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SEISMIC MONITORING OF STRUCTURES - AN IMPORTANT ELEMENT OF SEISMIC HAZARD REDUCTION

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SUMMARY

The earthquake phenomenon involves almost always numerous problems which cannot be solved exactly due to the lack of instruments for recording earthquake intensities and response of structures. Without such a record, damage and behaviour of structures during strong earthquakes cannot be compared to the seismic design criteria nor proper decisions concerning rational repair and reconstruction could be made.

The installation of networks for recording of strong earthquakes and the results which are obtained from them, has become an increasing need in the earthquake engineering and has considerable contribution to the overall activities for seismic risk reduction of existing urban media and for the minimizing of the damage to these structures under the effect of disastrous earthquakes.

The seismic monitoring of structure mainly refers to engineering aspects of the structure. The main purposes of the strong motion instrument network is providing of data on the dynamic behaviour of structures under the effect of earthquakes. The strong motion instruments installed on the structures enable obtaining of basic data on its behaviour during an earthquake, i.e., making decisions about further exploitation or the need for repair of the structure immediately after the occurred earthquake.To achieve this, instruments have been installed at previously defined points.

The application of the results is equally important both for the theoretical and fundamental investigations in the field of earthquake engineering and for application and practical investigations in the earthquake engineering.

INTRODUCTION

Data on the ground motion during earthquakes to which structures are exposed and behaviour of structures are fundamental for seismic hazard evaluation, definition of design parameters and criteria and for all other dynamic investigations in earthquake engineering. Without such data all investigations and analysis that follow would be based on assumptions. The irregularity in earthquake occurrence makes difficult the possibility to obtain immediately the most useful data. One of the possible ways to solve these problems is to establish a network of a greater number of instruments for recording ground motion and response of structures during strong earthquakes.

The main objective in seismic monitoring of structures (high-rise buildings, dams, power plants, bridges etc.) is to facilitate response studies that lead to improved understanding of the dynamic behavior and potential for damage to structures under seismic loading.

As a result of this understanding, design and construction practices can be modified so that future earthquake damage is minimized. Therefore, there are significant implications in (a) hazard reduction, (b) improvement of codes, (c) identification of seismic response characteristics of structural system that may be used in determination of strategies for improvement of their performances.

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Strong motion instrumentation of structures has been utilized since 1940's. Throughout the world, strong motion instrumentation networks have been installed on buildings, monumental and historic structures, bridges, dams, tunnels, pipelines and power plants. Recent strong earthquakes, Montenegro (1979), Mexico City (1985), Loma Prieta (1989), Landers (1992), Northridge (1994), and Kobe (1995) have yielded a wealth of structural response data from instrumented structures. These data have contributed to the evolution and enhancement of seismic analysis and design methodologies, seismic building codes and practices.

Considering the current interest in seismic monitoring and the need to improve earthquake resistant design and reduce seismic hazard on a world wide basis, the US-Macedonian joint scientific-research project "Seismic Monitoring of Structures" started to be realized in the beginning of 1997. The project is being realized by the Institute of Earthquake Engineering and Engineering Seismology (IZIIS), Skopje (R. Macedonia) in cooperation with USGS - Menlo Park (USA).

Presented in this paper shall be some ideas and results from this project. As the main concept and principle on the basis on which the network in the teritory of USA has been designed and developed is known , further on the main characteristic of the Macedonian network will be presented.

GENERAL ASPECTS OF SEISMIC MONITORING

The installation of networks for recording of strong earthquakes and the results which are obtained from them, has become an increasing need in the earthquake engineering and has considerable contribution to the overall activities for seismic risk reduction of existing urban media and for the minimizing of the damage to these structures under the effect of disastrous earthquakes. The application of the results is equally important both for the theoretical and fundamental investigations in the field of earthquake engineering and for application and practical investigations in the earthquake engineering.

The rapid development of networks for recording of strong earthquakes during the last twenty years has made a considerable contribution to the knowledge of the investigators that the theoretical investigations should have experimental proof - in the considered records - on the basis of which relevant decisions can be made.

