ROMANIAN SEISMIC DESIGN CODE: BENCHMARKING ANALYSES WITH REFERENCE TO INTERNATIONAL CODES AND RESEARCH NEEDS FOR FUTURE DEVELOPMENT

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ABSTRACT

The paper presents conclusions from a technical benchmarking study, performed in order to analyze the performance of the provisions concerning seismic design of reinforced concrete frame structures, as specified by the Romanian seismic code (P 100-1 / 2006). The Romanian code is analyzed with respect to the European standard EN 1998-1 : 2004, including its National Annex, and with the U. S. codes IBC 2009 and ACI 318 08. The benchmarking analyses were performed by designing a standard reinforced concrete structure according to each of the considered codes and by evaluating the seismic behavior of the structural designs thus obtained. Comparative assessments are made, as well as suggestions concerning potential future research directions, aimed to the improvement of the Romanian provisions in the field.

Keywords: seismic design code, reinforced concrete frames, P100, Eurocode, IBC 2009

REZUMAT

Articolul prezintă concluziile unui studiu de benchmarking tehnic, realizat în scopul analizei performanţei prevederilor codului românesc P 100-1 / 2006, referitoare la proiectarea seismică a structurilor în cadre din beton armat. Codul românesc este analizat în raport cu standardul european EN 1998-1 : 2004, inclusiv anexa sa naţională pentru România, respectiv cu reglementările americane IBC 2009 şi ACI 318 08. Analizele de benchmarking sunt realizate prin proiectarea unei clădiri-etalon, în cadre din beton armat, în acord cu fiecare dintre codurile considerate şi prin evaluarea comportării seismice a variantelor de structuri astfel obţinute. Sunt formulate aprecieri comparative privind exigenţele codurilor menţionate, precum şi sugestii referitoare la unele posibile direcţii viitoare de cercetare în perfecţionarea prescripţiilor româneşti în domeniu.

Cuvinte cheie: cod de proiectare seismică, cadre din beton armat, P100, Eurocode, IBC 2009

1. INTRODUCTION

The study presented in the following was performed during the period 2009-2011, having as main objectives:

- to determine the international state of the art of current seismic codes and of the trends in their evolution;
- to perform technical benchmarking studies, in order to obtain information on the performance of the Romanian seismic code, as compared with other codes worldwide, particularly European and U. S. codes;
- to formulate a set of research needs, principally on medium and long term, required for the development of the new generation of Romanian seismic codes.

The above objectives were pursued, separately, for new and existing buildings. The paper concerns only aspects regarding the seismic design of new buildings. Taking into account the very large extent of topics involved, the study was limited, for the current stage, only to issues regarding reinforced concrete structures.

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The paper presents a concise state of the art and perspectives of Romanian seismic codes, some of the results of the technical benchmarking analyses concerning provisions for the seismic design of new buildings and a set of research directions which should be followed in the next period for the future improvement of the Romanian seismic design code and, possibly, of Eurocode 8, Part 1 (CEN, 2004a).

2. BACKGROUND: STATE OF THE ART AND PERSPECTIVES OF ROMANIAN SEISMIC CODES

2.1. State of the art

The accession of Romania to the European Union in January 2007 had a strong impact on the legislation and regulatory basis of the country. The necessity of the harmonization between the Romanian and European regulations has imposed a concerted effort of the national organizations in charge with the coordination of standardization and regulatory activities, together with the professionals and specialists in the concerned fields. The harmonization process has included either the adoption of European norms, sometimes adapted to the national conditions, or the development of new regulations, conforming to those of the EU.

In the field of civil engineering, the main harmonization vectors were the adoption of European standards, norms and technical regulations, among which a central role is played by the structural Eurocodes.

The preparation for the adoption of Eurocodes started with the mid-decade of the past century, and several specialists in universities, research institutes and building design organizations were involved in the process. A significant number of Romanian regulations were developed, prior to the accession, in preparation of the harmonization with the European regulatory basis, as for instance, the new version of P100 1/2006, the Romanian seismic design code. In parallel, the development of National Annexes to the Eurocodes was started.

Today, the process is practically finalized, the Eurocodes being fully adopted as national standards, together with their National Annexes for Romania. Consequently, the conflicting standards have been withdrawn.

