SELECTION OF ACCELEROGRAMS AND EVALUATION OF RELIABILITY BY STEP-BY-STEP INTEGRATION

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SUMMARY

A number of studies, including the compilation of a computer program generating artificial strong ground motions, the discussion on effects of ground motion parameters on elasto-plastic responses of structures, the response analysis of two buildings undergone the Tangshan earthquake, and the suggestion on a method of reliability evaluation have been made. Some ideas about how to select accelerograms for step-by-step integration and how to analyze the results of the integration are given in this paper.

INTRODUCTION

In more and more countries, the step-by-step integration analysis was written in seismic design codes to some extent. With the development of computers, its application must be more wide. There are a few detailed reports on what kind of accelerigrams are more suitable as a standard excitation, and to which the structural response is very sensitive. In answer to this problem, several articles have been published in Chinese journals. In this paper, only main content is presented.

SIMULATED GROUND MOTION AND SAS-FILTERED WHITE NOISE

Considering standard and various applications, a computer program generating artificial motion has been compiled in following process. A common method of numerical simulation is used to generate a non-stationary process consisted of multiplying a stationary Gaussian process by an intensity function of time, I(t), (Fig. 1).

$$\ddot{X}(t) = I(t)\cdot\sum_{k=1}^{N} A(\omega_k)\cdot \mathrm{Sin}(\omega_k+\varphi_k) \quad (1)$$

here, $A^2(\omega_k)=4S_{\ddot{X}}(\omega_k)\Delta\omega$, $S_{\ddot{X}}$ is input power spectral density function (PSDF). As an acceleration response spectrum is determined to be a target spectrum, an approximate formula derived by M. K. Kaul (Ref. 1) is used to calculate input PSDF.

$$S_{\ddot{X}}(\omega) = \frac{\zeta}{\pi\omega}\cdot S_a^2(\omega)/\left\{-\ln\left[\frac{-\pi}{\omega T}\ \ln(1-r)\right]\right\} \quad (2)$$

In which, ζ is damping ratio of structure, T is duration, r is exceeding probability of response spectrum. Some results obtained confirmed the formula, especially if spectral function is smooth. In regard to the average spetrum of the 15 motions, which are compatible with the standard acceleration response spectrum in current design code for building in China, Fig. 2 indicates that they match very well. Subsequent iterations to provide better match of single record use a linear correction, as follows:

$$S_{\ddot{X}}(\omega)=S_{\ddot{X}}(\omega)\cdot S_a(\omega)\ (\text{target})/S_{ac}(\omega)\ (\text{computed}) \quad (3)$$

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The general flow chart of computer program ASEW is shown in Fig. 3. Various kinds of artificial motion with predetermined duration, different input PSDF (White noise or filtered white noise) or acceleration target spectra (the iteration is needed or not) can be generated.

In order to establish identical earthquake loads with (1) acceleration response spectra in design code, (2) artificial accelerogram for time integration,(3)PSDF for random analysis,a set of filtered white noise compatible with standrad acceleration response spectra (SAS-filtered white noise) has been provided from calculation. Substituting a suite of the parameters from Table1 into the well-known formula Kanai-Tajimi, we can obtain a formulated PSDF, filtered white noise. The average response spectra of artificial motions with those PSDF showed a close coincident with target spectra in main region of period (Fig. 4). This SAS-filtered white noise were several times utilized in follows.

The filtered white noise compatible with the response spectra in ATC-3. were obtained as well.

THE EFFECTS OF STRONG GROUND MOTION ON INELASTIC RESPONSE

The results of study on the relationship existed between the characteristics of ground motion and the structural responses may be utilized not only to evaluate the potential destructiveness under each accelerogram, but also to establish a more reasonable criteria for generating standard design earthquakes. By means of the convenient conditions of artificial motions the study has been done in time domain and in frequency domain, respectively.

The following main simulated motions are used: (a) band-limited white noise with some predetermined alteration in PSDF, (b) the SAS-filtered white noise, (c) the simulated motions with different prescribed durations, which all are compatible with the same standard spectrum. In principle, it is intended to ensure that the all characteristics of the motions for comparison are the same except one parameter. The method using same group of random phase angles, i.e. when an effect factor is studied, the same phase angles are adopted to generate different motions for comparison. In the use of this method, the reduce of size of samples for same function becomes possible.

