SOME RECOLLECTIONS OF RESEARCH ACTIVITIES

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BRIEF BIOGRAPHICAL NOTE

Horea Sandi was born in Sibiu (Romania) on January 20, 1932. He is married and has a daughter.

He graduated from the high school "Gheorghe Lazăr" in Sibiu, in 1950. Thereafter, he studied at the Institute of Civil Engineering (now Technical University) in Bucharest during 1950-1955 and at the Faculty of Mathematics of the University of Bucharest during 1950-1954. He received his PhD from the Institute of Civil Engineering with the doctoral thesis "Contributions to the Theory of Structural Design" in 1966. Between 1968-1969 he was a Humboldt Fellow at the Technical University in Hannover.

He started his professional activity in 1955 as a structural design engineer at IPCF (Railway Design Institute) in Bucharest. During 1957-1958 he was involved in research on physical modeling and on wave propagation at ISCH (Hydrotechnical Research Institute) in Bucharest.

His main professional activities during the next 43 years (1958-2001) took place at INCERC (Building Research Institute) in Bucharest, where he developed research on structural dynamics, structural safety and actions on structures, earthquake engineering and engineering seismology. Starting with 1978 he was the head of the Division of Earthquake Engineering and in 1993 became the chairman of the Scientific Council of the Institute. At INCERC, the main fields he dealt with were: experimental activities (mostly full scale analysis of dynamic characteristics of structures); analytical research (structural dynamics, dynamic interaction, probabilistic analysis of actions, analysis of safety and risk, macroscopic analysis of vulnerability and risk, engineering characterization of seismic intensity etc.); developing of computer programs (modular system for analysis of structural systems and of continua, processing of dynamic records, generation of artificial accelerograms, analysis of vulnerability and risk); drafting of standards on general design principles and on various actions (as a total, 12 structural design standards), as well as of earthquake resistant design code; integrated earthquake protection strategies; technical assistance to design institutes or to construction enterprises; research development strategies.

After 2001, he conducted research at the Institute of Geodynamics of the Romanian Academy on characterization of ground motion and on seismic conditions of Romania. Since 2006, he is honorary researcher at that institute.

His professional career also included teaching activities: from 1963 to 1986 at the Institute of Civil Engineering in Bucharest with courses on Strength of Materials, Structural Dynamics, Structural Stability, Theory of Elasticity, Theory of Shells and Testing of Structures; from 1994 to 2009 at the Technical University of Civil Engineering in Bucharest with courses on Environment Protection & Disaster Prevention, Probabilities & Statistics, Theory of Shells and Strength of Materials; from 1999 to 2003 at the "Ovidius" University in Constanţa with post – graduate lectures on Seismic Hazard and Risk. He has been a doctoral advisor since 1991 (first at INCERC and thereafter at the Technical University of Civil Engineering in Bucharest). He was invited to give lectures at: the Politecnico di Milano and University of Basilicata (at the latter: course on seismic risk, 1991) in Italy, Technical University Hanover and University of Bochum in Germany, University College London in UK and MIT and Purdue University in the United States. His international activities include: participation in projects under bilateral agreement or in the frame of COMECON programs (1963 – 1989) and in UNDP/UNESCO and UNDP/UNIDO Balkan Projects (1981-1984); consultancy work for UNIDO and UNDRO (1983, 1986); rapporteur at international conferences; convener of working groups of the European Association of Earthquake Engineering (1983-1998); lecturer at EAEE

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Regional Seminars on Earthquake Engineering (1973-1989); vice-president of the European Association of Earthquake Engineering (1982-1986); consultancy work for MVV – Mannheim for seismic evaluation of the heating network of Basel – Switzerland (1997); head of Romanian group involved in ENSeRVES (European Network for Seismic Risk, Vulnerability and Earthquake Scenarios) during 1997-2001; director of the international project on “Quantification of Seismic Action” in the frame of the NATO Program Science for Peace during 2005-2008; participation in two projects financed by the World Bank, aimed at seismic risk reduction in Romania (2006-2008); individual member of GAMM (Germany), AFPS (France) and IASSAR.

During his career he received several distinctions and awards: “Medalia Muncii” (Work Medal), 1966; “Steaua Romaniei” (Star of Romania) in knight category, 2000; prize of Romanian Academy for the contribution to the Monograph of the 1977 Earthquake in Romania; Diploma & medal for Opera Omnia of AICPS (Association of Structural Engineers) (2004); reverent INCERC (Building Research Institute) distinction at the age of 75 (2007); memorial medal at the 130-th anniversary of the establishment of the Polytechnic Society in Romania (2011).

