12WCEE 2000

SEISMIC MONITORING OF NUCLEAR POWER PLANTS; AN APPROACH TO OPTIMAL AND MORE ACCURATE SEISMIC DATA PROCESSING AND INTERPRETATION PROCEDURE

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SUMMARY

The seismic monitoring systems on NPP-s have two main functions: (1) to provide recorded accurate data on seismic input and dynamic behaviour of structures and the vital hardlines and processing control and protection systems, and (2) to enable automatic alarm, and, in some cases, automatic stoppage of the processes that go on in NPP-s in case of earthquakes with intensities higher than the previously defined values.

The exact records of the seismic input and dynamic response are important from two aspects: (1) they should enable fast inspection of NPP-s after earthquakes and (2) they should enable checking of the previous design and analytical models for definition of the seismic safety of the NPP-s.

The new regulations for seismic design of NPP-s anticipates a complex concept for definition of intensity of seismic motion. Apart from amplitudes (peak acceleration) and frequency characteristics (dominant frequencies), the new regulations consider also the energy characteristics (cumulative absolute velocity).

Presented in the paper is a concept for processing of accelerogrammes based on comparative analysis of two software packages: Kinemetrics SWS (Seismic Work Station) and the procedure developed at the Institute of Earthquake Engineering and Engineering Seismology. Both concepts are based on the same theoretical basis and represents derivatives of the main procedure developed at CALTECH Institute from Pasadena, USA.

Elaborated is a concept for definition of the input parameters; band-pass filter corner frequencies and slopes, elimination of DC components in the recorded accelerograms and calculation and selection of 100 most relevant values of frequencies for calculation of response spectra. Used as seismic input were two types of data: recorded accelerogrammes generated by biaxial shaking table (the applied acceleration and displacement time histories were used as reference and comparative signals) and "in situ" record of blast experiments.

INTRODUCTION

The seismic monitoring systems in nuclear power plants (NPP) represent part of the safety instrumentation installed for the purpose of:

- Alarming and (or) turning off individual systems of the NPP-s in case of an earthquake inducing motion of ground, engineering structures and equipment that exceed the previously defined amplitudes or spectral amplitudes of motion induced by strong earthquakes, and,

Providing of certain and accurate records of earthquake ground motion, motion of the structures and the equipment for the purpose of verification, evaluation and possible correction of the results obtained from previously performed field, analytical and experimental investigations.

The seismic monitoring of NPP-s is performed continuously, within a long time period, in several phases of construction and exploitation of the NPP-s.

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- In the phase of investigation of the site and design of the NPP-s, monitoring of the site and its surrounding is performed by use of seismographs for the purpose of obtaining recorded data on the seismic activity of the immediate surrounding of the site of the future NPP. These investigations are part of the experimental-analytical investigations for definition of the seismic parameters of the site.
- In the phase of construction of the NPP, monitoring by use of seismographs continues, but local accelerographs are also installed for recording of strong ground motion for the purpose of possible verification of the design seismic parameters.
- In the phase of operation of the NPP, integral seismic monitoring systems are installed. These have at least two functions:

Recording of:

- input earthquake motion (on the free field of the NPP site or at the foundation),
- dynamic behaviour (response) of the engineering structures and the equipment (if seismic instruments or sensors are installed on these) in the course of the seismic effect.

Protection of:

- structures, equipment and personnel in case of exceedence of allowable acceleration levels (previously defined design values), through alarming or eventual automatic shut down of certain systems of the NPP.

In this study are presented briefly the theoretical bases of the procedure for processing of accelerogrammes and interpretation of processed data. Comparative results from application of two procedures for processing of seismic data of the type of accelerogrammes are also presented. Presented in the form of conclusions and recommendations is a global concept for using the processed data in the process of exploitation, maintenance, modifications and modernization of NPP-s. Finally, some main recommendations for correct application of the programme package SWS for the needs of NPP "Kozloduy" are given.

