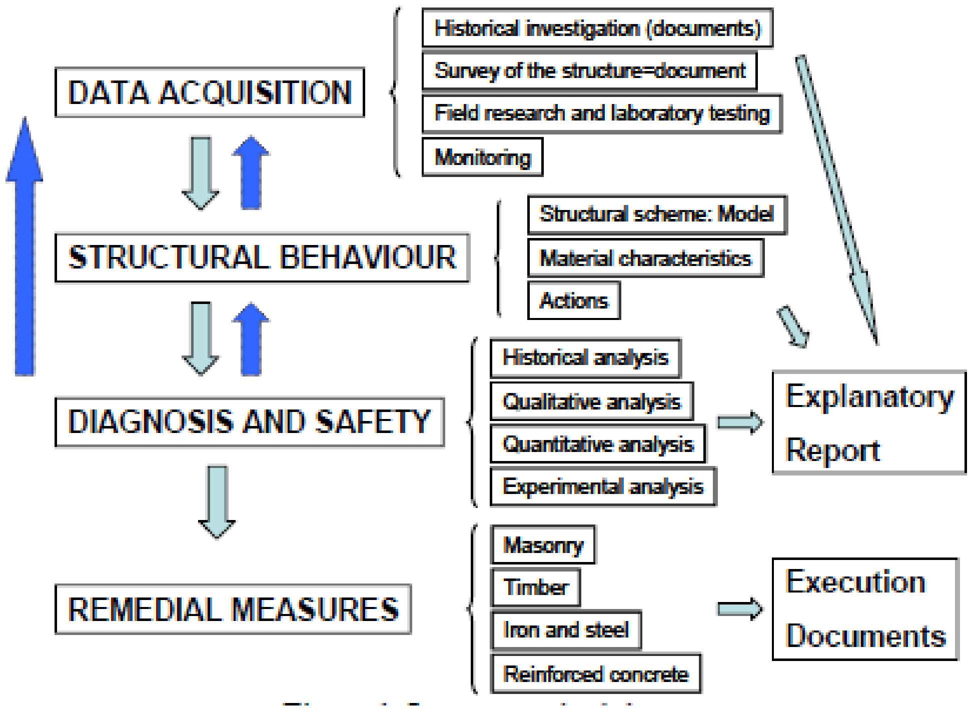

Fig. 15. ICOMOS methodology

After minor shaking, the building will be fully operational within a short time and the repair costs will be small. After moderate shaking, the building will be operational once the repair and strengthening of the damaged main members is completed. But, after a strong earthquake, the building may become dysfunctional for further use, but will stand so that people can be evacuated. In order to determine the residual strength, stiffness and ductility must using the information collected from site observation the damage in the structural system and non-structural elements. The nonlinear static evaluation procedure is known as the NSA method. Idealized roads of beam column concrete can be considered as: concentrated plasticity- plastic hinge or nonlinear spring hinge; and distributed plasticity with finite hinge zone, fibre section and finite element [16].

Modern European codes (EN 1998-1 and 1998-3, 2004) provide the rules for seismic design of new and existing damaged structures, respectively. Federal emergency management agency (FEMA) and applied technological council (ATC) work very actively in assessing conditions of structures after seismic events and for its upgrading. Current seismic design of structures is based on the presumed ductile response and yielding probability of some part of a structure, without transforming the structure into a mechanism of brittle failure. The Code provisions generally have two levels, limit state design, for earthquake resistant of buildings [52].

In the seismically active zones of southern and central Europe, unreinforced masonry (URM) structures are one of the most common types of buildings. Some of them possess a high historical value and could therefore be classified as part of the architectural heritage, requiring special attention with regard to their preservation and retrofitting measures [31].

Due to the great variety of structural configurations and materials used, rational approaches for the assessment of the seismic safety levels of such buildings are needed. The paper analyses the applicability of two contemporary seismic strengthening measures, namely the use of fibre-reinforced polymer composites and the implementation of base-isolation to achieve the desired, code-based seismic protection levels. A three-storey masonry building was considered in the study. Non-linear static analyses for different levels of seismic intensities were conducted on a mathematical model of the fixed-base, FRP-strengthened and base-isolated variants of the structure [31].

Setting a criterion on the evaluation of seismic safety of existing RC buildings is very important before structural redesign for design earthquake. Approach to the rehabilitation problem of a damaged building should be done in the following steps:
- Examination of a damaged building; development of alternative rehabilitation schemes;
- Examination of the feasibility as well as cost of each alternative;
- Final rehabilitation design.

Depending on the intensity of the earthquake and its effects, it affects the cost and duration of rehabilitation. Levels of Performance (Limit States in the EN) and Hazard Levels (Seismic action) of [11] adopts a fully performance-based approach for the evaluation and rehabilitation of existing buildings (Fig. 7): 1) *Near Collapse* (NC), the *Collapse Prevention* in US codes. The structure is heavily damaged, retains little residual strength and stiffness against lateral loads, but vertical elements can still carry the gravity loads. Most non-structural elements have collapsed; 2) The "*Significant Damage*" (SD) level, corresponding to the "*Life Safety*" (in the US) and to the local-collapse prevention performance level for which new structures are designed according to Part 1 of EN 1998. The structure is significantly damaged, but retains some residual lateral strength and stiffness and certainly its vertical load-bearing capacity. Repair may be uneconomical. 3) The "Damage Limitation" (DL) level, "Immediate Occupancy" in the USA[13]. The structure is only slightly damaged, without permanent deformations and do not need repair. Performance requirement Description Limit State of Near Collapse (NC). The structure is heavily damaged, with low residual lateral strength and stiffness, although vertical elements are still capable of sustaining vertical loads. Most non-structural components have collapsed. Large permanent drifts are present. The structure is near collapse and would probably not survive another earthquake, even of moderate intensity.

Limit State of Significant Damage (SD) - with some residual lateral strength and stiffness, and vertical elements are capable of sustaining vertical loads. Non-structural components are damaged, although partitions and infill have not failed out-of-plane. Moderate permanent drifts are present. The structure can sustain after-shocks of moderate intensity. The structure is likely to be uneconomic to repair. Limit State of Damage Limitation (DL) - only lightly damaged, with structural elements prevented from significant yielding and retaining their strength and stiffness properties. Non-structural components, such as partitions and infill, may show distributed cracking, but the damage could be economically repaired. Permanent drifts are negligible. The structure does not need any repair measures.

