SEISMIC INSTRUMENTATION ON STRUCTURES SOME EXPERIENCE AND RELATED PROBLEMS

YAPILARDA SİSMİK ÖLÇÜMLER, BAZI GÖZLEMLER VE İLGİLİ SORUNLAR

By

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ABSTRACT

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.

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.

The only way 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.

In this paper attention will be concentrated on code requirements for instrumentation of structures, particularly dams, and results obtained from some earthquake records.

INTRODUCTION

One of the largest networks of strong earthquake recording instruments in Europe was the one installed in former SFR of Yugoslavia. The major part of the network instruments, consisting of around 200 SMA-1 accelerographs and 150 WM-1 seismoscopes are still in operational state but their maintenance is no more centralized, and is performed by the seismological institutes of the individual republics of former Yugoslavia. Jet, the most part of these instruments, more than 150 SMA-1 and 100 WM-1, have been maintained by the Institute of Earthquake Engineering and Engineering Seismology, University "St. Cyril and Methodius" in Skopje and they are installed in the Republic of Macedonia (c.ca 140 SMA-1), Republic of Slovenia (c.ca 20 SMA-1), Republic of Croatia c.ca 6) and Federal Republic of Yugoslavia (15 SMA-1). Due to the known political developments in the Republic of Bosnia and Hertzegovina the instruments there has not been maintained at the moment. All the instruments located in the other republics of former Yugoslavia, which used to be maintained by the Institute of Earthquake Engineering and Engineering Seismology in Skopje are placed on structures, mainly on dams and a small part on high rise buildings.

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In 1988, in former Yugoslavia, a law was enacted for obligated seismic instrumentation of all high dams located in VII, VIII, IX and X degree seismic intensity zones. According to this law, it was expected that by 1993 more than 100 dams would be instrumented for strong earthquake recording as well as by instruments for induced seismicity recording. Since almost all the republics of former Yugoslavia have, mainly, overtaken all the existing technical codes, it should be expected that this law for obligated seismic instrumentation would be applied, as well, therefore, it was realistic to expect that in the coming period the number of the instrumented dams as well as the number of the seismological instruments would be, consequently, increased.

In this paper, there will be presented some experience of the work of network of strong earthquake recording instruments installed within the territory of former Yugoslavia. It will be stated, once more, that the bearer and the creator of the Strong Motion Program in former Yugoslavia was the Institute of Earthquake Engineering and Engineering Seismology in Skopje, i.e., the scientific, professional and technical staff if this Institute. Further in the text, a brief history of this network is given, with special emphasize to the results from the instrumentation of individual structures of high rise building and dam type. At the moment, all the activities described in this paper have been realized completely in the Republic of Macedonia, where more than 110 SMA-1 and around 60 WM-1 recording instruments have been installed.

BASIC CONCEPTS OF THE NETWORK

Yugoslavia, which in the case of this paper covers the territory of the former SFR Yugoslavia republics Bosnia and Hertzegovina, Monte Negro, Croatia, Macedonia, Slovenia and Serbia, is a region which was often subjected to disastrous earthquakes in the past. Many zones within this region have been exposed to their destructive effects for several times. Having in mind both the general need for ground motion data, to improve earthquake resistant design and reduce seismic hazards on a world wide basis, as well as the study of the intense seismicity of Yugoslavia, the realization of the project "Installation of Strong Motion Instrument Network on the Territory of Yugoslavia" was undertaken at the beginning of 1972.

The basic concept of the Yugoslav 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 Yugoslav strong-motion instrument network mainly contains two types of instruments: accelerographs SMA-1, manufactured by Kinemetrics, USA, and seismoscopes type WM-1, manufactured by the Astronomic-Geophysical Observatory in Ljubljana, Yugoslavia.

The distribution of strong motion instrument network on the territory of Yugoslavia is based on previous studies of seismotectonic structure and the seismicity of the country.

The fact that a great part of Yugoslavia in which the major cultural and industrial centers are located in zones of considerable seismic activity, fully justifies the necessity of such a network and its regular maintenance.

The strong motion program in Yugoslavia consists of five subactivities: network design, network operation, data processing, network management and research as well as application.All these activities are under the responsibility of IZIIS in cooperation with the Yugoslav Association of Seismology. By the year of 1975 in the realization of this project participated the CALTECH as a cooperative institution within the joint American-Yugoslav cooperative project.