PROCESSING OF DIGITIZED ACCELEROGRAMMES

The digitized accelerogrammes are processed by application of sophisticated and scientifically verified methodologies that enable obtaining of corrected and verified data on the amplitude-frequency content of the recorded earthquake motions.

The two principal tasks of this research programme are the following:

- interpretation of the mathematical bases and the theory of the procedure for processing of accelerogrammes, and,
- comparison of two methodologies for processing of accelerogrammes via processing of identical digitized accelerogrammes.

The subject of investigation are two programme packages:

- The programme package SWS (Seismic Work Station), "Kinemetrics", Pasadena, USA which is a commercial product of the firm [1], and,
- The programme package for processing of accelerogrammes that is applied in the Institute of Earthquake Engineering and Engineering Seismology (IZIIS) Skopje, Republic of Macedonia, which is applied in scientific and applicative investigations realized in IZIIS [2].

Comparative processing of accelerogrammes has been done on two types of records:

- Earthquake record obtained on a seismic shaking table (comparative tests of different types of accelerographs), and
- Blast record ("in situ" experiments made at the NPP "Kozloduy" site).

The results from the comparative processing of an accelerogramme and discussion as to essential correlation and differences between the IZIIS programme package and the SWS "Kinemetrics" programme package are presented in Chapter 3 of this study.

Standard procedure of processing of records

The Institute of Earthquake Engineering and Engineering Seismology has developed its own procedure for processing of strong motion accelerogrammes. Used as a basis for development of this procedure is the standard procedure of the Californian Institute of Technology -CALTEH, Pasadena, in which certain modifications have been made because of use of different equipment for digitization and data processing as well as certain improvements through the latest investigations in IZIIS. A detailed description of the procedure is given in IZIIS publication IZIIS 66-1977 [2].
The whole processing process can be divided into several phases:

- Digitization;
- Obtaining of uncorrected data;
- Instrumental correction;
- Computation of accelerations, velocities and displacements;
- Computation of response spectra and the Fourier amplitude spectrum.
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COMPARISON BETWEEN SWS "KINEMETRICS" AND IZIIS PROCEDURES FOR PROCESSING OF ACCELEROGRAMMES

Elaborated in this part, separately and comparatively, are two concepts for processing of accelerogrammes as follows:

- Programme package developed by "Kinemetrics" from Pasadena, USA, known as SWS - "Seismic Works Station";
- Programme package for processing of accelerogrames applied in the Institute of Earthquake Engineering and Engineering Seismology (IZIIS) in Skopje for all scientific and applicative research programmes in the field of earthquake engineering realized at IZIIS.

Comparative processing by use of both procedures have been made on two types of records:

- Earthquake record obtained on three different types of accelerographs (SMA-1, SMA-2 and SSA-2) generated by the biaxial shaking table in IZIIS from the longitudinal component of the El Centro earthquake, and,
- "In situ" record of a blast in the immediate vicinity of NPP "Kozloduy" recorded at level 61.7 on block 5 by SMA-2 instrument with serial number 263.

The main goals of these comparative analyses were:

- To analyze the effect of input parameters (characteristics of digital band-pass filters and frequencies for computation of response spectra),
- To make comparative analysis of both procedures by application of the same input parameters;
- To analyze the effect of time interval of digitization.

To gain an insight into the effect of the parameters of filters used in the process of processing of records, analysis of the effect of characteristics of filters given according to Table 1 was made. From the presented results in the same table, it is obvious that their effect is the greatest in computation of displacement (there is a difference of up to several centimetres).

