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ASSESSMENT AND REDESIGN OF EXISTING STRUCTURES CURRENT DEVELOPMENTS IN EUROPE

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ABSTRACT

In the seismic countries of Europe, structures and infrastructures built until very recently according to codes which were not adequate (some of them are still not so) have an unacceptably high level of risk. The safety problems posed by existing structures under normal types of loads have been considered by the scientific community since several years now, and a number of documents of fundamental and applicative nature are either available or in the making. For seismic actions, however, the state is less advanced, due to a later recognition of the gravity of the issue, to the much larger uncertainties associated with the action itself, with the complexity of the behaviour of the elements in a stage close to their ultimate and, finally, to the advanced technology required for an effective and economical upgrading. The european code for earthquake resistant design: Eurocode 8, contains a part, issued in 1996, titled: "Strengthening and Repair of Buildings". It is the first attempt to codify such a difficult design situation, and in a partial safety factors format. The structure of the document is outlined in the paper, with the focus on those steps which have the larger impact on the safety of the building after redesign, and on which efforts will need to be spent in the next period to reduce the now unavoidable wide margins of uncertainty.

KEYWORDS

Assessment, Codes, Existing Structures, Reliability, Strengthening

INTRODUCTION

The problem of existing structures is self aggravating by its essence, as old structures deteriorate at a faster rate and newer ones add gradually but continuosly to the total number of those to be classified as inadequate.

Modern construction industry is now well over a century old in many parts of the world, and the enormous amount of building construction due to urbanization which has taken place in the last fifty years is also clearly showing the signs of its age. In Europe, the dimensions of the problem are possibly wider than, for ex., in the USA and in Japan, since by tradition almost all buildings here, including the simple residential ones, are built "to last", and the percentage of those who are abandoned or demolished is negligible.

If the interest is restricted to existing structures exposed to seismic hazard, the problem reduces considerably in size, but what is left constitutes the hardest part of it. The seismic events occurred in the last few years around the globe have provided ample evidence that inadequate structures are not the old ones only, but the just recently completed as well. Be it due to the fact that several norms presently in vigour do not yet reflect the available state of knowledge, or that buildings have been designed in accordance with older, unsafe, norms, or without norms at all, or be it due to poor construction even if in formal accordance with some norms, the reality is that only a small fraction of all existing structures would pass favourably a close scrutiny of their antiseismic abilities.

And the picture would not be complete without at least a mention to one aspect of the problem which is peculiar to a small number of countries, and of regions within countries, but whose relevance is universal. It is the case of old historical centers, located in areas of moderate to large seismic activity: thousands of these are present in Italy only, many of them world famous and representing the living memory of the evolution of our civilization. These towns used to live with earthquakes, rapairing and rebuilding after their occurrence. What is now the correct attitude towards them? What are the acceptable prevention criteria that could be applied without depriving them of their essential features? These issues are debated at a national and international level in the mediterranean countries (old and seismic), and codes of conduct with principles and rules of general character have been agreed upon and start to be followed in practice.

For ordinary structures, the problems of maintenance, assessment and repair have been recognized by the scientific community in Europe since quite a long time. Examples are: the CEB (Comité Eurointernational du Béton) which cultivates the subject from more than fifteen years, has already published two documents of informative nature (CEB, 1983), (CEB, 1989), and is now developing one with the character of a guideline (CEB, 1996); the JCSS (Joint Committee in Structural Safety), which brings together specialists of reliability methods and problems from seven european and international associations: CEB - CECM - CIB - FIP - IABSE - IASS - RILEM, is also well advanced in the drafting of a document (JCSS, 1996) more formally based on a probabilistic approach to reliability evaluation of existing structures.

None of the referenced activities, however, considers explicity the seismic action, and it has been noted already how significant is this omission for seismically active countries.

Fortunately, the point has not been missed by the european authorities when planning the system of harmonized technical design rules which has become known as "Eurocodes".

Part 1.4 of the Eurocode 8 (Eurocode 8, 1996) deals with "Strengthening and Repair of Buildings", and its scope is defined in the document as:
- to provide criteria for the evaluation of the seismic performances of existing individual structures;
- to describe the approach in selecting necessary corrective measures;
- to set forth criteria for the design of strengthening/repair measures, including conception, structural analysis after the intervention, dimensioning of the new elements and of their connections to the existing ones.

