A VIEW ON CURRENT NEEDS OF STRUCTURAL HEALTH MONITORING IN ROMANIA

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CONTENTS

1. INTRODUCTION

The term "structure" is used in the paper in order to refer to loadbearing structures (LBS).

Consider the fundamental role of LBS's.

Note the importance and the increasing recognition of structural health monitoring (SHM) activities.

Without denying the high importance of qualified qualitative monitoring (usually based on visual inspection), this paper is concerned with monitoring relying on acquisition of instrumental data.

Techniques of processing mainly used are presented in [4]. Digital accelerographic instrumentation was thereafter stepwise acquired and installed [1].

Some relevant results, conclusions and advances due to the availability of strong motion records obtained to date are referred to:

- in Annex I (*on ground motion*) and

- in Annex II (*on structural performance*).

Three main orientations may be mentioned in this connection:

a) ad-hoc field surveys, aimed at estimating the state of health of a structure at a particular time, possibly subsequently to some special event (e.g. strong overloading), or prior to some intended intervention;
b) periodic, long term, data acquisition, intended to reveal the features of long term evolution of structural characteristics and performance;
c) automated data acquisition during events of relatively short overall duration, yet of special relevance, characterized by occurrence randomness.

To further define the scope of the paper, it is mentioned that it is concerned essentially with activities of category (c), more precisely with data acquisition during seismic events.

2. SOME REFERENCES TO STRUCTURAL HEALTH MONITORING ACTIVITIES IN ROMANIA

Main activities:

Category (a): initiated shortly after 1960 (data on microtremors and on ambient vibration).

Category (b): monitoring of large dams, of some important bridges (especially, Trans – Danube ones) etc.

Category (c): began with recording of a few strong motion accelerograms during the destructive earthquake of 1977.03.04 (*MGR* = 7.2, *Mw* = 7.5) and were considerably enhanced by the extension of recording network and the occurrence of the subsequent strong earthquakes.

A step of highest importance: the procurement of a first set of strong motion instrumentation, consisting of a strong motion accelerograph SMAC-B and thereafter of a few strong motion accelerographs MO-2. This made it possible to obtain during the destructive earthquake of 1977.03.04 the first instrumental information on strong earthquake motion of ground and of structures.

A token of recognition and gratitude to the Agency of International Development of the US State Department, for the generous aid provided after the earthquake referred to. Thanks to it, the strong motion network was considerably developed thereafter (mainly by installation of a network consisting [5] of numerous SMA-1 accelerographs), just in time to provide rich and particularly relevant instrumental information during the subsequent strong earthquakes of 1986.08.30, 1990.05.30 and 1990.05.31.

4. SOME OBJECTIVES AND REQUIREMENTS FOR THE DESIGN OF MONITORING SYSTEMS OF SEISMIC ACTION AND STRUCTURAL RESPONSE

In order to provide the monitoring system the capability to furnish the most relevant instrumental information on earthquake performance, it is necessary to consider this system as a kind of integrated network, on the basis of a clear specification of the main objectives pursued.

In order to gather relevant information for engineering purposes, it is necessary to think of the need of acquisition, during earthquakes, of instrumental (more specifically, accelerographic) information concerning:

a) the features of ground motion (in the neighbourhood of the structure of interest);

b) the features of structural performance.

3. SOME MAIN ASPECTS OF GROUND MOTION AND OF STRUCTURAL PERFORMANCE UNDER STRONG SEISMIC ACTION

The case of structures in elevation is considered at this point.

Seismic action on various structures of the category referred to is a consequence of the motion of the ground - structure interface.

The motion of ground and, consequently of the ground – structure interface, which is spatial, non-synchronous at different ground points, transient and irregular, is due to the propagation of seismic waves along the geological medium, from event source to structure site.

The phenomenon of ground-structure interaction influences at its turn, more or less, the motion of ground – structure interface, depending (speaking in broad terms) on the relationship of ground and structure impedances.

The ground - structure interface motion induces a motion of a structure as a whole, and this leads to oscillations, deformation and stresses.