In USA Overall damage; Collapse Prevention(CP) level; Severe; Life Safety (LS) level; Moderate Immediate Occupancy(IO) level; Light Operational level Very light General Little residual stiffness and strength, but load bearing walls function. Some exits blocked. Building is near collapse. No out-of plane failure of walls or tipping of parapets. Some permanent drift and damage to partitions. Building may be beyond economical repair. No permanent drift.

Negligible damage occurs. Power and other utilities are available, possibly from standby sources. Comparison with performance intended for (new) buildings under the NEHRP provisions, for the design earthquake Significantly more damage and greater risk. Somewhat more damage and slightly higher risk. Less damage and lower risk.

For analysis and evaluation conditions of tructure used software packages. However, the calculation of masonry buildings is very complex. Masonry is an anisotropic, heterogeneous, and non-linear composite material that has been widely used in developing countries [51]. Although the response of the walls is likely to become highly non-linear (have cracked), a linear static or response spectrum analysis using force reduction factors is likely to give sufficient information on these points in well-designed buildings of regular form. Non-linear static or dynamic analysis may be employed to investigate redistribution of forces between walls in existing buildings, where one or more walls reach their ultimate strength for a seismic intensity below that considered for design on model [30], Fig. 16.

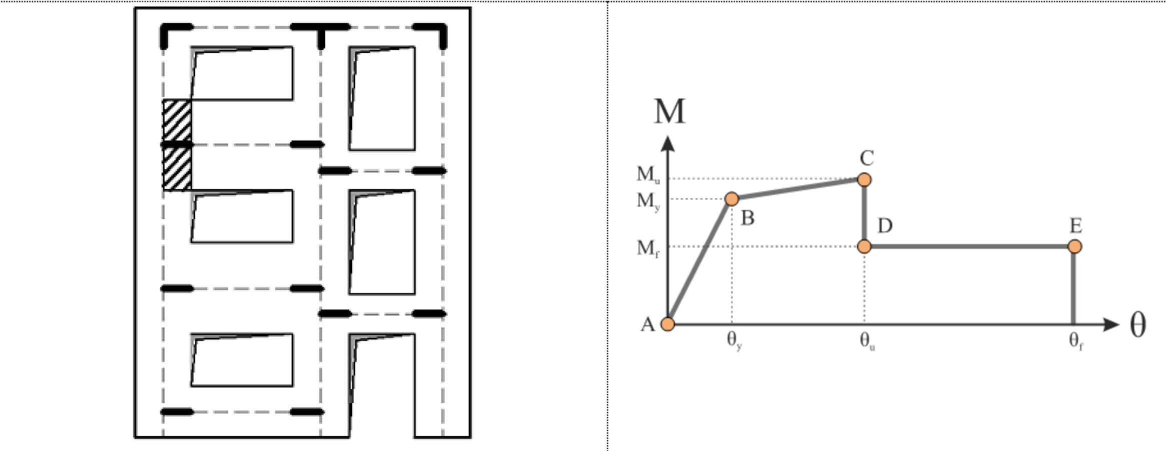

Fig. 16. Design model for masonry wall [30]

The flow diagram for the evaluation of the disease and the support of the diagnosis and the determination of the measures of therapy is attached in fig. 17.

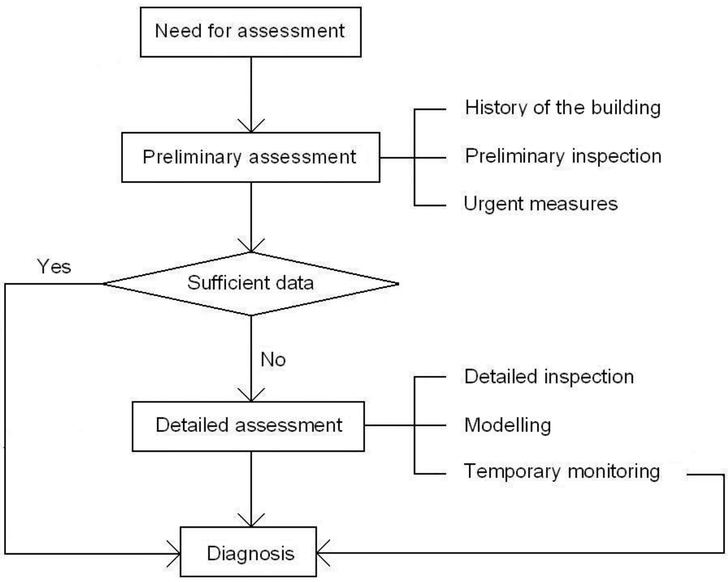

Fig. 17. Flowchart of the actions to be undertaken for the diagnosis of the building [22]

The relationship between strategies and measures applied in rehabilitation is shown in the flow chart in the figure 18. Flowchart of the actions to be undertaken in the phase of the structural assessment of the structure of building and make decision between repair and strengthening show in Fig. 19, and typical seismic strengthening methods for provide strength and ductility of structures in Fig. 20.

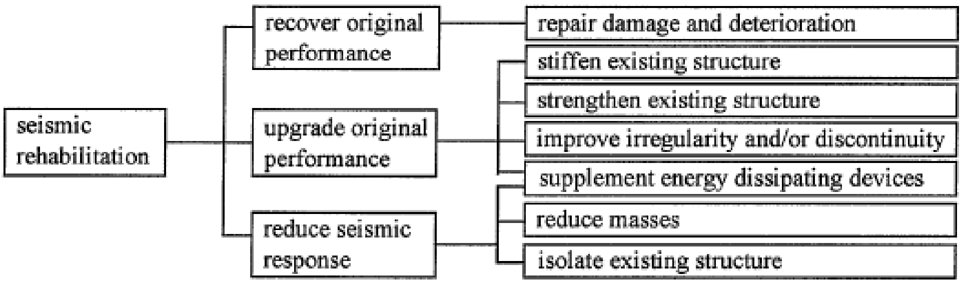

Fig. 18. Seismic rehabilitation strategy and measures, adopted from [51]