In the design of major structures and facilities such as important buildings, dams, bridges and power plants, it is highly desirable to know the ground motion at a specific site that would result from a particular earthquake event. As the return period of major earthquakes associated with a given portion of a fault is generally quite long, it is impractical to wait for data from the particular event in question. Instead, it is necessary to extrapolate from data which have been obtained from other events which are thought to be in some sense similar to the particular event under consideration. This extrapolation process can only be reliable if there is an understanding of the individual factors which affect the character of strong ground motion such as: the nature of the source mechanism, the influence of the wave propagation path, and the effect of the local topographic and soil conditions.

For this purpose, strong motion networks in Macedonia were developed with corresponding density in most active regions and with lower density in the regions with lower seismic activity, in order to study the following seismological and earthquake engineering aspects:(1) earthquake source mechanism, (2) wave propagation path, (3) effect of local topography, (4) free-field soil response at different soil conditions, (5) site amplification factors, and (6) structural response of different types of buildings and structures including soil-structure interaction. In areas of potentially unstable soils, strong motion records will help to determine the characteristics of the ground motions which might indicate landslides, subsidence, slumping and liquefaction.

Considering these reasons, in the beginning of the 70s, networks of strong earthquakes recording instruments were installed in several seismic regions in the world (USA, Japan, Italy, former Yugoslavia, Mexico, New Zealand, Iran, Turkey, Greece and others), thus, at present, there is a relatively high number of such networks, but still insufficient to cover all the seismically active regions in the world and to provide sufficient quantity of usable data. Therefore, a large number of countries in the engineering practice apply records obtained by other countries. However, having in mind that earthquakes are characterized by (1) the frequency and amplitude content, depending on the geological and the tectonic structure of the seismogene region; (2) the rate of the magnitude, i.e., the intensity of the earthquake; (3) the origin depth; and (4) the epicentral distance, it is obvious that they differ from those recorded in other areas, even in cases when earthquakes of the same intensity are considered. Therefore, it is necessary to use records from the actual seismogene region, or if used from another region, then one should be careful, and, if possible, use records from a region having similar seismo-tectonic characteristics.

A particular problem pose the records obtained by instruments placed at different types of structures. Apart from all the above state, in their case, care should be also taken about the type and the properties of the structure as well as the position of the instrument in it. Therefore, it is necessary, that the conclusions be brought very carefully and on the basis of more records.

INVESTIGATION BASIS

The strong motion instrument network installed on the territory of former Yugoslavia was one of the largest in Europe. It consisted of over 250 accelerographs type SMA-1 and about 130 seismoscopes type WM-1. The network was installed in the beginning of 1972 within the frames of the USA-Yugoslav scientific-research project entitled "Installation of Strong Motion Instrument Network on the territory of Yugoslavia". This project was realized by the Institute of Earthquake Engineering and Engineering Seismology (IZIIS) in Skopje in cooperation with the Californian Institute of Technology (CALTECH) in Pasadena until 1975 and then it was continued in cooperation with the United States Geological Survey (USGS) from Menlo Park until 1979. After this, the realization of the project was continued by IZIIS as a national project.

All the activities related to this instrument network were carried out by the scientific and professional collaborators of the Strong Motion Laboratory in IZIIS. Scientific-research in this field was also carried out simultaneously resulting in a number of bulletins and reports as well as numerous papers and presentations at scientific meetings.

Until 1991, the Macedonian strong motion instrument network was part of the instrument network of former Yugoslavia. It consisted of 110 accelerographs and 60 seismoscopes.

To provide a more detail insight, presented briefly further is the main concept and some of the main characteristics of this network.

Basic concepts of theMacedonian network

The basic concept of the former Macedonian strong motion network enables obtaining of basic information required for predicting the dynamic response of various types of structures, improvement of codes for aseismic design, understanding of the ground amplification effects as well as for better investigation and perceiving of consequences caused by earthquakes.

The selection of detailed locations for establishment of these instruments makes it possible to obtain records on 1) bedrock, 2) on a surface of characteristic soils (alluvial and deluvial sediments, 3) on structures (multistory buildings, dams, etc.). the instrument distribution, of both accelerographs and seismoscopes was made following this basic concept. Table 1 shows this distribution.