From the beginning of 1977, IZIIS works on the accomplishment of the USA-Yugoslav project "Establishment of 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 will serve as a supplement to the already established basic network. This project is of a multi-purpose nature and the results expected to be obtained will be used for better definition of the problem of understanding the influence of local soil conditions on the spectral amplitudes of ground motion as related problem in seismic microzoning studies.

Due to the limitations of this paper, a more thorough review of all the activities associated with the Yugoslav Strong Motion Network cannot be presented. Therefore, attention will be paid to thorough presentation of the instrumentation of structures and the results obtained from some earthquake records, while the remaining activities will be discussed only the the extent necessary for obtaining a clearer insight into the network itself.

Distribution of Instruments

According to the existing data on the seismicity and the seismotectonic structure of Yugoslavia, it has been concluded that in the first stage of accomplishment of the project, the network of instruments for recording of strong earthquakes should contain 100 accelerographs and 150 seismoscopes.

The selection of sites for strong-motion accelerographs has traditionally been made by seismologists and engineers primarily interested in the earthquake response of buildings and other structures. It is not surprising, therefore, that most strong motion instruments are concentrated near major population centres. The remaining instruments are spread over rather sparcelly throughout some of the more accessible seismically active zones in the world. Relatively few strong motion instruments have been deployed in integrated arrays designed for the purpose of gaining detailed information about the generation, transmission and local modification of strong ground motion.

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 for major earthquakes is 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. or this purpose, strong motion networks in Yugoslavia 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: earthquake source mechanism, wave propagation path, effect of local topography, free-field soil response at different soil conditions, site amplification factors, and 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.

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 (multistorey buildings, dams, bridges, etc.).

The basic strong-motion instrument network includes 100 accelerographs and 122 seismiscopes. 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. They are 76 accelerographs and 15 seismoscopes.

INSTRUMENTATION OF STRUCTURES

At the beginning of 1992, in the Yugoslav strong motion instrument network, 76 accelerographs are located on structures (multi-storey buildings and dams). It is expected that in the near future, the number of these instruments will be increased to 200, namely strong motion instruments will be installed on dams.

A bigger portion of these instruments has already been installed or will be installed in Macedonia, especially in Skopje, as a result of the high seismicity exhibited in this region. smaller portion has been installed on multi-storey buildings in Ljubljana, Banja Luka, Zagreb, Sarajevo, etc.

Our past experience from 232 earthquake records taken on buildings in Banja Luka, Skopje and Zagreb 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 buildings.

For instrumentation of structures in Yugoslavia, detail studies and analyses for definition of the minimum required number of instruments installed on different types of structures like high-rise buildings, dams, mines, etc. have been elaborated.

Instrumentation of Buildings

In principle, instrumentation of buildings depends upon more factors which influence the response of a structure during earthquake ground motions. These factors are: (1) conditions and ways of foundation, (2) architectural design, (3) structural design with special reference to floor systems, (4) size and height of buildings, (5) construction material, (6) distribution of expansion joints, etc. he proper understanding of the influence of these factors upon the response of structures would provide an adequate distribution of instruments.

The usual distribution of instruments is based on the theory of elasticity and testing of structures under small excitations.

However, the building instrumentation set up as based upon the expected elastic behaviour assumption should also apply for calculation of the inelastic response of structures. This holds more true if the fact is considered that the most important data obtained from instrumentation of buildings are related to the inelastic response of buildings, namely to buildings subjected to rather large amplitudes and long-duration earthquakes.

Location of Instruments

The optimum number of instruments and the number of floor levels where instruments should be located is a function related to the structural system of the building, architectural design, the size and the height of the building.

s a minimum requirement, the strong motion instruments should be installed on the bottom level basement or a ground floor) and on the topmost level (the roof) of the building. The purpose of the instruments installed at the lowest level is to record the input motion at basement level. For normal foundation conditions, instrumentation of the lowest level is carried out by a system of orthogonal accelerometers consisting of two horizontal and one vertical accelerometer. The instrument is located the closest possible or in the center of the plane and fixed to a foundation so that horizontal accelerometerss are placed parallel to the building axes. For special foundation conditions, it is necessary to install additional accelerometers, at least one horizontal, if differential horizontal motions are expected, and two vertical accelerometers if vibrational motion is expected, while the structure is characterized by rigid foundations.

