A PROBABILISTIC AND INTEGRATED METHOD OF GROUND MOTION ESTIMATE

J.L. Justo (I)
A. Jaramillo (II)
Presenting Author: J.L. Justo

SUMMARY

The most damaging ground motions that might act upon a given structure on a known site, during a stablished lifetime, for an accepted probabilistic risk, are estimated.

A master file has been created in a magnetic disc with 2.000 earthquakes and 5.000 records.

First the parameters of the most damaging ground motions, mainly peak acceleration (velocity or displacement), resonance period and peak spectral ratio, are estimated by probabilistic methods. Then, some records are selected. Through controlled scale changes, these records are adapted to the parameters previously calculated.

The method has been applied to some buildings in Seville.

INTRODUCTION

A method has been established to estimate the most damaging ground motion that might occur at a given site, for an accepted probabilistic risk, during a given lifetime of a structure.

The method has been outlined through several papers and scientific works (Ref. 1 to 4). By now it has been completely developed (Ref. 4), which justifies the present paper.

The method is based upon the use of real records instead of simulated ones (v. Ref. 3, 5 &6). A master file, accesible from different computer programs, has been created in magnetic support with 2.000 earthquakes and 5.000 records.

A record has been defined by a few parameters: maximum ground acceleration, velocity and displacement, duration,and peak spectral ratio for pseudo-acceleration and relative velocity (Ref. 3).

Statistical multiple regressions have been derived to estimate these parameters, with a standard error as small as possible, from ground conditions and the usual output of seismic risk studies: Intensity, Magnitude, fault distance, focal depth and type of source mechanism. As this phase has been treated in previous papers will not be discussed here (v. Ref. 4).

In this paper the second phase: selection and transformation of the most damaging records will be presented.

INTERDEPENDENCE BETWEEN PARAMETERS AND SCALE CHANGES

The selection of the most damaging ground motion is based mainly in three

(I) Professor of Soil Mechanics

(II) Assistant Professor of Soil Mechanics

University of Seville, SPAIN

parameters: peak acceleration, resonance period and spectral ratio, which are, fortunately, independent (Ref. 4). This allows them to be determined separately.

On the other hand duration increases when acceleration decreases. The statistical relationship between duration and resonance period is not linear, and the same applies to the regression of maximum velocity with peak acceleration and resonance period. For this reason changes in the scales of acceleration and time are allowed, but within established boundaries (Ref. 4), specially when a plastic calculation is to be made.

GENERAL CRITERIA

The first criterion of selection is the soil type upon which the structure is placed. Six soil types have been considered (Ref. 2). Only records corresponding to the same soil type of the structure are considered.

According to the fundamental period of the structure a method based upon acceleration, velocity or displacement is followed.

Depending to its characteristics, a structure may be more affected by high, medium or low frequency vibrations. These vibrations appear as predominant in the acceleration, velocity or displacement diagrams, respectively.

A comparison between the fundamental period of the structures and the resonance periods of the records for acceleration, velocity and displacement will decide whether we follow a method based upon acceleration, velocities or displacements.

DETERMINATION OF THE DESIGN INPUTS

For the determination of the seismic input, we start from two points:

a) A study of seismic risk for the site and soil type.

b) Fundamental period and damping ratio of the structure.

A ground motion will be damaging if the acceleration is high enough, independently of the values of resonance period and spectral ratio (Ref. 4). On the other hand, a motion with a smaller peak acceleration may be damaging if the spectral ratio is high and the resonance period approaches the fundamental period of the structure. Based upon this we employ the following formula for the determination of the total risk:

$$P = P(a_1) + P(a_{12}) \cdot P(T_r) \cdot P(R_{s1}) \qquad (1)$$

where:

P = Probability of having a seismic input more damaging than any of the selected ones.

$P(a_1)$ = Probability of having, during a lifetime t of the structure, a seismic input with a peak acceleration (velocity or displacement) $> a_1$ (v. fig. 1).

$P(a_{12})$ = Idem between a_1 and a_2 ($a_1 > a_2$).

$P(T_r)$ = Probability that the resonance period of seismic input, T_r, be between T_{min} and T_{max}, where $T_{min} < T_1 < T_{max}$, and T_1 is the fundamental period of the structure. $P(T_r)$ is obtained from Student distribution for different values of T_r.

$P(R_{s1})$ = Probability that the peak spectral ratio of the seismic input be $> R_{s1}$ (fig. 3).

