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SITE SPECIFIC ESTIMATION OF CUMULATIVE ABSOLUTE VELOCITY

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ABSTRACT

The presented paper shows some recent results for correlation between cumulative absolute velocity (CAV) and the macro-seismic intensity, magnitude and distance (attenuation functions). The analyses are based mainly on European strong motion data. The processing is performed separately for intermediate depth earthquakes (Vrancea seismic region), regional shallow earthquakes and moderate local earthquakes. The results show that CAV correlates with the intensity, magnitude and distance in a similar way as the peak values of strong motion. There is significant difference of expected CAV from local earthquakes and from strong regional seismic excitations. The local earthquakes, although producing high accelerations, are developing small CAV and respectively small damage potential. The analyses show that intermediate depth earthquakes may produce significant CAV on very large distances, i.e. they may affect large territories and produce damage. The attenuation functions developed are used for prediction of CAV on the site of Kozloduy NPP in Bulgaria.

Keywords: seismic, CAV, site specific, correlation, magnitude

1. INTRODUCTION

There is a continuing trend in the earthquake engineering community to look for a better evaluator of seismic motion damage potential. Most specialists agree that the peak acceleration is not always efficient as an indicator of the potential damage although it is simple for use and leads to direct estimation of inertia forces. The seismic design still relies on classical spectral theory and accelerations.

Probably the first attempt to introduce more sophisticated and complex approach for assessment of the damage potential of seismic motion in the nuclear industry is the EPRI approach for estimation of OBE exceedance. It is based on evaluation of classical quantities as maximal values of acceleration, velocity and spectral ordinates as well as evaluation of the cumulative absolute velocity (CAV) that is considered as a complex indicator of strong motion damageability. The CAV is estimated as an area under absolute accelerogram. In US NRC RG 1.166 there is a threshold given for CAV that is 0.16g*sec [1]. One should expect that under that limit the damage in an engineered structure is negligible.

As indicated in RG 1.12 and RG 1.166 special seismic systems have to be used in order to evaluate CAV. The CAV is estimated only from records on free field [1]. For that purpose a new seismic instrumentation system for Unit 6 of Kozloduy NPP has been installed within a joint project with IAEA. The IAEA delivered the hardware in the late 2001. The system was installed at the end of September 2002.

One essential feature of the new system is that it is covering the requirements both of US NRC RG 1.12 and 1.166. Among those is the procedure for OBE exceedance. As known the procedure includes two basic steps: the first one is a comparison of the registered acceleration and velocity response spectra with the defined OBE spectra at the site; the second step is to compare the calculated CAV value of the registered event with the code value of CAV, that is 0.16g*sec.

The bounding values used in US NRC RG 1.166 are based on registered data and damage estimation mainly in USA [2], [3]. One of the main objectives of that approach has been the estimation of high frequency cut off of seismic excitations. The analyses are based on records that generally correspond to frequency content compatible with US NRC RG 1.60 response spectra. As known there are many nuclear sites in Eastern and Central Europe affected by long period excitations produced by intermediate depth earthquakes. Such excitations are not covered by EPRI analyses.

For adjusting and operation of the new seismic system of Unit 6 we have performed detailed analyses for estimation of expected CAV at the site of Kozloduy NPP. The reasons for that are following: the site specific free field response spectra of Kozloduy NPP are different from those in US NRC RG 1.60; the seismic hazard at the site is governed by Vrancea seismic sources (intermediate depth earthquakes) that are not covered by EPRI analyses; structural vulnerability according to EMS (European Macro-seismic Scale) may differ from those in MMI scale (used by EPRI). The presented hereafter results are part of the analyses for assessment of the CAV standardized value for the site of Kozloduy NPP. Although the analyses are site specific the results achieved are related to the broader issue of applicability of CAV for damage prediction.