If the plan of the building is large or if it has variable foundation conditions, it is desirable to install three additional axial instruments strategically well arranged.

Having in mind the variety of buildings in respect to their architectural design, structural systems and height, it is very difficult to define the optimum number of instruments and their location at the intermediate levels. Using mode shapes obtained from full-scale forced vibration studies, it is possible to define precisely the locations of the instruments at the intermediate storeys. This problem should be solved for each structure separately after a detail study of the structural system and definition of the expected response due to earthquake motion.

The required number of instruments per floor as well as arrangement of these instruments primarily depend upon the height of the building and its stiffness characteristics. Instrumentation of intermediate levels of low buildings of uniform stiffness is not necessary since the number of mode shapes is smaller but the possibility of their prediction larger.For small buildings with nonuniform stiffness, instruments should be installed also on intermediate storeys. It is also recommended that intermediate levels of all buildings higher than GF + six storeys should be instrumented, especially if the stiffness is uniform in one of the intermediate levels, only. For tall buildings, at least one of the intermediate levels should be instrumented.

DATA PROCESSING

Data processing in central to the entire strong-motion program; it serves as a focal point for the functions of archiving the records, processing of data, and dissemination both the data and information about the program to the user community. In the archival phase, all records are stored by station and cataloged both by event and station. In data processing, all significant records are digitized after which the raw digitized data are used to generate the following: uncorrected and corrected acceleration time histories; velocity and displacement time-histories; and various forms of frequency domain spectra (response spectra and Fourier spectra.

The ground motion characteristics during an earthquake represent the basis for solving of earthquake engineering and engineering seismology problems. These characteristics can be obtained from strong motion instrument recordings.

The three components, as recorded by the accelerographs the response of the instrument to the earthquake ground motion. Due to the limited capability of the instruments, the response gives a proper ground acceleration only for a very small frequency range. On the other hand, for calculation of many earthquake engineering and engineering seismological problems, the exact functions of acceleration, velocity and ground displacement at a wider frequency range, response spectra, Fourier spectra and other ground motion information are required.The determination of all these ground motion characteristics necessitates detail processing of the recorded accelerograms.

The most serious problem for strong motion data processing is the determination of the exact ground acceleration function, the so called correct acceleration data at wider frequency range. In the past, these data used to be obtained by application of several methodologies. Recently, in order to obtain more correct information of the accelerograms many authors work on the development and unification of a standard strong motion processing procedure.

The IZIIS data processing system involves with in-house development, but much of it is patterned after the methodology developed by CALTECH-Pasadena, USA.

The application of the data processing method developed at IZIIS-Skopje, has been presented by the data processing results considering the Montenegro and Banja Luka earthquakes.

OBTAINED RESULTS

Since 1973, several strong earthquakes have occurred on the territory of Yugoslavia, (the Montenegro coastal area - 1979, M= 7.0; Kopaonik - 1980, =6.3; Banja Luka-1981, M=5.4) and the neighbouring countries (Friuli, Italy-1976, M=6.5; Vranchea, Romania - 1977, M=7.2, Thessalonika, Greece - 1978, M=6.3, etc.). Many earthquakes of moderate intensity (M=2.5 : 5.5) have occurred, too.

In this period, 931 accelerograms have been obtained out of which 548 by instruments installed on free field and 383 by those installed on different structures.

Due to the lack of space for more detailed information on the results obtained by the Yugoslav strong motion network, only the records of the earthquakes (Montenegro coastal area - 1979 and Banja Luka 1981)will be considered hereinafter. Some of the activities of IZIIS with respect to this network will be presented in a brief review of these earthquakes, recorded accelerograms and the results of their analyses.

Montenegro earthquake of April 15, 1979

The disastrous earthquake which occurred in Montenegro coastal area on April 15, 1979 with epicenter at 41 48' north latitude and 19 00' east longitude, focal depth of h = 40 km and a magnitude M = 7.2, as well as the foreshock of April 9, 1979 and the stronger aftershocks occurring within the period of several months after the main shock, have been recorded by all strong motion instruments (29 SMA-1 accelerographs and 21 M-1 seismoscopes), installed on a wide area of about 50.000 km.sq. These instruments are a part of the Yugoslav strong motion instrument network.

