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Meaning and evolution of building codes: Eurocode 8 and reinforced concrete constructions in seismic zones

G.Sara' & R.Nudo
Dipartimento di Costruzioni, University of Florence, Italy

ABSTRACT: Control of realization process - design and execution phases - of earthquake-resistant buildings is committed to specific codes; their efficacy, in turn, is tested on the basis of building performance (vulnerability degree) exhibited in occasion of seismic events. Evaluation of effectiveness and modalities characterizing the performance of current seismic codes, with particular reference to R.C. buildings, form the object of this study which has been conducted according to a historical-evolutionary perspective

1 INTRODUCTION

Codes aim is to ensure obtainment of constructive products with adequate standard reliability.

That is achieved by elaboration of unifying suitable metodologies relating to the whole design-construction process, from qualification of technical operators to acquisition of data on surroundings actions and structural elements and materials, to modelling for verifications and, finally, to checking operations.

Resort to appropriate safety margins, depending on degree of reliability attributed to the whole design-construction process, permits to pursue atteinment of required construction reliability level, quantified by the construction success probability against aggressive agents.

The codes set is, therefore, a starting-point as regards the design and execution phases of the realization process, conditioning final constructive product which has to be in conformity to it. On the contrary, it is an end-point as regards the processes connected with forming of knowledge (theoretic-experimental) and technology inheritances, being a consequence of them.

Building code instructions, of a substantially compulsive nature (prescriptions), are obviously supplemented in their role by design and execution customary practice rules (suggestions, recommendations); these rules, not compulsive, in remote times exercised entirely the role that in recent times is largely provided by code prescriptions.

In the case of buildings in seismic zones, an important contribution to knowledge inheritance is provided, in addition to theoretical modellings for prediction of seismic response of architectonic-structural systems, by analysis of damages and by investigations on the relative causes.

The evaluation of efficacy and consequently the judgement on validity of code tools can be carried out by checking the actual achievement of their intrinsic target, namely the actual attainment of an adequate reliability standard level. Naturally it is very important to achieve this goal yielding the greatest possible freedom in the designing choices.

The best way to evaluate such an effectiveness is checking the actual capacity of code tools to predict and prevent potential sources of vulnerability as suggested by theoretical analysis and, most of all, by that fundamental experimental survey represented by seismic failures analysis.

A research on evolution of seismic codes, intended as "trait-d'union" between technological-cognitive inheritance and buildings realization process, can prove to be helpful both for a critical examination of current codes (national and over-national) and their trends, and for identification of potential sources of vulnerability connected with the set of constructive rules applied to old works and then as guide for interventions on them.

2 CODES FOR R.C. BUILDINGS IN SEISMIC ZONES: CODES PATTERN AND COMPARATIVE SINOPTIC TABLE

Survey is conducted with reference to seismic codes, italian national and european over-national, relating to R.C. buildings in seismic zones.

A comparative analysis of various normative documents points out the background presence of a common structure or pattern of such documents, according to what, on the inside of various partition topics, different instructions can be disposed (ref. first column of table 1).