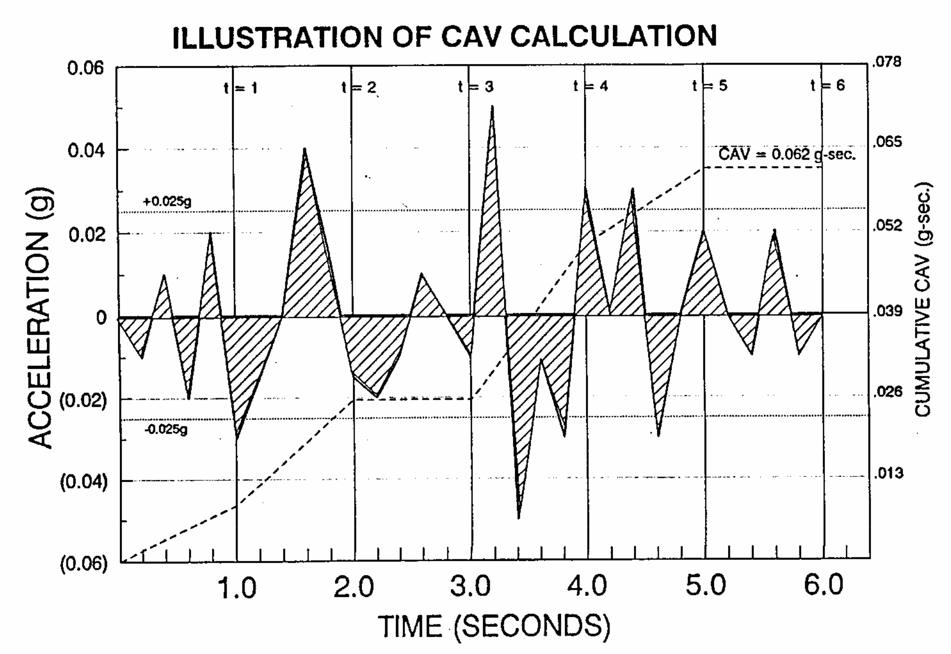

Fig. 1. Standardized CAV calculation [3]

2. METHODOLOGY FOR STANDARDIZED CAV CALCULATION

According to US NRC RG 1.166 the CAV defined in equation (1) is used to incrementally calculate CAV in one-second intervals as follows:

(1) $$CAV = CAVi + \int_{ti-1}^{ti} ABS[a(t)]dt$$

Where a(t) is an acceleration value in one-second interval where at least one value exceeds 0.025 g and i=1, n (n is equal to the record length in seconds).

Figure 1 illustrates this process assuming a sampling rate of 5 samples per second [3]. In a real earthquake record, the data will be analyzed in each one-second interval at the data-sampling rate, usually 50 to 200 samples per second. The threshold of 0.025g is a significant assumption for definition of standardized CAV. If that value is changed the CAV value of the record will change also. If the value is assumed zero, then the CAV will depend of the duration definition. The change of that limit may have influence of the correlation between CAV and seismic damage as discussed in other analyses [3], [4]. The best correlation between CAV and damage has been estimated for threshold 0.02g [4]. In the further presented analyses a threshold of 0.025g is used.

3. STRONG MOTION DATA BASE

A strong motion database is constructed to reflect the seismic features of the Kozloduy site. The seismic hazard at the site is governed by three types of sources: local sources within the 30km area around the NPP, shallow sources at distances 30 to 150km, and intermediate depth sources – Vrancea source region. Those sources generate different seismic motions: the local sources are able to generate earthquakes with magnitudes up to 5; the regional shallow (depth up to 30km) sources generate magnitudes up to 7; the Vrancea intermediate depth (100-150km) sources are 320km away from Kozloduy site and may generate magnitudes up to 7.5. For all the analysis the European Strong-Motion database is used [5]. We have added strong motion records from Vrancea source zone (strong events in 1977, 1986 and 1990) as well as records from local Bulgarian sources. The following table represents the main features of the database, separated according to the seismic characteristic of the investigated site.

Table 1. Main features of the database

Data base	Total number of records	Number of records with CAV≠0	Number of records with defined local intensity
Regional sources	3188	1568	786
Local sources	134	90	14
Vrancea sources	86	76	0

The locations of the records are presented in figure 2 [5]. It could be seen that the database covers most of the active seismic zones in Europe, however the biggest part of the records are from Italian and Greek earthquakes.

An essential feature of the database is the indication of seismic intensity felt on recorder site. The seismic intensity is according to European Makroseismic Scale (EMS) [5]. As known the EMS is a modernized MSK scale and it is often used for risk analysis of urban areas. The reason is the detailed description of the damages for different type of structures. According to that scale there are 5 damage grades: level 1 represents small architectonic damages; level 5 corresponds to total damage. The structures are divided in 6 vulnerability classes from A to F. The vulnerability classes D, E and F correspond to engineered structures with good ductile behavior. The structure damage starts with intensity 6 where one may expect nearly 25% of the structures with moderate level of seismic design to have damages of grade 1. Also some 5% of the structures with high level of seismic design may have damages of grade 1. In a similar way the damages are defined up to intensity 12.

The records in the database are indicated with seismic event, for each event there is an estimation of magnitude according to different magnitude scales. In the present analyses Ms is used because of the relatively long epicenter distances applicable for prediction of strong effects on the investigated site. This assumption may lead to some incorrectness when analyzing near field records. For each event the focal depth is presented and for each recorder site the distance to the epicenter is given, too. A graphic presentation of the data is shown in figures 3 to 5.

Each recorded component of seismic motion is considered as an independent record. No additional filtration or data processing has been applied. Only corrected acceleration time histories are used. The additional records from Vrancea sources and from local Bulgarian sources are corrected according to the uniform procedure of the European database. All additional records are taken at free field. The European database contains also records at structures and dams.