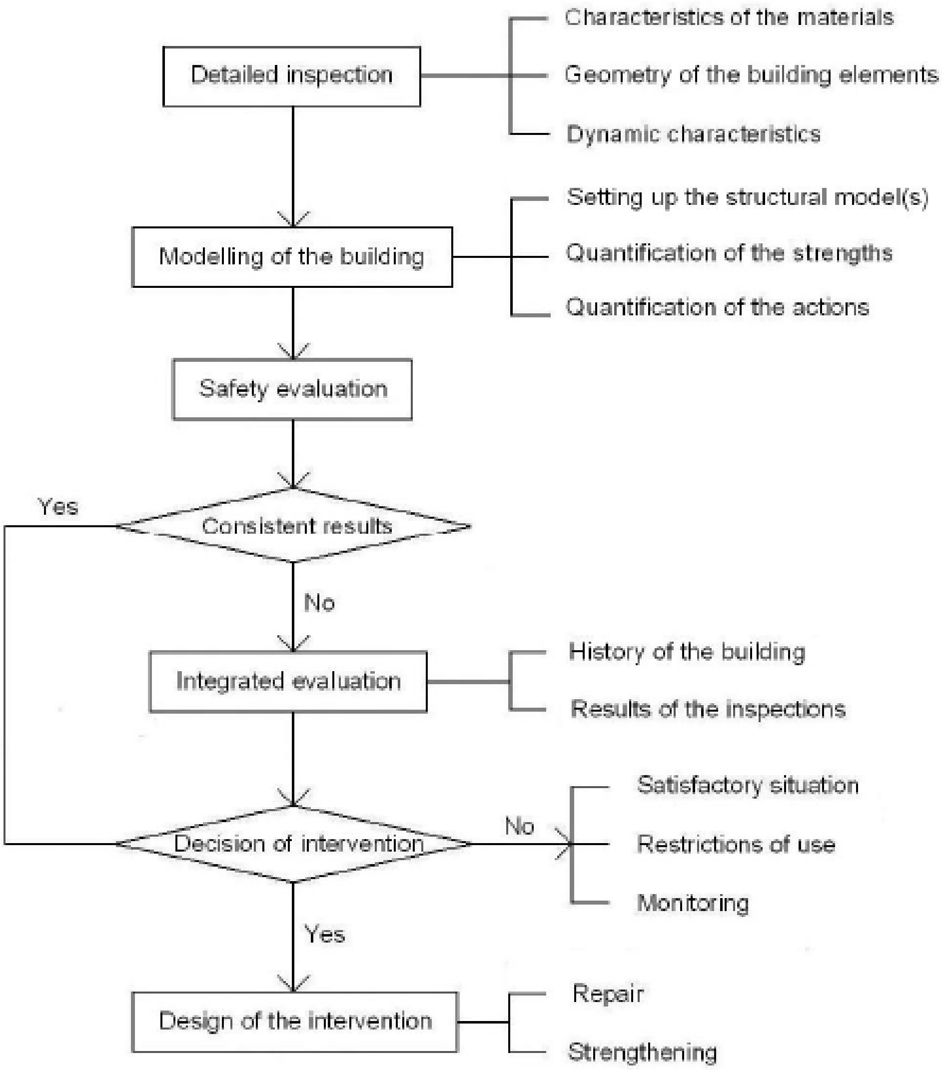

Fig. 19. Flowchart of the actions to be undertaken in the phase of the structural assessment of the building [22]

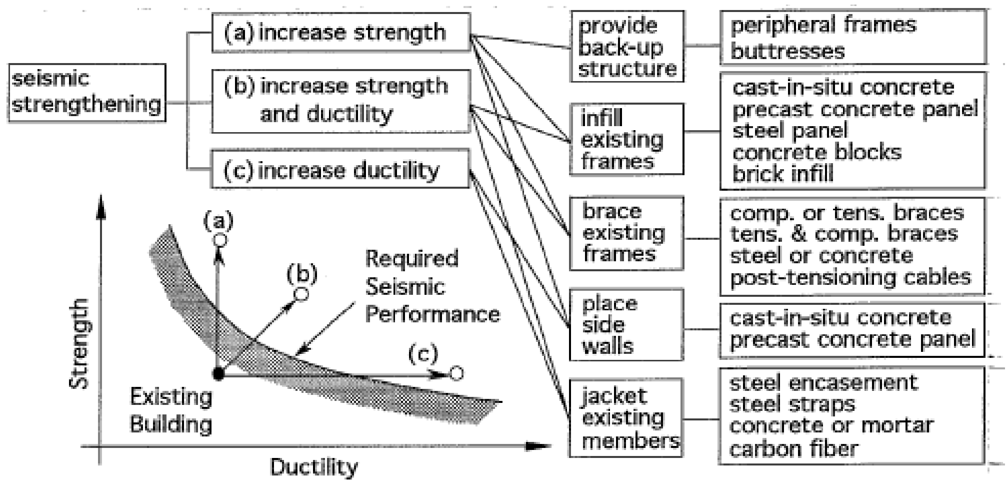

Fig. 20. Typical strengthening methods [22b]

For historical buildings, i.e. architectural heritage overview of the procedure for selection of retrofitting technique showed in Fig. 21, adopted from [48] and [50].