An Annex to Part 1.4 contains additional criteria and constraints applicable to monuments and historical buildings.

The following presentation is intended to outline the character and a few salient features of Part 1.4 of EC8. The document, issued in 1995, will be used experimentally for a period of three years and subsequently revised on the basis of the comments formally presented by CEN member countries.

EUROCODE 8 PART 1.4. CHARACTER OF THE DOCUMENT

All Eurocodes qualify themselves as "performance oriented" and "reliability based". The target reliabilities associated with the set of desired performances, these latter defined in terms of two or more limit-states of structural performance, are nominally satisfied through the use of a partial safety factors format.

Apart from the fact that a number of the partial factors can be and has been separately calibrated by means of probabilistic models, the procedure is essentially deterministic, and the question of how much reliability is achieved in any given structure is not pursued in practice.

It is recognized that besides the rationality of the procedures adopted and the technical knowledge on which they are based, the main source of legitimacy for this simplified implementation lies in the acceptance by the society of the performances demonstrated by the structures built according to it. The same would apply to a fully probabilistic code as well: the number of pragmatical choices which are necessary to compensate for the lack of exhaustive knowledge would not allow to define it other than a set of operational rules for producing designs under official public approval.

Some codes can be better than others, however, because of a greater flexibility in incorporating the feed-back from observed performances and of a richer articulation allowing to better account for the interaction between uncertainty sources.

After the labour of a regeneration that has lasted about twenty years modern codes for the design of new structures can be said to possess the qualities of flexibility and articulation to an adequate extent, and also a sufficient number of iterations has already occurred between code provisions and practical application to make the former acceptably reliable.

A comparable background is not available, unfortunately, for existing structures. This is the main argument of those opposing the idea of a code for such structures, in favor of less binding documents as for ex. a guideline.

A guideline, however, is the appropriate tool for problems of specialized nature and limited size, while the interventions on existing structures are becoming more and more common by the day, so that an official public position is needed in the same way as for the new structures.

Writing such a code is, admittedly, an act of courage and of imagination, since it cannot be conceded that some of the necessary ingredients need to be tentatively invented for the occasion. Among them:

a) design of new structures is a forward-only moving procedure, and its product is automatically deemed to be good if the rules have been respected. On the contrary, the prelude to any intervention is a diagnosis, to ascertain whether and of what sort such intervention is needed. The concept of assessment may not be intuitively foreign to a good engineer, but he needs to have well defined operative rules to restrict the area of subjectivity, in the interest of a more uniform safety and of a more balanced use of the resources;

b) the uncertainties that one may have in the face of an existing structure are not necessarily larger than for a future one, but they are of a different sort, and often less amenable to standardized treatment;

c) the possible typologies of intervention are almost uncountable, and the technologies used may be innovative: both aspects would require in principle the derivation of appropriate new sets of safety factors;

d) the society is not yet prepared in general to set safety standards for the old structures that have to be strengthened, and standards derived on a purely economic (i.e. excluding the concept of utility) cost-benefit analysis are not necessarily the most rational ones on a wider context.

The solution proposed by EC8 Part 1.4 for the above mentioned problems can be reduced to a single dominant concept.

Once the differences between a redesign and a design situation have been clearly identified, and *indications* are given on how to account for these differences on the analysis procedures and on all the safety elements which are used, the two processes of design and redesign should follow identical courses, with a minimum of unavoidable exceptions.

In this way, the recognizedly formalistic but officially approved design procedure for new structures is extended naturally to the existing ones, lending to these latter a comparable level of safety.

OUTLINE OF EUROCODE 8 PART 1.4

The document consists of four main chapters ordered in logical sequence: *Information for structural assessment - Evaluation - Decision for structural intervention - Redesign.*

Information

Indications are given on the sources where to collect the information from, the inspection procedures to be followed, etc.

Worth to be noted is the fact that the information is finalized to categorize the structure within the same framework of the main document for new structures (henceforth called EC8) with respect to: Structural type, Subsoil conditions, Importance category. When this is not feasible, "appropriate allowance must be made for the consequent uncertainty".

Evaluation

Seismic Action. The reference seismic action is the one foreseen in EC8 for the typology and the seismic area under consideration. The possibility of a reduction of the value of the peak ground acceleration is contemplated, however, as a consequence of:

a) an accepted reduction of the remaining life of the structure, in cases where this decision makes sense, and provided actions are taken so that at the end of the assumed life the building is actually demolished, or fully upgraded;

b) a possible higher value of the acceptable probability of exceedance "in order to optimise broader social economical and/or historical goals".