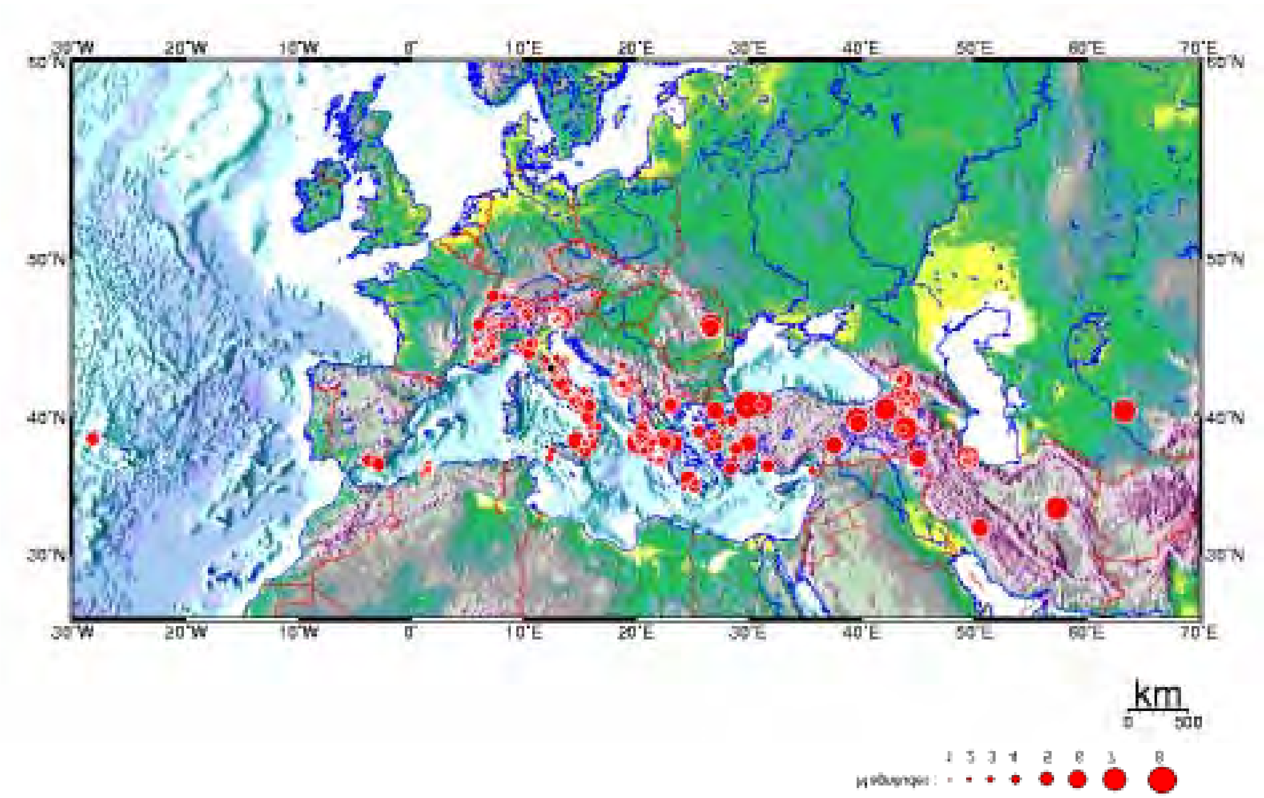

Fig. 2. Location of the strong motion recording stations

Table 2. Database summary: magnitudes, intensity, and distances

Database	M_s		Distance (km)		I_{MSK}	
	max	min	max	min	max	min
Regional	7.8	2.55	401	2	X	II
Local	5.2	2	34	2	VII	IV
Vrancea	7	6.3	319	4	-	-

Tables 2 and 3 are showing summary of other important features of the database. As it could be seen the database is covering a very large range of seismic excitations with significant effects on civil structures (EMS intensity up to 10). The mean value of acceleration of the regional sources is 0.09g, i.e. there is very large number of records with small maximal accelerations. As we are looking for effects on engineered structures we have selected records with defined Ms, and CAV greater then 0.02g.sec. In that way the number of records of the regional sources is limited to 967 with magnitudes between 4 and 7.8. The Vrancea source records are limited to a number of 68.

The records with defined intensity on site are mainly from the regional sources. Graphical presentation of the data is given in figure 6. As shown there are a significant number of records with low PGA and low CAV but relatively high intensity. In order to reduce the insignificant records we have selected from each event only the closest records and also in cases of equal epicenter distance those with higher CAV. The number of significant records with defined local intensity has been reduced to 291. The minimum acceleration of the database with indicated intensities is 0.02g, and the minimum intensity considered in the database is 3.

Table 3. Database summary: CAV, acceleration, velocity

Database	CAV (g*s)		Acceleration (g)		Velocity (g*s)	
	max	min	max	min	max	min
Regional	3.3548	0.00312	1.2627	0.025	0.10183	0.00001
Local	0.4122	0.00503	0.3618	0.02605	0.00993	0.00038
Vrancea	0.6064	0.0039	0.2971	0.0253	0.07313	0.0013