Table 1. Evolution of seismic codes for R.C. buildings

INSTRUCTIONS		ITALIAN TECHNICAL CODE - 1924	ITALIAN TECHNICAL CODE - 1962	ITALIAN TECHNICAL CODE - 1986	EUROCODE 8 - 1988
1 Definition of construction general features					
1.1 Definition of placing site characteristics		Seismic codification of the site zone (until 1927)	Seismic categorization of the site zone (1927-1975)	Seismicity degree of the site zone (since 1975)	Max. ground acceleration of the site zone Type of soil profile
1.2 Definition of building general characteristics		Characteristics of regularity of framed structural system (until 1935)			Building configuration: characteristics and class of regularity Type of structural system: -type of earthquake-resistant structural system -class of ductility
2 Design of buildings					Design of regular buildings
2.1 Placing requirements					
2.1.1 Foundation soil requirements		Foundation on stable and homogeneous soils exclusively (until 1975) Steep sloping soils: foundation on compact rock (until 1930)	Foundation on stable and homogeneous soils exclusively (1924-1975)	Potentially unstable soils (sloping or subject to liquefaction soils): check of implantation stability (since 1975)	Potentially unstable soils (sloping or subject to liquefaction soils): check of implantation stability
2.1.2 Distance among buildings requirements		Street nearness: observance of min. roadway width (until today) Isolation: observance of min. distance (until 1975) Adjacency: structural indipendence (until 1962)	Street nearness: observance of min. roadway width (from 1924 until today) Isolation: observance of min. distance (1924-1975) Adjacency: suitable distance (1962-1975)	Street nearness: observance of min. roadway width (since 1924) Isolation: reference to municipal regulations (since 1984) Adjacency: observance of min. distance (since 1975)	Adjacency: observance of min. distance
2.2 Building requirements					
2.2.1 Building type requirements	2.2.1.1 Building on the whole	Height: observance of max. height (until 1975)	Height: observance of max. height (1924-1975)		Height: reference to national regulations Building configuration: regular (if possible)
	2.2.1.2 Building components	Roofs: light roofs (until 1962) Overhangs: not allowed except for balconies and cornices (observance of max. overhanging extent) (until 1962) Stairs: overhanging stairs not allowed (until 1935) Foundations: -columns-foundation connections: columns fixed in compact rock, general plate or base frame (until 1935) -foundation layer: compact rock or implant in solid soil if possible (until 1930) Non-structural walls: -filling and partition walls: requirements about making (until 1962) -openings: requirements about strengthening (until today)	Floors: requirements about R.C. hollow-tile floors (slab thickness, transversal reinforcement) (1935-1962) Overhangs: not allowed except for balconies, cornices, framed and walled bow-windows (observance of max. overhanging extent) (1962-1975) Stairs: overhanging stairs allowed on condition of observance of max. overhanging extent exclusively (1935-1975) Foundations: -columns-foundation connections: columns fixed in compact rock, general plate (obligatory for very soft soils) or base frame (1935-1975) Non-structural walls: -filling walls: requirements about making and high panels (1962-1975) -partition walls: requirements about making and connections (1962-1975) -openings: requirements about strengthening (from 1924 until today)	Foundations: -foundations connection: connection by a grid of beams (otherwise verification of relative displacements effects) (since 1975) -foundation layer: soil zone scantly subjected to seasonal variations of water content (since 1975) Non-structural walls: -filling and partition masonry walls: requirements about high and large panels (since 1975) -openings: requirements about strengthening (since 1924)	Foundations: code section not yet available (EC8 - part 5) Non-structural walls: requirements about filling masonry walls making
2.2.2 Materials and structural elements requirements	2.2.2.1 Materials				Concrete: requirements about min. strength Bars: -steel: requirements about mechanical characteristics (ultimate strain, ultimate and yielding stress) -critical regions of earthquake-resistant elements (high stresses zones): high bond longitudinal bars
	2.2.2.2 Frames	Beams: -beams with corbelled ends exclusively -requirements about cross section dimensions -requirements about longitudinal reinforcements (until 1935) Columns (regular structural systems): -requirements about cross section dimensions -requirements about longitudinal reinforcements (otherwise calculation) (until 1935)			Beams and columns: -requirements about cross section dimensions -requirements about reinforcements (longitudinal reinforcements, transverse reinforcements in critical regions) Beam-column joints: -beam-column eccentricity: observance of max. eccentricity -requirements about reinforcements
	2.2.2.3 Single or coupled structural walls				Structural walls: -requirements about thicknesses -requirements about reinforcements Coupling beams: requirements about reinforc.

Table 1. (continuation)

