

## ON THE EFFECTS OF USING WIDE RANGE EARTHQUAKES

S. CECCONI, V. GIULIANO, L. LAZZERI  
 AMN S.p.A., Via G. d'Annunzio 113, I-16121 Genova, Italy

G. PEZZI  
 Università di Genova, I-16121 Genova, Italy

### SUMMARY

In the seismic analysis of nuclear power plants it is common practice to use wide frequency range spectra for earthquakes, representing envelopes of many registered earthquakes on very different soil conditions. However this enveloping action should be made for the case of the response of structures rather than for the input and, particularly for non linear response (due to plasticization or other non linear actions), one could question whether applying the enveloping action at two different stages yields similar results. To give some elements for an answer to these questions a limited amount of calculations were performed. The research went through the following three steps :

- a) three synthetic time histories A,B,C have been generated by means of SIMQKE and another home made computer code. Their envelope E is the spectrum given by regulatory guide 1.60, each of the three time histories represents a high, medium or low frequency time history
- b) typical stick models or frame models have been generated with a certain degree of multimodal response; the eigen frequencies of the models have been changed so that the whole earthquakes range is considered
- c) elastic analysis have been performed by means of time histories and response spectra (earthquakes A,B,C,E have been considered). Output data are given in terms of displacements and maximum accelerations; SAPIV code has been used to perform these analyses.
- d) non linear analyses have been performed by means of SAKE code; the development of plastic hinges at different moment levels has been postulated, so that non linear analysis has been performed.

The ratio of the yield moment to the maximum elastic moment recorded during the elastic analysis has been analyzed as a parameter and values in the range 0.5 + 1.0 have been considered. Responses in terms of ductility ratio have been recorded for each run.

Conclusions : some conclusions (at least valid for the range of data considered) may be drawn as follows :

- a) in the elastic range there is not much difference between the responses of the structures to earthquake E and the envelope of the responses to the three earthquakes A, B,C.
- b) in the plastic range there is an increase of the ductility response D with a decrease of the ratio R of the yield moment to the maximum elastic response; anyhow the relationship between the ductility and ratio R is somewhat irregular. Typical D-R curves are given for various structures eigenfrequencies
- c) in the plastic range too the response of the envelope earthquake is quite similar to the envelope of the responses to three different earthquakes.

## 1. Introduction

The seismic analysis of nuclear power plants is generally performed by means of conventional earthquakes, whose response spectra have been obtained by enveloping the response spectra of many registered earthquakes /1/. The response spectrum of Regulatory Guide 1.60 /2/ is a typical example. Synthetic time histories may be generated to match the prescribed response spectra, many methods are available and they will not be described here.

However the registered earthquakes have frequency characteristics quite different as they are generally much less rich in frequencies and that is obvious due to the procedure used to obtain the envelop response spectrum. Let S be a generic structure which will be characterized by its frequency vector and eigenmodes matrix and let Ee be the envelope earthquakes which will be supposed to be obtained as an envelop of three earthquakes (high frequency, medium, low) :

$$(1) Ee = \Gamma (En, Em, Ee)$$

where  $\Gamma$  denotes an enveloping function and En , Em , Ee mean high, medium and low frequency earthquakes. Then the maximum response will be calculated as follows

$$(2) A = H(S, Ee)$$

where A is maximum accelerations, S is the structure characteristics and H denotes the structure characteristics function. Let then  $A_H$  ,  $A_M$  ,  $A_L$  be the structure response to the high, medium and low frequency earthquakes as

$$(3a) A_H = H (S, En)$$

$$(3b) A_M = H (S, Em)$$

$$(3c) A_L = H (S, EL)$$

then let

$$(4) A' = \Gamma (A_H, A_M, A_L)$$

The aim of this paper is a discussion whether the two responses A, A' are equal or different; both elastic and non linear analyses are performed. In the case of non linear responses a discussion will be given in terms of increments of ductility ratios values as a function of the decrease of maximum structural yielding moment.

## 2. Analytical tools

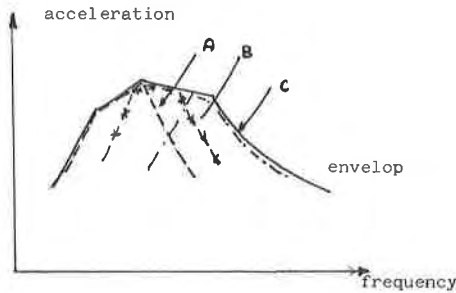
The following computer codes have been used for the relevant analyses :

- SIMQKE /1/ to generate time histories compatible with prescribed response spectra
- CTHRS /2/ to the same aim
- SAP IV /3/ to perform the linear analysis (both time histories and response analyses have been performed
- SAKE /4/ to perform non linear analyses for dummy frames under prescribed earthquakes.