Table 1. Computations of acceleration, velocity and displacement by the same values of filter parameters obtained by SMA-2 accelereograph

Band-pass filter		"Kinemetrics"- SWS procedure			"IZIIS" - procedure		
Lower boundary freq. (Hz)	Upper boundary freq. (Hz)	Accele-ration (cm/s/s)	Velocity (cm/s)	Displace-ment (cm)	Accele-ration (cm/s/s)	Velocity (cm/s)	Displace-ment (cm)
0.03-0.05	33 - 35	281.24	31.56	12.34	281.0	31.253	11.715
0.075-0.1	33 - 35	280.26	30.42	9.94	280.0	30.597	9.864
0.05-0.10	33 - 35	280.65	30.32	9.05	280.3	30.430	9.113
0.10-0.20	33 - 35	280.72	29.80	8.07	280.5	29.785	8.046

The selection of frequencies for computation of response spectra has been done based on the regulations for aseismic design of nuclear power plants Regulatory Guide 1.60 [10], Regulatory Guide 1.61 [11] and design spectra of acceleration from design and local earthquake for free field, horizontal and vertical component, used in design and construction of NPP "Kozloduy". Selected are a total of 100 values of natural frequencies for a single-degree of freedom system (Table 2) for which the maximum values of spectral quantities shall be defined in the "Kinematrics" and "IZIIS" procedure.

Table 2. Interval for computation of Ground and Floor Response Spectra

Ground Response Spectra		Floor Response Spectra	
Frequency range (Hz)	**Increment (Hz)**	**Frequency range (Hz)**	**Increment (Hz)**
0.5-3.0	0.10	0.5-1.6	0.10
3.0-3.6	0.15	1.6-2.8	0.20
3.6-5.0	0.20	2.8-4.0	0.30
5.0-8.0	0.25	4.0-9.0	0.50
8.0-15.0	0.50	9.0-17.0	1.00
15.0-18.0	1.00	17.0-22.0	2.00
18.0-22.0	2.00	22.0-34.0	3.00
22.0-34.0	3.00		

To compare the difference between the two procedures, the El Centro earthquake record - longitudinal component obtained by SMA-2 accelerograph has been used as an input data. The record was processed by use of the Kinemetrics and IZIIS procedure for the same boundary frequencies for the band-pass filter and the same frequencies for computation of response spectra. Selected as boundary frequencies of the band-pass filter were: (0.05 - 0.10) Hz and (33 - 35) Hz, in accordance with the theoretical criteria for use of filters in processing of accelerogrammes.

The values of acceleration, velocity and displacement obtained by use of the "Kinemetrics" and "IZIIS" procedure are presented in Table 3.

Table 3. Acceleration, velocity and displacement by the El Centro earthquake record - longitudinal component obtained by SMA-2 accelerograph with same values of filter parameters

Procedure	Band-pass filter		Acceleration (cm/s/s)	Velocity (cm/s)	Displacement (cm)
	Lower boundary freq. (Hz)	Upper boundary freq. (Hz)			
"Kinemetrics"	0.05 - 0.10	33 - 35	280.65	30.32	9.050
"IZIIS"	0.05 - 0.10	33 - 35	280.30	30.43	9.113

The effect of the digitization interval, i.e., the "sample rate" has been analysed based on accelerogrammes obtained by three different types of accelerographs: SMA-1, SMA-2 and SSA-2. The accelerogrammes have been obtained by the shaking table in IZIIS - Skopje excited by the "El Centro" longitudinal component.
For that purpose, the accelerogramme obtained by SMA-1 has been digitized on a digital table of the type of Drawing Board II, Calcomp digitizer, products division Anahein, USA, with a specially prepared software for that purpose and processed by the IZIIS procedure with a sampling rate of 100 samples/sec.

The accelerogrammes obtained by accelerographs type SMA-2 have been digitized with a standard speed of 256 samples/sec., while the SSA-2 accelerogrammes have been recorded by 200 samples/sec.

While processing the accelerogrammes, the lower boundary frequency of the band-pass filter has been 0.05 to 0.10 Hz, while the upper boundary frequency of the band-pass filter has been selected depending on the performances of the recording system, i.e., (25 to 27) Hz in SMA-1 and (33 - 35) Hz for the SMA-2 and SSA-2 instruments.

Table 4 shows the obtained values of acceleration, velocity and displacement. Fig. 1 show the comparison between both the procedures for response spectra of absolute acceleration. As clear from the figure, there are differences but they are not so great.

