

A new approach of the Romanian seismic code for buildings

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ABSTRACT: The impact of the strong earthquakes of Romania, generated by the persistent intermediate depth source zone of the curvature of Carpathians in 1986 and 1990, made it necessary to revise the regulatory basis of earthquake resistant design. The revision tackled more or less all categories of provisions, like design principles, zoning, methods of design, layout and detailing. New chapters, concerning the protection of equipment and the mitigation of risk affecting the existing building stock, were added to the design code. More recently, the row of moderate magnitude, but rather high epicentral intensity, crustal earthquakes, having occurred in 1991 in Western Romania, raised new problems in relation to the regulatory basis. Data are given on the evolution of the regulatory basis, on the methodological impact of recent earthquakes, on the modifications adopted and on their background.

1 INTRODUCTION

Romania was struck during last five decades by several strong earthquakes. The most important ones were generated by the source zone located outside of the curvature of the Carpathians, referred to usually as the Vrancea zone. Those events occurred on 10 November 1940 (M=7.4), 4 March 1977 (M=7.2), 30/31 August 1986 (M=7.0), 30 May 1990 (M=7.0) and 31 May 1991 (M=6.2). The first two earthquakes referred to were destructive, leading to heavy losses (Balan et al., 1983). The latter ones produced also damage, sometimes strong. More recently, in 1991, a row of crustal earthquake occurred in Banat (Western Romania), out of which the strangest ones were those of 12 July 1991 (M=5.7), 18 July 1991 (M=5.6) and 2 December 1991 (M=5.5) (the numerous aftershocks did not reach M=5.0). These events produced heavy damage in villages located close to the epicenters (intensities ranged up to VIII).

The earthquakes referred to had a direct impact on engineering activities. Some first instructions of the Ministry of Public Works were endorsed in 1942 for the protection of public works. A first zoning standard was endorsed as STAS 2923-52, with new versions STAS 2923-63, STAS 11100/1-77 and STAS 11100/1-91(92). A design code for buildings and industrial structures was endorsed as P.13-63, with new versions P.13-70, P.100-78, P.100-81, P.100-91(92). Besides those most significant regulations, other regulatory documents were

developed in parallel.

After the period of development and endorsement of a first rather complete regulatory basis in the early sixties, when the community of design engineers became aware of the specific problems involved by earthquake protection and practically all structures designed were nominally also earthquake protected, the impact of the 1977 earthquake represented a turning point of activities of this field. The community of specialists was well prepared to investigate the earthquake effects and to summarize that experience. The seismic zoning was improved. The design spectra were revised, based on the first strong motion records obtained in Romania. Detailed provisions aimed to provide ductility to reinforced concrete members were introduced. Explicit 3D input for 3D structural analyses was specified.

The impact of the more recent strong earthquakes was of considerable importance and it raised the need of revision of the whole regulatory basis of earthquake resistant design and some main consequences of this impact are presented further on. Some main aspects concerning the experience of the earthquakes are dealt with. The implications for seismic zoning are presented. Some main aspects concerning the content and the philosophy of the new design code are discussed. Some specific features of the main chapters of the code are then presented.

2 SOME DATA ON THE EXPERIENCE OF RECENT EARTHQUAKES

These data refer basically to the earthquakes having occurred after the destructive event of 1977.

A first category of information of highest importance is represented by the numerous instrumental data which could be obtained due to the considerable development of the strong motion network after the 1977 earthquake (thanks mainly to the generous aid provided by UNDP/UNESCO and by the US Government). Several records with PGA's exceeding 0.2 g were obtained in 1986 and 1990. More important than that, one disposes now of sequences of 2 or 3 records due to different events pertaining to the same category of strong intermediate depth events. The main conclusions derived from the records of 1986 and 1990, of motion due to intermediate depth Vrancea earthquakes (Radu et al., 1990, Sandi et al., 1991) were as follows:

1. The influence of local conditions on the spectral content of ground motion was always strong and evident, but the influence of focal mechanism and of radiation pattern on the spectra was by no means less important.

2. The attenuation for intermediate depth earthquakes was always lower than what literature shows for crustal earthquakes.

3. Besides that, the attenuation is highly random and the randomness should be considered even in spectral terms (various spectral components are radiated mainly in different directions for different events).