All the mentioned codes are running on a CDC 6600/7600 computer at Bologna University, with which AMN is permanently connected.

### 3. Generation of time histories

Let E denote an earthquake time history compatible with the response spectrum prescribed by Regulatory Guide 1.60 /5/ and let A,B,C denote three earthquakes, whose envelop is earthquake E as shown in fig.1 . Time histories compatible with the envelop and each partial



Envelop and partial earthquakes

Fig.1

was assumed as sufficient.

earthquake has been generated by means of SIMQKE and CTHRS codes; the comparisons between response spectra and compatible time histories are shown in figs. 2a,d . In all the cases a reasonable approximation was obtained particularly in the acceleration plateau zone, while some discrepancy is present in the high frequency range; however for the present applications the approximation

### 4. Elastic response

#### 4.1 Stick model

As a first test a conventional stick model has been tested it represents the model of an actual building of the box type (see fig.3), i.e. characterized by the presence of stiff shear walls and box structures. The building is very rigid, so that its acceleration pattern is strongly dependent from the soil structure interaction, this phenomenon has been simulated by conventional springs after Whitman and Richart /5/ . By changing these springs three cases have been obtained , the fundamental eigenfrequency are listed in table 4.1.1, together with the earthquake most interesting for the structure.

Table 4.1.1

Stick models eigen frequencies (cps)

<u>Case</u>	<u>1st</u>	<u>Earthquake of interest</u>
4.1.1	9.66	C
4.1.2	6.30	B , C
4.1.3	4.83	B

The results have been compared in terms of maximum displacements, base shear and base moment M; all the time histories have been generated by means of SIMQKE (other cases

generated by means of CTHRS have not been reported as essentially yielding the same results) code and the structure has been analyzed by means of SAP4. The results are reported in table 4.1.2, 3, 4

Table 4.1.2

Stick model results / Displacements (mm)

	<u>Envelop E</u>	<u>Earth.A</u>	<u>Earth.B</u>	<u>Earth.C</u>	<u>Results Envelop</u>
Case 4.1.1	9.66	5.40	8.12	9.91	9.91 , C
Case 4.1.2	21.38	14.60	20.16	20.77	20.77 , C
Case 4.1.3	45.90	36.50	46.60	33.87	46.60 , B

Table 4.1.3

Stick model results / Base shear ( $10^4$  tons)

	<u>Envelop E</u>	<u>Earth.A</u>	<u>Earth.B</u>	<u>Earth.C</u>	<u>Results Envelop</u>
Case 4.1.1	4.87	3.32	4.19	4.26	4.26 , C
Case 4.1.2	4.78	3.61	4.21		
Case 4.1.3	7.28	5.82	7.36	5.32	7.36 , B

Table 4.1.4

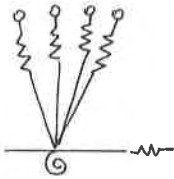
Stick model results/Bending moment ( $10^5$  tm)

	<u>Envelop</u>	<u>Earth.A</u>	<u>Earth.B</u>	<u>Earth.C</u>	<u>Results Envelop</u>
Case 4.1.1	7.29	4.26	6.21	7.43	7.43 , C
Case 4.1.2	8.20	5.56	7.69	7.92	7.92 , C
Case 4.1.3	11.90	9.23	12.00	9.03	12.00 , B

From the results shown in tables 4.1.1/3 it was concluded that the two procedures (i.e. enveloping of the input or of the output) yielded the same results, the small differences found being ascribed to time histories approximations. The generalization of these results may be questioned on the basis of being based on a structure with very few important eigen modes; however it should be mentioned that many modes are seldom necessary for an accurate representation of the structural response to an earthquake. Besides box type rigid structures resting on soft-medium soils have a behaviour, which is accurately represented by these results and they are quite often encountered at least in Italy

## 4.2 Cluster models

Other tests have been performed on a different type of structure; in this case a very complex model was condensed dynamically so that its behaviour was represented by a cluster of sticks, on a common base each representing an important eigenmode of the structure. The model is shown in fig.4, the sticks elements (each dynamically representing an eigenmode of the structure on a fixed base) and the conventional Whitman springs constitute the model.