Among the structural Eurocodes, one of the most important for the building stock in Romania, from the regulatory point of view, is that concerning the design of structures for earthquake resistance, Eurocode 8. Included, together with Greece and Italy, amongst the European countries most affected by earthquakes, Romania was hit, since the catastrophic March 4, 1977 earthquake, by four other strong subcrustal seismic events, with moment magnitudes M_w ed 6 and originating from the Vrancea source. In addition, the series of crustal earthquakes in Banat, with magnitudes up to $M_w = 5.6$, which occurred in 1991, revealed the destructive potential of seismic sources located in the south-western part of the country. In this specific context, the existence of detailed and up-to-date seismic code is a key factor for the reduction of seismic risk in Romania.

The development of P 100-1 / 2006 (MTCT, 2006) has represented a milestone in the progress of Romanian seismic codes. The code concerns the seismic design of new buildings, being part of a regulatory package, structured similarly to Eurocode 8 parts and including also a code for the seismic evaluation of existing buildings (P 100-3 / 2008, MDRT, 2009). The code answers to both the requirements of harmonization with European norms and the necessity of implementation in Romanian regulations of recent advances in the field. The P100-1 / 2006 code has prepared the adoption, starting from 2011, of the homologous Eurocode, EN 1998-1, as the Romanian standard SR EN 1998-1 (ASRO, 2004), together with its National Annex for Romania (ASRO, 2008). The compatibility and similarity between the Romanian and the European code has represented an essential factor in the transition to European norms.

The P 100-1 / 2006 code implements important elements of progress with respect to its previous version, P 100-92 (MLPAT, 1992). However, factors as the generally higher degree of complexity of the new code, the newly introduced concepts and methods, the notation modification or the different code structure pose difficulties to many of the building design practitioners in Romania. In order to facilitate the assimilation of the new code, an additional volume of commentaries and design examples was published. Additionally, in 2007, the Technical University of Civil Engineering Bucharest provided a program of postgraduate courses aimed to the better understanding of the new provisions.

At present, five years after its publication, the P100 1/2006 code is undergoing a revision process. The new version of the code will be enforced most probably in 2012 and will introduce a series of enhancements, with respect to the 2006 version. The author of the paper has contributed with her observations and comments in the national consultation launched after the development of the first draft of the revision.

2.2. Perspectives and future needs

According to the normal cycle of code development, the preparation of the next version should start immediately after the code has been enforced. This is due to the time needed both for additional research and for the actual development of the code. The process, applicable to the U. S. codes, is illustrated by the ATC-57 report (ATC, 2003), which also specifies the need of performing intermediate revisions during the development cycle.

The Eurocodes undergo a similar process, in which a continuous maintenance of the codes is performed, together with a regular revision, which is typically scheduled at intervals of about 5 years. The revision and maintenance procedures are regulated by CEN / TC250, the Technical Committee 250 of the European Committee for Standardization. According to the CEN / TC250 Newsletter (CEN, 2011), the European Commission's "Programming Mandate M / 466", concerning the future work for the Eurocodes, was recently finalized. The work will probably begin i n 2013.

As the Romanian seismic design code, P 100-1, is harmonized with Eurocode 8, it is considered that it should undergo a similar maintenance and revision process as the European norm. As a member of the EU, Romania will take part to the Eurocode revision; however, a parallel work should be done for the national seismic design code, P 100-1. This would be beneficial for several reasons: it would ensure a proper harmonization with the European norms, it would allow the clarification and implementation of certain non-conflicting issues of national interest, for instance those regarding the quantification of the seismic actions and, additionally, it would allow the implementation in the new code of the recent advances resulting from the Romanian research in field. The work goes beyond the envisaged 2012 version of the P100-1 code. The draft of the code is already public and it can form the basis for establishing the objectives of the revision program and of the pre-normative research work that should be carried on in the future.

3. TECHNICAL BENCHMARKING STUDIES

3.1. Technical benchmarking and its application to regulatory documents

In its original definition, benchmarking is "the process of continuously measuring and comparing one's business processes against comparable processes in leading organizations to obtain information that will help the organization identify and implement improvements" (Andersen and Petersen, 1996).

Initially used for comparing corporate strategies, the benchmarking procedure was recently extended for assessing the performance of industrial products. The procedure is called, usually, "technical bench-marking" or "product benchmarking", and it is being applied extensively in automotive industry.