It goes without saying that decisions with respect to point b) can only be taken by public authorities.

Material Properties. For the characteristics values of the strength of concrete and steel, reference can be made to the classes foreseen in EC8 only if all of the following conditions are met:
- the values are indicated in the original design documents, and these are fully available;
- there are no indications of inadequacy due to poor construction, or of degradation due to age;
- results of in-situ tests are available, confirming the design indications.

If one or more of the conditions above is not met, direct tests are mandatory, either destructive or not, to be made on homogeneous portions of the structure, and the characteristic value must be determined as the lower 5% fractile of the measured values.

The partial safety factors γ_M to be applied to the characteristic values of the strengths can be reduced, if adequate sampling or in-situ tests of the materials have been carried out. In the Appendix (informative) the suggested reduced values of γ_M are:

γ_s = 1,05 (instead of 1.15) for steel reinforcement
γ_c = 1,20 (instead of 1,40) for concrete

Modeling. Modeling of the structure for the purpose of the analysis requires essentially the knowledge of the geometry and an estimate of the stiffness properties of the elements, including the in-plane stiffness of the floors and that of the foundation and foundation soil.

Whenever possible, ambient (or forced) vibrations should be used to check the calculated fundamental period.

Analysis. The analysis is to be carried out by using one of the methods allowed by EC8 depending on structural type and regularity class, for the same seismic loads combination and with the seismic action affected by a properly selected value of q (force reduction factor in EC8). The last point is a critical one for older structures, for ex. reinforced concrete structures, due to the different (lower) bond properties of steel bars, insufficient transverse reinforcement both for ductility and for shear resistance, inadequate lap splicing in hinge zones, etc. The ductility assumed at a global level for the sake of the analysis should be afterwards related to and checked with the ductility available at a local level.

More accurate analyses as, for ex., non linear static or dynamic analyses, may also be used, if the necessary data are available and can be relied upon.

Verification. If the standard elastic methods of analysis have been used, the verifications are carried out on a section by section basis, by checking the following inequality:

$$\gamma_{Sd} \cdot Ed = \frac{1}{\gamma_{Rd}} Rd$$

where:

γ_{Sd} is a model uncertainty factor, to be applied and quantified based on judgment, depending on the degree of uncertainty related to the structural model used.

Ed is the local action effect due to the seismic combination, including capacity design effects.

γ_{Rd} reflects the uncertainty on the resisting mechanism. Indicative values of γ_{Rd} are proposed in the Appendix, as γ_{Rd} = 1,30, 1,10, 1,0 for importance categories I and II, III and IV, respectively. The values above should presumably be understood as applicable for a given degree of uncertainty and different importance categories.

Rd is the strength of the section/mechanism evaluated with the revised γ_M factors values.

Decision for structural intervention. Whenever the outcome of the assessment phase is negative a structural intervention is required. After the intervention, the safety requirements of EC8 for new constructions have to be fulfilled.

Some guidance is given in Part 1.4 on the possible types of intervention; a selected list includes the two alternative solutions of strengthening a sufficient amount of structural elements without changing the main resisting system, or to modify this latter in the sense of making it more regular by additions/separation of parts, and elimination of inadequate portions of it. By now well experimented techniques of inserting bracings inside the building (steel truss bracings, structural walls, infill walls, etc.) which take up most of the horizontal action, or of isolating the building at its base, are also mentioned.

It is mandatory that the redesign documents include the justification of the type of intervention selected and the description of the expected structural performances.

In some cases the assessment in view of the upgrading is carried out for a group of buildings, and a criterion is needed to set priorities among them. To this purpose, a priority index is developed in the document. For all earthquake resisting elements and for all the critical sections the following ratio is calculated:

$$L_{Ri} = \frac{R_{di} - E_{di}(N.S.A.)}{E_{Ei}}$$

where:

R_{di} is the design strength of the section evaluated in the assessment phase

E_{di} (N.S.A.) is the action effect of all the permanent and variable actions entering into the seismic combination, excluding the seismic action itself

E_{Ei} is the effect of the design seismic action.