He has been a full member of ASTR (Academy of Technical Sciences of Romania) since 1999, vice-chairman of its Division of Civil Engineering since 1999 and chairman of the same since 2007. He was nominated honorary professor at the Technical University of Civil Engineering in Bucharest in 2004 and doctor honoris causa of the Technical University in 2007.

His publication list includes 3 books as a single author, 9 co-authored books and more than 220 articles and papers (more than half in English, French etc.). Among them, more than 50 papers were presented at World or European Conferences on Earthquake Engineering.

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1. INTRODUCTORY THOUGHTS

Looking back at the activities and results to date, a first duty is to think of who contributed to the personal capability to work and, to some extent to succeed, in the specific field of research tackled.

In the first place, to mention my first family, i.e. my parents and my younger sister, who made all possible efforts to provide conditions for an appropriate life and a comprehensive, good quality, education. Of no lesser importance was the environment of good quality life and of cultural interest created by my present family, i.e. my wife and our daughter.

The good quality of sources of formal education, starting from the primary school, up to the faculty, represented also a factor of highest importance. A very special and important chance was represented by the possibility, about six decades ago, to study in parallel Civil Engineering and Mathematics. Both faculties were at that time of good quality, the latter one being definitely excellent (ten of my professors were members of the Romanian Academy). The knowledge acquired at the two faculties was mutually complementary and compatible. It was very encouraging to become aware of the variety of mathematical branches that provided practical tools of investigation of engineering problems.

A new professional chance was the fact that, after about three years of practical engineering activity, by pure fate, my career continued in the frame of INCERC (Building Research Institute), Bucharest, as a researcher in the Division of Structural Mechanics. Colleagues were friendly and genuinely interested in research. Personal initiative of management of time was largely at hand. As an example, it was possible to have an in-depth look at the Russian translation of the classical six volume treatise on Physics by Arnold Sommerfeld, and this was a source of inspiration for the paper [2] (for references, see the excerpts from the Extensive list of publications 1960-2010, given at its turn in [A.1.3]). Western professional literature was severely prohibited at that time, due to ideological reasons, but there existed a good compensation: excellent and very cheap literature in Russian, authored by Soviet or by Western scientists, was largely at hand. Political and ideological pressure was rather moderate and gradually weakened, so life was quite livable. Travels to the West were initially severely prohibited, but in 1968 it became possible to benefit from a Humboldt fellowship in Western Germany. Quite numerous trips abroad followed, which did not require political compromises. Obtaining the exit visa was nevertheless a random process. I was invited, at the expense of the organizers, to the 8th World Conference on Earthquake Engineering (San Francisco, 1984) and to the 9-th World Conference on Earthquake Engineering (Tokyo / Kyoto, 1988), but I could not give suit to these invitations, because the exit visa came too late. In 1976 I had not been allowed to lecture to the Regional Seminar on Earthquake Engineering because the invitation was ... personal. And so on.

Finally, another major professional chance was represented by the incidence of the destructive earthquake of 1977.03.04, followed by the strong earthquakes of 1986.08.30, 1990.05.30 and 1990.05.31. Among other, the rich instrumental information obtained due to the appropriate function of the considerably extended strong motion network, following the generous aid provided by the Agency of International Development of the US State Department after the 1977 event, represented a major source of information. Its use lay among other at the basis of extensive analytical work and of knowledge about the features of the seismicity of Romania. Nevertheless, the interpretation of qualitative aspects of the information on earthquake effects and features of structural performance was equally important.

2. FIELDS OF ACTIVITY

The subsequent data and comments are concerned with the research activities which I considered to be the most relevant ones. They are by far not exhaustive if we would like to think of all problems raised during the long research activity in which I was involved.

2.1. Analysis (especially mathematical modeling) of specific physical (mechanical) phenomena

Mathematical modeling, especially for dynamic phenomena, represented a field of constant interest. A common feature: the problems tackled in this way were of engineering interest, while the mathematical tools used exceeded standard engineering education. A special event: by chance, I found in 1953, as I was a student, in a bookstore of a remote industrial town, Hunedoara, the Russian translation of B. Van der Pol's and H. Bremmer's book on the two-sided Laplace – Carson transform (1950, Oxford). I became immediately enthusiastic about it and used it thereafter routinely in performing calculations concerning (linear) dynamic phenomena. This transformation leads to the use of an analytical extension (in the sense defined in the frame of the theory of complex functions) with respect to the use of the Fourier transform. This technique was extensively used in my book [A.1.2], as well as in the summary views of [53] and [83].