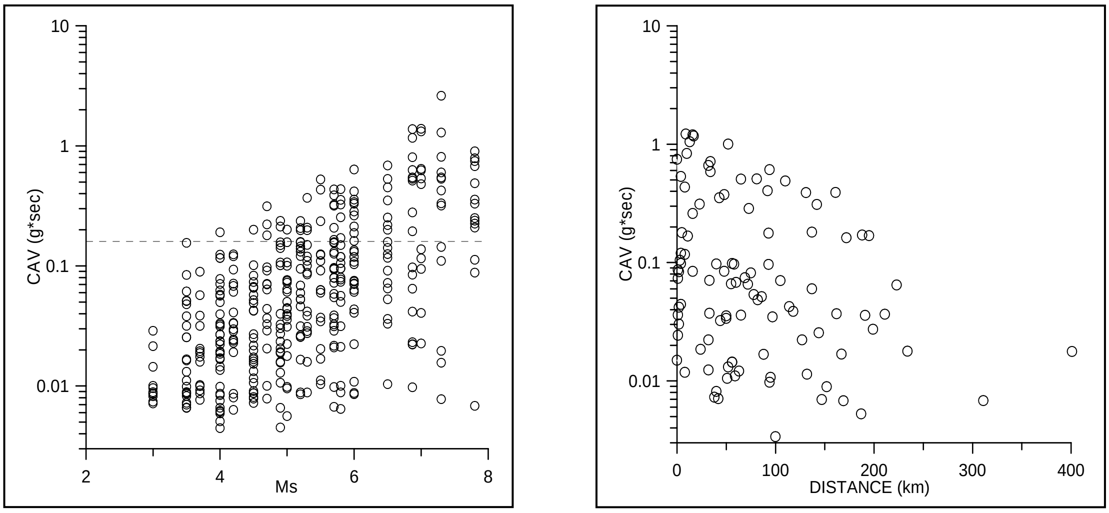

Fig. 3. Regional sources: CAV versus magnitude M_s and distance (5km window)

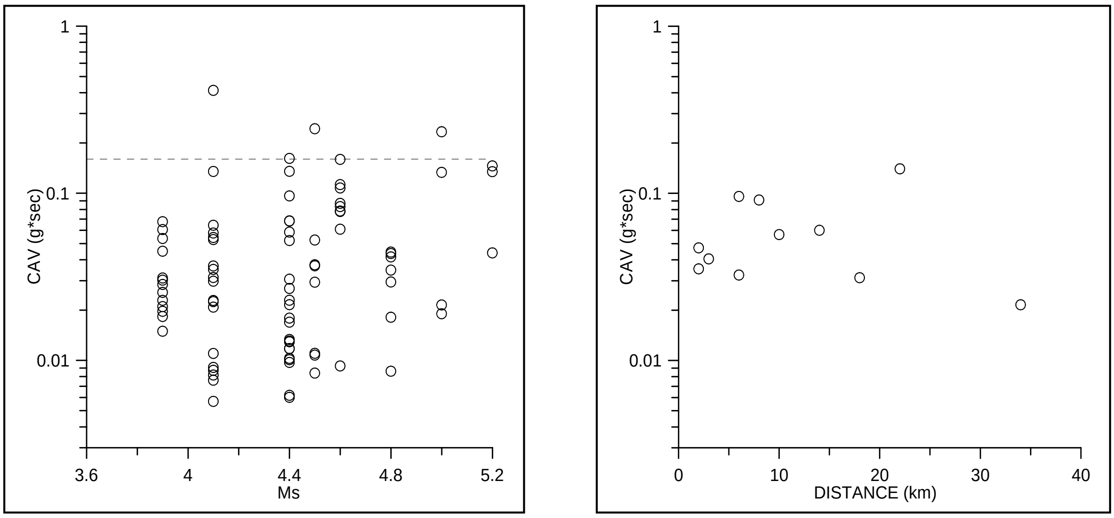

Fig. 4. Local earthquakes database: CAV versus Ms and distance (5km window)