The assessment, by benchmarking of the performance of regulatory documents becomes, gradually, a largely used procedure. In this case, the regulatory document is analyzed according to principles that are similar to those used for the technical benchmarking of industrial products. Such procedures were applied in the cases of the Australian regulations for occupational health and safety (Productivity Commission, 2010), the Colombian regulations for potable water and sewer services (Marquez and Garzon Contreras, 2007), or the energy performance building regulations on incorporation of renewable energy sources in Belgium, Denmark, France, the Netherlands and United Kingdom (European Commission, 2010).

From the point of view of the research presented in this paper, the application of the technical benchmarking procedures signifies the comparative assessment of the performance of

Romanian seismic design provisions, with respect to the homologous European and U. S. documents.

A parallel study was performed for the Romanian regulations concerning seismic assessment and rehabilitation of existing buildings. The structural analyses performed for each of the two studies were presented in detail in (Craifaleanu et al., 2011a and 2011 b).

Both studies were performed in view of the improvement of Romanian seismic codes, by integrating the recent progress in the field.

3.2. Methodology

The benchmarking procedures were applied to a typical nine-story reinforced concrete frame structure, designed according to the Romanian seismic design code. The phases of building design, as well as the results, are presented in Annex I (informative) of the P 100-1 / 2006 code (MDLPL, 2007), which provides design examples for various types of structures. The structure was chosen due to its topological and typological simplicity, as well as for the advantage of the availability of a detailed description of the design.

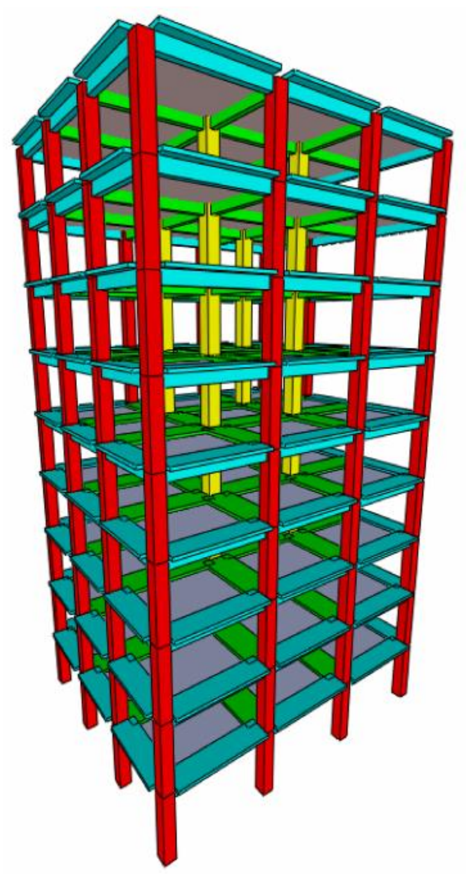

Fig. 1. Model of reinforced concrete frame structure used in technical benchmarking analyses

The analyses were focused on the comparative evaluation of the structure characteristics that resulted from the seismic design according to Romanian, European and U. S. regulations, and, in particular, of the longitudinal and transversal reinforcement areas. The seismic behavior of each resulting model was assessed by nonlinear static and dynamic analyses. The analyses were performed by using the computer program SAP2000 (CSI, 2009).

The regulations taken into account were: the Romanian code, P 100-1 / 2006, Eurocode 8 (EN 1998-1 : 2004) (CEN, 2004a) and Eurocode 2 (EN 1992-1-1 : 2004) (CEN, 2004b), the corresponding Romanian standards (SR EN), together with their National Annexes, the U. S. model code, IBC 2009 (ICC, 2009), ASCE 7-05 (ASCE, 2006) and ACI 318-08 (ACI, 2008). It should be pointed out that the above mentioned U. S. codes include clauses from the "*Recommended Provisions and Commentary for Seismic Regulations for New Buildings and Other Structures*", FEMA 450 (FEMA, 2006). Additionally, procedures and methods from ATC 40 (ATC, 1999), FEMA 356 (FEMA, 2000) and FEMA 440 (FEMA, 2005) reports were used in the nonlinear static analyses performed in the presented study.

The input parameters were chosen in order to ensure, as possible, the required equivalences. In all analyses, seismic forces were determined according to the P 100-1 / 2006 code.

3.3. Results

3.3.1. Analysis of design solutions

Concerning the *longitudinal reinforcement*, the following observations were made (Fig. 2).

- For beams, the reinforcement areas computed according to the Romanian codes were close to those resulting according to European norms.