The total risk P is strongly influenced by social-economic factors. Following the report ATC-3 (Ref. 7), we define the following levels:

a) Damage level. Corresponds to inputs having a 39% risk of being exceeded during the lifetime of the structure.

b) Collapse level, with a risk of 10%.

The boundary (design) inputs, not exceeding these risks, may be classified in four groups:

1. $a_{max} = a_1$ $T_r = T_{min}$ R_s as large as possible
2. $a_{max} = a_1$ $T_r = T_{max}$ " " " " "
3. $a_{max} = a_2$ $T_r = T_1$ " " " " "
4. $a_{max} = a_1$ $T_r = T_1$ $R_s \leqslant R_{s1}$

The peak spectral ratio, R_{s1}, must obey the equation:

$$a_1 R_{s1} = a_2 R_{smax} \qquad (2)$$

where R_{smax} is the maximum peak spectral ratio for the soil type and damping ratio of the structure.

Equation 2 assures that the elastic response for the first mode of the -- structure is similar for the records of groups 3 and 4.

T_{min} and T_{max} are found through iterations, so that the elastic first mode response of the four groups of inputs be similar. Otherwise in the P(%) of inputs not allowed for design, we would have records less damaging than the allowed ones.

The step by step procedure is as follows:

1. P is stablished as stated above. $P(a_1)$ is stablished, by trial, with the criterion that the response be as low as possible. For a given value of $P(a_1)$, a_1 is obtained as will be indicated in the next paragraph (v. fig. 1). In this way we eliminate all inputs having an acceleration larger than a_1, independently of resonance period and peak spectral ratio.

2. A value of R_{s1} is assumed and the corresponding value of $P(R_{s1})$ is found (v. fig. 3). T_{min} and T_{max} are assumed and $P(T_r)$ is found. By means of equation 1, $P(a_{12})$, and hence a_2 are found. Through iterations, R_{s1} is found so that it will fit equation 2. In this way we equal the response of groups 3 and 4 of inputs.

All this is done through a computer program that uses as inputs P, $P(a_1)$, T_{min} and T_{max}, and as outputs a_1, a_2 and R_{s1}.

3. T_{min} and T_{max} are found next from response spectra as indicated below:

a) A pair of values of T_{min} and T_{max} and the corresponding R_{s1} are taken. Starting with the allowable spectrum with maximum peak spectral ratio, we considerer the interval defined by the abcissae $T_1 x T_r / T_{max}$ and $T_1 x T_r / T_{min}$. We must check that, outside this interval, in all spectra, nowhere is $R > R_{s1}$, where R is the spectral ratio. If somewhere is $R > R_{s1}$, we change T_{max} or T_{min} so as to avoid this, and initiate a) again.

b) We end when we have found allowable spectra in which, outside the interval indicated in a), the maximum R is somewhat smaller or equal to R_{s1}. The corresponding records will be selected for groups 2 and 1 respectively. In this way we assume that the maximum response of groups 1 and 2 (for the first mode) is similar to the one of group 4.

If we are using an elastic method of calculation, and so scale changes are not important, we may use an envelope of spectra.

The selected records will be those that better fit the previous conditions, and whose scale changes are allowable for the calculation method employed. Duration might also be included in the selection of records, when a plastic calculations is to be made.

APPLICATION TO THE BUILDING OF THE FACULTY OF ARCHITECTURE OF SEVILLE

As an example, we have applied the method to this building.

The foundation ground is type 3 (soil of medium consistency).

Table I shows the average horizontal resonance period (T_r) for acceleration and velocity in soil type 3 and average medium period (T) for displacement, and the corresponding standard errors.

Table I

Average period (T_r) and standard error (S.E.) for acceleration, velocity and displacement in soil type 3.

	$\log T_r(s)$	S.E.
Acceleration	log 0.29	0.20
Velocity	log 1.66	0.39
Displacement	log 5.3	0.21

As the indicated building is already built, its dynamic characteristics under ambient vibrations were measured and compared with the ones obtained from the Spanish Norm (table II).

Table II

Measured and calculated period (s) of building.