Tri-linear restoring force models of building, stiffness deteriorating (Fig. 5), were used in this investigation of both single-degree and multidegree of freedom systems (SDOF and MUOF). The calculated results of SDOF were ploted as mean ductility response spectra with two levels of strength expressed by the ratio"λ" of yieding strength of structure to maximum peak acceleration (here, λ=0.2 and λ=0.8, the peak is 0.2g) (Ref. 2). the three typical shear-type buildings, the structural parameters of which are listed in Table 2, were analyzed. In every storey of the structures, the yielding interstorey drifts were taken as one third of those calculated in accordance with response-spectra-based model analysis.

<u>In time domain</u>, the peak acceleration, the duration of excitation, and several statistical parameters (the mean, the standard duration, the number of crossing the zero line, the number of the acceleration pluses exceeding a given threshold, the number of the pluses areas of which exceeding a threshold) were investigated. It is concluded that:

1) The effects of the alteration at single point of accelerogram with longer stationary segment on both elastic and inelastic earthquake response is insignificant. It is defective for us to take a peak to be an unique quantitative criteria.

2) Insofar as the artificial motions compatible with the same standard response spectrum are concerned, longer duration can not be responsible for larger inelastic responses, the responses under these motions with different duration are near to each other (Fig. 6). If, therefore, maximum inelastic response is only interesting, we can use shorter duration, for example 10-20 sec.

3) One of the statistical parameters, the number of acceleration pluses with larger areas is correlative with maximum inelastic response (Table 3 and Fig. 7).

<u>In frequancy domain</u>, the PSDF with various spectral parameters, as inputs generating artificial motions, are investigated, as follows:

1) The motions of a band-limited white noise added a narrow band increament around the periods 0.3 and 1 sec., respectively, brought larger effect on elastic responses of structures with period 0.3 and 1 sec., respsctively, but did small on inelastic structures, although their initial periods still are 0.3 and 1 sec. (Fig. 8).

2) It is proved that the larger areas of PSDF with same shape are input, so that the stronger inelastic responses are brought (Fig. 9). In reason, it should add the implication of area when we say "Frequency content".

3) The increase of the area of the PSDF in lower frequency region, especially the area of the region in which the frequency is lower than the fundamental initial frequency of the structure, produced larger increase of structural responses (Fig. 10-11).

4) Four groups of artificial motions with four different filtered white noise PSDF (Table 4), produced four elastic acceleration response spectra, inelastic spectra, and the responses of 3 4-storeyed structures as shown in Fig. 12. They emphasized the previous mentioned results.

It is seen, obviously, that PSDF is the most inportant parameter for elasto-plastic responses of buildings (Ref. 3), which is an overall parameter for whole accelerogram.

TWO EXAMPLES UNDERGONE EARTHQUAKE

In order to research the applicability of artificial ground motion compatible with response spectra in design and the principle of selection of reasonable excitations two practical buildings undergone Tangshan earthquake (1976) were analyzed. Four types of artificial motions and several natural records are used as input: (I) An ensemble of 20 motions compatible with the one of standard response spectra in design code in China, (II) The motions, at the end of the fourth cycle of iteration, their calculated response spectra are closely matched, (III) SAS-filtered white noise, the period of its filter is modified until equating to the predominant period of the site soil of the building, (IV) The motion, the acceleration response spectrum of the site studied by Zhou Xiyuan (Ref. 4) is used as the target.

Two buildings were studied respectively. One is the 52m high 13-storeyed R/C frame structure in Tianjin (Fig. 13). The part above 6th storey collapsed during Tangshan earthquake. The interstorey drifts shown in Fig. 14 illustrated that the responses under both the motions I and II are corresponding to actual (partly collapsed) during earthquake and more closely than the El Centro record (N-S) (1940).

The other is number 10 Apartment building, a 19-storey prefabricated R/C frame structure (Fig. 15). The sets of actual records during the Tangshan earthquake were obtained at basement, 5th, 10th and 17th storey. The interstorey drifts calculated from both actual records and artificial motions were shown in Fig. 16. Here, W01 and W03, being structural responses from the records at the basament during the Tangshan earthquake after shock are in close coincidence with the records of the superstructure (Ref. 5). The results show that the responses of wave IV are the most close to actual records of superstructure, that of wave II are secondery. Obviously, the closer the spectral characteristics of an input motion are to that of the site of a building, the closer the structural responses of this motion are to actual.