- For columns, the reinforcement amounts computed according to the Romanian and European codes were identical, as the reinforcement was determined by the minimum reinforcement ratio of 1%, which is the same in both codes.

Similar observations resulted from the comparison of longitudinal reinforcement areas obtained according to the U. S. and to the Romanian regulations, respectively.

Additionally, it should be noted that the necessary reinforcement amounts in beams, determined according to U. S. regulations, result smaller that those determined according to European norms, especially along beam spans and at the upper levels of the structure.

The *transverse reinforcement* at the ends of the beams, computed according to the Romanian codes, is given, for the entire structure, by the minimum reinforcement ratio. The same applies for the transverse reinforcement in the central part of the span, for the 3 upper floors of the structure. It should be mentioned that, even at stories 1…6, the transverse reinforcement that resulted along the span of the beams does not exceed with more than 50% the amount corresponding to the minimum reinforcement ratio. For corner columns, the transverse reinforcement was determined from detailing requirements.

The comparison between the amounts of reinforcement in beams revealed that the highest requirements are those of U. S. codes, followed by those in European norms and finally, by those of Romanian codes.

Concerning the transverse reinforcement in columns, the amount determined according to Romanian codes satisfies the requirements of European norms only for perimeter columns, whereas for interior columns, it appears as insufficient. The amounts of transverse reinforcement in columns, determined according to the U. S. codes ACI 318 08 and IBC 2009, are greater than those required by the Eurocodes, at the upper stories, and smaller at the lower stories.

3.3.2. Assessment of the seismic behavior of the considered structure by using nonlinear analysis procedures

The seismic behavior of the structure designs obtained according to the considered codes was analyzed, in order to assess their performance. For the analysis, both static and dynamic nonlinear procedures were used.

Fig. 2. Actual longitudinal reinforcement areas for benchmarking model (green and yellow rectangles) vs. reinforcement areas determined according to European norms (plain text). Example for a transverse frame

For nonlinear static analysis, the lateral load patterns applied in all cases were those specified by the P100-1/2006 code. These patterns are practically similar to those in Eurocode 8. The methods used in the analyses were: the nonlinear static methods in the Romanian code, the capacity spectrum method in ATC-40, the coefficient method in FEMA 356, as well as the equivalent linearization method and the displacement modification method, both in FEMA 440.

For nonlinear dynamic analysis, the three components of the INCERC March 4th, 1977, accelerogram were applied simultaneously to the structure. Also, in two additional cases, the NS component of this accelerogram was applied, separately, on each horizontal direction, according to an older practice.

The response of the analyzed structures is strongly influenced by the large-amplitude quasi-sinusoidal pulse, characteristic to the NS component of the considered accelerogram. This leads to the simultaneous plastification of several structural elements.

Both static and dynamic nonlinear analyses confirmed that the structural model designed according to the P 100 1 / 2006 code, considered with its actual reinforcement, satisfies the requirements of European and U. S. codes, from the point of view of longitudinal reinforcement. However, it appears that the model is deficient in what concerns the transverse reinforcement of certain beams and columns of the structure.

Concerning the assessment of the seismic behavior of the various structure designs by nonlinear static analysis, the considered methods yielded to rather similar results, from the point of view of observed behavior. The development of plastic hinges in beams, followed by plastic hinge occurrences in the columns of the first story was

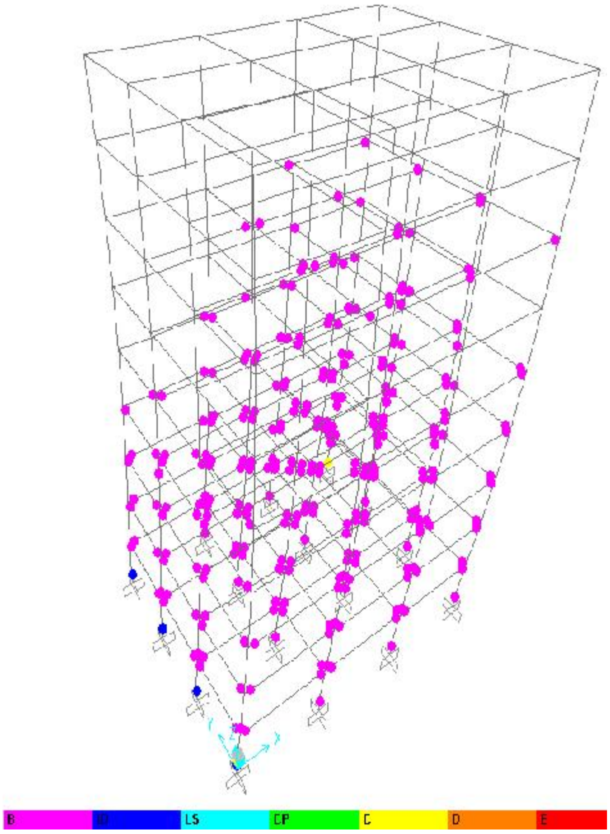

Fig. 3. Plastic hinges at the moment of the maximum top displacement, for one of the time history analysis cases