During 1979, these earthquakes gave about 300 accelerograph records and 50 seismoscope records out of which 54 accelerograph records on 8 seismoscope records have been obtained by instruments installed on structures. Such large number of records obtained from one epicentral zone represents a unique worldwide example and it can be used as a basis for detailed investigation of characteristics of the Montenegro earthquake and for other investigations related to the earthquake engineering and engineering seismology in general.

To define the ground motion characteristics during the main Montenegro earthquake of April 15, 1979, from many obtained records, eight horizontal components of four representative accelerograph records taken at Ulcinj, Bar and Petrovac, have been analyzed. For each of the analyzed records time histories of the corrected acceleration and calculated velocity and displacement time histories are given, and running Fourier spectra plots as well as response spectrum for absolute acceleration and relative velocity are presented for the following records: (1) Ulcinj, Hotel "Olimpic" (Ulcinj-1), (2) Ulcinj, Hotel "Albatros" (Ulcinj-2), (3) Bar, Town Assembly Building (Bar) and (4) Petrovac, Hotel "Oliva" (Petrovac).

For the corrected values of acceleration, velocity and displacement time histories their maximum values have been determined. The maximum values of acceleration, velocity and displacement are given in Table 1.

Table 1

Record	Component	Maximum values of		
		Acceler. (cm/sec**2)	Velocity (cm/sec)	Displac. (cm)
Ulcinj	W-E	235.2	47.385	12.702
Hotel"Olimpic"	N-S	279.4	39.198	10.401
Ulcinj	W-E	218.1	27.931	9.724
Hotel "Albatros"	N-S	168.1	19.414	6.473
Bar	W-E	352.4	51.337	14.996
Town Assembly Blg.	N-S	357.1	41.339	9.894
Petrovac	W-E	298.6	24.532	3.031
Hotel "Oliva"	N-S	427.3	39.846	9.470

Being space limited, it is impossible to showand discussed all the analyzed time histories, the Fourier amplitude running spectra and other response spectra, the principal characteristics of ground motion of the above mentioned records, only the record Ulcinj-1 obtained at Hotel "Olimpic" shall be presented (Fig.1) and discussed.

The record taken in Ulcinj, at Hotel "Olimpic", component W-E is characterized by a length of intensive part of the record of about 12seconds with predominant period of ground motion of about 1.5 sec. in the first part and a gradual decrease of this period in the second part. The absolute acceleration response spectrum has significantly expressed the ordinates around the period of 1.5 sec. The N-S component of this record (Fig.2)has the same duration of the intensive portion of ground motion, however, the predominant period is gradually decreasing from 1.5 to 1.1 sec. The absolute acceleration response spectrum has very expressed ordinates around the period of 1.1 seconds (Fig.3).

The earthquake of Banja Luka in 1981

Banja Luka and it environment is one of the most active seismic regions in Yugoslavia. Only the earthquakes of the latest history, those of 1969 with I = VIII-IX degrees in MCS scale shall be mentioned here causing enormous damage and killing people (15 were killed while about 1250 persons were slightly to seriously injured).

On august 13, 1981 at 2.58 a.m. the area of Banja Luka was struck by an earthquake of M = 5.3 or I = VII-III degrees in MCS scale.

This earthquake caused significant material damage and considering its consequences it is one of the strongest which affected this region in the recent history.

In the area of Banja Luka 9(nine) accelerometers have been installed, out of which 2(two) on the ground an 7 (seven) on 2(two) structures.

In the following Table 2, the maximum values of the obtained records have been presented.

Table 2

Site	Location of instrument	Maximum acceler.(cm/sec**2) N-S	W	E-W
IMB nstitute	ground	506.4	257.4	386.8
Seismological station	ground bedrock	65.2	43.6	72.3
Apartment bldg.	basement	307.2	91..5	268.9
"BK-2"	VI floor	371.1	242.0	269.7
	XII floor	367.1	280.0	197.4
Apartment bldg.	basement II entr.	368.8	120.5	225.4
"BK-9"	IV floor I entr.	382.4	214.9	352.7
	IV floor II entr.	419.2	222.4	364.7
	IV floor III ent.	416.2	162.4	351.1

Fig.4 shows the principal characteristics of one of the buildings (building BK-2 having GF = 12 floors) on which the instruments have been located (showing a plan and section) with location of the instruments on the obtained records Figs.5 and 6).

More detail information about these records is given is separate publications of IZIIS.