Table 4. Acceleration, velocity and displacement by the El Centro earthquake record - longitudinal component obtained by SMA-2 accelerograph with same values of filter parameters

Accelero graphs type	Band-pass filter Lower boundary freq. (Hz)	Upper boundary freq. (Hz)	Acceleration (cm/s/s)	Velocity (cm/s)	Displacement (cm)
"SMA-2"	0.05 - 0.10	33 - 35	280.65	30.32	9.05
"SSA-2"	0.05 - 0.10	33 – 35	-282.76	-29.93	-8.46
"SMA-1"	0.05 - 0.10	25 – 27	278.50	30.18	10.18

In July 1996, in the course of realization of this project, "in situ" investigation was performed in the immediate surrounding of NPP "Kozloduy", by use of explosives in bore holes specially prepared for that purpose. Although the explosions were of a low intensity, they still were recorded by some instruments from the system of seismic monitoring installed on the nuclear power plant.

To get a better insight into some advantages and disadvantages of one or the other procedure, a real record obtained at level 61.7 on block 5 by the SMA-2 instrument with a serial number 263, was processed for longitudinal (LONG), transverse (TRAN) and vertical (VERT) direction. From the recorded record, a record with a duration of 7.6 sec referring to the explosion with the greatest charge was processed.

The processing was done by the two processing packages packages - Kinemetrics and IZIIS. It should be mentioned that the algorithm used in processing of the accelerogrammes by use of the Kinemetrics procedure is not known to us.

While processing the record by use of the IZIIS procedure, it was concluded that the "DC" (direct component) of the signal is eliminated with this procedure. This is presented in Table 5.

It was concluded that the Kinemetrics procedure does not involve elimination of DC of the signal which is present in the very record which results in non-real values of acceleration, velocity and displacement which is presented in Table 5 and figure 2 (VERT).

By elimination of the DC component from the input values for processing by the Kinemetrics procedure, more realistic values are obtained for acceleration and velocity, but those for the displacement still deviate from the real values presented in Table 5. Even after such additional correction, the long period components are still present in the results obtained by use of the "Kinemetrics" procedure. To eliminate them and for the purpose of obtained more realistic values of acceleration, velocity and displacement and their corresponding graphic presentations, a band-pass filter with lower boundary frequencies of 0.3 - 0.4 Hz was used, in compliance with regulations 10, 11 and 12. The obtained values given in Table 5.
For the purpose of a better insight between the IZIIS procedure and the Kinemetrics procedure (with and without "DC" components in the signals) presented is a comparison done for the response spectra of absolute acceleration. In figure 3 for the longitudinal component, transverse component in figure 4 and for the vertical component - in figure 5.

Table 5. Acceleration, velocity and displacement by obtained by SMA-2 accelereograph under blast efect

Procedure	**Compo-nent**	**Band-pass filter** Lower bou-nd. freq(Hz)	Upper boun. freq. (Hz)	**Accele ration (cm/s/s)**	**Velocity (cm/s)**	**Displace ment (cm)**
"IZIIS"	LONG. TRAN. VERT.	0.05 - 0.10	33 - 35	6.2 3.5 16.0	0.118 0.169 0.249	0.033 0.071 0.037
"Kinemetrics"	LONG. TRAN. VERT.	0.05 - 0.10	33 - 35	-9.92 25.09 15.98	9.41 36.36 2.59	-5.23 -20.10 -1.45
"Kinemetrics" (remove DC offsets in data)	LONG. TRAN. VERT.	0.05 - 0.10	33 - 35	-6.32 -3.82 17.28	0.23 0.33 -0.46	-0.14 -0.18 -0.23
"Kinemetrics" (remove DC offsets in data)	LONG. TRAN. VERT.	0.30 - 0.40	33 - 35	6.26 3.80 17.06	-0.11 0.15 0.25	0.01 -0.02 -0.01