observed in all cases. A structural overstrength ratio of up to 50% was obtained for certain models, especially due to detailing rules (minimum reinforcement ratio, minimum number of rebars etc.).

The verification of the seismic behavior by nonlinear dynamic methods revealed, for the stage of the maximum attained displacement, the occurrence of plastic hinges in beams, followed by the spreading of hinges in the columns from the first 2-3 stories of the structure and by the significant degradation of the strength capacity of one of the corner columns.

3.4. Benchmarking conclusions

The benchmarking study revealed that the resulting longitudinal reinforcement areas in beams and columns were rather close for all the three categories of codes analyzed. Moreover, there were several columns for which the reinforcement was governed by the minimum reinforcement ratio, which is the same in the considered codes.

In what concerns the transverse reinforcement, the lowest values were required by the Romanian code and the largest, by the U. S. code. The Eurocode requirements were in an intermediate position.

The nonlinear analyses showed a satisfactory seismic behavior of all models, from the point of view of the order of occurrence of plastic hinges in the structures and of the distribution and amplitude of plastic deformations. However, it should be noted that differences, significant in some cases, were observed between the displacements corresponding to the "performance point", computed by the different static nonlinear methods used in the study.

Due to the limited extent of the analyses, the above conclusions should be considered only preliminary. Supplementary research, based on a broader structure typology, is needed to further substantiate and to add generality to the study.

4. PROPOSALS FOR THE IMPROVEMENT OF THE ROMANIAN REGULATORY BASIS FOR EARTHQUAKE RESISTANT DESIGN OF BUILDINGS

The technical benchmarking analyses presented previously were integrated in a larger research, which

No.	Proposal / research direction	Scope	Term	Substantiation
1.	Improvement of the procedures for the selection and scaling of design accelerograms	- P100-1, ch. 3 - National Annex for Romania of Eurocode 8, Part I	Medium	The code requirements are difficult to satisfy, whether real or simulated accelerograms are used. These requirements are not fully validated from the point of view of their relevance with respect to real seismic records. The deficiencies are obvious especially when the selected accelerograms need to match design spectra with long control periods (T_C) as, for instance, in the case of the T_C = 1.6 s in the Romanian code. In this case, the long horizontal segment of the design spectrum (T = 0.16 s…1.6 s) imposes large, unrealistic, spectral amplitudes in the short period range.
2.	Improvement of the understanding and modeling of the influence of local site conditions on the frequency content of ground motions, for the relevant sites in Romania	- P100-1, ch. 3 - National Annex for Romania of Eurocode 8, Part I	Medium / long	In the current Romanian code (and, as well, in the revised version that is in preparation), the influence of local site conditions on the frequency content of ground motions is taken into account implicitly, by means of the shape of the design spectrum, dependent on the value of the control period, TC. This is justified by the specific seismological and geological conditions of Romania. The approach is different from that in Eurocode 8, where a specific soil factor, S, is included. Some relatively recent studies (Sandi et al., 2004), have shown, however, that there are certain types of sites in Romania where the influence of local site conditions could be explicitly put in evidence. Additional field tests, combined with information from seismic records obtained on these sites from previous earthquakes, could give a better image of the above mentioned influence.
3.	Improvement of the evaluation of behavior factors, *q*, for different structure types	- P100-1, ch. 5…9 - Eurocode 8 Part I (EN 1998-1:2004), chapters 5…9	Medium	The behavior factors are not among the Nationally Determined Parameters (NDPs), i.e. their values are specified in the main body of Eurocode 8, Part I. Thus, their better evaluation could be part of the future research work needed for the improvement of Eurocode 8. As the values of the behavior factors in P100-1 (including the new revised version of the code) are different from those in Eurocode 8, additional research is needed in the future for their improved substantiation, as well.
4.	Improvement of the evaluation of α_u/α_1 ratios	- P100-1, ch. 5…8 - Eurocode 8, Part I, ch. 5…8	Medium	The α_u / α_1 ratios take into account the influence of some of the factors that provide structural overstrength, especially of structural redundancy. They are used in the calculation of the behavior factors, i. e. this proposal is subsidiary to the previous one. The separate study of the overstrength sources can lead to a more rational evaluation of the α_u / α_1 ratios.