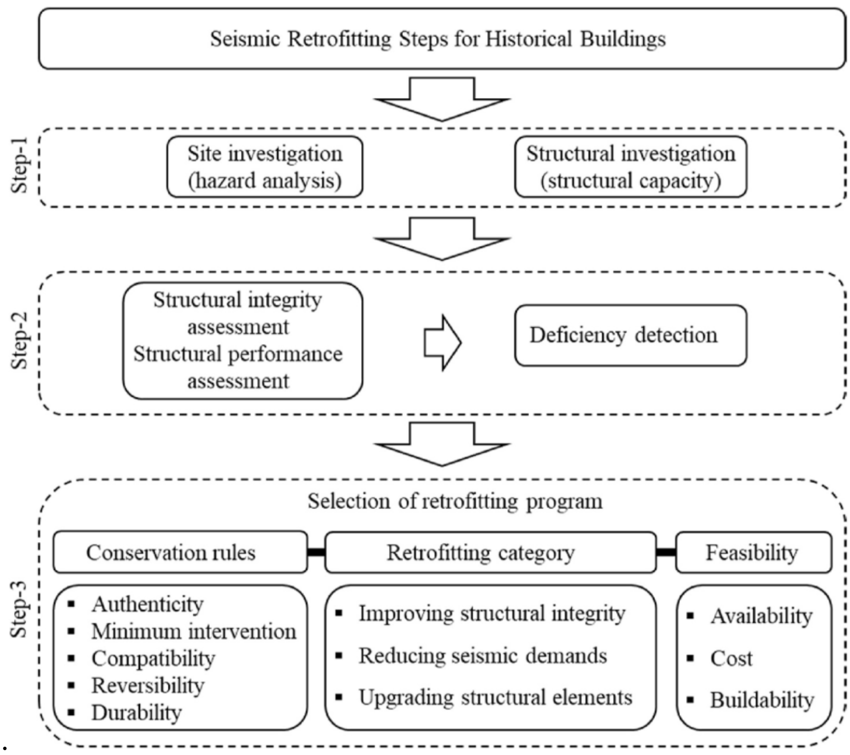

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Fig. 21. Overview of the procedure for selection of retrofitting technique for heritage buildings

The diagram shown in Figures 17 to 21 can be useful for making adequate decisions about the type and scope of interventions on the structures of concrete and masonry buildings. Buildings of architectural heritage are also included.

In *seismic rehabilitation*, analyses are made to estimate the safety and performance of the building prior to and after rehabilitation. The knowledge factor is used in the evaluation of the capacity of the cross sections and of elements to account for possible uncertainties.

Frequently level of knowledge is assumed to be limited factor is 0.75; for medium 0.90 and 1.00 for comprehensive level [11].

The performance goal of the strengthening needs to be defined. Is it merely tore instate the building to its condition before it was damaged by the earthquake, or is it to be upgraded and if so to what level? Damaged members need to be reinstated at least to the level that they can safely carry their gravity loads; otherwise they must be replaced. Grouting under pressure of cracks in concrete and masonry with epoxy mortar is a well-established technique which is quite reliable in reinstating the concrete to its previous capacity. Jacketing and plating, as previously described, can also be used to reinstate and strengthen damaged elements. Additional elements can then be added to take the demand
away from inadequate members under conditions of earthquake loading.

4. Rehabilitation/structural intervention on structures of buildings

4.1. Some rehabilitation of RC and masonry structures of buildings

Initial considerations may include the following.

(a) Damaged elements are likely to need repair or replacement.

(b) Irregularities in plan leading to tensional response (with an adequate arranged shear walls). Adding shear walls or cross-bracing reduce the torsional eccentricity.

(c) Irregularities in elevation giving rise to soft or weak storeys should be eliminated.

(d) Lack of tying together of a building may well be a concern in masonry buildings.

(e) Non-structural elements need protection (cladding elements, chimney, parapets, i.e.).

(f) Geotechnical aspects should be addressed (possibility of slope instability at or near the site, and foundation movements).

General criteria for the choice of a structural intervention: cost, both initial and future; durability of original and new elements, possibility quality control, materials; aesthetics and duration of work. *Technical criteria* guidelines for the choice of the intervention scheme: possible increases local ductility; and spreading the areas of inelastic behaviour as much as possible across the entire structure should be one task of intervention. Mass reduction, addition of new structural elements; base isolation; addition of new elements (bracing or infill walls) may be selected [41]. Braced frames are generally considered to be stiff systems in the elastic range. Their nonlinear response depends on their ability to redistribute forces between bays and drifts between stories. Important considerations for upgrading the seismic resistance of existing including investigation of existing structural characteristics, identification of significant deficiencies, and selection of appropriate upgrade criteria and retrofit systems are given in [23]. A review of strengthening schemes for RC buildings was shown in [46].

To prevent disaster in the future earthquakes, the existing deficient buildings need to be retrofitted. The basic requirements of rehabilitation and investigations of various retrofit techniques should be considered before selecting retrofit schemes. One way of retrofitting of the columns in RC multi-storeyed buildings is concrete jacketing [19] and [44].

Furthermore, methods are categorized based on the nature of the structure, application, and possible availability. A comparison of each method’s advantages and shortcomings is presented in terms of economy, sustainability, and buildability. Disruption to the continued occupation of a building is important. The transformation of the existing RC walls into anti-seismic shear walls is presented in [35]. In [37] state of research on seismic retrofit of concrete building structures (typical configurations and details) in the US is given.

New methods are often based on fiber reinforced polymers (FRPs) as new materials for intervention. Confinement of columns with composite materials leads to increase of lateral deformations. Deficiencies [53] have been identified during the seismic assessment of the building may be modified for improved earthquake resistance and/or deformation capacity within the seismic upgrading (such as the addition of shear walls [20]). Concrete, steel or fiber reinforced polymers (FRP) are normally used for the jacket. Steel and FRP jacketing are very popular in many countries since they have the advantage of a minimal increase of cross sectional dimensions, can be executed quickly with little interruption to the use of the structure while work is carried out [19].

Focus during the last few decades has been on seismic retrofitting and strengthening techniques using composite materials, both RC and masonry buildings structures. This review attempts to systematically investigate URM structures and commonly used retrofitting methods based on type and previous studies. Some examples for intervention on RC structure are shown in Fig. 22, for strengthening RC columns, for special details with anchorage and strengthening top and bottom of columns Fig. 23, and for column-beam joint on Fig. 24.

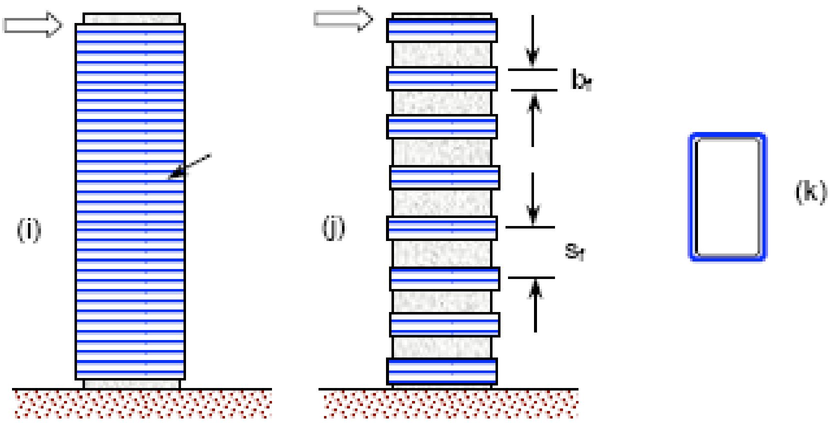

Figure 22. Schematic illustration of RC element strengthened in shear with externally bond: i) complete FRP wrapping; j) discrete strips of FRP; k) four sided wrapping of columns as i) and j), after [38]