INSTRUCTIONS		ITALIAN TECHNICAL CODE - 1924	ITALIAN TECHNICAL CODE - 1962	ITALIAN TECHNICAL CODE - 1986	EUROCODE 8 - 1988
2.3 Reliability verifications					
2.3.1 Calculation of response to design seismic actions	2.3.1.1 Calculation of design seismic actions	Calculation of storey horizontal seismic forces: -direction of the seismic action: according to two principal directions (until 1962) -live load masses: in full (until 1935) -distribution coefficients: decreasing toward the base (until 1935) Calculation of vertical seismic forces (until 1962)	Calculation of storey horizontal seismic forces: -direction of the seismic action: whatever direction (1962-1975) -live load masses: reduced (from 1935 until today) -distribution coefficients: constant (1935-1975) -intensity: depending on seismic category (1927-1975) Calculation of vertical seismic forces: for overhangs exclusively (1962-1975)	Calculation of storey horizontal seismic forces (by simplified dynamic analysis; modal analysis obligatory for buildings with relatively high fundamental period): -direction of the seismic action: according to two orthogonal conventional directions (since 1975) -live load masses: reduced (since 1935) -distribution coefficients: linearly decreasing toward the base (since 1975) -intensity: depending on seismicity degree, elasto-plastic normalized response spectrum and coefficients of foundation, behaviour and importance (since 1975; importance coefficient since 1984) Calculation of vertical seismic forces: for overhangs, great span horizontal members, thrusting members exclusively (since 1975)	Calculation of storey horizontal seismic forces (by simplified dynamic analysis; modal analysis obligatory for buildings with relatively high fundamental period): -direction of the seismic action: according to two orthogonal conventional directions -live load masses: reduced -distribution coefficients: linearly decreasing toward the base -intensity: depending on max. ground acceleration, elastic normalized response spectrum and factors of site, behaviour and damping Calculation of vertical seismic forces: for overhangs, great span horizontal members, thrusting members, beams bearing columns exclusively
	2.3.1.2 Calculation of effects due to design seismic actions	Modelling of the structural system: beams modelled as elements suitably restrained at the ends (until 1935) Definition of seismic actions combinations: horizontal seismic action in a single direction at a time or vertical seismic action (until 1975)	Modelling of the structural system: system of elastic frames (1935-1975) Definition of seismic actions combinations: horizontal seismic action in a single direction at a time or vertical seismic action (1924-1975)	Modelling of the structural system: spatial system of earthquake-resistant elastic elements (since 1975) Calculation of storey torsional moments: referring to conventional eccentricity of storey horizontal forces (since 1975) Definition of seismic actions combinations: horizontal seismic action in a single direction at a time plus vertical seismic action (since 1975) Calculation of combined effects: internal forces and deformations (since 1975)	Modelling of the structural system: spatial system of earthquake-resistant elastic elements taking into account the influence of non-structural filling masonry walls Calculation of storey torsional moments: referring to conventional eccentricity of storey horizontal forces Definition of seismic actions combinations: by means of combination coefficients Calculation of combined effects: internal forces and deformations
2.3.2 Verifications	2.3.2.1 Calculation of response to overall design actions	Definition of design actions combinations: dead loads + live loads + seismic actions (until today)	Definition of design actions combinations: dead loads + live loads + seismic actions (from 1924 until today)	Definition of design actions combinations: dead loads + live loads + seismic actions (since 1924)	Definition of design actions combinations: by means of importance and combination factors Calculation of design internal forces for beams and columns: elastic internal forces with redistribution (when allowed) and adjustments based on consideration of limit equilibrium and 2nd order effects
	2.3.2.2 Definition of limit capacities	Definition of max. allowable stress for not rocky soil (until 1962)			
	2.3.2.3 Reliability verifications	Verifications: according to allowable stresses method (until today)	Verifications: according to allowable stresses method (from 1924 until today)	Verifications: according to allowable stresses method (since 1924)	Verifications (according to limit states method): ultimate resistance, ductility (check of max. axial force), global stability (overturning and sliding), foundations (EC7 and EC8 - part 5, not yet available), damage limitation (adjacent buildings displacements, interstorey drifts)
3 Design of strengthening operations on buildings		Design of repairing operations on buildings	Design of repairing operations on buildings	Design of code adaptation or improvement operations on buildings	
3.1 Type of operation	3.1.1 Operations on building type characteristics	Building on the whole: reduction of height according to building design instructions (until 1935) Components: -reduction of overhangs extent according to building design instructions (until 1962) -stairs: substitution of overhanging stairs by stairs supported by frame (until 1935)		Building on the whole: reduction of non-structural masses, creation and adaptation of joints, modification of building morphology to decrease torsional effects (suggested measures) (since 1986)	Code section not yet available (EC8 - part 1.4)
	3.1.2 Operations on structures	Structure on the whole: demolition and reconstruction of heavily damaged members and supported structural components (until 1975) Foundations: consolidation according to building design instructions (until 1935); repairing or consolidation (from 1935 until 1962)	Structure on the whole: demolition and reconstruction of heavily damaged members and supported structural components (1924-1975)	Structure on the whole: modification of structural system through alteration or addition of structural elements (suggested measure) (since 1986) Foundations (code adaptation): consolidation according to building design instructions if possible (since 1986)	
3.2 Reliability verifications				Verifications (code adaptation): see verifications for building design taking into account the influence of non-structural filling masonry walls (since 1986)	

Recognition and pointing out of such pattern permits an effective setting of single prescriptions and a better reading of codes in order to examine modalities and effectiveness by which the same exercise their role of reliability warranters of constructive process and his product, the construction.

Also, reference to a common codes pattern makes easier comparison among contents of different codes for a critical evaluation of them and determination of evolutionary trends.