4. The intensities prescribed by the zoning map in force at that time were exceeded at several locations by intensities estimated on the basis of records. Moreover, in case of rescaling of intensities for higher magnitudes (like those of 1940 or of 1977) the cases of exceedance become rather frequent and serious.

The conclusions 1 and 4 were strongly confirmed by the records obtained in 1991 during crustal earthquakes.

The records obtained on buildings (as a rule couples of records at basement and top floor levels) put to evidence the ability of several structures to resist top floor accelerations in the range of 0.4 to 0.5 g with only minor damage. The influence of PGA on the apparent natural periods of structures and on ground to top floor amplification was also made evident (Radu et al., 1990).

The observation of performance of buildings put to evidence the gradual increase of damage due to several earthquakes, when proper rehabilitation measures were not adopted. In some cases damage following the 1986 or 1990 events was even heavier than that observed after the destructive earthquake of 1977. Structural damage occurred less frequently, but the rigid non-structural components of numerous buildings were often heavily affected. It turned out that earthquake protection

in this direction is connected with a major economic stake. The need of investigating and deriving full constitutive laws concerning the cumulative nature of damage should represent a major matter of concern for the future, given the frequent occurrence of intermediate depth earthquakes especially.

3 MODIFICATION OF SEISMIC ZONES

The improvement of seismic zoning of Romania was undertaken subsequently to the 1990 earthquakes. Macroseismic information on earlier earthquakes was considered too, but the main category of information used was represented by the instrumental data obtained in 1977, 1986 and 1990. The relationships between seismic intensity and instrumental data used were based on developments of (Sandi, 1990). The instrumental parameters EPA and EPV (ATC, 1978) (on which intensity estimates relied) were rescaled assuming magnitude intensity relationships for intermediate depth earthquakes starting from data of (Balan et al. 1983). The rescaled values EPA and EPV were basically enveloped and the seismic zones were redrafted essentially on this basis. The seismic zoning, as presented in the 1991 version of the Romanian design code, is expressed in terms of a couple of maps: the basic seismic coefficient k_s , which corresponds basically to the ratio EPA/g , and the corner period of the dynamic factor, T_c . The values of k_s range from 0.08 to 0.32 (geometric progression with ratio $2^{1/3}$) and the values of T_c are 0.7, 1.0 and 1.5 respectively, for different zones. Note also, that the maximum value of the dynamic factor is 2.5. More details on this subject are given in (Sandi et al. 1991, Pacoste et al. 1991). The return period of values k_s is very low, of about 50 years for the zones affected by intermediate depth earthquakes. This low level was adopted in order to avoid a too strong increase of design forces in comparison with values used before.

The zoning standard includes a map expressed in terms of MSK intensities, which is consistent with the couple of maps of the code, on the basis of developments of (Sandi, 1990).

The more recent experience of the 1991 earthquakes referred to put to evidence again the need of revision of the zoning map for the zones affected by crustal earthquakes. Corrections were adopted for the province of Banat, but it is obvious that such corrections are necessary also for other zones, perhaps first of all for the zone affected by earthquakes generated in the Fagaras chain of mountains.

The newly adopted zoning maps, concerning the parameters k_s and T_c formerly discussed, are reproduced in following figures.