At all storeys the following summation over the resisting elements of the storey is carried out:

$$G_R = \frac{\Sigma\, w_i \cdot (L_{Ri})^{\lambda}}{\Sigma\, w_i \left(\frac{1}{L_{Ri}}\right)^{\lambda}}$$

which has the meaning of a global resistance index for the storey. The factors w_i account for the consequences of the element failure on the global stability of the building, and are expressed as:

$w = w_1 \cdot w_2$ where:

w_1 = 1 for brittle failures, w_1 = 0,5 for ductile failures

w_2 = 1,5 for foundations, 1,0 for columns and walls, 0,5 for beams

The exponent λ reflects the significance of local deficiencies on the overall resistance: it may be assumed as equal to 1 for low redundancy, and to 0,5 for normally redundant structures.

With G_R being the lowest storey index for a building the priority index is defined as

$$Ip = (1 - G_R) \cdot I_o$$

where the reference priority index I_o depends on the use of the building, i.e.,

I_o = 2,5 for buildings with frequent large occupancies

I_o = 1,5 for schools, hospitals

I_o = 1,0 for residential buildings

Redesign. Once the need for an intervention has been recognized, and the type of it has been established, the ensuing redesign process does not differ conceptually from ordinary design, apart from some additional aspects of technical nature having to do with the connections of the new parts with the old ones.

A number of mechanisms of force transfer are reviewed, namely: adhesion, friction, resin layers, clamping effect of steel across interfaces, transfer through fasteners, dowels, anchors, and anchoring of new reinforcement. For each mechanism the exploitable strength and the associated safety elements are given.

Anchoring of additional steel bars in concrete or in masonry requires special attention. It is not allowed to rely entirely on bond: the bars must be provided of end plates, or welded to existing ones, provided these latter are adequate for carrying the extra bond stress.

If full anchorage of new reinforcement is not feasible, its strength should be appropriately reduced, and the consequences of this defect on the local ductility should be taken into account.

The new design has to be classified with reference to structural typology and regularity class, which may be different from those prior to the intervention. Then the structural analysis may proceed according to the methods foreseen in the EC8.

The critical steps on which depend the success of the operation from the point of view of the safety requirements are two: a) a correct evaluation of the global "ductility" of the structure as strengthened, and of the corresponding value of the q-factor; b) the composite behavior of the new and old parts of the strengthened elements, and in particular the definition of the partial factors γ_{Rd} and γ_M. The first point determines the intensity of the seismic forces to be used for the verification, the second determines the resistance side of the verification.

Of course the solution would always exist of using accurate non linear methods of analysis to determine the value of q, and accurate non linear models for describing behavior and strength of the elements. But this is out of practice for new structures, which are easier to model, and it would be out of reality to impose it for existing strengthened structures. One has to accept the fact that the control of safety for these structures (buildings of ordinary importance) cannot be as strict as for the new ones. Since judgement plays a larger role, a larger scatter on the safety actually achieved is to be expected.

CONCLUDING REMARKS

Uncertainties are the dominant factor in the assessment and in the redesign of structures located in a seismic environment, to an extent unknown in the cases of normal environmental actions.

The goal of achieving a uniform level of safety when intervening on a population of structures cannot be obtained with a sharpness comparable to that achievable in designing a population of new structures.

The question whether it would be better to treat the problem using a probabilistic or a deterministic code is besides the point: if the information were available the former could be used to calibrate the latter, with a precision sufficient for all practical purposes.

Eurocode 8 has made the choice, consistent with its overall philosophy, to produce a deterministic, partial safety factors format type of code for covering the assessment and redesign processes of existing structures. The structure of the code is the same as that for new design, which is commonly deemed to be rich and flexible enough for incorporating additional information. At present, the designer is given the responsibility of a number of choices that can only be made on a subjective basis: accumulation of experience will reduce the space of subjectivity to more usual levels.

REFERENCES

CEB (1983). Assessment of Concrete Structures and Design Procedures for Upgrading (Redesign). *Bull. d'Information, n. 162.*

CEB (1989). Diagnosis and Assessment of Concrete Structures: State-of-Art Report. *Bull. d'Information n. 192.*

CEB (1996). Assessment and Redesign of Existing Reinforced Concrete Structure. *Bull. d'Information*, in preparation.

EUROCODE 8 (1996). Design Provisions for Earthquake Resistance of Structures. Part 1.4: Strengthening and Repair of Buildings. *ENV. 1998-1-4, CEN* - Brussels

JCSS (1996). Reliability of Existing Structures. In preparation.