As regards partition topics of the recognized common paradigm, they appear closely connected with traditional design phases:

a) identification of design object (system and relating environment) by definition of placing site characteristics (point 1.1) and building general characteristics (point 1.2);
b) identification of design problem: new buildings design (point 2) and design of interventions on existent buildings (point 3);
c) indication of binding requirements on construction relating to placing (point 2.1), to building type (point 2.2.1), to structural characteristics (point 2.2.2);
d) indication of procedures to perform reliability verification: analytical modelling of affecting actions and structural system for prediction of seismic response (point 2.3.1), procedures for evaluation of predictable demand and capacity, definition of conventional conditions of reliability (point 2.3.2).

As regards targets, connected with end purpose to ensure suitable standard reliability to buildings, instructions relating to building design can be summarily classified as follows:

a) prescriptions directed to check demand (internal forces and deformations) (point 2.2.1) and related prediction (points 2.3.1 and 2.3.2.1);
b) prescriptions directed to check structural capacity (strength and ductility) (point 2.2.2) and related prediction (point 2.3.2.2);
c) prescriptions directed to check building reliability through demand-capacity balance (point 2.3.2.3).

It is worthwhile to observe that binding prescriptions of direct type, aimed to check demand (point 2.2.1) and capacity (point 2.2.2), have a substantial function to provide for lacks of prediction analysis.

Investigation developed in this paper has been conducted referring mainly to following normative documents owing to their greatest meaning: 1924 National Technical Code (first italian code of a national extent while the previous ones - beginning from the 1884 one - were of a local extent as rebuilding codes as a result of seismic events), 1962, 1986 (current italian code, referring to 1974 general law), 1988 draft of Eurocode 8. Obviously, for a correct interpretation of above mentioned codes, the same must be considered according to their connection with remaining codes set and, particularly, to codes relating to actions and safety standards, to design rules for constructions realized by various techniques, to works regulation in seismic zones or not.

The codes instructions (only the ones specifically reported by seismic codes), divided on the basis of previously mentioned topics, are juxtaposed in table 1.

As regards modality of presentation, instructions are reported in a concise manner referring exclusively to qualitative aspect; therefore modifications of a quantitative nature, from a code to the other, are not pointed out. Moreover, are bracketed periods during which specific prescriptions remained in force, through a succession of normative texts.

3 REMARKS ABOUT CODES EVOLUTION

A comparative analysis of instructions relating to considered normative documents leads to some interesting remarks about codes evolutionary process. Such observations are reported in an orderly way in this section with reference to topics previously mentioned.

(a) Identification of design object.

(a1) Definition of placing site characteristics. The seismic characteristics of site are defined with a growing accuracy starting from definition of a generic seismic liability, passing to a more detailed and rigorous seismic zonation, coming finally to quantification of seismic input in terms of ground acceleration and to evaluation of influence of different soil types.

(a2) Definition of building general characteristics. Recent european draft code (1988 Eurocode) attaches particular importance to definition of building general characteristics (regularity of architectonic-structural whole, type and ductility characteristics of structural system). That because of recognition of outstanding influence exercised by them on building overall behaviour - particularly with reference to dynamic and elasto-plastic aspects - hard to subdue to analytical control. Analogous aims concerning more elementary problems - analytical difficulties were related even to the elastic analysis of framed structures - are noticeable in corresponding instructions of 1924 italian code.

(b) Constructive requirements (new buildings design).

(b1) Placing requirements. Foundations: prescriptive rules are gradually replaced by check requirements mainly (process allowed fundamentally by technological progress). Distance among buildings: increasing attention to problem of joints hammering (denoting increasing attention to problems of damageability owing to deformation excess).

(b2) Building type requirements. Gradual decrease of prescriptive limitations on aspects related to constructive components with structural function; instructions tend to concentrate on foundations and filling walls topics (such evolution appears to be encouraged by technological progress, evolution of calculation tools, introduction of specific prescriptions about requirements on structural elements, increase of checks).

(b3) Structure requirements. Materials: for the first time, in Eurocode 8, materials of higher and more reliable performance are required for constructions in seismic zones. Structural elements: in the Eurocode 8 appears a sequence of prescriptions aimed to ensure - in the case of regular buildings and relating to preestablished ductility levels - reliability of predictions derived by conventional approximate analysis procedure (approximations relating primarily to elasto-plastic response, dynamic behaviour, influence of non-structural walls). This goal is pursued by adopting provisions, based on design criterion of strength hierarchy, aimed to attainment of structures characterized by suitable and predictable failure mechanisms. Prescriptions of the same nature, related to reliability pursuit, are present in 1924 italian code.