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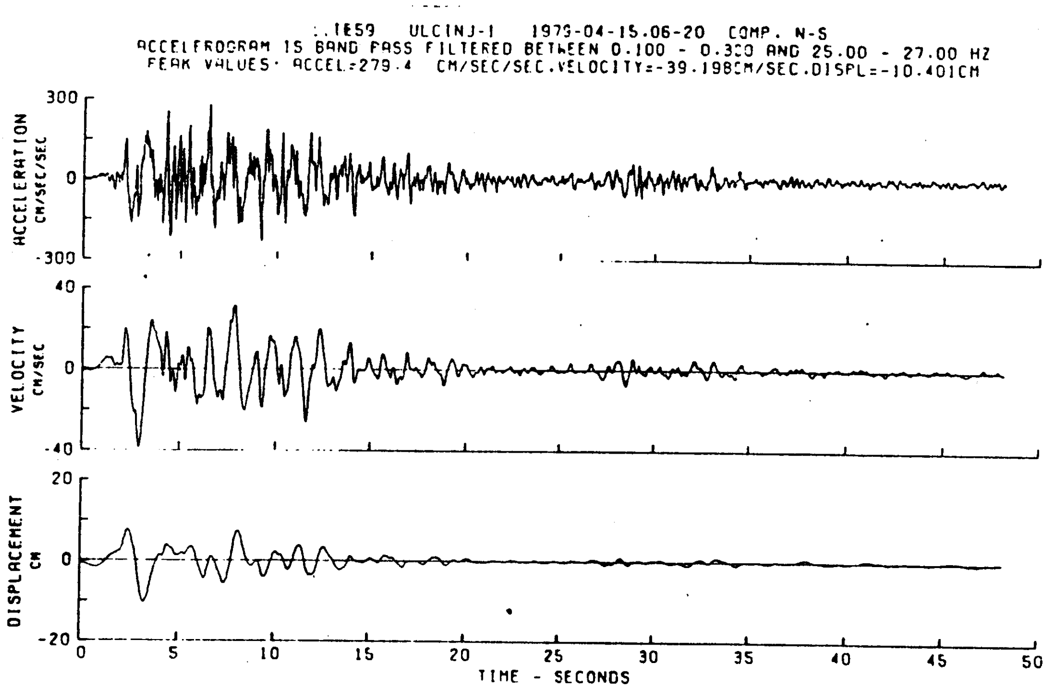


Fig.1.

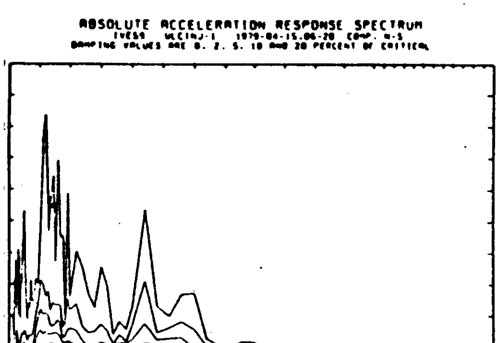


Fig. 2.

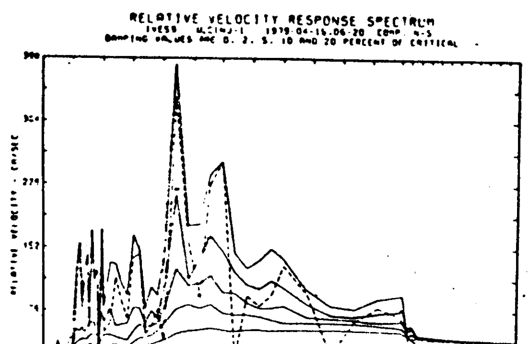
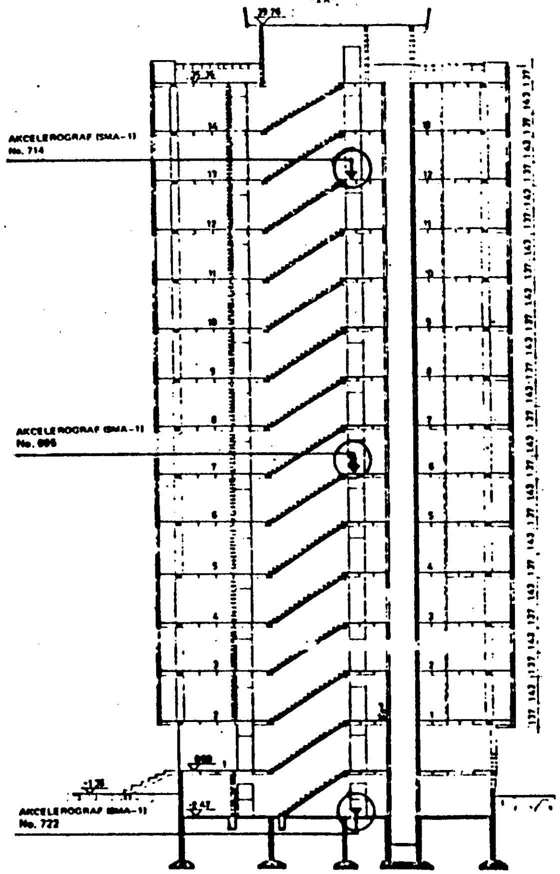