The main problems dealt with, leading to publications, were as follows:

2.1.1. Equations of spatial behavior

Inspired by a paper by A. Lurie, presenting a tensorial approach to the theory of shells, a first publication, [1], was concerned with a quite homologous formulation of the equations of space curved bars, going up to their dynamics and stability.

2.1.2. Dynamic interaction problems

Reading about two roles of the ground in seismic oscillations of structures, namely that of agent transferring the disturbance and that of deformable support, it appeared that the literature at hand suffered from a lack of consistency. The attempt to provide consistency in this field led to the formulation of ground – structure interaction equations, [2], [3], alternatively in the time domain (where Volterra integral equations of the first kind were derived) and in the complex frequency domain specific to the Laplace – Carson bilateral transform (where algebraic equations were derived). A homologous approach was adopted for plate – halfspace interaction [4] (where also a Hankel transform was used) and then for water – dam interaction, [17] (where non – synchronous motion of the ground – dam interface was also considered). Other cases of dynamic interaction were dealt with on the basis of homologous approaches too [6] etc. Non – linear interaction became a matter of concern subsequently to the experience of the destructive Vrancea earthquake of 1977.03.04 and is dealt with later.

2.1.3. Non-classical eigenvalue problems

When reading publications on structural dynamics problems, I remarked again a shortcoming affecting the usual procedures of analysis of dynamic phenomena: the formulation of equations of motion relied everywhere on the (implicit and non discussed) use of Kelvin-Voigt types of constitutive laws for materials and structural members, which led to the result that modal damping is proportional to eigenfrequencies, while several experimental data showed that modal damping is practically constant. It was obvious that, in order to obtain more realistic results, the type of constitutive laws used had to be changed. A standard option of this latter nature, based on a formulation in the time domain, would bring severe complications, because the type of equations of motion would become much more complicated, with severe consequences for the possibilities to obtain analytical solutions. After numerous attempts to eliminate these shortcomings, it turned out that using the Laplace-Carson bilateral transform offers a very promising way of treatment of the problem. In this way, the equations of motion led to a linear algebraic eigenvalue problem depending upon the complex circular frequency $p = \chi + i\omega$, with very interesting consequences. Moreover, the attempt to use constitutive laws of the generalized Maxwell type offers possibilities of good approximation of physical performance as well as considerable advantages in the analytical treatment. The system of eigenvalues corresponding to a dynamic system corresponds at its turn to the system of branches of a complex function, that may be represented by means of a Riemannian surface corresponding to the ensemble of various eigenvalues. The reducibility to classical eigenvalue problems, where real, constant, eigenvectors exist, was analyzed, for the case of Kelvin-Voigt constitutive laws, by T. K. Caughey and M. E. J. O'Kelly about five decades ago. In case of non-reducibility to a classical eigenvalue problem, the eigenvectors are at their turn complex functions of p. They are no longer orthogonal and the more general concept of pseudo-orthogonality had to be introduced. The points $p = p'$ for which multiple eigenvalues exist are ramification points of the Riemannian surface. The diagonal matrix of eigenvalues must be replaced at such points by a matrix including Jordan type submatrices. At these points a complete basis of eigenvectors ceases to exist and chains of principal vectors are to be additionally introduced. The ramification points of the Riemannian surface are singular points of the eigenvectors that are bound to be replaced by principal vectors, and the Taylor expansion, valid for the case of eigenvectors at points p with non-multiple eigenvalues, has to be replaced around these points by means of expansions including non-integer powers, some of them negative, reflecting in this way the singularity referred to. The non-classical eigenvalue problem was dealt with first in [22] and, thereafter, in a more extended way, in the book [A.1.2].

2.1.4. Dynamic wind effects

The use of the concept of random functions, increasingly dealt with in literature, appeared to be very attractive for the analysis of several dynamic problems. Various dynamic problems could be conveniently treated in this way. A first publication prepared was [8], where dynamic wind action and oscillation phenomena induced to flexible structures were dealt with. The model of wind action adopted was a time-stationary random field, for which cross correlation and coherence characteristics of time dependence of wind pressure at different points were used. The analytical developments referred to lay at the basis of developing of practical rules of specification of wind action as a spatial action, in the frame of the standard endorsed in 1975 and in its further editions (see item 2.1). Much more developments concerning seismic oscillations followed.