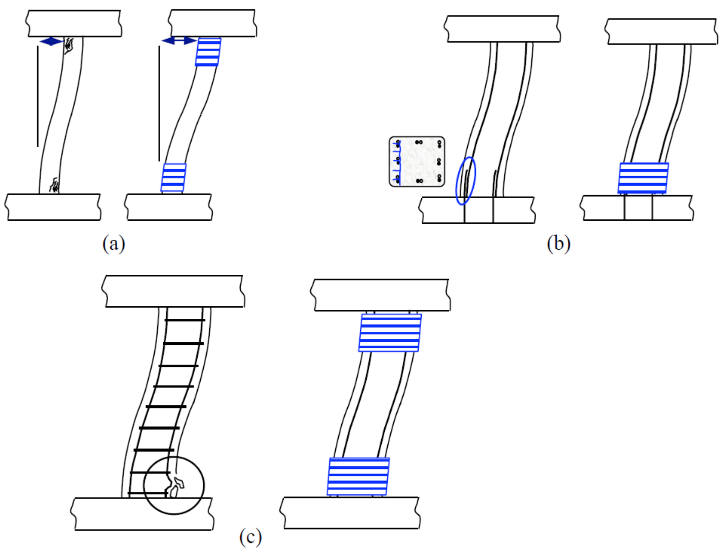

Fig. 23 Confinement of RC element with composite materials to: a) increase lateral deformation; b) prevent lap splice failure; c) delay rebar buckling

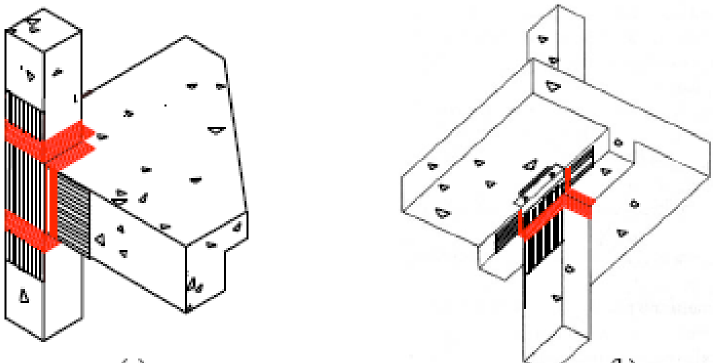

Figure 24. Typical composite material configurations for beam-column joint strengthening, a) external, b) interior joints [35]

Comparative strengthening columns wit FRP a) jacketing; and b) steel cage technique using steel straps or c) steel plates showed in Fig. 25.

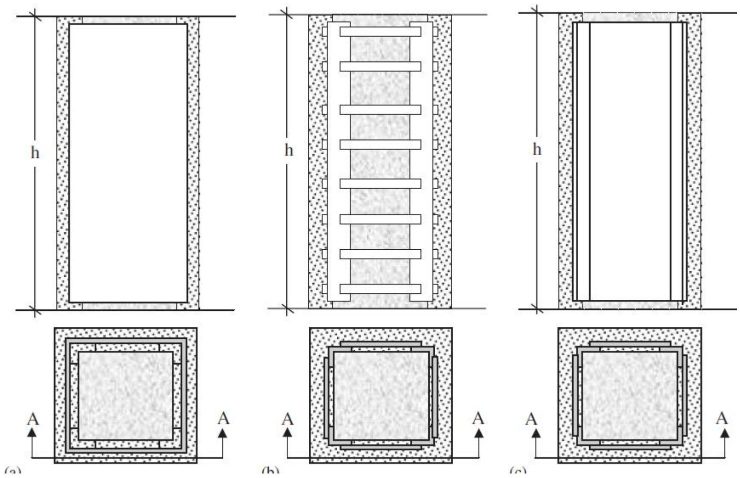

Fig. 28 Strengthening columns: a) jacketing; b) steel cage technique using steel straps or c) steel plates, after (Thermou and Elnashai, 2006) cited in [19] and [35]

Insufficient bearing capacity of slab structures can be strengthened by increasing its thickness and by placing additional reinforcement. The integration of the existing and the new layers of slab, i.e. the force transfer between old and new concrete layer, is of prime importance [17]. For this purposes, steel dowels or anchors can be used. For beams and RC columns similar procedures are used. Method for integration new and old concrete are show in Fig. 29.

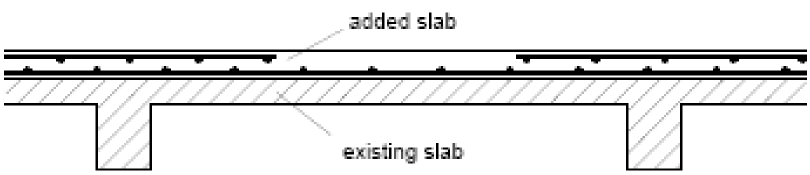

Fig. 29 Strengthening of a slab (concrete to concrete)

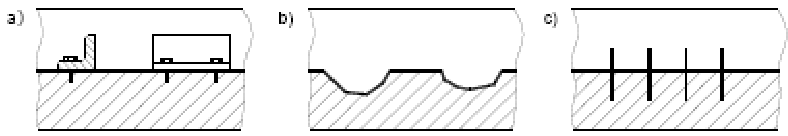

Fig. 30. Integration of the new and existing slab, after [35]

A deferent method for enlargement RC columns and jacketing application in Fig. 31 was shown.