The motion of the structure is at its turn spatial, non-synchronous at different points, transient and irregular, and is characterized, in numerous cases of strong seismic action, by post-elastic deformation of some structural components, which may go up to local collapse, if not to general structural collapse.

Finally,

a) it is important to adopt *wireless solutions* in order to avoid damage (and acts of vandalism) to cables;

b) in order to adopt the most efficient instrumentation, it is appropriate to adopt *solutions based on single degree of freedom accelerometers*, installed strategically, which may provide relevant, but make it possible to avoid acquisition of redundant, data.

5. SOME COMMENTS ON THE STRATEGY OF DEVELOPING OF MONITORING ARRAYS

The critical problem raised in practice is represented by the limits to resources required by installing, maintaining and operating the monitoring systems.

Against the understandable wish of professionals to obtain rich and comprehensive information on the earthquake performance of structures, the financial constraints raise harsh limits.

This fact requires a concern for the adoption of an optimal strategy of monitoring, obtaining most relevant results with a minimum of expenditure.

A few comments are due in relation to both problems raised.

(a) As known, dense arrays were installed in various parts of the world, in order to analyze the non-homogeneity of ground motion.

One aspect that was little dealt with in this connection is the consideration of spatial features of ground motion, paying attention to the non-synchronousness of motion at different ground – structure interface points.

This aspect may be significant on one hand for the analysis of seismic action affecting extended in plane structures (multi-span bridges, large dams, large halls etc.) and, on the other hand for acquiring information on the (tilting) rotation components of the ground – structure interface, especially for masts, antennae etc..

(b) In order to get a picture of the motion of a structure as a whole, it is desirable to imagine a picture of its deformation during a future event and to identify its most relevant degrees of freedom. *The design of the local network should provide means to obtain the corresponding relevant instrumental information.*

In the past, it was usual to install, for storeyed residential buildings, not more than one accelerometer per floor. This solution, imposed by the scarcity of resources, is able to provide limited information on structural performance (e.g. missing data on the motion components concerning overall torsion).

There are, nevertheless, various situations in which the motion components of overall torsion are relevant, be it due to implications of dynamic asymmetry, or to occurrence of more severe damage to some of the structural components.

6. FINAL CONSIDERATIONS

1. The importance of monitoring of strong earthquake events, including ground motion and structural performance both, as a major direction of SHM, which is widely recognized and was convincingly confirmed by the experience and results of Romania, *confirms at its turn the need of progress in developing the existing strong motion networks.*

2. The MEMSCON Project, aimed firstly at installing soon a more modern local monitoring system in an appropriate structure, represents *an important step for a larger scale development / modernization of the SHM activities in Romania.*

3. The option for a *wireless local network* represents a most desirable solution to the monitoring of structural performance, due to its reliability.

4. The present trend to develop high performance 3-axis accelerometers represents a direction of undeniable interest. On the other hand, this may be not the most efficient solution if the performance of a structure as a whole is to be monitored. *On the contrary, the use of 1-axis, or even of 2-axis accelerometers may be more advantageous in case the performance of a structure as a whole is pursued.*

5. When designing a network for monitoring of a definite structure, it is necessary to benefit from the *cooperation of a well qualified structural engineer*, able to anticipate the features of structural performance, in order to provide to the system a highest efficiency.

6. *The author expresses his readiness for future cooperation in the MESCON project.*

The MEMSCON project, to which the workshop is devoted, concerns the opening of a new, more modern, step of SHM activities in Romania.

It is normal to open these activities by a pilot project which, in fact, means experimental instrumentation of a relevant structure (e.g. a residential building).

It is most desirable that a qualified structural engineer participates in the choice of the structure and, also in the design of the monitoring network to be installed.

After verifying the functional quality and capability of the network, benefitting from this first specific experience, a strategy of instrumentation of several other relevant structures is to be adopted.

ANNEX I. REVIEW OF MAIN RESULTS ON FEATURES OF GROUND MOTION AND OF SEISMIC CONDITIONS, RELYING ON STRONG MOTION DATA OBTAINED

The destructive earthquake of 1977.03.04: *a landmark for earthquake engineering activities in Romania.*

While during the previous destructive earthquake of the twentieth century, that of 1940.11.10 (*MGR* = 7.4, *Mw* = 7.7) the professional community was not prepared to learn from that direct and important experience,

the situation was different in 1977, when the professional community benefitted from quite appropriate education, from the existence of quite advanced research activities and from the activity of numerous strong, quite well qualified, design bureaus. On the other hand, the fact that a few accelerographs were already operational was of paramount importance too.