Mode	Measured	Calculated
1st	0.412	0.439
2nd	0.142	0.146
3rd	0.08	0.09

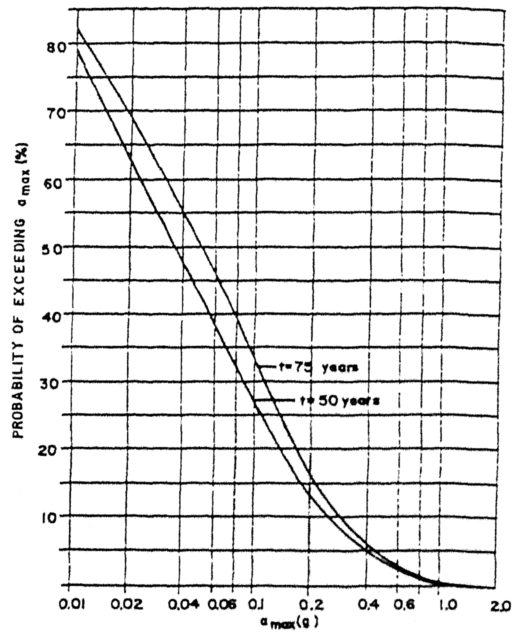

FIG.1 PROBABILITY OF EXCEEDING PEAK HORIZONTAL ACCELERATION a_{max} (g) IN SEVILLE IN TIME t

Comparing tables I and II, it is clear that, in this case, a study in accelerations is required.

Seismic risk study

We start from a seismic risk study of Intensities in Seville (Ref. 8).

From the return period, T_s, for every Intensity, the probability of having in t years, an earthquake, at the site of $I > I_i$ is:

$$P(I_i) = 1 - \left(1 - \frac{1}{T_s}\right)^t \qquad (3)$$

The lifetime of this building is fixed in 50 years. The values of P are indicated in table III:

Table III

Probability of having an Intensity $> I_i$

I_i	T_s (years)	P(I) %
≥ VIII	225	19.96
≥ VII	50	28.43
≥ VI	27	84.84
≥ V	10	99.48
≥ IV	6	99.98

It is assumed that the probability of having I ≥ IX is negligible.

The probability of having an Intensity, I, will be:

$$p(I) = P(I_i) - P(I_i + 1) \quad (4)$$

$$\text{where } I_i \leq I < I_i + 1 \quad (5)$$

The probability of having an acceleration > a will be:

$$P(a) = \sum_{I=XV}^{I=VIII} P(a/I) \cdot p(I) \quad (6)$$

where P(a/I) is the probability of having an acceleration > a given that Intensity is I, and is shown, for every soil type, on a world-wide basis, in table IV.

P(a) is shown in figure 1.

In equation 1, $P(a_{12})$ is obtained by difference from figure 1, and the same applies to $P(T_r)$ respect to figure 2. $P(R_{s1})$ is obtained from figure 3.

Following the method indicated in this paper we obtain the results of table V:

Table V
Parameters of inputs obtained for the building

	a_1(g)	a_2(g)	T_{min}(s)	T_{max}(s)	R_{smax}	R_{s1}
Collapse level	0.39	0.142	0.229	0.742	10.4	3.8
Damage level	0.13	0.032	0.216	0.783	10.4	2.55

Selected registers are indicated in table VI.

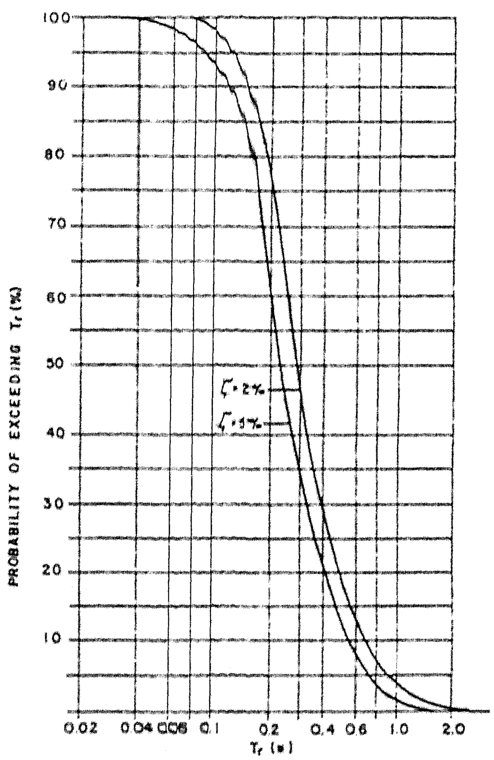

FIG 2. PROBABILITY OF EXCEEDING A RESONANCE PERIOD T_r, FOR HORIZONTAL GROUND MOTION, IN SOIL TIPE 3, FOR TWO DAMPING RATIOS (ζ)