2.1.5. Pluri-dimensional modeling of seismic input

A look at most earthquake resistant design codes shows that seismic action is specified implicitly assuming that the ground – structure interface motion is represented by an SDOF (usually, rigid body horizontal) translation. This model may be acceptable in most cases for practical design, but it is non-realistic due to some undeniable factors, among which the finite speed of propagation of seismic waves is the most common. A first aspect, tackled in [26], was the case of non-synchronous motion of ground – structure contact points. This problem required the use, as main unknown quantities, of the absolute seismic displacements instead of the traditionally used relative displacements. The technique adopted was somewhat different from that used by R. Clough and J. Penzien, but it was equivalent to that. The deterministic approach to the problem was followed by a stochastic approach, corresponding to stationary random motion.

2.1.6. Modeling of random wave propagation

These latter developments required in turn to specify in stochastic terms the motion at the level of ground – structure interface. To deal with this need, a stochastic model of ground motion as that of a continuum was proposed. A 6DOF model (three translation components and three rotation components) for ground motion at a point was adopted. The model was time – stationary, while the main emphasis was on specifying cross correlation and coherence characteristics for motion at different points of the continuum [59], specifying consequently a 6×6 coherence matrix. This made it possible to fully specify the seismic input for the case of non-synchronous ground – structure interface motion. These developments were somewhat refined in [175], [176]. The main ideas of this work were applied already in [44], where artificial multi-component accelerograms were generated, and in [47] where, due to uncertainties concerning the equivalent wave propagation speed, a parametric approach to the analysis of oscillations of multi-span bridges was adopted.

2.1.7. Stationary vs. non-stationary modeling of random functions

A look at some codes where stochastic models are explicitly referred to, as well as at numerous other publications concerned with spectral analysis of seismic motion shows that the basic stochastic models accepted are implicitly models of stationary random motion. On the other hand, seismic motions are always transient, which means non-stationarity, and this non-stationarity is frequently so strong, that the use of concepts and characteristics that concern stationary phenomena becomes obviously questionable. This remark raised to me the problem of trying to contribute in some way to a more consistent approach in the field referred to. The starting point was provided by the joint consideration of the classical Wiener-Khinchin relations for the case of stationary random functions and of the generalized Wiener-Khinchin relations for the case of non-stationary ones. The novel approach to non-stationary random functions was based on rotations of $\pi / 4$ in the planes of time arguments $t1$ and $t2$ (replaced by $t'1 = (t1 + t2) / 2$ and $t'2 = t2 - t1$ respectively) and, in a homologous way, in the plane of circular frequency arguments $\omega 1$ and $\omega 2$. The generalized Wiener-Khinchin relations were rewritten with respect of the newly introduced variables, which made it possible to define some new concepts. This approach made it also possible to explicitly consider the case of stationary functions as a limiting case when one of the newly introduced circular frequencies, $\omega' 2$, tends to 0. The alternative use of functions and relations referred to was discussed in [95].

2.1.8. Developing of computer software

Starting with 1963, a few primitive digital computers became available for modest engineering calculations. The first calculations we performed were related to simple problems of structural dynamics, going up to roughly determined response spectra. Starting with 1970, reasonable quality computers, like IBM-360 and IRIS-80, became available. This made it possible to develop quite well performing computer programs. The most important software developed was a modular system of linear analysis, which made it possible to tackle problems concerning trusses, plane or spatial frames or continuous systems reducible to some kinds of finite elements. The most complex structural systems dealt with were:

- the new trans-Danube three-span steel bridges at Feteşti and Cernavodă (models: 3D moment resisting frames), 1977 [47];
- the structure of the main exhibition hall of Bucharest, consisting of an r.c. infrastructure supporting a 96 m steel structure dome, 1982 [79];
- the structure of an NPP reactor building (Unit 3) of Cernavodă, where the effects of wrongly deviated prestressing members of the dome were analyzed (model: axi-symmetrical shell, for which 36 terms of the Fourier expansion with respect to the azimuthal angle were considered in order to deal with the effects of deviated cables), 1987.

The theoretical basis of this software was discussed in my book [A.1.1]. Other components of the software developed concerned the integration of linear or non-linear equations of motion, processing of seismic accelerograms, generation of artificial accelerograms (e.g. [44]) etc. After 1990, this software was gradually replaced by imported software, relying on more advanced IT techniques.

2.1.9. Seismic action at floor level

At the time of design of the first NPP of Romania, INCERC was involved in several specific activities, of analytical, computational or experimental nature. Specific software was developed for this goal, assuming linear performance. Seismic action was represented in terms of (stationary) spatial random motion. The bearing structure was dealt with as a spatial system, for which normal mode characteristics were considered. Safety problems raised by the floor design conditions were taken into account [67], [99].