Table 1

Location	Instruments	
	Accelerographs	Seismoscopes
On bed rock	9	9
On characteristic soil	19	34
On structure	78	11
Total	106	54

Besides, the network also includes instruments installed by IZIIS for the requirements of other projects and financed by other investors. These instruments are mainly installed on characteristic structures and locations foreseen for structures of capital importance.

From the beginning of 1977, IZIIS works on the accomplishment of the USA-Yugoslav project "Establishment to a Three-Dimensional Network for Detail Investigation of Problems Related to Ground Motion During

Earthquakes and its Effects upon Response of Surface Layers and Structures" which serve as a supplement to the already established basic network. This three-dimensional network has been installed in the Ohrid area, Republic of Macedonia.

The strong motion program consists of five subactivities: (1) network design,(2) network operation,(3) data processing,(4) network management and (5) research as well as application. All these activities are under the responsibility of IZIIS - Skopje.

SEISMIC MINITORING OF STRUCTURES

One of the main purposes of the strong motion instrument network is providing of data on the dynamic behaviour of structures under the effect of earthquakes. The strong motion instruments installed on the structures enable obtaining of basic data on its behaviour during an earthquake, i.e., making decisions about further exploitation or the need for repair of the structure immediately after the occurred earthquake.To achieve this, instruments have been installed at previously defined points.

The seismic monitoring of structure mainly refers to engineering aspects of the structure. The instruments are located at characteristic points of the base and the structure and the possibly obtained records are an invaluable parameter for verification of the mathematical model of the structure and its behaviour under the effect of a real earthquake.

An important element of the strong motion instruments installed on the structures are their output information. It is desirable that these be in such a form that they could provide an information on the intensity of an earthquake immediately after its occurrence. Based on this, a decision could be made regarding further exploitation of the structure. For instance, if the structure is designed for a = 0.25 g as a design parameter, and the maximum amplitude of recorded ground acceleration is less than this value, a decision can be made, with a great reliability, for further exploitation of the structure with no particular repair or strengthening. However, when the recorded acceleration is greater than 0.25, it is desirable, in case when there are no visible signs of damage, to perform a special study and define the stresses and strains in the structure caused by the forces from the recorded earthquake.

As can be seen from Table 1, included in the strong motion instrument network of Macedonia were also a total number of 78 SMA-1 accelerographs that were installed on different type of structures high-rise building, dams, industrial facilities, etc.). Table 2 provides a review of structures on which these instruments were installed and the number of instruments.

The total number of installed structures in Macedonia and number of instruments does not include the structures and the instruments of the three-dimensional instrument network installed in Ohrid.

Table 2

Structures		No.of Instruments	
		SMA –1	WM -1
		Accelerographs	Seismoscopes
High-rises building	Structures	10	4
	Instruments	32	4
Dams	Structures	11	5
	Instruments	34	7
Bridges	Structures	3	/
	Instruments	12	/
Total	Structures	24	9
	Instruments	78	11

Our past experience from 232 earthquake records taken on buildings in Banja Luka (Bosnia and Hercegovina), Skopje (Macedonia) and; Zagreb (Croatia) and 229 records on dams supports the experience of other countries such as USA, that more studious approach is necessary for determination of the number of instruments and their location in the course of instrumentation of structures.

Project For Seismic Monitoring

The seismic instrumentation of the structures should provide exact information on the seismic input and the structural response during the earthquake. The distribution of the instruments is therefore of crucial importance. Their number varies depending on several parameters the most important of which are: the seismological and geological characteristics of the site, the foundation conditions, the type of the structure and the geometrical shape.

The instrument locations are selected on the basis of dynamic analysis of the mathematical model of the structure and the experimentally defined dynamic characteristics of the structure by means of forced vibrations or measurement of ambient vibrations of the structure.

Seismic monitoring of structures is planned, designed, carried out and organized for each structure taken separately. The parameters for elaboration of a seismic monitoring project can be defined on the basis of: (1) Seismic regime of the micro- and the macro-region; (2) Dynamic and strength characteristics of the local soil; (3) Mode of foundation; (4) Type and dynamic characteristics of the structure; (5) Soil-foundation-structure interaction; and (6) Geometrical shape of the structure.