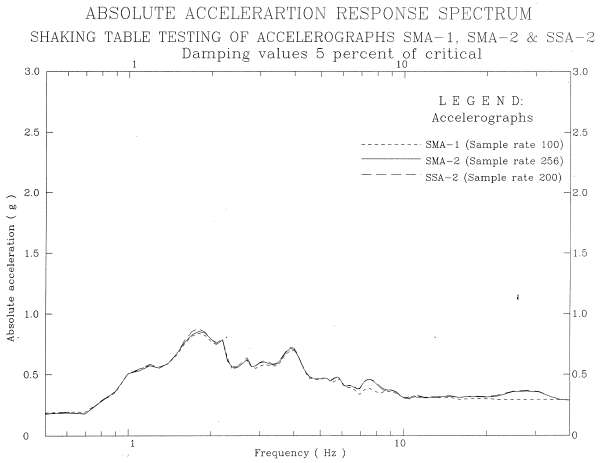

Figure 1.Response spectra of absolute acceleration graph, El Centro, Comp. LONG SMA-1, Band pass filter limits (0.05 ÷ 0.10) Hz and (25 ÷ 27) Hz SMA-2 and SSA-2,Band pass filter limits (0.05 ÷ 0.10) Hz and (33 ÷ 35) Hz.

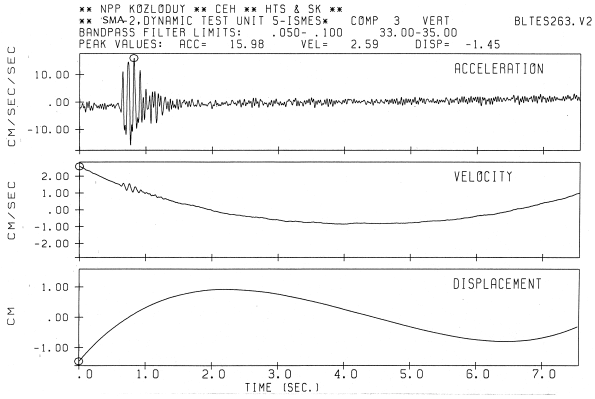

Figure 2. Acceleration, velocity and displacement graph obtained by using the Kinemetrics procedure BLAST-TEST, Comp. VERT; Band-pass limits: (0.03 ÷ 0.05)Hz and (33 ÷ 35) Hz.

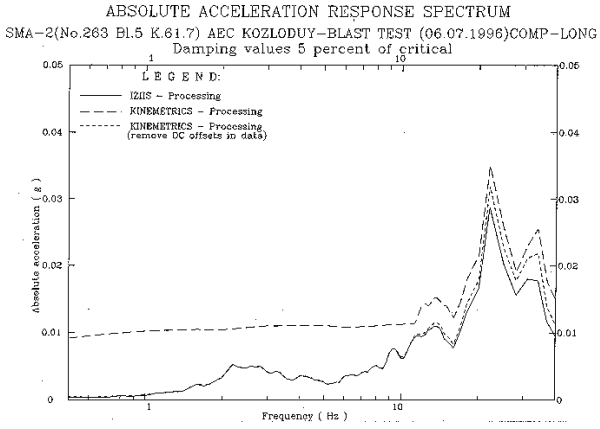

Figure 3.Response spectra of absolute acceleration graph, BLAST-TEST, Comp. LONG;Band pass filter limits (0.05 ÷ 0.10) Hz and (33 ÷ 35) Hz