EVALUATION OF RELIABILITY

Although it is discouraged to use fewer input motions for structural analysis, we have to do so regularly in practical engineering due to limited computer time. It is significant to study for this case. Here, an approxmate analytical method of results calculated by time integration for evaluation of reliability of building and decision of needed number of input motions in the case of small samples has been suggested.

First of all, 100 artificial motions, SAS-filtered white noise, were input 12 SDOF and one 4-degree of freedom systems for time integration. Those ductility factors as results were checked for probability distribution by K-S check. The results listed in Table 5 show that the distribution of extreme value Gumbel can not be denied in the case of both 5% and 10% significance level, and only in one sample the normal distribution has been denied in the case of 5% significance level. Therefore, the normal distribution is acceptable for the study in the case of small samples.

On the basis of normal distribution, the ralationship between the following four parameters is conducted. First of them is Reliability index of estimate:

$$\hat{K}=\frac{|\overline{X}-L|}{S} \tag{4}$$

in which, $\overline{X}$ is mean of samples, S is deviation of samples, L is threshold. Similar to it is the reliablity index of ensemble:

$$K_p=\frac{|\mu-L|}{\sigma} \tag{5}$$

in which, μ is mean of ensemble, σ is deviation of ensemble. Corresponding to K_p is Probability of accepting:

$$P= P(X<L)=\Phi(K_p) \tag{6}$$

Defined Confidence level is expressed as

$$P_c= P(\overline{X}+\hat{K}\cdot S<\mu+K_p\sigma)$$

$$= \Phi \left(\frac{\hat{K} - K_p}{\sqrt{\frac{1}{n} + \frac{\hat{K}^2}{2(n-1)}}} \right) \quad (7)$$

in which n is the Number of samples.

Only one of the tables listing above-mentioned relationship is shown (Table 6) due to limited length. Thus, according to the number of sample and the results of time-integration not only reliability of system can be obtained, but also it is possible to know if the number of samples is enough to ensure certain reliability.

CONCLUSION AND SUGGESTION

Following ideas and suggestions are provided to the users of step-by-step integration and the compiler of design code.

(1) Both natural and artificial ground motions can be used for response analysis. Although natural records are more true in feature, artificial ones are more convenient and have meaning of probability. It is possible to use more widely in future, if it can be developed reasonably.

(2) The simulated motions compatible with standard response spectra in design code are standardized ones, in use of which only shorter duration is enough for study on maximum inelastic response. It, therefore, may be suitable in design buildings.

(3) It is suggested that compiler of design code observe a number of elastic and inelastic responses of natural and artificial motions; and pick up the several sets, the responses of that are closer to mean spectra than others; then provide these motions as inputs in design.

(4) For selection of motions, one of the principles, besides the peak of accelerogram must depend on design intensity, should be in correspondance with the spectral characteristic of input accelerogram to the characteristic of the site of interest (including predominant period and shape especialy, in the region where the frequency are lower than the fundamental initial frequency of the structure).

Precation:

a) It is likely to bring unsafe only to satisfy the correspondance of the fundamental period of a building to the predominant period of the site of interest.

b) The method using the ground motion with changed integration time intervals in order to satisfy the correspondance of the dominant period of the motion to the predominant period of the site soil, should not be couraged.

(5) Although response envelope is often used to analyze the integration results, in the deterministic manner, the method based on probability may have a future. It, here, only is a test to put foward the above-mentioned method to determine the size of samples and reliability of building.

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(5) Wang Kaishun, Wang Wenzhen,"Earthquake Response Analysis of the 10th Apartment Building-A 19 Storey Prefabricated Reinforced Concrete Frame Structure," 7 WCEE, 1980, Vol. 5.

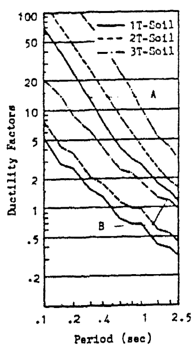


Fig.7 Mean Ductility
(3 for each type)

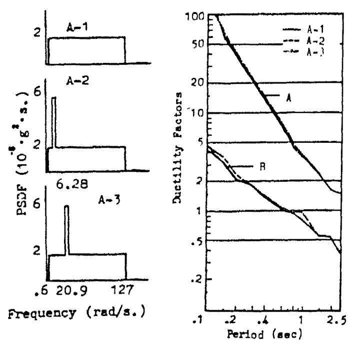


Fig.8 PSDF and Mean
Ductility Responses
(3 for each type)