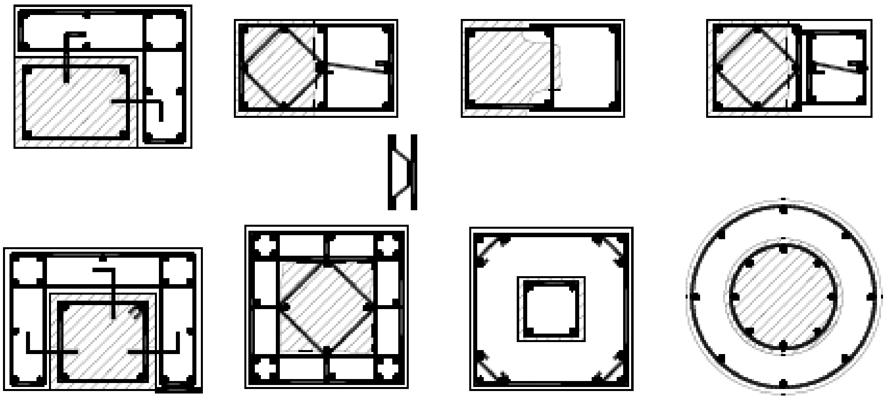

Fig. 31. Jacketing of columns, after [27]

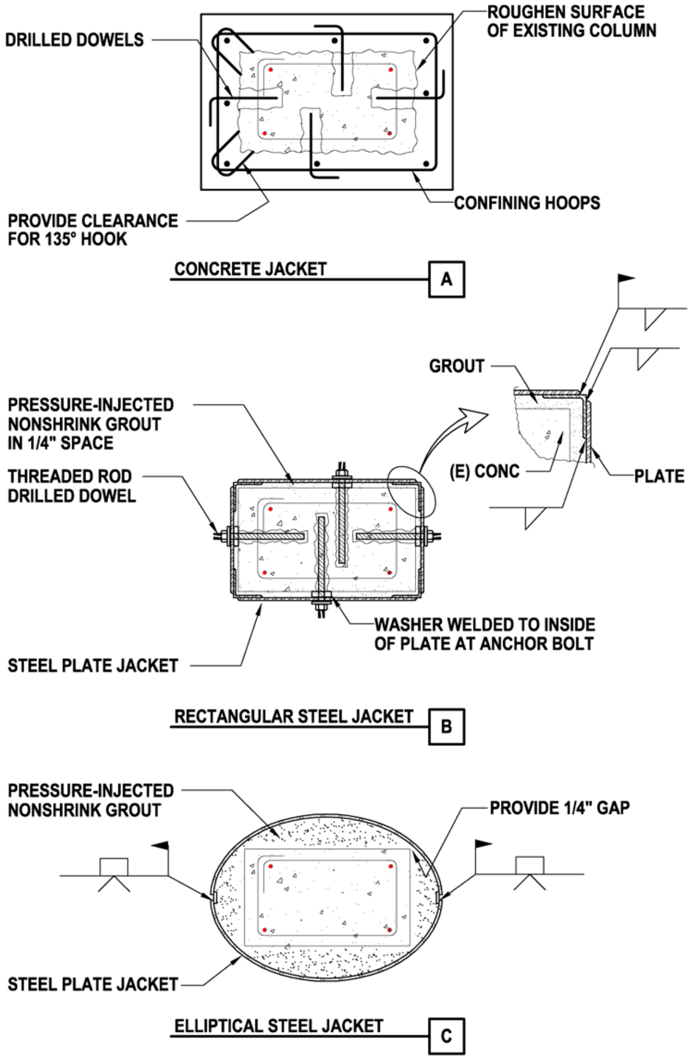

Fig. 31. Schematic illustration of RC element strengthened with different method, Concrete and steel jacketing of columns [35] and USA practice, cited in [19]

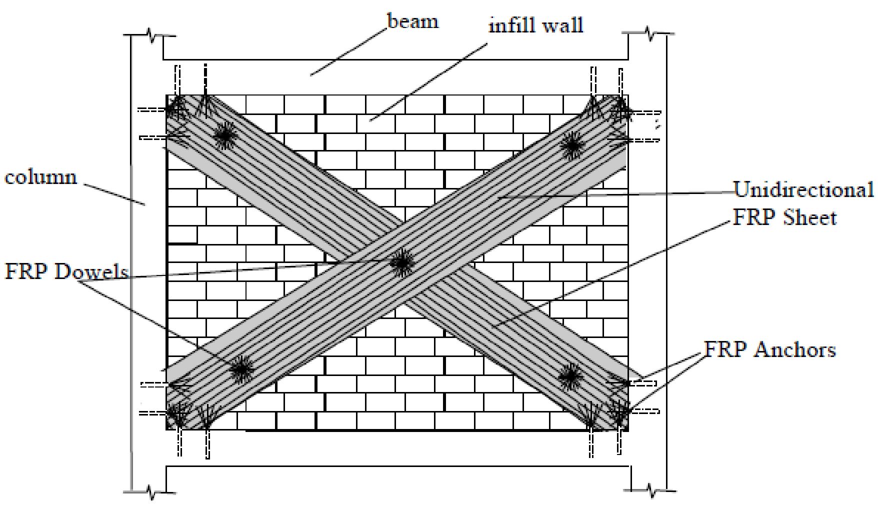

Fig. 32. FRP strengthening method for reinforced concrete frames with infill walls [38]

The performance goal of the strengthening needs to be defined. Is it merely toreinstate the building to its condition before it was damaged by the earthquake, or is it to be upgraded and if so to what level? Damaged members need to be reinstated at least to the level that they can safely carry their gravity loads; otherwise they must be replaced. Grouting under pressure of cracks in concrete and masonry with epoxy mortar is a well-established technique which is quite reliable in reinstating the concrete to its previous capacity. Jacketing and plating, as previously described, can also be used to reinstate and strengthen damaged elements. Additional elements can then be added to take the demand away from inadequate members under conditions of earthquake loading. ASCE/SEI Standard 41-06 is a valuable tool for structural engineers and the public for improving seismic performance of existing buildings.

In [5] discuss the application of *cost–benefit analysis* to thechoice of performance level. Achieving higher performance levels implies higherinitial costs, but it also impliesa potential for future savings due to reduced damage in future earthquakes.

4.2. Upgrading of historic buildings

A number of special considerations apply to historic buildings, including:

(a) Their historical significance implies that they need preserving for many future generations, so the return period of the design needs to be correspondingly long.

(b) The upgrading needs to pay particular attention to the cultural and architectural values of the original construction. Balancing the need to prevent future damage while preserving the original delight and value of an old building is perhaps as much an art as a science, particularly where the 'original construction' has been built and altered over many years.

(c) Often, it will be difficult to gain full knowledge of the properties of the materials and methods of construction.