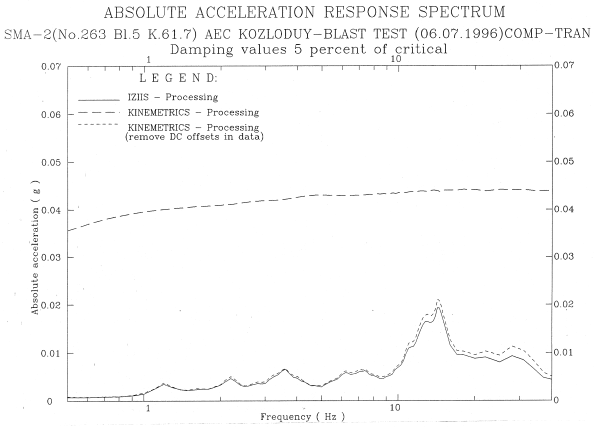

Figure 4.Response spectra of absolute acceleration graph, BLAST-TEST, Comp. TRAN;Band pass filter limits (0.05 ÷ 0.10) Hz and (33 ÷ 35) Hz

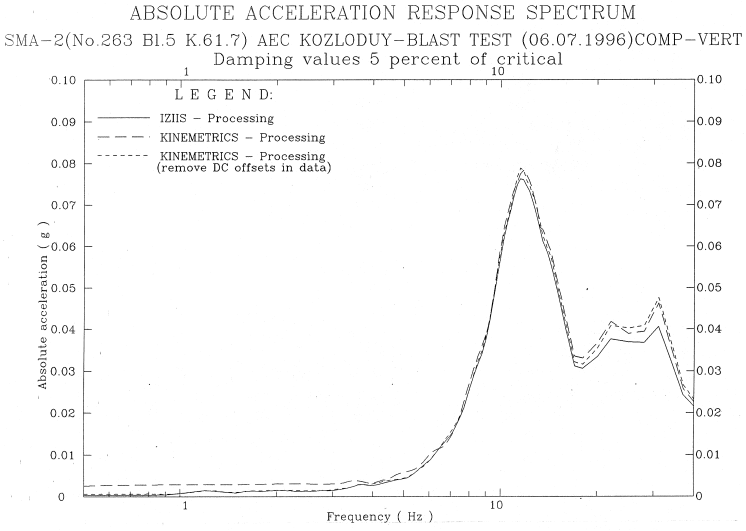

Figure 5. Response spectra of absolute acceleration graph, BLAST-TEST, Comp. VERT; Band pass filter limits (0.05 ÷ 0.10) Hz and (33 ÷ 35) Hz

CONCLUSIONS AND RECOMMENDATIONS

Based on the previously presented theoretical bases of the procedure for processing of accelerogrammes applied in IZIIS and the performed processing and results obtained by analysis of a record from a real earthquake and record obtained from explosion, the following conclusions and recommendations are arrived at:

Characteristics of Filters

The theoretical conditions are satisfied if the lower boundary frequencies of the band-pass filter of 0.05 to 0.1 Hz are selected, however on the basis of regulations, it is correct to work also with lower boundary frequencies of a band-pass filter of 0.3 to 0.5 Hz.
Based on the regulations, for accelerogrammes obtained on SMA-2, SMA-3 and SSA-2, it is correct to select upper boundary frequencies of band-pass filter of 33 to 35 Hz, whereas for accelerogrammes obtained on SMA-1, these frequencies should be 25 - 27 Hz (due to the dynamic characteristics of the accelerograph).

Frequencies for Computation of Response Spectra

The values of the frequencies for computation of response spectra should be defined according to the regulations. Use of identical values of frequencies is recommended for all the accelerogrammes. It was concluded that these frequencies and the frequencies from the design spectra of acceleration of NPP Kozloduy are compatible.

Digitization Interval

The technical characteristics of equipment imposes the use of the following digitization intervals: for SSA-2 Δt = 1/200s, for SMA-2 and SMA-3 Δt=1/256s and for SMA-1 Δt = 1/100s or Δt = 1/50s (depending on the performances of the digitizing equipment.).

Similarities and Differences Between Procedures for Processing of Accelerogrammes Used by "IZIIS" and "Kinemetrics" SWS

- It has been concluded that in processing of identical accelerogrammes obtained from a record of an actual earthquake, both procedures (the one used by IZIIS and the one used by Kinemetrics SWS) yield approximately the same results. Presented in this report is the theoretical basis of the procedure for processing of accelerogrammes used by IZIIS which is probably the same or similar to SWS. From the results, it may be concluded that different algorithms and programme solutions are most probably used. These generate the differences. This is particularly manifested in instrumental correction of accelerogrammes where different algorithms for numerical filtration are most probably used.