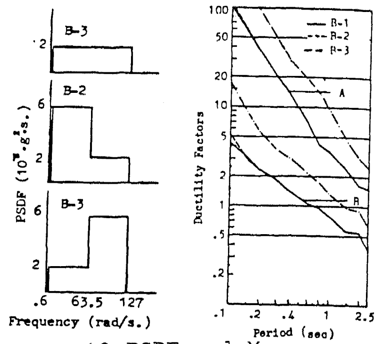


Fig.10 PSDF and Mean
Ductility Responses
(3 for each type)

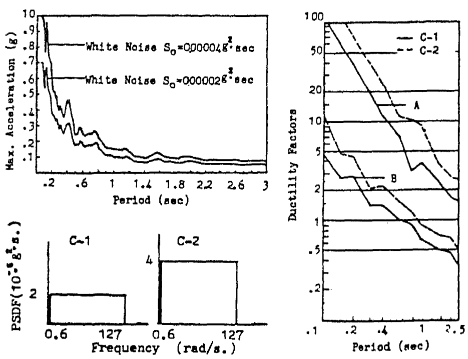


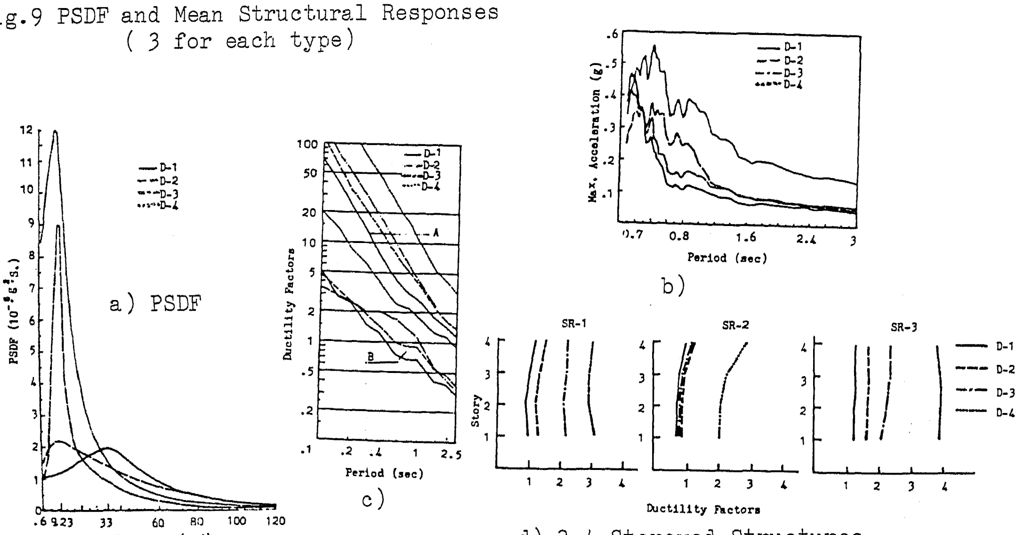
Fig.9 PSDF and Mean Structural Responses
(3 for each type)

TABLE 4 SPECTRAL PARAMETERS OF 4 TYPES OF FILTERED WHITE NOISE

No.	TYPE	A_0	A_1	W_1	W_2	Q
D-1	1T-Soil SAS	0.00224	5.89	42.89	51.18	0.546
D-2	∂_1	0.00224	5.27	38.26	48.31	0.61
D-3	∂_2	0.00224	2.55	23.8	33.68	0.707
D-4	3T-Soil SAS	0.00494	4.20	19.57	29.14	0.741

$$A_i = \int_0^{\infty} G_{\ddot{x}}(\omega)\,\omega^i\,d\omega \qquad G_{\ddot{x}} = 2S_{\ddot{x}}(\omega)$$

$$W_1 = A_1/A_0 \quad W_2 = \sqrt{A_0/A_2} \quad Q = \sqrt{1 - \frac{A_1}{A_0A_2}}$$