Note also that the dynamic factor β has

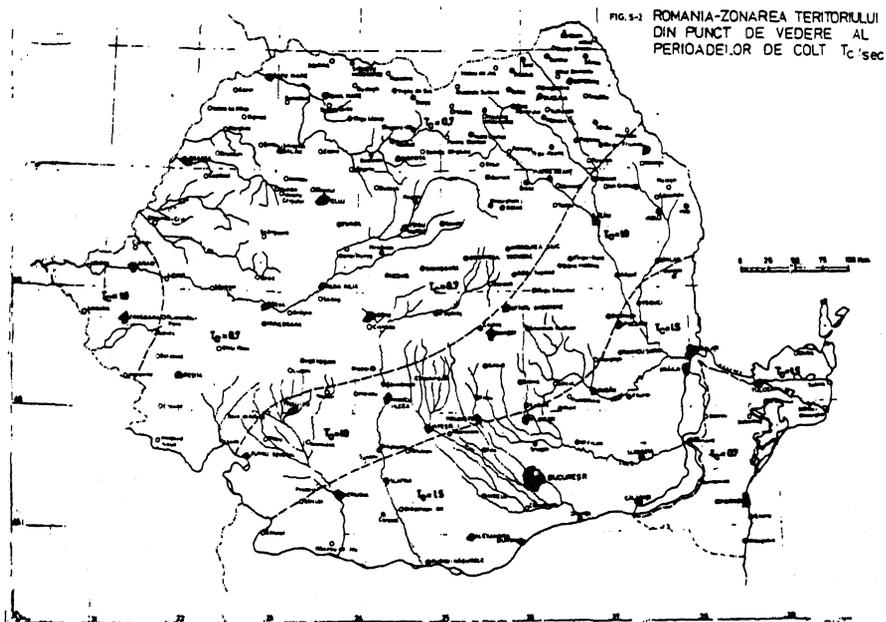
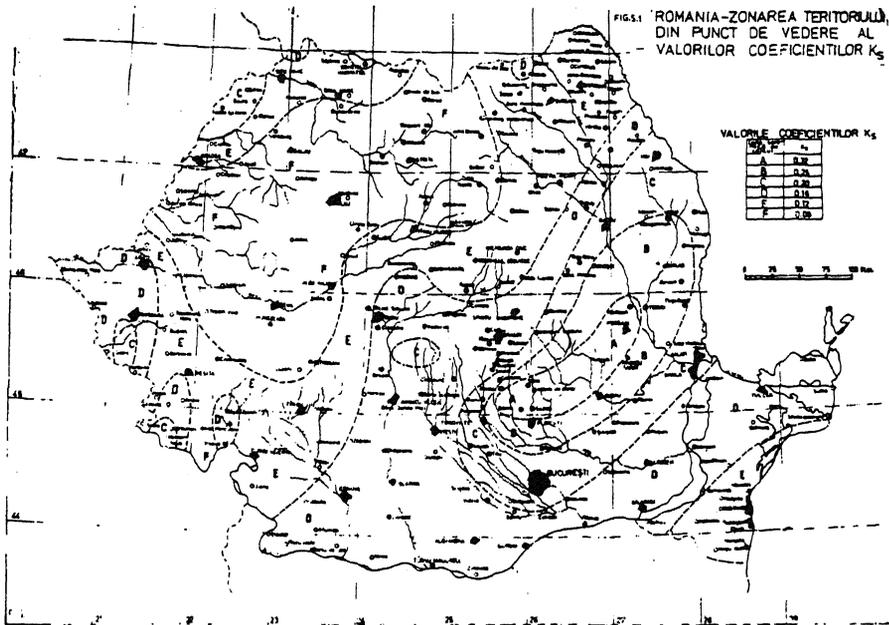
a maximum value 2.5 (for $0 < T < T_c$), and then decreases linearly up to a minimum value 1.0.

4 CONTENT OF THE NEW DESIGN CODE

The content of the new earthquake resistant design code is as follows:

1 General

- 2 Earthquake resistant design principles
- 3 Planning and location of structures
- 4 Layout of structures
- 5 Structural analysis
- 6 Rules of verification
- 7 Provisions for reinforced concrete structures
- 8 Provisions for steel structures
- 9 Provisions for masonry structures



- 10 Design of installations and equipment
- 11 Evaluation of existing buildings
- 12 Measures of intervention on existing buildings
- 13 Conditions for construction activities
- Annex A Zoning of the territory of Romania
- Annex B Simplified methods of analysis
- Annex C 3D analysis
- Annex D Details regarding reinforced concrete structures
- Annex E Details regarding steel structures
- Annex F Classification of installations and equipment

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5 GENERAL

The code covers essentially design rules for buildings and engineering structures (except special structures like bridges dams, retaining walls, nuclear structures). It pays attention first to the adoption of solutions in broad terms, providing recommendations for siting, layout and detailing. In depth recommendations are provided for layout, with regard to the requirements of general symmetry, appropriate distribution of masses and stiffnesses, appropriate foundation systems, limiting when necessary and possible height, as well as masses located at high places, adoption of simple shapes in a horizontal plane, adoption of solutions sufficient ductility and rigidity, adoption of appropriate solutions for non-structural components.