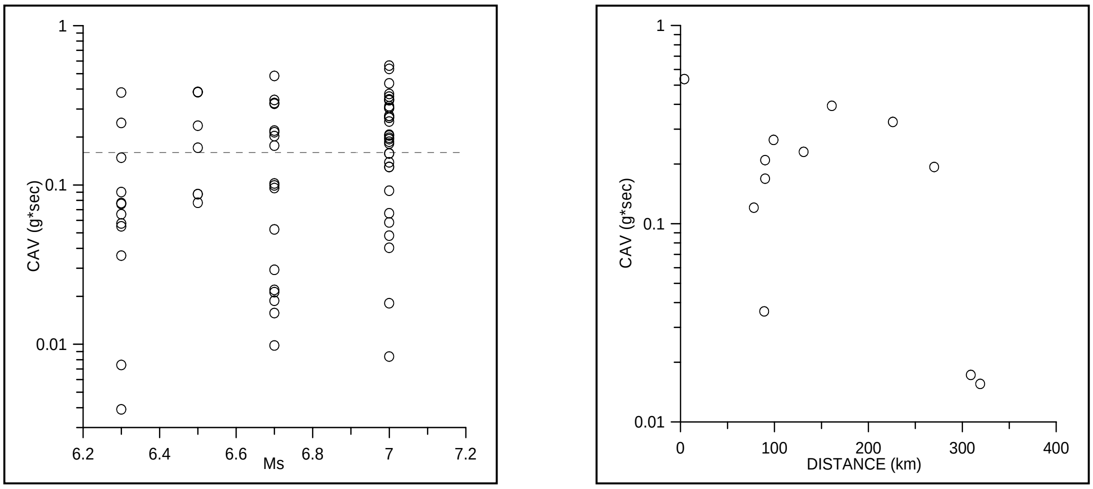

Fig. 5. Vrancea database: CAV versus magnitude Ms (6.3-7) and distance

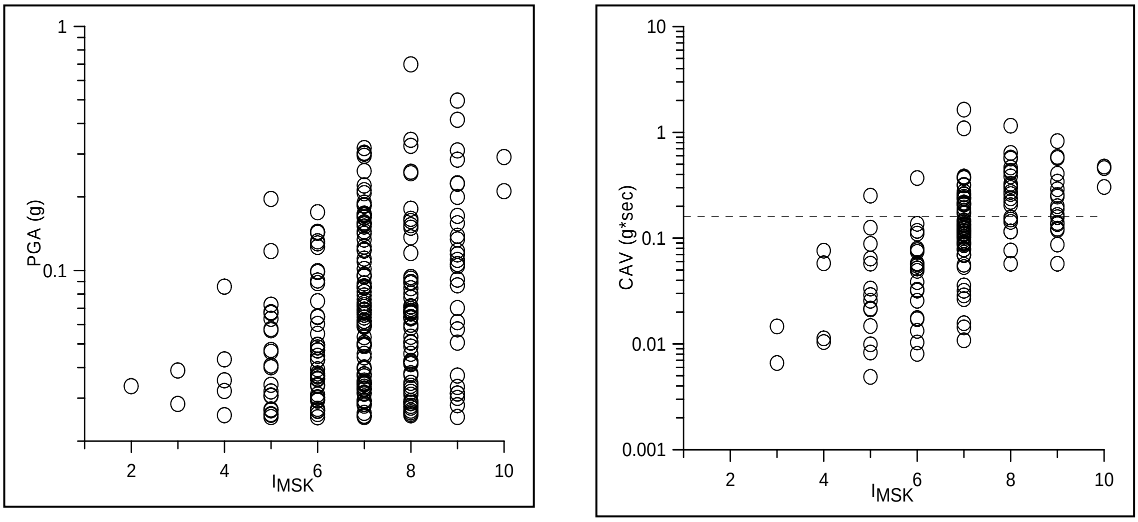

Fig.6. Regional sources. PGA and CAV versus IMSK (EMS)

4. CORRELATION BETWEEN EMS AND CAV

Considering figure 6 it should be expected that there is some correlation between CAV and macro-seismic intensity. Similar correlation should exist also between peak ground acceleration and macroseismic intensity. The engineer experience is that acceleration is a poor predictor of seismic effects, i.e. it is difficult to predict PGA based on intensity estimation. As data is available mainly from regional sources we have performed a simple analysis to look for an exponential fit to the data. The result is presented below with the equations (2) and (3).

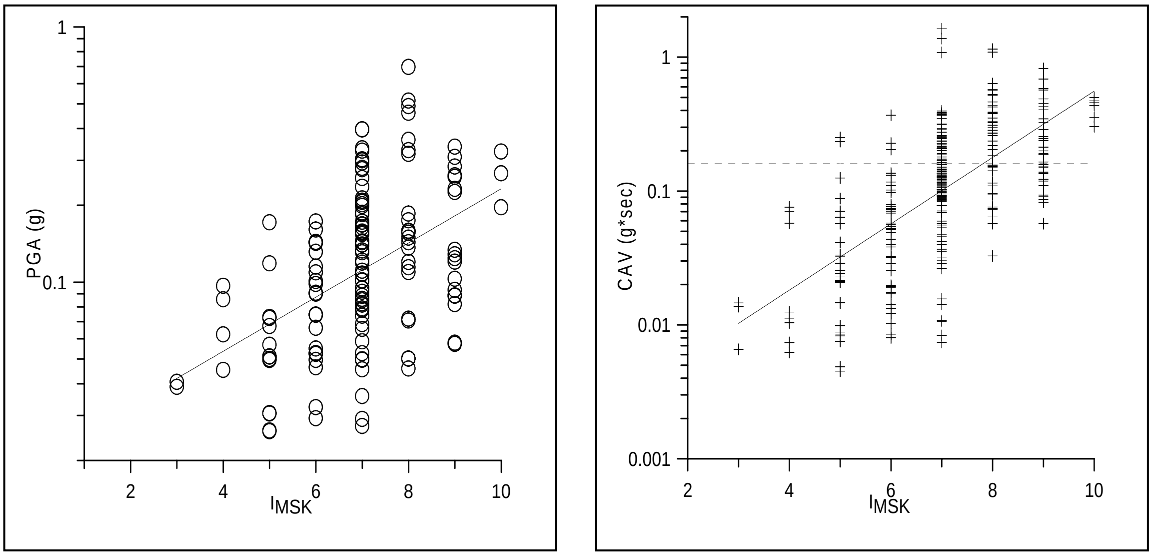

Fig. 7. Correlation between PGA, CAV and intensity MSK

A graphic presentation of the equations and their fit to the data are shown in figure 7.