(d) As far as possible, strengthening measures should be reversible, so that they can be removed and modified without damage to the original, if in future more effective measures are developed. In practice, this may be difficult to achieve fully, but the strengthening measures should 'respect, as far as possible, the character and integrity of the original structure' (Feilden 1987) citrate in [5]. Prepared by ICCROM (International Centre for the

Study and Restoration of Cultural Property, Rome). These contain much practical advice on the issues involved.

Seismic isolation technique has the potential to protect both structure and non-structure from earthquake damage, while minimising the intervention required to a single isolation plane. It is therefore particularly suitable if preservation of the existing architecture.

In the most frequent types of historic masonry (double or three-leaf masonrywith loose connection between leaves), there is a more or less continuous vertical joint within the thickness of masonry. The failure of those types of masonry in compression is characterized by the occurrence of vertical cracks on the faces of masonry.). Actually, although the two families of cracks open at almost the same vertical load, the transverse ones grow faster. Thus, the failure of masonry is due to simultaneous compression and out-of-plane flexure of the leaves. It should be noted that cracks within the thickness of masonry are not visible or detectable (unless significant out-of-plane deformation of masonry has occurred).Such cracks may be due to decay of materials, as well as to previous normal and seismic actions on the structure including arches and domes (Fig.10).

The behaviour of masonry elements under in-plane shear is of major significance for the seismic response of buildings, as documented by typical damage, i.e. diagonal or bi-diagonal cracks in walls and spandrels. Thus, numerous research works were devoted to the behaviour of masonry under shear. It is well known that in historic buildings subjected to seismic actions, the out-of plane behaviour of (solid or with openings) walls may be critical. The vulnerability to out-of-plane actions is due to typical characteristics of historic masonry buildings, namely, the flexible floor and roof diaphragms, as well as the defective connection between floors/roof and walls (allowing for significant out-of-plane deformations of walls), the defective connection of walls at building corners, the presence of openings close to the corners [21], [31], [36] and [47].

This paper covers the following topics [47] and [51]:

- Design strategies for strengthening;
- Assessing the seismic adequacy of existing buildings;
- Methods of strengthening;
- Assessing earthquake-damaged buildings;
- Special considerations for historic buildings

Among the *possible* options are the following.

(a) Addition of shear walls;

(b) Cross-bracing;

c) Passive dampers;

(d) Jacketing of concrete frame elements.

(g) Reinforcing wall-to-floor connections-The connection of a timber floor to supporting masonry walls may be improvedby bolted to the existing floor;

(h) Guniting of masonry walls - Masonry walls can be strengthened adding a thin layer of mortar to one or both faces. The layer is strengthened with a light mesh reinforcement, and the mortar is;

(i) Seismic isolation

Floors play a vital role in seismic resistance by distributing the inertial forces generated in an earthquake back to the lateral resisting elements, and by tying the entire structure together. The strength and stiffness of timber floors can been proved by screwing additional plywood sheets to the floor joists and providing. Adding steel cross-bracing to an inadequate concrete or steel moment frame building is an alternative technique to the addition of concrete shear walls.

A number of special considerations apply to historic buildings, including:
(a) Their historical significance implies that they need preserving for many future generations, so the return period of the design needs to be correspondingly long.
(b) The upgrading needs to pay particular attention to the cultural and architectural values of the original construction.
(c) Often, it will be gain full knowledge of the materials and methods of construction.
(d) As far as possible, strengthening measures should be reversible, so that they
can be removed and modified without damage to the original, and should ‘respect, as far as possible, the character and integrity of the original structure’

Eurocode 8 provides Simple rules for masonry buildings without calculation (simple MB). The need for structural rehabilitation of heritage buildings is, motivated by:
- The existence of visible defects in the building;
- Damage after a particular event that affects its stability (earthquake, etc.);
- The change of the use of the building for most severe conditions; and
- Requirement of the competent authority, for instance, when there is an increase in the actions (earthquake action, traffic action, etc) imposed by new codes [22] defends the adoption of the following principles:
- Guarantee of structural safety;
- Respect for the cultural value of the building;
- Minimum intervention;
- Reversibility of the intervention;
- Integration on the whole building;
- Compatibility of the materials;

The purpose of the *historical survey* is to understand the conception and the *significance of the building*, the techniques and the skills used in its construction in both the structure and its environment and any events that may have caused damage. Direct observation of the structure is an essential phase usually carried out by a qualified team and to give an subsequent investigations decay and damage and applied urgent measures. Tests usually aim to identify the mechanical characteristics of the materials and of the structure (and any discontinuities). The structural scheme and damage also survey.

Before redesign intervention on structure designer must be determine whether or not the safety levels are acceptable, by analysing the present condition of both structure and materials. The safety evaluation is therefore an essential step in the project of restoration [22b]. Understanding the complexity of an ancient building or monument, uncertainties regarding material characteristics, the unknown influence of previous phenomena and imperfect knowledge of alterations and repairs carried out in the past. For chose appropriate decisions must used adequate mathematical model. For safety evaluation, can combined analysis of the information obtained from each of them, which
may lead to the 'best judgement'.

The term masonry here refers to stone, brick and earth based construction adobe. Materials have a very low tensile strength and may easily show cracking within elements. Local intervention techniques are applied to a group of members that suffer from structural deficiencies and a combination of these techniques. Another effective technique consists in the application of FRP (carbon or glass fibers) confine completely the column. The column in all directions and injected with cement grout or epoxy resin.

Crack injection is a versatile and economical method of repairing RC structures. The effectiveness of the repair process depends on the ability of the adhesive material (epoxies) to penetrate into the fine cracks of the damaged concrete. This repair method can be used in minor (<0.1 mm), medium (<3 mm) size cracks, and large crack widths (up to 5 - 6 mm). In case of larger cracks, up to 20 mm wide, cement grout, as opposed to epoxy compounds.

Shotcrete is used as a repair method for RC and MS. Shotcrete can be applied to almost any surface; it can also be used in combination with RC jacket. It achieves excellent bond to most competent surfaces.

Addition of new reinforced concrete walls is one of the most common methods used for strengthening of existing structures [20]. Method is efficient in controlling global lateral drift and reducing damage in frame members and achieved a regular building configuration [13]. Seismic rehabilitation of substandard R.C. buildings with masonry infill.