Fig. 3.



STANBENA ZGRADA "BK-2" (P+12), BORIK – BANJALUKA
Poprečni presek

STANBENA ZGRADA "BK-2" (P+12), BORIK – BANJALUKA
Osnove VI i XII sprata

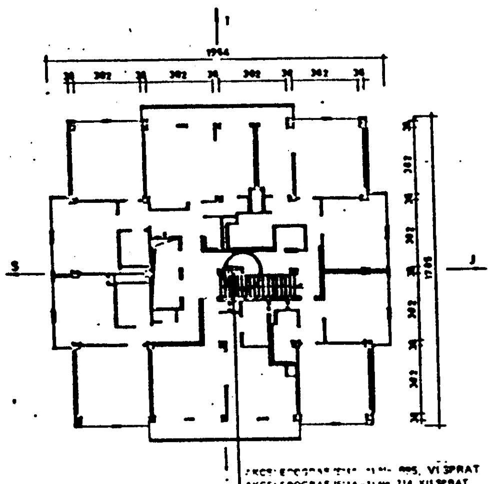
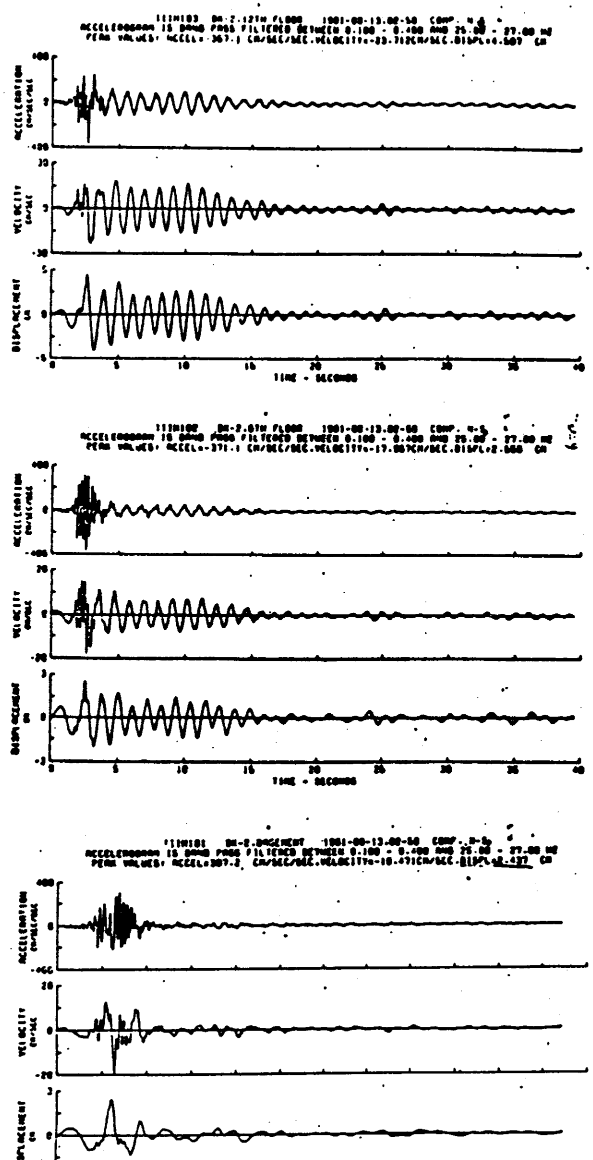


Fig.4.