The design parameters of seismic action are differentiated with respect to the seismic conditions (expressed in spectral terms), to the allowable ductility demand and to the importance of structures designed. The importance classes considered in the code represent a more detailed approach than that of the standard of general design principles, which is concerned with all categories of buildings or other works. An importance factor of design forces takes the values 1.5, 1.2, 1.0, 0.8, for buildings or other structures of importance classes I to IV, as defined in the code. The highest importance category includes buildings that are necessary for recovery after earthquakes or which, if damaged, could engender heaviest consequences.

6 CLASSIFICATION OF METHODS OF ANALYSIS AND 3D ANALYSIS

The code provisions implicitly accept the use of two basic representations of seismic action at ground level: design spectra and

design accelerograms. Design spectra are fully prescribed for horizontal translational acceleration components. Values independent of natural periods are prescribed for the vertical translational component. The concern for the rotational components is present only in relation to rotation in the horizontal plane and two approaches are adopted here: in case of separate analysis for action along one single (horizontal, translational) component, prescribing of a conventional eccentricity;

- in case of 3D analysis, prescribing of a conventional value for the amplitude of rotational disturbance (in Annex C, which is referred to further on).

The code considers two design methods denoted by A and B, respectively. These methods differ from the viewpoint of modeling of seismic action and of structures, as well as by the way of checking layout and detailing conditions and structural performance. The approach to structural design, aimed to control structural response by imposing the zones where post-elastic (plastic) deformation is to develop in case of strong action, appears to be to date a unique case in national regulations.

The method A, which is compulsory for all structures, considers in a simplified, implicit and approximate way the aspects of dynamic and non-linear structural performance, without making explicit the mechanism of plastic behaviour in case of high intensity seismic action. According to this approach, design is made for conventional code forces, applying additionally rules aimed to provide a favourable performance from the viewpoint of rigidity and ductility.

The method B makes it possible to put to evidence the features of non-linear performance, using a time-history approach on the basis of use of design accelerograms of ground motion. Successive corrections of the strength and stiffness characteristics of structural components and the verification of deformation capacity in comparison with homologous demands makes it possible to obtain, with a high likelihood, the desired plastic mechanisms. The method B is recommended for structures of high importance and for repetitive structures.

3D analysis is recommended mainly for structures for which there is a significant coupling of oscillations in different vertical planes and/or with overall torsion oscillations. 3D structural models are used and expressions are given for participation factors corresponding to natural modes, where the contributions of seismic action along two orthogonal horizontal translational directions as well as for the component of rotation in a horizontal plane are simultaneously considered. The ground model is based on developments of (Sandi, 1982). The three components referred to which contribute to

the participation factors are assumed not to be cross-correlated. The amplitude of the rotational component for a definite natural mode is obtained by dividing the amplitude of translational components (assumed to be similar) by a conventional wave length (determined on the basis of a conventional propagation velocity and of a non-dimensional factor that was calibrated by means of a parametric analysis).

7 REINFORCED CONCRETE STRUCTURES

The frequently recurring strong earthquakes (as referred to previously) made it compulsory to adopt earthquake protection measures all over the territory. This led to the solution of implementing in the general standard for design of concrete members also detailed provisions for the earthquake resistant design. Under these conditions only general design principles presented in section 2 of the code were kept in section 7, with the necessary adaptations. The resistance conditions, the global ductility requirements (including the definition of favourable mechanisms of energy absorption for specific structures, like frames or shear wall structures), the local ductility requirements at the level of sections, the rules of avoiding non-ductile failure due to various causes, conditions for limiting damage to non-structural components, conditions concerning materials, are presented there.

The behaviour factor ψ (which plays the role of $1/q$, according to the symbols used e.g. in the Eurocode 8) are assigned values of 0.2 to 0.25 for storied frames, 0.15 to 0.2 for one-storey halls, 0.25 for shear wall structures, 0.3 for structures with flat slabs, 0.35 for chimney-like structures, and for elevated tanks, 0.25 for silo structures. Some separate instructions for special structures increase some of these values.

8. STEEL STRUCTURES

The most relevant provisions on steel structures concern the local ductility and the behaviour factor.

The local ductility is provided by restricting the width-to-thickness ratio in compressed parts of member sections. Three classes are provided for this ratio: class 1 concerns the plastic behaviour of members, class 3 concerns the elastic behaviour and class 2 is intermediate.