Cluster model

Fig.4

Table 4.2.1

Cluster models eigen frequencies

<u>Mode</u>	<u>Frequency (cps)</u>
1	3.17
2	5.08
3	6.57
4	10.71
5	12.97
6	17.74
7	19.06

The results of the different analyses are shown in table 4.2.2.

Table 4.2.2

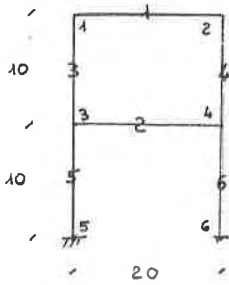
<u>Time history</u>	<u>Max displ (m)</u>	<u>Max Mom (tm)</u>	<u>Max Shear (t)</u>
E	0.103	$9.07 \times 10^6$	$4.15 \times 10^5$
A	0.117	$8.82 \times 10^6$	$4.19 \times 10^5$
B	0.091	$7.26 \times 10^6$	$3.19 \times 10^5$
C	0.053	$4.52 \times 10^6$	$1.82 \times 10^5$

From these results it appears that the same conclusions already drawn in paragraph 4.1 do apply.

## 5. Non linear response

As mentioned earlier some non linear analyses have been performed by means of SAKE /4/

computer code; strong limitations exist in the code as regards the modelling capability , however a very simple code was chosen just to make the analysis as easy as possible, besides the choice of the model did reflect the limitations of the code. Consequently a symmetric structure was selected to make the hypotheses on the beam contraflexure point (midpont) not influent; the actual structure is shown in fig.5, non linear rotational springs were added



at each joint to cause non linear response. A parametric change of the frame elastic eigenfrequencies was accomplished by varying the elastic modulus, consequently the model eigenfrequencies were selected as follows :

Table 5.1

SAKE model	Model	Model	Eigenfrequencies (f cps)
Fig.5	5.1	5.67	6.60
	5.2	3.70	4.35
	5.3	11.80	13.70

Next an elastic analysis was performed to yield the maximum seismic moments and the "non linear moment" (cracking-yielding moments in SAKE) was selected to be some percentage of it, the ratio of the non linear moment to the maximum elastic moment is indicated as parameter R, while the ductility ratio(D is the other parameter. In figs 6a,b,c the Dv.R curves have been reported for each model ; further it should be mentioned that the parameter D is actually a relative parameter, being the ratio of maximum to "linear rotation", however its selection has been found proper as better indicating the amount of non linear response.

No general conclusions may be drawn due to the large simplifications involved in these analyses, however some reasonable results may be drawn. The envelop of inputs seems to be again quite near the envelop of the outputs, however softening of the structure seems to take place (as it is obvious due to cracking or yielding) and this causes irregularities in the curves pattern and shape.

## 6. Conclusions

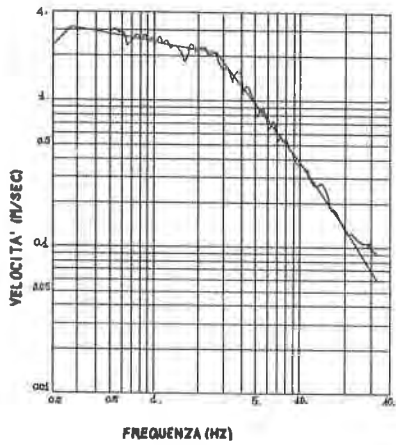
Some general conclusions can be tentatively drawn from the analyses which have been performed, as it is given herein

- a) in the elastic range there is not much difference between the responses of the structures to the envelop earthquake and the envelop of the results of the seismic excitations

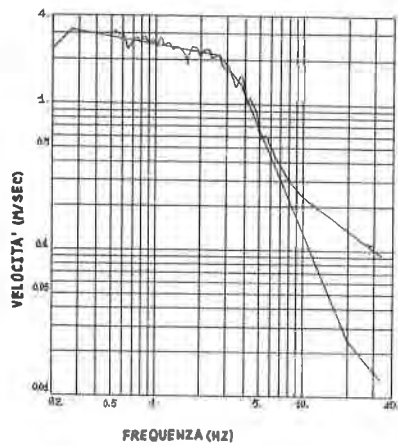
- b) in the plastic range too the envelop earthquake does not give results very different from the envelop of the results
- c) large advantages can be obtained if the real earthquakes are considered rather than the "wide range" envelop ones, particularly in the non linear range
- d) some Dv.R curves have been produced, a decrease in the structures capability produces increases in ductility however the curve is somewhat irregular as a consequence of structures softening and possibly time histories irregularities.