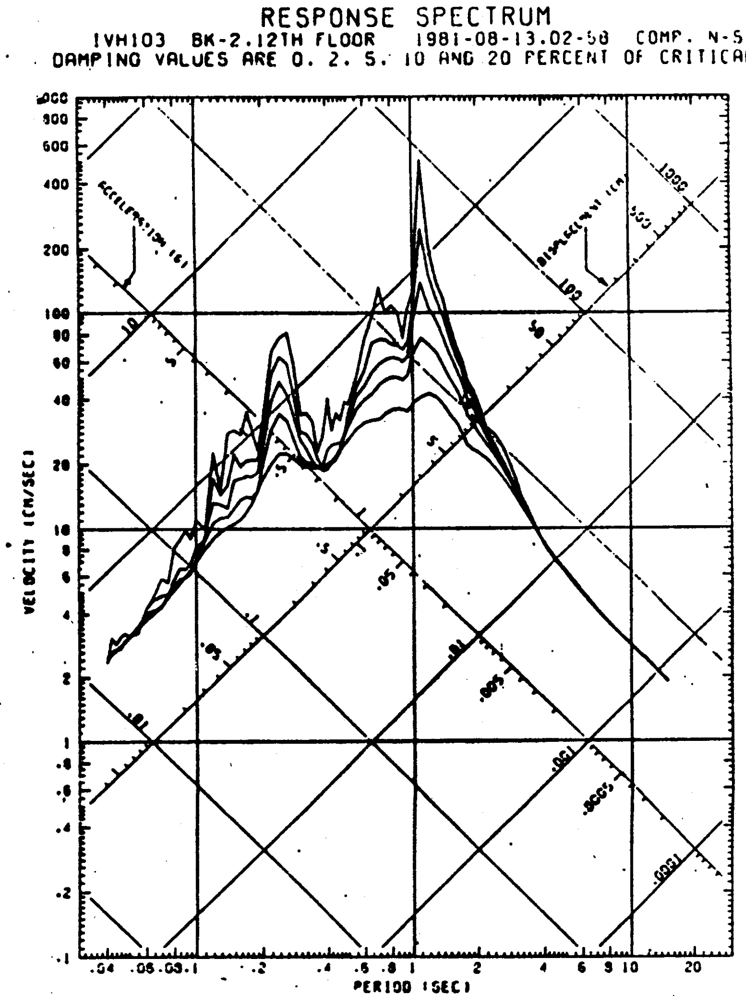

RESPONSE SPECTRUM
IVH103 BK-2.12TH FLOOR 1981-08-13.02-58 COMP. N-S
DAMPING VALUES ARE 0. 2. 5. 10 AND 20 PERCENT OF CRITICAL
VELOCITY (CM/SEC)
PERIOD (SEC)

Fig. 6.

YAPILARDA SİSMİK ÖLÇÜMLER, BAZI GÖZLEMLER VE İLGİLİ SORUNLAR

Vladimir MİHAİLOV

Deprem şiddeti ve yapı davranışının ölçümlenmesindeki eksiklik nedeniyle, deprem olgusu hemen her zaman kesin olarak çözümlenememiş pek çok problem bulundurur. Şiddetli depremler sırasındaki hasar ve yapı davranış kayıtları olmaksızın ne boyutlandırma ölçütleri için karşılaştırma yapılabilir ne de uygun onarım ve güçlendirme konusunda doğru karar alınabilir.

Yapının maruz kaldığı deprem ve yapı davranışına ait bilgiler, deprem riskinin kestirilmesi, boyutlandırma parametreleri ve ölçütlerinin saptanması ve deprem mühendisliğindeki bütün diğer dinamik araştırmalar için esastır. Bu bilgiler olmaksızın yapılan inceleme ve hesaplamalar sadece varsayımlara dayanır. Deprem beklentisindeki belirsizlik en yararlı verileri hemen elde etme olanağını güçleştirmektedir.

Bu problemleri çözmenin tek yolu, deprem hareketini ve şiddetli deprem sırasındaki yapı davranışını saptamak amacıyla çok sayıda aletten oluşan bir ağ kurmaktır.

Bu çalışmada dikkat, yapıların, özellikle de barajların, aletle donatılması konusundaki yönetmelik kayıtları ile bazı depremlerden elde edilen verilere çekilmektedir.