FRP techniques for strengthening /upgrading may be noted as following:

• Externally bonded FRP (EBR).
- FRP plate bonding.
- FRP Confining or jacketing.
• Sprayed fiber reinforced polymers.
• Near Surface Mounted with FRP.
• Prestressed FRP.

Constructed structures provide context to aesthetic, cultural, social, archaeological, and technological issues for future generations to treasure. Seismic behaviour for masonry structures is highly dependent upon material properties, geometry, unit arrangement, connections, foundation, etc.

Steel bracing can be a very effective method for global strengthening of buildings. of external steel systems minimum disruption to the function of the building and its occupants. to provide a significant increase in horizontal capacity of the structure. Moreover the comparison between conventional and innovative devices showed that shape memory alloys (SMA)-based devices are far more effective than rubber isolators in reducing seismic vibrations.

In general, seismic rehabilitation may aim to either recover or upgrade the original performance or reduce the seismic response [42]. The crack injection (epoxy resin injection or grout injection) technique and the member replacement (substitute part of the damaged member) may apply.

The type of intervention includes (EC8):

(a) Injection of cracks.
(b) Local replacement of damaged concrete and steel.
(c) Using thin steel plates for strengthening of RC slabs or beams.
(d) Confinement of RC element (mainly of columns) by means of collars, spirals, etc.
(e) Providing additional RC layers for flexural or shear strengthening of beams.
(f) Providing infill in the frames.
(g) Providing reinforced concrete jackets on columns.

The types of intervention on masonry buildings are as follows [11]:

(a) Reduction of the mass, by removal of heavy roof covering, and parapets, etc.
(b) Reduction of the eccentricity between the mass and the stiffness centers;
(c) Addition of new bracing walls;
(d) Improvement of the connections horizontal diaphragms with vertical elements;

(e) Improvement of the diaphragmatic action of the floors;
(f) Improvement of the quality of the masonry (by grouting);
(g) Repair of cracked walls;
(h) Application of vertical and horizontal confining elements to the walls;
(i) Application of transversal confinement to the edges of masonry piers;
(j) Strengthening of buildings by means of steel ties.

For ordinary buildings seismic risk assessment is typically carried out for the performance condition of life safety and collapse prevention, related to a seismic hazard scenario related to a 10 % probability of exceedence in 50 year or 475 year return period. For historic buildings in city centre and in case of assets of particular value, it might be more appropriate to consider the performance condition of damage limitation or significant damage associated to lower-intensity and shorter return period seismic hazard [9], [21], [32], [38] and [46-47]. ISMEP project. A most important criterion of distinguishing vulnerability approaches for Historic buildings, is whether the method is purely empirical, i.e. based on observation and record of damage in past earthquake, from which a correlation between Seismic Vulnerability and Risk Assessment of Historic Masonry Buildings in Italy

Direct techniques use only one step to estimate the damage caused to a structure by an earthquake, employing two types of methods; *typological* and *mechanical*: *Typological methods*—classify buildings into classes depending on materials, construction techniques, structural features and other factors influencing building response. *Mechanical methods*—predict the seismic effect on the structure through the use of an appropriate mechanical model, which may be more or less complex, of the whole building or of an individual structural element. *Indirect techniques* initially involve the determination of a damage index[45], by establishment of the relationships between damage and seismic intensity(peak ground acceleration, PGA),supported by statistical studies of post-earthquake damage data.

The rapid screening ATC-21 techniques extensively used in the U.S. Conventional techniques are essentially heuristic, introducing vulnerability index for the prediction of the level of damage. There are essentially two types of approach: those that qualify the different physical characteristics of structures empirically and those based on the criteria defined in seismic design standards for structures, evaluating the capacity-demand relationship of buildings ATC-13 and ASCE [3]. Uncertainty is treated explicitly through a probabilistic approach. The capacity of the structure, spectral displacementand inter-story drift limit is defined for different levels of damage. The ACI code for Assessment, Repair, and Rehabilitation of Existing Concrete Structures (ACI 562M-16) states that the design of the repair system shall consider the properties and installation of the repair materials and systems. *Hybrid techniques* combine features of the methods described previously, such as vulnerability functions based on observed vulnerability and expert judgment.

4. Conclusion and final remarks

This paper provides an overview of the literature on the behaviour of historic RC and masonry elements and buildings. Thus, selected publications are evaluated related to the behaviour of elements in compression, diagonal compression, in-plane shear and out-of-plane bending. Yet, this is a prerequisite for a reliable assessment of the current state of historic structures and, by way of consequence, for the selection of adequate intervention techniques for their preservation.

Damage affects the behaviour of individual components differently. Some exhibit ductile modes of post-elastic behaviour, maintaining strength even with large displacements (which is desirable). Others are brittle and lose strength abruptly after small inelastic displacements (which is undesirable) [14]. The task now is to identify acceptable forms of damage and desirable building behaviour during earthquakes. Failure of RC columns happened primarily due to the lack of lateral reinforcement.

The present seismicity of the region, characteristics of the ground motions, and damage mechanisms must be investigated. In high-seismicity area, rehabilitation of buildings must provide ductile (convenient mechanism) instead of brittle behaviour. In frame structures, the damage is likely to occur at first in the beams and then in columns (columns in frame should be stronger than beams). Members must be detailed properly in order to have large ductility (despite seismic energy). It is very important to provide rigid diaphragm action (floor slabs are stiff in its own plane).

It is very important to choose an adequate structural system and foundations and to provide the capacity and limiting deformation. It is necessary to achieve the basic performance of foundations in its strength, stiffness and ductility. Those documents provide a framework and guidelines for evaluation conditions and decision of the type of intervention on damaged structures [19].

Seismic evaluation of the existing structures is a complex task. Use of sophisticated evaluation and strengthening procedure is reasonable when the level of knowledge for the structural system is relatively high. Use of advanced technology materials is only recommended, when concrete quality of the existing buildings is relatively good [17] and [19].

In decision process for the degree and the type of intervention, the following factors are considered: the layout of structural system; the strength of structures; the flexibility of structures and their ductility. The ductility requirements for RC buildings are: strong columns – weak beams; adequate shear reinforcement, so that bending mode of failure is provided; confined compression zones with close hoops or ties (EC8).

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