References

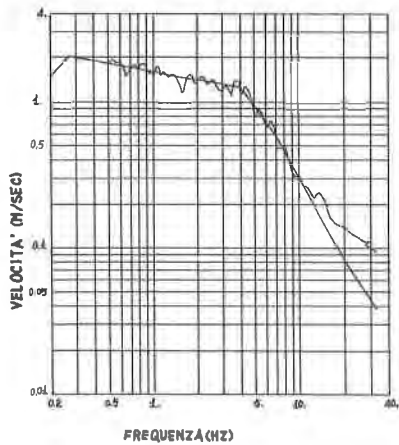
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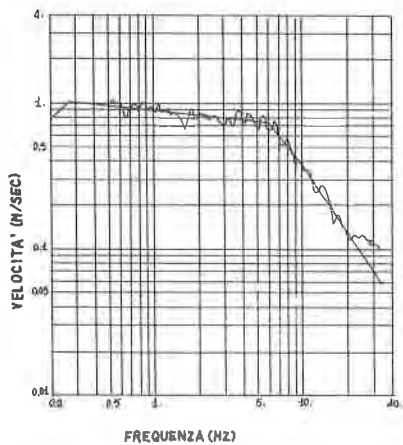
Spectrum for Envelop Earthquake  
Fig.2a



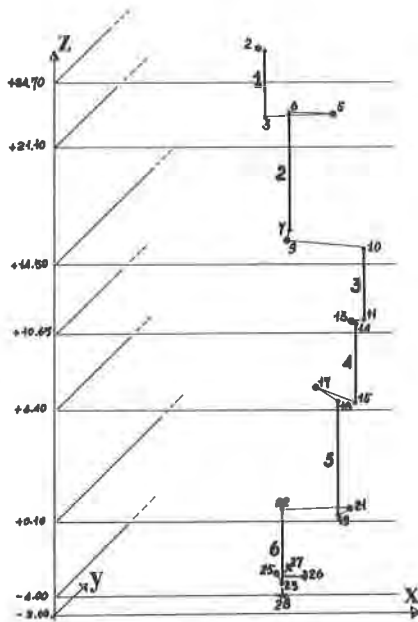
Spectrum for A Earthquake (1)  
Fig.2b



Spectrum for B Earthquake (2)  
Fig.2c



Spectrum for C Earthquake (3)  
Fig.2d

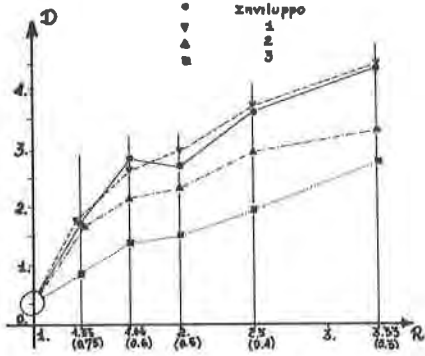


Stick model

Fig.3

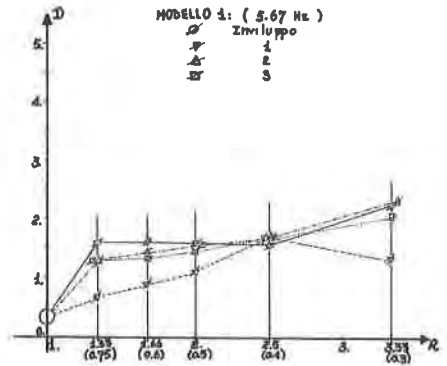
MODELLO 2: ( 3.74 Hz )

• Sviluppo  
 ▽ 1  
 ▲ 2  
 ■ 3



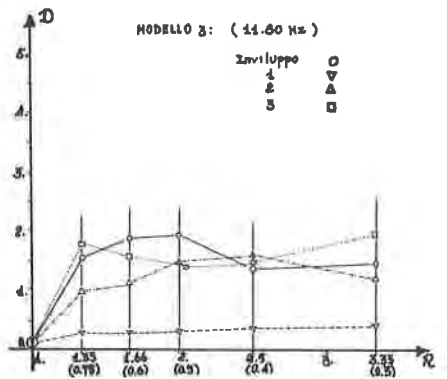
Dv.R relationship for model 2

Fig.6b



Dv.R relationships for model 1

Fig.6a



Dv.R relationship for model 3

Fig.6c