- While computing the response spectra and other spectra, almost identical results are obtained for the same frequencies which points to the fact that the same algorithms are most probably used for computation in both procedures.

- While processing a record from a blast recorded on the dome of Block 5, it has been concluded that the IZIIS procedure correctly computes all the time histories and spectra.

- While using the Kinemetrics procedure, it has been concluded that the algorithms for instrumental correction of accelerogrammes obtained on SMA-2 (and certainly on SMA-3 since these have the same technological solutions), and digitized on SMP-1 Digitizer, could not eliminate the DC direct components of the accelerogramme signals. For this purpose, a programme has been elaborated for elimination of the present direct components which should be used prior to instrumental correction of accelerogrammes obtained on SMA-2 and SMA-3.

REFERENCES

1. "Kinemetrics - Operating and Instructions Manuals" for: - Accelerografs type: SMA-1, SMA-2, SMA-3, DSA-1, DSA-3, SSA-2; - Playback Devices type: SMP-1, DSP-2; - Digitizing System SMP-1; - Data Retrieval PC based Software Package QTSSA; - Data Processing Software Package SWS (Seismic workstation)
2. Dimitar Petrovski, Nove Naumovski, "Processing of Strong Motion Accelerogramms", Part -1, "Analytical Methods", *Publication No. 66, IZIIS*, Skopje, Macedonia, 1979
3. Mamucevski, D. and Dojcinovski D. (1996) Seismic Monitoring System of NPP Kozloduy, Report IZIIS 96-74
4. Mamucevski. D., Dimitrovski, T. and Vitanovski N. (1995), "NPP Kozloduy, Section HTS and SK, 1. Repair and Calibration of Three Accelerographs type SMA-2, 2. Comparative Shaking Table Testing of SSA-2, SMA-2 and SMA-1" IZIIS 95-04, Skopje, Macedonia
5. Mihailov, V. and Celebi M., (1999) Seismic Monitoring of Structures - An Important Element in Seismic Hazard Mitigation for Urban Media, Mac – U.S. Research Project – Progress Report 1998/99
6. Mihailov, V. Dojcinovski, D. and D. Mamucevski, (1994), "Seismic monitoring on structures: Some experience and related problems", *10th European Conference on Earthquake Engineering*, Vienna, Austria,
7. Mihaiulov, V. and Dojcinovski D. (1998) Analysis of Records Taken by SMA-1 acclerograph Installed on HPP "Moste", Earthquake of April 12, 1998 12^h 55' and M=5.5, IZIIS 98-32, Skopje, Macedonia
8. Mihaiulov, V. and Dojcinovski D.(1995) Processing of Records from the earthquake of May 1, 1995 obtained on HPP "Strezevo" dam; Report IZIIS 95-24
9. Regulatory Guide 1.12, 1974, "Instrumentation for Earthquakes", U.S. Atomic Energy Commission, 1974
10. Regulatory Guide 1.60, 1973, "Design Response Spectra for Seismic Design of Nuclear Power Plants", American Nuclear Society, 1973
11. Regulatory Guide, 1.61, 1973, "Damping Values for Seismic Design of Nuclear Power Plants", American Nuclear Society, 1973
12. Standard ANSI/ANS - 2.2 – 1978, "Earthquake Instrumentation Criteria for Nuclear Power Plants", American Nuclear Society, 1978
13. Standard ANSI/ANS - 2.10 – 1979, "Guidelines for Retrieval, Review, Processing and Evaluation of Records, obtained from Seismic Instrumentation", American Nuclear Society, 1979
14. Standard IEEE 344-1987, "Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations", The Institute of Electrical and Electronics Engineers