The spectral features of the Bucharest – INCERC record were unusual and took by surprise even some recognized international experts (some of them even denied initially the record quality).

This experience had an important impact for research activities, as well as for engineering practice (among other, the design code was considerably revised).

The much richer instrumental information obtained during the subsequent strong earthquakes of 1986.08.30 (*MGR* = 7.0), 1990.05.30 (*MGR* = 6.7) and 1990.05.31 (*MGR* = 6.1) added a considerable amount of relevant information.

A most important direction of investigation concerned the spectral content of ground motion, in correlation with local conditions [19, 14, 15, 11].

Cases for which the dominant period of motion was unusually long were observed, besides cases for which the dominant period was short.

The sites for which spectral analyses were performed could be broadly categorized into:

a) sites for which there exists a tendency to stability of the spectral contents (e.g. the case of Fig. I.2);

b) sites for which there exists a tendency to variability of the spectral contents (e.g. the case of Fig. I.1).

Some main results and conclusions of ground motion and on seismic conditions of Romania:

1. *An in depth engineering survey was organized after the earthquake of 1977.03.04* [3]. Statistical damage spectra derived for various areas of Bucharest revealed the tendency to heavier damage for structures pertaining to longer period spectral bands and provided a factual support for subsequent analytical work.

2. *The traditional concept of macroseismic intensity proved to be not satisfactory from the viewpoint of engineering problems.* The concepts of global intensities and of intensity spectra were introduced. An international project sponsored by the NATO Office of Brussels [7, 2, 12, 8] was developed. A proposal to update the concept of intensity was forwarded during the 14th ECEE.

The analyses performed confirmed the categories of ground conditions corresponding to categories (a) and (b).

The data of Fig. I.1 illustrate the case of sites of category (b).

During one event, the importance of the long period spectral peak is about the same for the City of Bucharest and for its surroundings.

The long period spectral peak observed in Fig. I.1 for the 1977.03.04 event should have been about equally important for this extensive area.

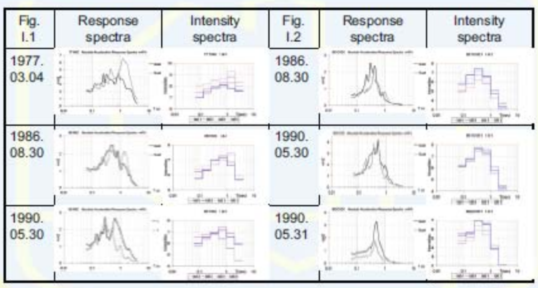
3. *The instrumental information at hand made it possible to perform in depth analyses on the features of / attenuation for the earthquakes of 1986.08.30, 1990.05.30, 1990.05.31* [16, 13]:

investigation was performed first in global terms, then also in directional and spectral terms;

differences for the rates of attenuation from one event to the other were revealed;

the high scatter of attenuation and the spectral differences of the rates of attenuation were put to evidence;

the azimuthal directivity of radiation, in spectral terms, was investigated.



ANNEX II. SOME RELEVANT RESULTS ON FEATURES OF STRUCTURAL PERFORMANCE

Some buildings in the range of ten storeys were instrumented by means of couples of accelerographs, at basement and top levels.

The top floor level records provided relevant information on structural performance. Visual examination and RFS analyses of the records were performed.

The sequences of RFS's for the two horizontal directions, obtained for a nine storey building located in Bucharest, are in Fig. II.1.

The results for the event and the direction characterized by the most severe motion, are reproduced in Fig. II.2.

Fig. II.2 shows that the most important spectral component of motion was of abut 1 Hz. and that the dominant frequency gradually decreased.

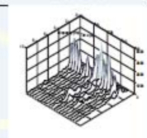
Fig. II.1	1977.03.04	1990.05.31
Transversal		
Longitudinal		

Fig. II.2