d) 3 4-Storeyed Structures

Fig.12 PSDF and Mean Structural Responses

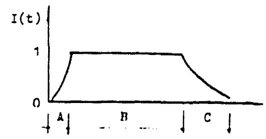


Fig.1 Time Intensity

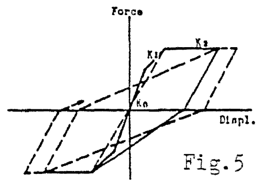


Fig.5

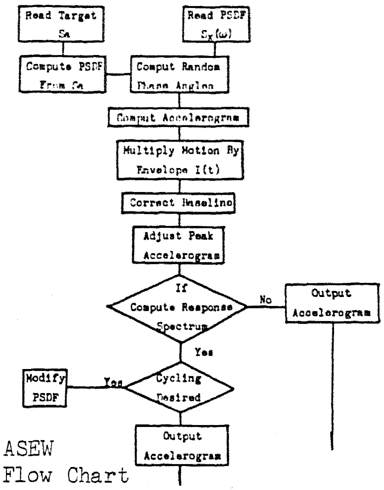


Fig.3 ASEW Flow Chart

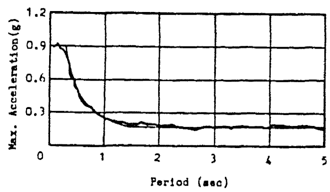


Fig.2 Mean Response Spectrum and Target Spectrum

TABLE 1 PARAMETERS OF FILTER AND S_0 OF SAS-FILTERED WHITE NOISE (10 sec)

Type of Soil		1T-Soil	2T-Soil	3T-Soil
Period		0.16	0.25	0.68
Damping Ratio		0.6	0.7	0.8
PSDF S_0	Intensity 7	0.0000027	0.000005	0.0000206
	Intensity 8	0.0000106	0.00002	0.0000825
	Intensity 9	0.0000425	0.00008	0.00033

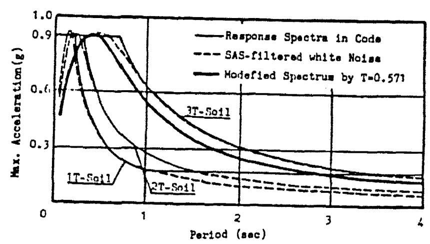
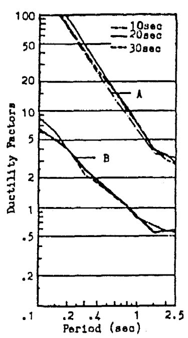
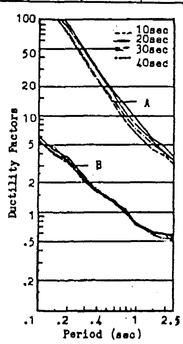
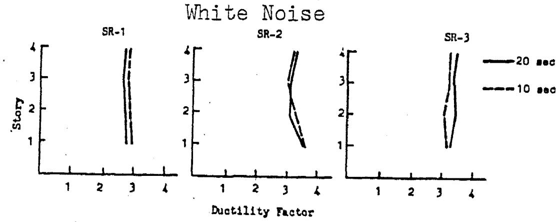


Fig.4 Response Spectra of SAS-filtered White Noise







a) After Iteration (5 for each type) b) No Iteration (10 for each type) c) 3 4-storeyed Structural Responses

Fig.b Structural Response under Motions with Different Durations

TABLE 2 PARAMETERS OF THREE 4-STORYED STRUCTURES

No.	Period	Story	Mass t·sec/cm	Stiffness t/cm	Modle 1	Modle 2
SR-1	T =0.362	1	1	2500	0.347	-1.000233
		2	1	2500	0.653	-1.000116
	T =0.126	3	1	2500	0.879	-0.000116
		4	1	2500	1	1
SR-2	T =2.336	1	1	60	0.347	-1.00007
		2	1	60	0.652	-1.00003
	T =0.811	3	1	60	0.879	-0.00003
		4	1	60	1	1
SR-3	T =0.487	1	1	1000	0.288	-0.632
		2	1	1000	0.529	-0.759
	T =0.222	3	0.5	500	0.834	0.201
		4	0.5	500	1	1

TABLE 3 STATISTIC PARAMETERS IN TIME DOMAIN OF MOTION OF SAS-FILTERED WHITE NOISES FOR 3 TYPE OF SOIL

Type of Soil	No.Waves	Mean M(g)	Sta. Devia-tion δ(g)	Num.of Crossing Zero	Num.of Pluses Value(g) ≥.05	.05< ≥.1	.1< ≥.15	≥.15	Num.of Pluses Areas(g·sec) ≥.005	.005< ≥.01	.01< ≥.02	≥.02
1T-Soil	1	-0.0005	0.0488	145	345	136	16	1	125	18	3	0
	2	0.0001	0.0491	153	356	118	21	42	130	20	4	0
	3	-0.0002	0.0471	154	360	115	22	4	138	15	2	0
2T-Soil	1	-0.0008	0.0552	122	321	139	35	4	91	26	6	0
	2	0.0001	0.0565	121	322	138	32	7	88	24	9	1
	3	-0.0004	0.0542	128	332	134	30	3	97	24	8	0
3T-Soil	1	-0.0017	0.0726	74	249	158	76	16	41	15	13	6
	2	0.0005	0.0731	75	272	141	66	20	43	14	12	7
	3	-0.0007	0.0682	88	273	149	64	13	59	8	14	8