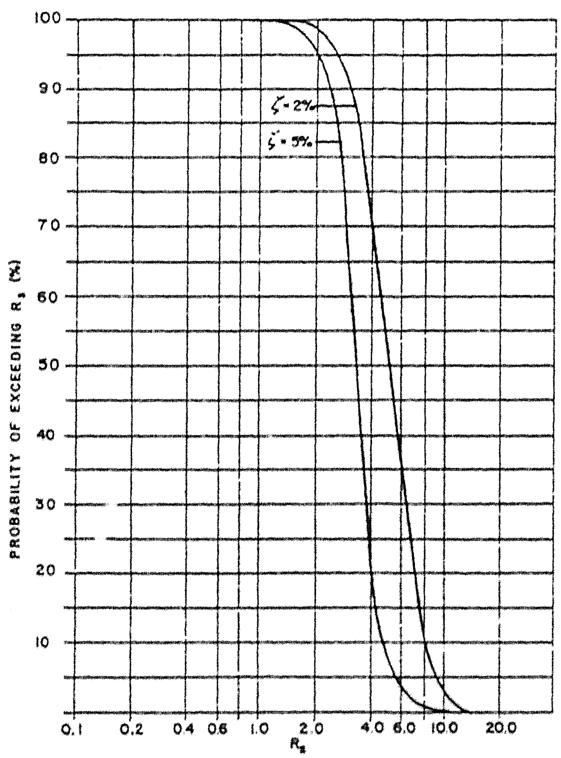

FIG 3. PROBABILITY OF EXCEEDING PEAK SPECTRAL RATIO $R_s = \frac{(PSA)max}{a_{max}}$, IN SOIL TYPE 3, FOR TWO DAMPING RATIOS (ζ)

Table IV

Probability (%) of exceeding a certain horizontal peak acceleration for different Intensities and soil types.

	GROUND	N	a_{max}(g) AVERAGE	S.E.	P (%) 1.00	0.50	0.20	0.10	0.05	0.02	0.01 a_{max}(g)
III≤I<IV	All	13	.0093	.7334	.7392	1.7019	4.7563	9.5732	17.6978	34.1737	43.6377
	5	1	.0606								
	5.1.6	2	.0531	.0519	2.2891	2.9930	5.0337	10.2633	58.8212	93.2109	95.9395
	6	1	.0476								
	2	4	.0291	.5867	3.1462	4.8868	9.3393	16.0277	27.4240	50.1494	67.3613
	3	11	.0051	.7356	.6697	1.3141	3.1341	6.9890	11.1653	22.7136	35.4939
	3.4	11	.0051	.7356	.6697	1.3141	3.1341	6.9890	11.1653	22.7136	35.4939
	4	0									
IV≤I<V	All	124	.0111	.5508	.0683	.3225	1.8680	5.6057	13.7643	33.4301	52.9344
	5	3	.0224	.8843	5.2149	8.5466	15.8382	24.3055	35.2375	52.1247	64.7923
	5.1.6	3	.0272	.9649	5.3943	9.0951	17.2376	26.5832	38.3370	55.3513	68.5642
	6	0									
	2	23	.0139	.5495	.3950	1.1719	4.3563	9.8538	19.3118	49.4949	53.5597
	3	82	.0093	.5334	.0134	.0347	.7185	2.3939	8.6764	26.6213	47.5129
	3.4	83	.0096	.5497	.0147	.0303	.7490	2.3336	8.6222	26.1831	46.6737
	4	1	.0012								
V≤I<VI	All	283	.0186	.5565	.1231	.6074	3.4325	9.9121	22.4495	47.7839	68.2703
	5	15	.0425	.3749	.1062	.5492	4.2313	15.8335	40.9649	79.0093	93.3294
	5.1.6	36	.0246	.4510	.0362	.4461	3.6786	12.3539	30.6729	64.4158	84.7278
	6	19	.0229	.4751	.1299	.5141	2.3677	9.4099	22.9420	53.4729	75.1371
	2	57	.0225	.4779	.0403	.2567	2.1042	7.6262	20.7795	50.4842	73.3284
	3	178	.0149	.5661	.0747	.3362	2.3969	7.3932	17.7272	41.0939	62.0184
	3.4	183	.0149	.5507	.0654	.3493	2.2946	7.3061	17.2356	40.7125	61.8325
	4	5	.0154	.3433	.2155	.3391	.9745	2.2232	5.7556	22.4533	51.7378
VI≤I<VII	All	177	.0243	.5561	.5593	2.0567	8.3326	13.4093	35.2329	61.3663	78.6002
	5	12	.0569	.5453	2.1083	5.4302	16.5620	32.5536	53.4015	78.4438	99.0389
	5.1.6	35	.0813	.6373	5.0252	11.4557	27.4293	44.6430	63.0266	82.7013	91.7331
	6	13	.0849	.8924	19.5358	17.1138	32.4493	46.3391	69.7503	77.1833	86.1911
	2	33	.0415	.5824	1.3422	4.9352	13.5434	27.5183	16.5714	72.2485	96.3073
	3	174	.0214	.5450	.1330	.6638	3.3563	11.3499	24.9553	52.0864	72.6703
	3.4	136	.0215	.5416	.1293	.6455	3.3127	11.9162	25.3140	52.3373	73.0013
	4	2	.0342	.2751	5.9467	7.4496	11.0709	17.1921	33.3324	72.6833	64.3472
VII≤I<VIII	All	97	.1311	.2720	.6313	1.7573	25.0360	66.4541	93.3465	99.8297	99.9354
	5	3	.1457	.1317	1.2937	7.6341	20.7133	33.3035	56.4471	93.9303	99.3743
	5.1.6	13	.1317	.2151	.2532	7.4215	13.8296	32.9916	37.3135	47.0875	54.9316
	6	3	.1074	.1822	.1032	.7030	19.9428	37.2222	49.7535	91.5613	53.3322
	2	3	.1316	.5103	6.4332	14.7127	16.6367	53.3376	78.0418	92.3215	95.7613
	3	73	.1347	.2432	.3762	1.9914	23.6369	79.1547	36.3752	93.9431	99.9994
	3.4	77	.1275	.2543	.4375	1.1234	27.3462	66.2176	94.3559	99.3016	99.9978
	4	4	.3532	.2433	.6793	1.4318	4.9371	17.1135	54.0958	91.0353	97.2311
VIII≤I<IX	All	11	.2226	.3094	3.0507	14.1282	55.8333	85.5273	56.3781	99.6516	99.4283
	5	2	.3137	.3952	22.9339	49.2283	61.0332	39.6335	86.3723	99.3238	92.0963
	5.1.6	2	.3137	.3952	23.0339	49.2283	61.0332	80.6335	86.3723	99.3283	92.0963
	6	3									
	2	3	.2835	.4253	1.5434	6.5502	87.2245	97.3355	99.1317	99.6436	99.7759
	3	5	.1557	.3274	5.2721	11.9517	39.6459	67.7132	94.4933	95.8561	93.1493
	3.4	5	.1557	.3274	5.2721	11.9517	39.6459	67.7132	36.4933	95.8561	93.1493
	4	0									