2.1.10. Base isolation

Base isolation represents currently a widely used and successful technique aimed at reducing the effects of seismic action upon structures. This works well, without implying special difficulties, for most seismic areas, yet such areas are characterized by relatively short expected dominant periods of ground motion. The interest of adopting such procedures in Romania is easily understandable, but there is a but. Instrumental strong motion information obtained during last decades in Romania makes it obvious that expected relevant strong motions are characterized, for important areas of Romania (Bucharest included) by unusually long dominant periods. This raises special problems for the use of base isolation systems, which should be designed such as to lead to fundamental periods of the structure – isolation system in the range of several seconds. This problem was dealt with in [196], [A.2.7], where considerations on specific hazard and risk were presented too.

2.2. Analysis (especially mathematical modeling) of safety and risk problems

2.2.1. Passage to the limit state method

The limit state method of structural design and safety verification was initiated in Soviet Union before the second world war. The war delayed its endorsement to 1955. Meanwhile, due to its advantages, the method was gradually refined and endorsed in Europe, leading to the current basis of Eurocodes. Shortly after having been endorsed in Soviet Union, due rather to political than to technical reasons, studies for its understanding were initiated in satellite countries, under COMECON control. A commission chaired by Prof. Vasile Nicolau, rector of the Institute of Civil Engineering of Bucharest, was set up in 1960. Inside that, working groups, to draft various specific codes, were organized. Prof. Mihail Hangan, with whom I had been in close cooperation, was asked to chair the drafting of codes for verification of structural safety and for specification of various design loads. (I was not satisfied to deal with merely this task, but I wanted to also have a critical look at the method. I had earlier remarked a gap in current approaches in the field of structural design. While the entire education in the field of structural mechanics was deterministic, the limit state method relied on the explicit recognition of the randomness of factors determining structural safety. Various distributions of random variables characterizing load intensities or material strengths had started to be used. I became aware of the fact that this gap should be bridged in some way.) Prof. Hangan himself, who had a fine grasp of the shortcomings of various engineering approaches, asked me to critically analyze the validity of the limit state method. The outcome was published in [7], where a comparison of the analytical approaches and of some illustrative quantitative results corresponding to the limit state method and to a consistent probabilistic procedure respectively, was presented. The work on codes based on the limit state method was partially completed by the publication of „conditional" codes P.6-62 (for safety verification) and P.7-62 (for loading specification), which were applied experimentally, jointly with codes of design for r.c. structures, for steel structures etc. On this basis, homologous standards were developed and were endorsed in 1975 and 1976. They were in use for about three decades, up to the moment when regulations compatible with Eurocodes started to be drafted.

I was the author of twelve of the standards (one on principles of safety verifications, two on classification and design combinations of actions, nine on specific actions). I tried to introduce on one hand some hints, shortly commenting from outside the approaches corresponding to the limit state method, on the other hand some provisions aimed to lead to a better control of structural safety. As specific cases, I mention the standards on meteorological actions. For snow action, I introduced a sensitivity factor of structures (based on probabilistic risk analysis) which increased the reference snow weight for lightweight structures, in order to keep risk constant, irrespective of structure weight (several engineers were unhappy with this approach, because lightweight roof structures became more severely loaded). For wind action, I introduced an annex concerning spatial oscillations, relying on the approach of [8] and on the calibrations of spatial coherence factors derived by A. Davenport, according to a publication by M. F. Barstein.

2.2.2. Orientation of doctoral thesis

The theoretical interest and the practical importance of this field convinced me to opt for it when specifying the object of my doctoral thesis. Prof. Hangan was my first doctoral advisor up to his premature passing away, in 1964 (the new doctoral advisor was Prof. Panaite Mazilu, in whose chair I was active for a long time, under part time job conditions). My doctoral thesis [14] relied on the introduction of a Hilbert space of loadings, where distributions corresponding to various loads could be calibrated. The structural strength characteristics were characterized in terms of conditional probabilities, while safety an risk had to be estimated on the basis of appropriate adaptations of the formula of total probabilities. Some developments corresponding to Poissonian stochastic processes were necessary too. Among the applications developed, the most significant concerned the analysis of non-linear seismic oscillations of a simple structure, going up to risk estimate and optimization attempt. The developments of the thesis corresponded to what was referred to in literature as 3-rd level probabilistic approach. I was not interested in developments corresponding to 2-nd level probabilistic approaches, which were much more fashionable at that time. Several preparatory analyses had been performed in relation to the thesis preparation [5], [9], [12], [13] and quite numerous subsequent developments, referred to later, relied on it.