All the above stated components have a partial and interactive effect upon the dynamic characteristics and the dynamic behaviour of the structures. However, in dynamic analyses of the mathematical model of the structure and experimental testing of full scale structures (full scale tests by forced vibrations and analysis by ambient vibrations), the structure and the local ambient are treated as an integrity so that the final concept of instrumentation for seismic monitoring is defined on the basis of results from dynamic analyses of the mathematical model of the structure and the experimentally defined values of dynamic characteristics of the structure, i.e.,(1) natural frequencies, (2) damping capacity of the structure; (3)vibration mode shapes of the structure.

Accordingly, it is necessary to elaborate a separate project for seismic monitoring of each structure in order to: (a) establish an optimal system of seismic monitoring instruments, and (b) obtain practically usable and compatible data in case of an earthquake.

Data obtained by means of the seismic monitoring equipment may serve for multiple purposes. They are very useful for: (1) verification of previous computations and analyses, (2) analysis of the stress state and level of safety of the structure after the earthquake effect, and (3) optimization of the process of design of future structures.

It is necessary to mention however that seismic monitoring of structures in many countries has been an obligatory part of osculation already for decades.

OBTAINED RESULTS

Since 1973, several strong earthquakes have occurred on the territory of former Yugoslavia, (the Montenegro coastal area - 1979, M= 7.0; Kopaonik - 1980, =6.3; Banja Luka-1981, M=5.4, Negotino 1985, M=5.1, Bitola 1994, M=5.2) and the neighbouring countries (Friuli, Italy-1976, M=6.5; Vranchea, Romania-1977, M=7.2, Thessaloniki, Greece-1978, M=6.3, etc.). Many earthquakes of moderate intensity (M≥3.5) have occurred, too.

In this period, 1206 accelerograms have been obtained out of which 823 by instruments installed on free field and 383 by those installed on different structures. Presented below are therefore only the results from the records obtained from instruments located on dams in Macedonia and buildings in Banja Luka (Bosnia and Herzegovina).

The results from the records of these earthquakes shall be presented in the tables and the graphic presentations (records and response pectrum) that are given below. Apart from this, the locations of the instruments installed on the dam body shall be presented for the purpose of getting a thorough insight into the seismic monitoring of these dams and the results from such a monitoring.

More detailed data on these records and the obtained results can be obtained from the publications of the Institute of Earthquake Engineering and Engineering Seismology.

Table 3

Data on SMA-1		Date on Record 28-09-1985 M=5.1								
		Component N 150 S			Component N 60 S			Component Up.		
Location	No.	Acc. cm/s/s	Vel cm/s	Displ. cm	Acc. cm/s/s	Vel. cm/s	Displ. cm	Acc. cm/s/s	Vel. cm/s	Displ. cm
Dam Crest	1158	-46.7	-2.299	0.300	40.4	1.453	-0.093	-33.3	-0.828	-0.033
Cent. Part	1156	-20.0	-0.637	0.049	17.0	-0.434	-0.024	14.2	0.409	0.015
Lover Part	1155	-12.8	-0.253	0.007	12.4	-0.235	-0.008	6.2	-0.151	0.006
Free Field	2809	5.3	-0.131	-0.005	-3.6	0.109	-0.003	-4.0	0.067	0.002