Table VI
Selected registers

Level	Groups	Site	Earthq. date	a_{max} (g)	Tr (s)	R_s
Damage	1 & 2	Carbon dam	9-II-71	0.069	0.25	2.55
	3	Honokaa	29-XI-75	0.046	0.15	10.4
	4	Ferndale, City Hall	10-XII-67	0.278	0.18	2.56
Collapse	1 & 2	Managua Esso	23-XII-72	0.34	0.36	3.8
	3	Honokaa	29-XI-75	0.046	0.15	10.4
	4	L.A. 533, S. Fremont	9-II-71	0.256	0.23	3.65

The scale of the records corresponding to the collapse level has been changed to adapt them to the parameters of table V, and they have been reproduced in figure 4.

A dynamic elastic calculation has been carried out. The results have been compared with the ones obtained with the Spanish and the American UBC Norms. As a rule the dynamic analysis give results somewhat less than obtained with pseudo-static methods.

REFERENCES

1. Justo, J.L., and Bayán, B., 1973. "Ground motion as a function of seismicity". 5th World Conf. Earthq. Eng., Rome, 2:1654-1658.
2. Justo, J.L., Lorente de No, R., and Arguelles, A., 1977. "An integrated estimate of ground motion". 6th World Conf. Earthq. Eng., New Delhi, 1:541-546.
3. Justo, J.L., Lorente de No, R., and Arguelles, A., 1978. "A probabilistic estimate of ground motion". 6th Europ. Conf. Earthq. Eng., Dubrovnik, 1:167-174
4. Jaramillo, A., 1983. "Método probabilístico e integrado de estimación de las acciones sísmicas". Ph. D. Thesis, Univ. of Seville.
5. UNESCO, 1980. "Informe final de la conferencia intergubernamental sobre la evaluación y la disminución de los riesgos sísmicos". "Terremotos". Blume, Barcelona, 323-360.
6. Petrovsky, J.T., 1980. "Microzonificación sísmica y problemas conexos". "Terremotos". Blume, Barcelona, 50-68.
7. Applied Technology Council, 1978. "Tentative Provisions for the Development of Seismic Regulations for Buildings". Washington, DC: U.S. Department of Commerce.
8. Justo, J.L., and Gentil, P., 1982. "El riesgo sísmico de Sevilla". "Contribución a una Posible Revisión de la Norma Sismorresistente Española". Asociación Española de Ingeniería Sísmica, Madrid, 17-26.