2.2.3. Analysis of recurrence of variable actions

Some research projects of INCERC were aimed at specifying design parameters for meteorological actions (snow and wind). The observation data on meteorological actions had to be subject to statistical analysis for this purpose. Two alternative procedures have been used in this connection: on one hand the Gumbel procedure, based on consideration of yearly maxima as random variables; on the other hand, the Richter procedure, as used in the analysis of earthquake magnitude recurrence. I took a position against the Gumbel procedure, since the exclusive consideration of yearly maxima is an arbitrary option (we performed alternative processing using monthly maxima and the outcome was, of course, different). Subsequently to the option for use of Richter techniques (relying basically on a stochastic process model instead of a random variable model), a pluri-dimensional analysis (as required e.g. by the directional analysis of wind cases recurrence) became possible. Remarking that, out of random variable distributions used, only the Gumbel and Fréchet distributions are compatible with the features of stochastic processes, a generalization, represented by the use of a Gumbel-Fréchet family was proposed [211]. This generalization makes it possible to calibrate distributions such as to obtain a better approximation from the view point of compatibility with observation data and to pass also in a convenient way to the case of pluri-dimensional characterization of recurrence.

2.2.4. Structural safety verification

Verification of structural safety, as performed usually in design, relies on some conventional combinations of internal forces, as specified by design codes. A more consistent approach is nevertheless of interest, at least in order to achieve a control of implications of code provisions. An attempt in this view was made considering the random walk of the vectors of internal forces (and moments) at critical sections of a structure, represented as linear combinations of vectors of internal forces corresponding to the natural modes [78].

2.3. Impact of strong earthquakes

2.3.1. General

The occurrence of the destructive earthquake of 1977.03.04 had a severe social and economic impact in Romania. On the other hand, it had an important positive scientific impact, even at an international scale. Considering the information provided and the scientific problems raised, it represented a turning point in my personal activity. The main points to be mentioned here are:

- the first direct strong motion instrumental data obtained in Romania, which revealed some specific features of highest importance of ground motion and of structural performance (note here that the much richer instrumental information obtained during the strong subsequent earthquakes of 1996.08.30, 1990.05.30 and 1990.05.31, due to the radical increase of the strong motion network provided by the generous post-1977 aid project supported by the Agency of International Development of the USA State Department, completed radically the knowledge in this field);
- the severity of the impact of the 1977.03.04 earthquake raised the need of a major revision of the philosophy of the Romanian earthquake resistant design code;
- the impact of the 1977.03.04 earthquake, to which the impact of the off-the-Adriatic-coast earthquake of 1979.04.15 was added, raised the interest of UN agencies to provide support and scientific assistance for studies aimed at controlling and reducing seismic risk, which led to the setting up of two UNDP sponsored Balkan projects;
- the observed effects of the 1977.03.04 event raised the need to reconsider the concept of seismic intensity, as well as the problem of non-linear ground-structure interaction;

The personal reaction to these challenges was to get involved in several corresponding research activities and projects, about which some data are subsequently given.

2.3.2. Impact of instrumental data on ground motion

The data on ground motion records revealed the amplitudes and spectral features of ground motion, led to studies on attenuation and on the spectral contents, in connection with studies on the factors that lead to stronger influences of the local geological conditions or, alternatively, of the features of the source mechanisms [48], [72], [81], [118], [119], [156], [164], [169], [170], [194], [207], [213]. The most comprehensive view on the features of ground motion is provided in [217].

2.3.3. Revision of the earthquake resistant design code

The data on the severity and spectral contents of ground motion during the 1977.03.04, provided first of all by the ground motion record of INCERC, but also by wide visual observation, revealed several major shortcomings of the earthquake resistant design code P.13-70. A corresponding revision action promptly organized benefitted from the discussions we had with several highly qualified post-earthquake visiting groups, out of which the Japanese group led by K. Nakano deserves to be especially referred to. The main modifications I introduced, while drafting of some parts of the new code P 100-78, were:

- the recalibration of the basic factor, reflecting the amplitude of reference ground acceleration, which became close to the actual extreme values (while in the past it had been much smaller, since it had included also the reduction factor reflecting the influence of post-elastic performance etc.); the calibration of the reference acceleration amplitude was frankly estimated to correspond to a return period of about 50 years, which is very low if compared with the return period of 475 years, stated in many codes to have been adopted (however, are such statements also always true?);
- the adoption of a strongly modified expression of the dynamic factor (velocity / acceleration corner period: 1.5 s), which became practically proportional to the response spectrum of the INCERC record (while in the past the corner period had been in the range of 0.3 s, as in the Soviet code, inspired by values adopted in California);
- rules to provide ductile performance, especially for r.c. structures: limitation of mean compressive stresses in vertical bearing members, preventing of shear force failure etc. (the different philosophy of colleagues familiar with the school concerned with the static performance of r.c. members had to be overcome).