(2) $$\mathrm{Ln(PGA)} = 0.24\ I - 3.9\ [g]$$

(3) $$\mathrm{Ln(CAV)} = 0.57\ I - 6.3\ [g.sec]$$

Equation (2) is leading to relatively low accelerations for high intensities and relatively high accelerations for low intensities in comparison with the well-known relation of MSK scale (the origin of the EMS). For example the equation (2) is showing acceleration 0.08g for intensity 6, the corresponding MSK acceleration is 0.05g. Equation (3) is giving CAV about 0.056g*sec for intensity 6. The threshold of 0.16g*sec corresponds to intensity 7.8. As already mentioned even for moderate intensities, i.e. intensity 6 and 7 some damages in well-engineered structures could be expected. Opposite to the belief that the CAV threshold of 0.16g*sec is a conservative estimated limit for seismic damage, the database shows quite high probability that damage may occur at significant lower CAV levels. It shows also that there is significant number of records with CAV lower than 0.16g*sec for which intensity 9 has been assigned at recording site.

There is also a hypothesis that the CAV correlates better with damage than most of the other seismic motion parameters do. Indeed, the correlation of CAV with intensity is better than that of the PGA. However the correlation is not very strong.

5. CORRELATION BETWEEN CAV AND MS. ATTENUATION CURVES FOR CAV

For the aim of seismic hazard analysis usually the seismic sources are described with maximum expected magnitude. Based on that and using attenuation curves for different strong motion parameters one could predict the seismic effects on an arbitrary site. The European strong-motion database has been used by Ambraseys et al. for prediction of PGA and spectral accelerations [7]. We use a similar approach for prediction of CAV. Using the data from regional sources we have found strong correlation between Ms and average CAV, figure 8.

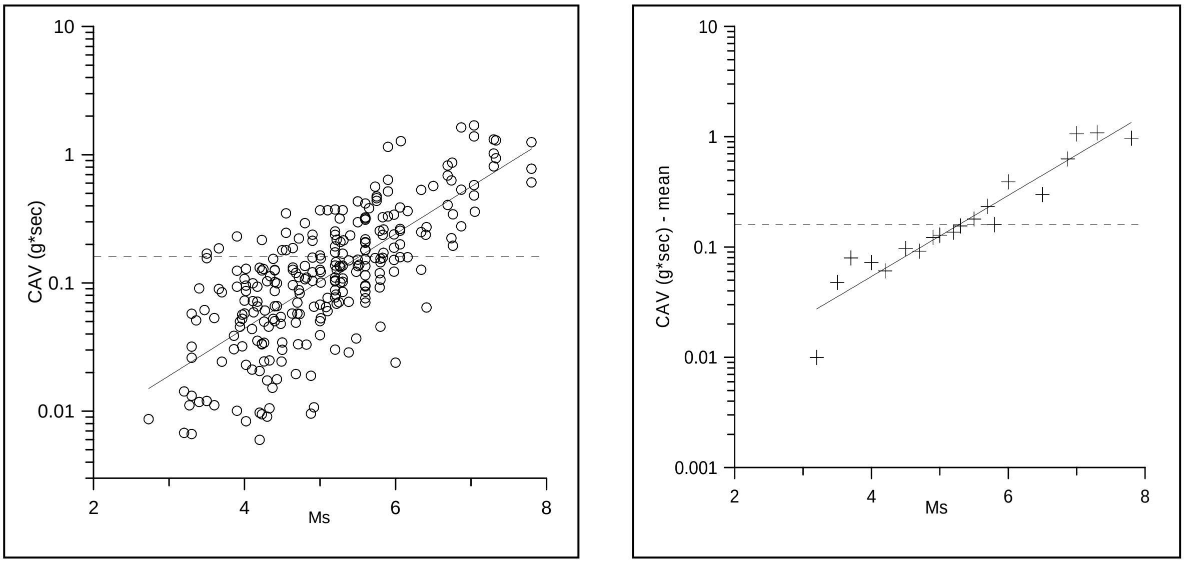

Fig. 8. Exponential fit CAV versus Ms, data from regional sources

(4) $$\mathrm{Ln(CAV)} = 0.846\ \mathrm{Ms} - 6.3$$

The analyses follow the main feature of the procedure applied by Ambraseys et al. [7]. The attenuation model used includes magnitude and distance as independent variables. The general form of the equation is:

(5) $$\log(\mathrm{CAV}) = B_0 + B_1 * M_s + B_2 * \log(R) + \sigma * P$$

Where R=SQRT(h2 + d2), h is epicenter distance, d is depth of hypocenter; Ms - surface wave magnitude. The standard deviation of log(CAV) is σ and the constant P takes a value 0 for mean values, 1 for 84% and -1 for 15% values of CAV respectively.

A direct one-stage regression analysis has been used. The coefficients computed are given in Table 4. The procedure is applied to each one of the constructed databases.

Table 4. CAV attenuation function coefficients

Database	B0	B1	B2	σ
Regional sources	-2.88	0.44	-0.565	0.37
Local sources	-3.55	0.606	-0.461	0.21
Vrancea source	0.13	0.139	-0.81	0.3

We have not used additional separation of records according to soil type at site as it is frequently done [7]. Also the regression analyses applied are quite simple, nevertheless the standard deviation of log(CAV) is within the expected range for that sort of processing. We have to stress on the fact that the coefficients computed apply only for the distances and magnitude ranges of the database used.