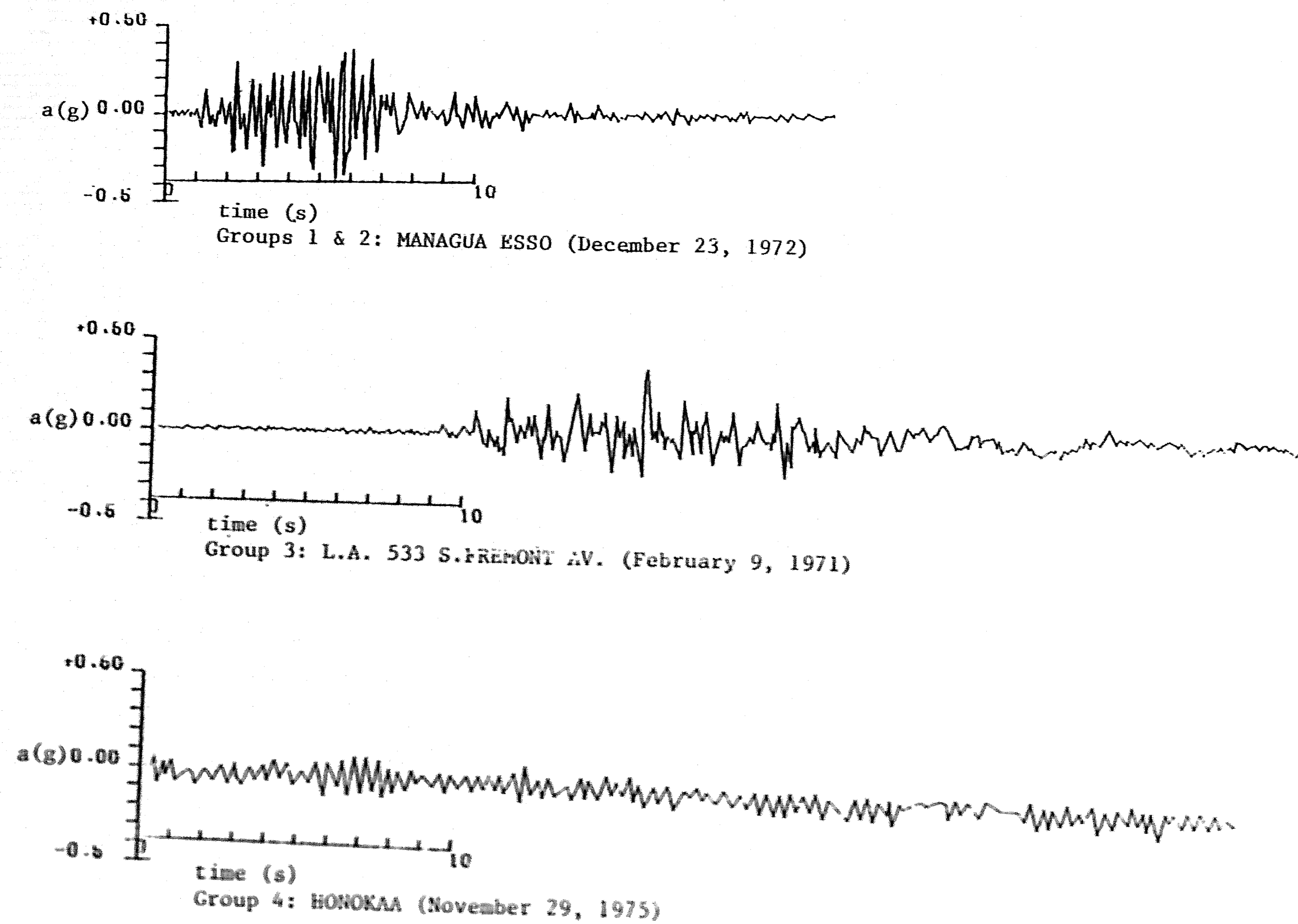

Fig. 4. Selected inputs for collapse level of a building in Seville.