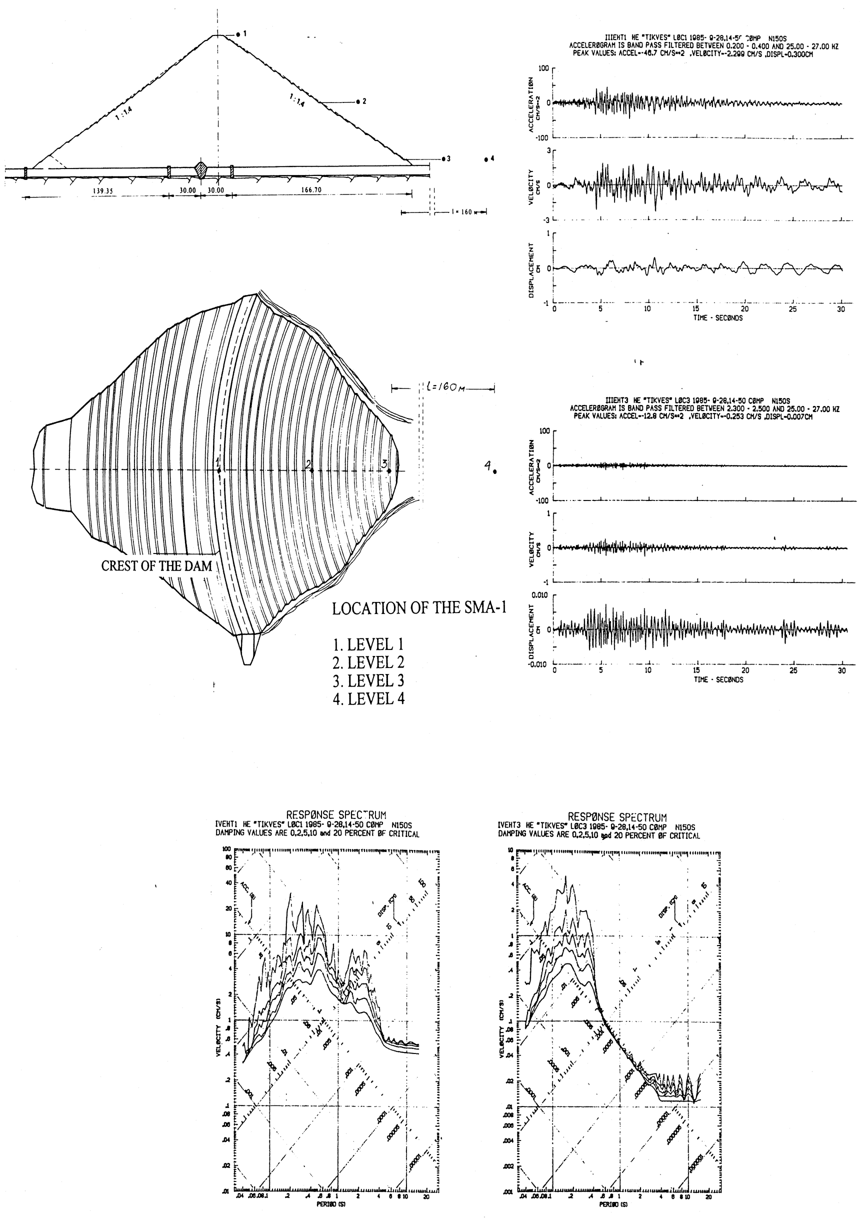

Fig.1 Seismic monitoring on the Tikves Dam. Location of Instruments, Accelerograms and Response Spectrum from Negotino Earthquake of Sept. 28, 1985.

Table 4

Site	Location of instrument	Max. acc. (cm/s2)		
		N-S	V	E-W
IMB Institute	ground	506.4	257.4	386.8
Seism. station	ground bedrock	65.2	43.6	72.3
Apartment building "BK-2"	basement	307.2	91.5	268.9
	VI floor	371.1	242.0	269.7
	XII floor	367.1	280.0	197.4
Apartment building "BK-9"	basement II entr.	368.8	120.5	225.4
	IV floor I entr.	382.4	214.9	352.7
	IV floor II entr.	419.2	222.4	364.7
	IV floor III entr.	416.2	162.4	351.1