Note: in the subsequent version of the code, P 100-81, an annex specifying the input for the analysis of spatial performance was added among other.

2.3.4. Some comments on the decisions influencing codes

In April 1985, I participated in a meeting in Perugia, where E. Rosenblueth was present too. During a break, we discussed the calibration of earthquake loading in Mexico, determined by the recent information on ground motion features. I asked him why such undercalibration. He replied that this was due to the pressure by construction enterprises. The bitter experience of the destructive earthquake of 1985.09.19 convinced specialists to be frank. The reference acceleration value of 0.4 g, adopted for the Pacific coast, was stated to correspond to return periods in the range of decades, while crossing the boarder into USA, the same value is stated to correspond to a return period of 475 years.

In July 2004, I participated in a meeting in Moscow, on NATO – Russia scientific cooperation. There, I asked an American seismologist how it is possible that the reference acceleration of 0.4 g in the most severe zones of California is stated to correspond to a return period of 475 years. The answer was that the seismologists had proposed for that return period a value of 0.8 g, which raised problems for construction companies. Consequently, the reference acceleration was reduced to 0.4 g, but the corresponding return period modification was not mentioned.

2.3.5. Special problems raised

The observed effects of the Vrancea earthquake of 1977.03.04 led to two main major suggestions for research activities:

- redefining the concept of seismic intensity in terms that are more relevant for the characterization of ground motion and more appropriate from the point of view of the engineering concepts and activities;
- consideration of the non-linear ground - structure interaction phenomena (as unavoidably occurring during strong earthquakes).

2.3.5.1. Redefining seismic intensity

The analysis of earthquake effects shows that the spectral features of ground motion are of highest importance for the destructiveness of ground motion upon various categories of structures. Yet, the traditional concept of intensity completely neglects this fact and is blind with respect to the spectral features of ground motion. This leads frequently to wrong intensity estimates and possibly to other malefic consequences too. A case study on this subject was presented in [209]. After some attempts in two directions, in [50], [52] and in [77], [89] respectively, a quite complex and comprehensive system was proposed in [137]. This system allows to start from alternative basic definitions of intensity and makes it possible to determine global intensities, intensity spectra etc. A project sponsored by the NATO Office was conducted on this subject in 2005 – 2008 [A.2.8]. Various aspects of the problem were dealt with in [180], [181], [182], [195] and, most recently, in [216].

2.3.5.2. Investigating non-linear ground – structure interaction

Engineering analyses, jointly with direct, instrumental or visual observation, reveal the fact that partial alternative uplift, if not even significant partial alternative post-elastic compressive strain in foundation ground, may occur to several categories of structures during strong earthquakes. This is in direct contradiction with a quite widely accepted structural design philosophy requiring post-elastic behavior to occur exclusively in structures, while foundation ground post-elastic performance is to be prevented. In fact, I examined several actual situations where one can state that the structure is more resistant than the ground, ergo non-linear performance of the ground – structure interface is bound to occur. Such situations are frequently not even inconvenient. On the contrary, in many such situations structures were implicitly protected against heavy damage. I can mention in this connection the developments of [70], as well as the contributions of A. Pecker [11ECEE] and G. Gazetas [13ECEE].

In 1991 I participated in a symposium on the design of shear wall structures, organized by AFPS in Paris. Th. Paulay was a member of a panel during a panel discussion on some problems of the field. He was arguing in favor of the design strategy of confining post-elastic behavior to the structure, while protecting the ground against such phenomena. I intervened, mentioning that such a strategy may be non-realistic for some important categories of buildings, for which the structure is bound to be stronger than the ground. I also mentioned that non-linear ground performance may be advantageous, in the sense that it limits the stresses induced to structures, and this phenomenon may have protected numerous buildings against collapse during the event of 1977.03.04. Finally, the limitation of amplitude of non-linear performance is basically a problem of providing stability of buildings against overturning. Note that the approaches of the later contributions of A. Pecker [11ECEE] and G. Gazetas [13ECEE] rely on the same philosophy.