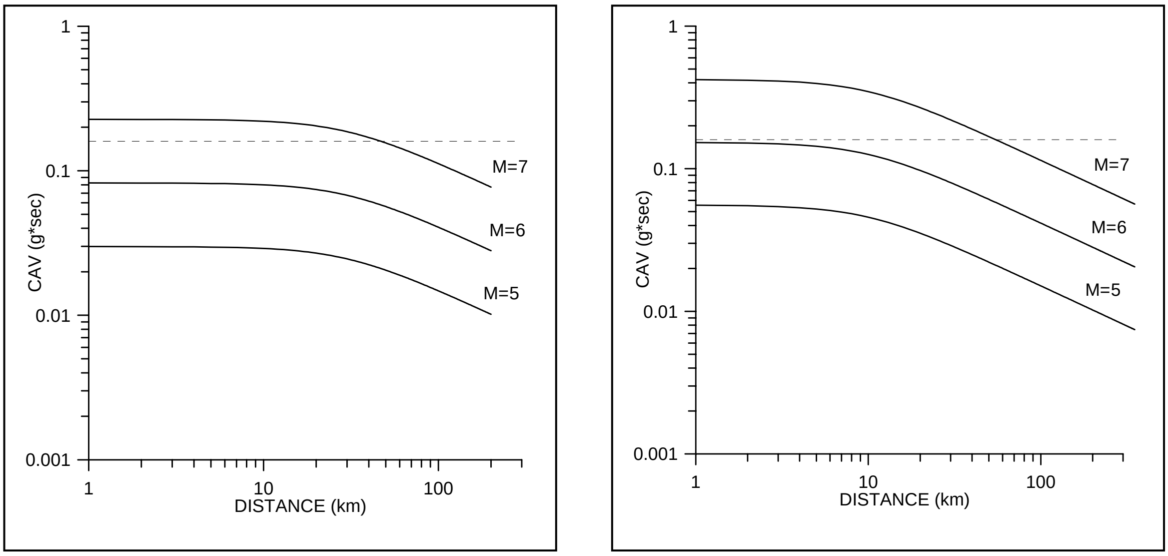

Fig. 9 CAV attenuation curves for h=30km and h=10km; regional sources

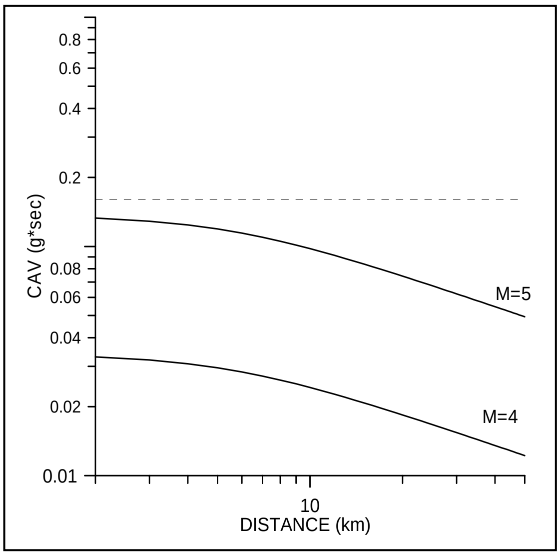

Fig. 10. CAV attenuation, h=5.5km; local sources

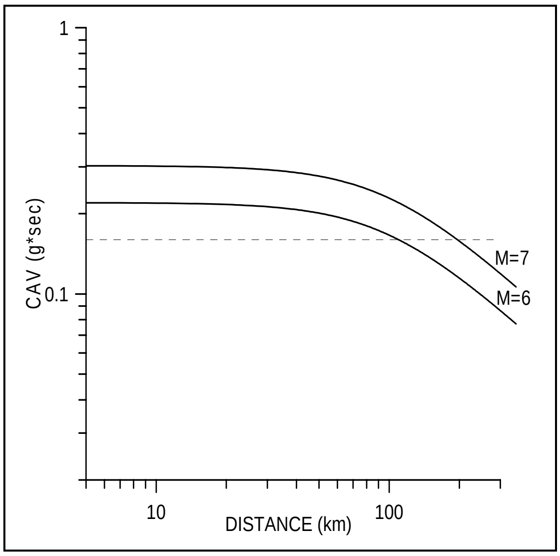

Fig. 11. CAV attenuation curves, h=100km; Vrancea source

Comparing the results obtained (figures 9 to 11) it is obvious that the local sources may hardly produce CAV values greater than the limit of 0.16g*sec. Regional sources generate CAV values greater than the limit if either they are close to site or magnitude is greater than 6. The Vrancea source generates strong motions with high damage potential (results are valid for magnitudes 6 to 7); the CAV remains high and almost constant for great distance (affected area is large). The attenuation curves are shown for their valid ranges in figure 12.