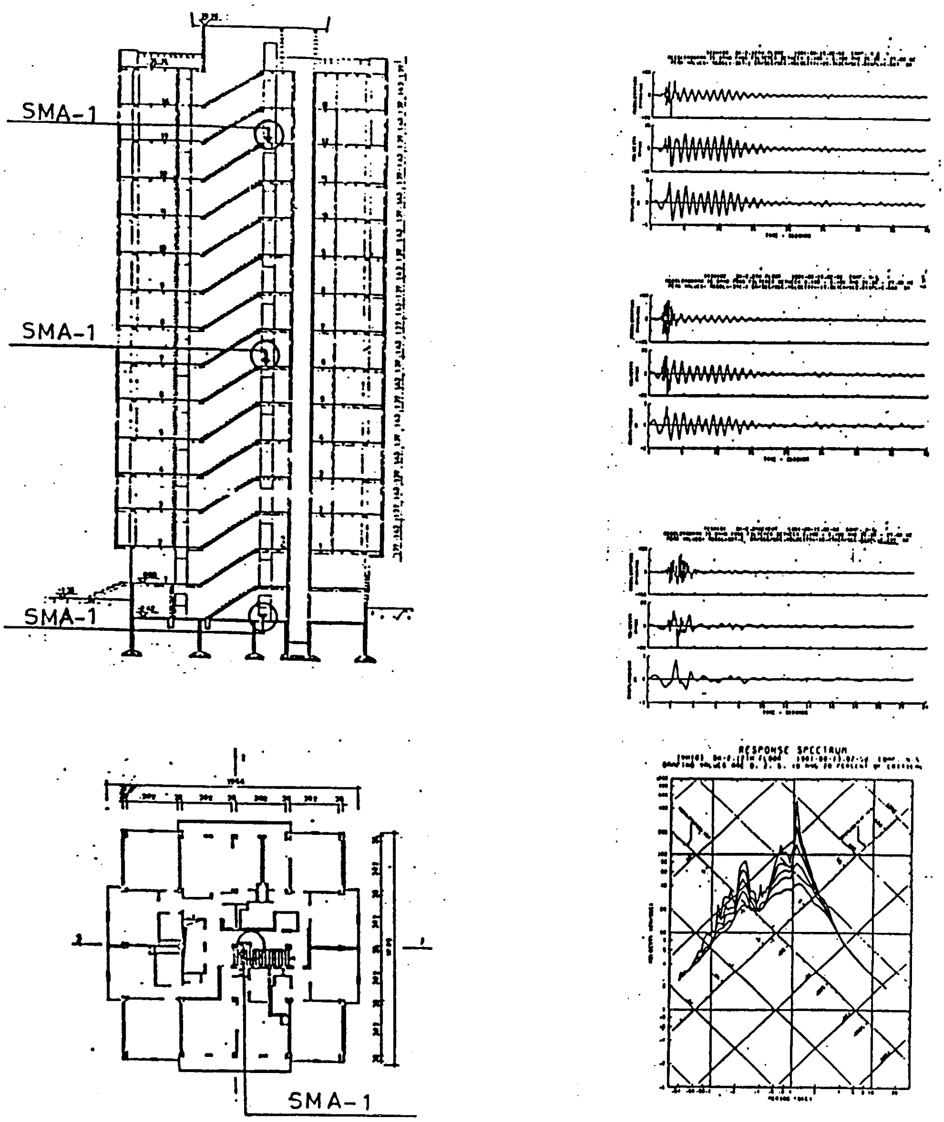

Fig.2 Seismic monitoring of 12 story building, location of instruments, accelerogram and response spectrum

CONCLUSION

On the basis of the above presented results and the long term experience of seismic instrumentation of structures in Macedonia, the following conclusions can be drawn:

The seismic monitoring of structures is still an actual problem in earthquake engineering. The results from processed earthquake records make considerable contribution to experimental and analytical studies of the dynamic behaviour of structures. All these contribute, directly, towards optimization of the process of design and construction of aseismic structures.

The existing number of instrumented structures is relatively small, even on world scale. Its increase is necessary by instrumentation of structures, particularly those constructed by the application of newer technologies and methods of design. It is technically and economically justified, since the cost of the instruments, compared to the total investment value of the structures is symbolic.

Data on the ground motion during earthquakes to which structures are exposed and behaviour of structures are fundamental for seismic hazard evaluation, definition of design parameters and criteria and for all other dynamic investigations in earthquake engineering. Without such data all investigations and analysis that follow would be based on assumptions.

Significant efforts are required to provide rational protection of structures against seismic effects. Seismic instrumentation is one of the most rational ways of protection.

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