(c) Reliability verifications (new buildings design).

(c1) Modelling of seismic actions. From modelling of seismic actions on the basis of static analysis, code procedures evolve to modellings based on more or less sophisticated dynamic analyses, attentive to plastic dissipation.

(c2) Modelling of structural system and evaluation of response to seismic actions. From early simplified elastic analyses, code procedures evolve, taking advantage of automatic calculation tools, to more and more advanced and complete elastic analyses (by considering effects due to spatiality, filling walls, 2nd order phenomena).

(c3) Verifications. A more refined and realistic procedure to define concomitance of seismic and non-seismic actions, by referring to suitable factors determined on the basis of probabilistic considerations, emerges from Eurocode 8. Moreover reference of Eurocode to ultimate limit state for strength verifications - looking at actual plastic resources of structural elements - must be pointed out; a particular care is also devoted to check absolute or relative displacements in order to reduce damages (working limit state).

(d) Design of strengthening operations on existent buildings. An increase of interest in this problem, after recent earthquakes occurred in the national territory, can be observed in italian codes.

4 CONCLUSIONS

The developed analysis points out two principal factors as characterizing the normative documents evolution in the last decades: on the one hand, evolution of analytical tools - more and more realistic and effective also because of contribution of automatic calculation techniques - for check of structural response; on the other hand, technological progress with development of more effective constructive and checking procedures. It is worthwhile to remark that technolological progress owing to diffusion of constructive techniques, like use of damping devices and base-isolation systems, in a short time will request drawing of new normative chapters.

In order to evaluate critically effectiveness of codes evolutionary trends, as regards safeguard against seismic vulnerability sources, can be useful to consider response of nominally earthquake-resistant R.C. buildings to recent seismic events.

With a particular reference to damage investigations conducted on the occasion of Irpinia italian earthquake of 1980 (Richter magnitude about 6.5) main observed sources of vulnerability are here reported according to the selected topics (Sara', 1985).

(a) Definition of placing site characteristics. Sources of vulnerability: underestimation of actual site seismicity as related to regional seismicity and to mechanical and morphologic characteristics of placing site.

(b) Structure. Sources of vulnerability: lack of suitable ductility in critical regions of the structure (ends of columns, joints of frames, bases of structural walls, walls coupling beams).

(c) Modelling of structural system. Sources of vulnerability: inadequate consideration of spatial characteristics of earthquake-resistant structure and consequently missed or insufficient evaluation of torsional effects due to asymmetry and disproportion in plan; missed or insufficient evaluation of complementary elements influence, structural or not (staircase structure, filling walls).

(d) Reliability verifications. Sources of vulnerability: lack of checks about ductile capacities of critical regions of structure; lack of checks as regards deformability (rampant stairs, bow-windows, adjacent buildings).

(e) Executive modalities. Sources of vulnerability: deficiencies relating to quality of concrete casting (mixture, components segregations, recasting), to steel reinforcements disposition (stirrups, bars anchorage and spacing, concrete cover), to weakening due to conduits passage.

While the last mentioned source of vulnerability can be attributed to lacks in control modality of the work - during and after realization - the other sources appear, in part at least, to be referable to lacks in regulations that governed design of constructions in question.

Current italian code, in spite of some improvement with respect to codes ruling buildings damaged by Irpinia earthquake, is not sufficiently watchful on most of potential sources of vulnerability now pointed out.

On the contrary, the same sources of vulnerability, on the whole, are opposed rather effectively by Eurocode 8 provisions.

However it is useful to point out that it should be preferable to devolve check of ductility more upon analytical verifications, in a way to reduce the numerous prescriptive restraints of Eurocode 8 - from regularity characteristics to limitations of geometric type on structural elements - at present justified by necessity to take precautions against uncertainties and difficulties about modelling of dynamic behaviour of the elasto-plastic system.

On the other hand, codes development ought to go in this direction, that is toward sharpening of reliable analytical procedures, just as consented by automatic calculation resources. By this way, the track followed starting from far-off 1924 italian code should be repeated, on a different level. Also at that time, indeed, difficulties connected with modelling of building seismic behaviour induced to issue restrictive prescriptions - as regards constructive regularity and related geometric characteristics of structural elements - subsequently ousted by powerful evolution of analytic tools.

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