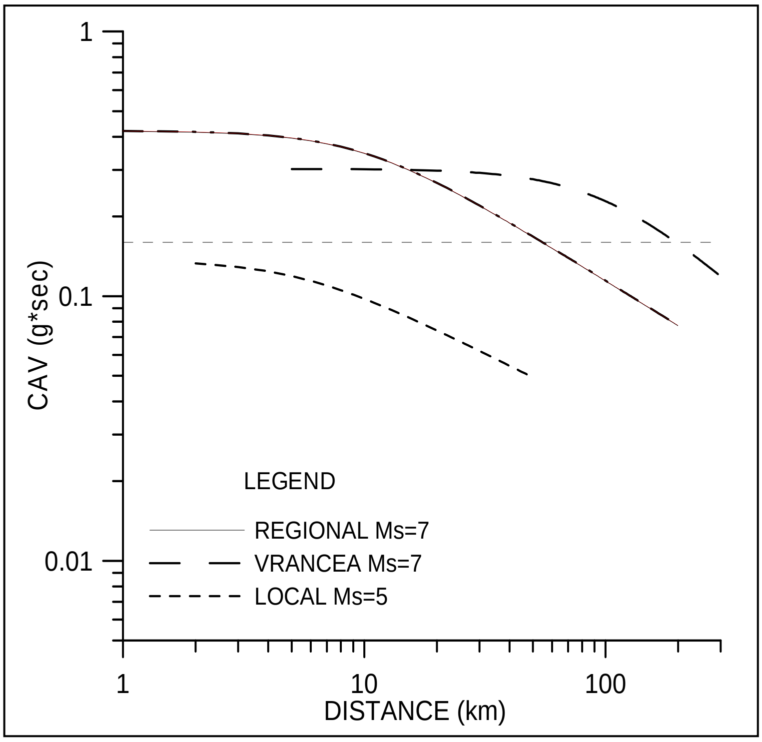

Fig. 12. Comparison between attenuation curves for regional, local and Vrancea sources

6. SITE SPECIFIC CAV

Using the estimated attenuation curves the expected CAV at the site of Kozloduy NPP could be computed, as shown in Table 5. We have assigned maximum expected magnitude and typical distance and depth for seismic sources around the site. The mean value of prognostic CAV is lower than the threshold value of 0.16g*sec for all potential sources around the site, although events with the characteristics used are governing the SSE of the plant. For comparison we use the attenuation low of Ambraseys et al. [7] for prediction of PGA from local and regional sources and also the corresponding attenuation function for Vrancea source [8]. The corresponding acceleration attenuation functions are given by equations (6) and (7).

Table 5. Prognostic CAV at the site of Kozloduy NPP

Sources	Ms	h	d	PGA (mean)	CAV (mean)
		km	*km*	*g*	*g*sec*
Regional	7	150	30	0,04	0,09
Local	5	5	5	0,19	0,12
Vrancea	7.8	330	100	0,16	0,14

(6) $\log(PGA) = -1{,}39 + 0{,}266Ms - 0{,}922\log(R\ ) + 0{,}25\sigma$ (g) for local and regional sources [7]

(7) $PGA = 10{,}225\exp(0.458M)(Rh+25^{)-1.307}$ (g) for Vrancea sources [8]

The prognostic results show that Vrancea earthquakes may produce the most serious effects at the site of Kozloduy NPP. The PGA produced by local earthquakes is higher but the corresponding CAV value is lower in comparison to the effects of Vrancea earthquakes. The PGA produced by local sources is equal to SSE maximum acceleration at the site but the CAV remains under the threshold for OBE exceedance.

The usual design practice is to use PGA values that are approximately mean plus one standard deviation in order to introduce conservatism. When selecting threshold value for CAV the conservative approach is to select mean value minus one sigma. Considering the US NRC RG 1.166 threshold it appears that, most probably, the 0.16g*sec will hardly be exceeded at the site investigated. Unfortunately, it does not mean that the OBE of Kozloduy NPP will not be exceeded during the lifetime of the plant.

7. CONCLUSIONS

The analyses performed show that CAV is better predictor of damage in comparison to PGA. Unfortunately, there is significant variation of the values and the certainty for damage prediction using CAV is not very high.

European data used shows that intensity 6 may correspond to CAV mean values that are about 0.06g.sec. The nuclear facilities are rugged structures that poses usually much more seismic margin than the ordinary structures. In the same time we have to take into account that the turbine units and some of the auxiliary facilities are designed according to common industry standards. Because of that the conservative approach requires careful estimation of the criteria for OBE exceedance.

The attenuation functions derived may be used for preliminary estimation of expected CAV values at site. It is also possible to perform probabilistic hazard analyses using those curves in order to predict probability for exceedance of some predefined level of CAV.

It is needed strongly to emphasize that the procedure for OBE exceedance outlined in several documents of EPRI and US NRC is much more sophisticated and deeper in content than the estimation of CAV values. This study is only an effort to discuss one particular aspect in a specific seismic environment.

The results presented are an attempt to analyze one of the parameters that may describe the damage potential of strong motions. The accumulation of strong motion data and the more detailed description and analyses of the damage caused should contribute for better understanding of the phenomena.

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