No.	Proposal / research direction	Scope	Term	Substantiation
1.	Improvement of the evaluation of the displacement amplification coefficient, *c*, used in nonlinear static procedures	- P100-1, Annexes D and E - Eurocode 8, Part I, Annex B (informative)	Medium	Over time, several expressions have been proposed for this coefficient, without being considered as definitive. The *c* coefficient depends, among others, on structural overstrength. A better evaluation of overstrength (see proposal 3) would also improve the evaluation of *c*.
2.	Improvement of the methods of identification of failure in structural members, as well as of the correspondence between the nonlinear analysis results and the actual damage state of members and structures	- Provisions concerning nonlinear analysis in P100-1 and Eurocode 8, Part I	Medium / long	Most of the models currently used by structural analysis programs do not provide reliable estimations of damage and collapse.
3.	Development of new modeling and analysis methods for reinforced concrete shear walls, that would optimally utilize the advanced capacities of current structural analysis software	- Romanian code CR2-1-1.1 (Reinforced concrete shear walls design)	Medium	The advanced capacities built in modern structural analysis software are not fully used in the methods specified by current codes. Even if there is a constant need of simple design methods, more sophisticated procedures should also be specified and documented by the codes.
4.	Improvement of shear design procedures for reinforced concrete elements	- P100-1, ch. 5 - EN 1992-1:2003 - EN 1998-1:2004	Medium	Recent studies (Cladera and Mari, 2007) have shown that evaluations made by the current method lead to shear capacity values that can differ from test results, both in the conservative and in the unconservative way. According to the cited reference, the evaluations performed by using ACI 318-02 procedure are better from the point of view of their compliance with test results.
5.	A greater implementation of performance based concepts in the Romanian seismic code, including description, assessment, prediction, monitoring and accounting for the specific characteristics of building stock in Romania	Romanian seismic design, evaluation and rehabilitation codes (P100-1 and P100-3)	Medium / long	The Romanian seismic codes, as well as Eurocode 8, Part 1 and Part 3, take into account in a relatively simplified manner the aspects concerning building performance, by comparison with U. S. codes. Further studies are needed.
6.	Research for the gradual alignment of safety levels across EU Member States	Integration in the program planned by CEN for further harmonization of the EN Eurocodes	Medium / long	This is part of the harmonization strategy of the EN Eurocodes, in which Romania will take part as a EU member. Once established, the harmonized safety levels should also be implemented in the Romanian national seismic code.

also included a detailed investigation on the state of the art of current seismic design codes in various countries. The trends in the development of these codes, as well as the future research plans intended for their improvement were also studied. The final goal was to formulate a set of recommendations for the future enhancement of the Romanian seismic design provisions in general and, in particular, of those concerning reinforced concrete frame structures.

The launching, starting from 2012, of a research program, with objectives on short, medium and long term, is considered, by the author of the paper, as the subsequent necessary step for the preparation of the next version of the Romanian seismic code.

The strategy documents elaborated in Europe and in the U. S. for the preparation of a new generation of seismic codes provide an important starting point in this direction. The alignment to these strategies will contribute to the integration of Romanian research into the international networks. In the case of the improvement of the Eurocodes, this can be made directly, by the active participation of Romania to the process, as a member of the European Committee for Standardization, CEN.

Apart from the general international directions, there are certain national research issues, which should be also included in the program.

A set of proposals for this future research program, part of them resulting from the conclusions of the technical benchmarking studies, are presented in the following.

5. CONCLUSIONS

The Romanian seismic design code is presently undergoing a revision process, which is planned to be finalized in 2012. According to the usual procedure, a new research program should be launched following its enforcement, in order to prepare the next version of the code. This would ensure, on one part, the coordination with the development of the new generation of Eurocodes, expected by the end of the current decade, and, on the other part, the incorporation of future findings in the field. The paper presented a set of proposals for this future research program, some of them resulting from a technical benchmarking study of the Romanian seismic design code, performed with respect to European and U.S. codes.

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