2.3.6. UN initiated Balkan projects

The impact of the destructive earthquakes of Vrancea (1977.03.04) and off the Adriatic Coast (1979.04.15) convinced the UN agencies to organize two important projects aimed at improving the earthquake protection in the Balkan region: The UNDP / UNESCO / UNDRO Project RER 79 / 014 on earthquake risk control and reduction (1981 – 1983), which had five WG's, and the UNDP / UNIDO Project RER 79 / 015 on earthquake resistant design (1982-1984), which had six WG's. The coordination of the WG's was assigned to the participating respectively. I acted as convener of WGB, on vulnerability studies, of the Project RER 79 / 014 [65], [66], and consultant to WGD, on risk reduction, of the Project RER 79 / 015, for which I drafted an annex of the final report, concerning the analytical treatment of risk. The activity initiated in the frame of the Project RER 79 / 014 was continued at enlarged scale in the frame of a project under the auspices of EAEE [82], [101] and was further developed in several frames (e.g. [107]).

The initiatives of UN Agencies and of EAEE seem to have considerably increased the interest of engineers in becoming familiar with the basic concepts of risk analysis and in using these concepts.

2.3.7. Risk analysis at macroscopic scale

The use of concepts like elements at risk, hazard, exposure, vulnerability, risk etc. makes it possible to perform a risk analysis at a macroscopic scale, as required in order to develop actions aimed at controlling and mitigating seismic risk. This field offers room for extensive analytical developments in case one takes into account the variety of situations that can be met in practical activities. This point of view was at the basis of the comprehensive developments of [82], of the more in depth analysis related to geographically extended networks [71], [191], or of developments concerning evolutionary vulnerability due to the cumulative effects of successive earthquakes [138]. Moreover, approaches like that of [82] make it possible to pass to a pluri-dimensional hazard analysis, generalizing in the sense discussed in [178], [200] the 1D approach developed in [107] in relation to a probabilistic convolution of hazard at source level and random attenuation in order to derive site hazard characteristics (which is equivalent with Mc Guire's approach of 1995).

2.3.8. Parametric analysis of seismic risk

Parametric analyses of seismic risk may be quite instructive in order to provide a basis for developing protection strategies. This idea was at the basis of studies like those of [116] and [143], which presented results on the influence of protection strategies upon the risk of damage and failure.

2.3.9. The decision on the intervention on existing structures

A look at the vulnerability and risk affecting existing structures located in seismic areas reveals in numerous cases high, intolerable risks. This raises to responsible factors the task to adopt a decision on eventual intervention, in the sense of strengthening or removing various existing works, in terms of timing the intervention etc. Attempts of discussing these problems were presented, among other in [58] and [63].

2.3.10. Obstacles to earthquake risk control and reduction

The experience of the post-event period of the destructive earthquake having occurred in Romania on 1977.03.04 reveals a wide discontent concerning the actions required for control and reduction of the seismic risk affecting the existing building stock. Strengthening of vulnerable buildings was achieved just for a tiny fraction of the stock under discussion. Various factors were blamed for this situation. I made an attempt of discussing the causes of this situation in [148]. Factors of various nature were pointed out in this connection.

2.4. Experimental work

The most relevant field of experimental work in which I was involved, was the recording and analysis of low amplitude motions (microtremors and ambient vibrations). This activity became possible in 1963, when INCERC received a Soviet MIKS system (multichannel investigation of structural oscillations). To this, a homologous, analog, Kinemetrics system was added in 1978, due to the post-earthquake aid of the Agency of International Development of the USA State Department. The experimental work was started with recording oscillations of relatively tall standardized buildings. Attention was paid to spatial oscillations, that could be investigated (at that time, when analog techniques only were at hand) by means of appropriate combined electrical connections of various seismometers [10], [18]. A biography of the natural periods of the 165 m tall Argeş – Vidraru arch dam was obtained during its erection [15]. The same was done for the 24 story Bucharest - Intercontinental Hotel [25]. The most completely investigated structure was that of the main exhibition hall of Bucharest – EREN/ROMEXPO. The oscillations of the upper ring, supporting the steel dome of the 96 m span structure were mainly investigated. This was done first in 1976, thereafter after the strong earthquakes of 1977, 1986 and 1990, as well as after the corresponding rehabilitation interventions [79], [157].

LIST OF PUBLICATIONS (1960-2010)

A. Books

A.1. Books written integrally:

1. *Metode matriceale în mecanica structu-rilor* (*Matrix methods in structural mechanics*), Editura Tehnica, Bucharest, 1975

2. H. Sandi: *Elemente de dinamica structurilor* (*Elements of structural dynamics*), Editura Tehnica, Bucharest, 1983
3. H. Sandi: *Structural dynamics, structural safety, earthquake engineering. Selected Publications,* Editura AGIR, Bucharest, 2012

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3. H. Sandi: *Asupra interacţiunii între teren şi construcţie în cazul solicitărilor seismice* (On the interaction between ground and structure in case of seismic action), ***Studii şi Cercetări de Astronomie şi Seismologie***, 2, 1961
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