The behaviour factor ψ are assigned values that are similar to those of EC 8-1988 or of the Californian Code ECOSOC-1986. These values are 0.17...0.20 for multi-storey frames and 0.20...0.37 for one-storey structures, 0.5...0.65 for cantilevers. For concentric

vertical truss bracings they are 0.25 for diagonals acting only in tension and 0.50 for V-bracings. In order to increase the local carrying capacity of compressed diagonals attention is paid to the slenderness factor and to the connections between diagonals and horizontal or vertical members, respectively. A special verification is prescribed for the zones of column bases and for anchor bolts. A value of 0.18 is adopted for ψ in case of eccentric truss bracings.

Some general requirements are prescribed for the design of multi-storey buildings and for one-storey halls as well.

9 EQUIPMENT AND SERVICE SYSTEMS

The provisions concerning the earthquake protection of equipment and service systems were considerably developed in comparison with the homologous provisions of the previous code. Attention is paid to an appropriate classification of equipment (5 categories, including A : critical equipment; B,C,D: support equipment of different classes of importance ; E :various less important types). Alternative qualification methods are considered (in-depth engineering analyses, tests, simplified analyses and engineering judgement). The use of floor design spectra is explicitly recommended for higher category equipment. Rules for the formulation of qualification reports are specified, in relation to each of the four methods of qualification referred to. In case of use of simplified analyses the design spectrum is to be multiplied by 2.0 for category A equipment, by 1.5 for category B equipment and by 1.0 for equipment of categories C,D,E. Rules are prescribed for locating and installing equipment and service systems and that includes some detailing provisions. Particular attention is paid to some support functions of service systems, like permanent safety lighting.

The Annex F of the code presents a comprehensive list of categories of equipment used in buildings with various special functions.

10 PROVISIONS CONCERNING THE EXISTING STRUCTURES

The evaluation of the level of aseismic protection of existing structures and the design of upgrading works represent activities of highest difficulty for civil engineers. These activities, which are connected with the pathology of various works and are bound to meet a virtually unlimited manifold of specific situations, can be hardly covered by regulations of the same kind as those concerning newly designed structures. This is the reason for which such provisions are almost absent at a world level.

The problem of the existing building stock

is particularly acute in Romania, due to the size of the area affected by high intensities and to the high recurrence rate of strong earthquakes. The economic constraints play also a paramount role in this connection.

The sections 11 and 12 of the code considered an hierarchy leading to a differentiated treatment of:

- various structural categories of the existing building stock, according to the degree of difficulty implied by the evaluation/intervention activities;
- investigation methods (five levels of methods are considered in this relation);
- activities implied by various urgency categories of intervention;

The main quantitative criterion to be estimated on the basis of such investigations is a ratio

$$R = \frac{\text{actual bearing capacity of a structure}}{\text{required bearing capacity, according to code}}$$

The value of R, together with the category of importance, are used, to determine:

- the urgency category (U_1, U_2, U_3) to which the investigation and intervention works pertain;
- the minimum values R required for the verification of upgraded structures.

11 CORRELATION WITH OTHER DESIGN REGULATIONS

The regulatory basis of structural design includes, besides the code for earthquake resistant design, standards for general design principles (verification of structural safety and reliability), for classification and design combinations of actions, for various specific actions, for the design of basic components of plain, reinforced and prestressed concrete, of steel etc. and of some types of buildings (shear wall buildings, large panel buildings). The basic approach to structural design is semi-probabilistic (limit states method).

12 FINAL REMARKS

The further development of earthquake resistant design regulations is considered to be a steady task. It is expected that, in a few years, a new version of the code will be developed. Some additional topics are to be dealt with, among which provisions for earthquake resistant design of foundations. It is expected that seismic conditions will be described in terms of a system of maps with different return periods and that the level of protection will be specified by return periods differentiated with respect to verification criteria and with respect to the importance of structures dealt with. 3D analysis is to be dealt with in a more complete way, considering also cases of multi-support structures

with explicit specification of non-synchronous input at different ground-structure contact points. The behaviour factor is also to be reconsidered. Precise specifications on how to carry out time-history analyses are to be developed too. Preparatory work in these directions is under way since some time.

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