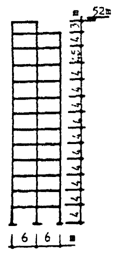


Fig.13 A R/C Frame in Tianjin

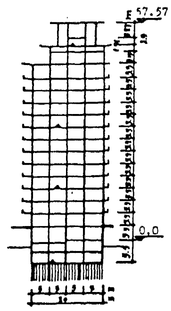


Fig.15 A R/C Frame in Beijing

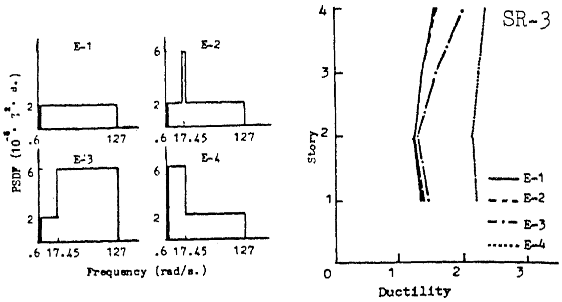


Fig.11 PSDF and Mean Responses of 4-storey Structure (3 for each type)

TABLE 5 RESULTS OF K-S CHECK

		Normal Distribution			Gumbel Extreme Distribution		
	Period(sec)	Dn	α=5%	α=10%	Dn	α=5%	α=10%
SDOF Elastic Structure	0.2	0.0777	ND	ND	0.0425	ND	ND
	0.4	0.0767	ND	ND	0.0745	ND	ND
	0.8	0.072	ND	ND	0.685	ND	ND
	1.0	0.0429	ND	ND	0.0737	ND	ND
	1.5	0.0575	ND	ND	0.063	ND	ND
	2.0	0.0831	ND	ND	0.0441	ND	ND
SDOF Inelastic Structure	0.2	0.0701	ND	ND	0.0958	ND	ND
	0.4	0.0665	ND	ND	0.0805	ND	ND
	0.8	0.0673	ND	ND	0.1096	ND	ND
	1.0	0.122	ND	D	0.0517	ND	ND
	1.5	0.0532	ND	ND	0.0619	ND	ND
	2.0	0.1369	D	D	0.0673	ND	ND
4-Storied Inelastic Structure	1st Story	0.0605	ND	ND	0.0636	ND	ND
	2nd Story	0.0675	ND	ND	0.0601	ND	ND
	3rd Story	0.0595	ND	ND	0.0808	ND	ND
	4th Story	0.063	ND	ND	0.0841	ND	ND

Dn =0.13403 if n=100 α=5%

Dn =0.12067 if n=100 α=10 %

ND — can not deny D — deny

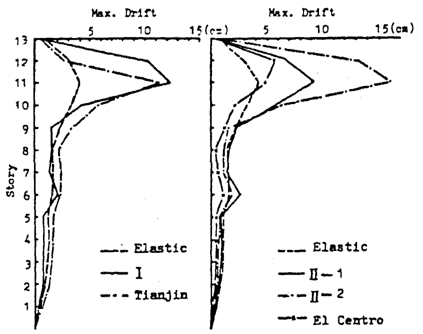


Fig.14 Evelops of Interstorey Drifts

TABLE 6 PROBABILITY OF ACCEPTING (n=5)

λ \ P_c	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	0.97	0.99
1.0	0.8039	0.7824	0.7584	0.7309	0.6985	0.6588	0.6062	0.5248	0.4712	0.3721
1.2	0.8517	0.8321	0.8097	0.7835	0.7521	0.7126	0.6591	0.5738	0.5162	0.4075
1.4	0.8908	0.8735	0.8532	0.8290	0.7991	0.7607	0.7071	0.6189	0.5578	0.4396
1.6	0.9218	0.9069	0.8891	0.8673	0.8396	0.8031	0.7504	0.6605	0.5963	0.4691
1.8	0.9455	0.9332	0.9181	0.8989	0.8739	0.8398	0.7890	0.6987	0.6320	0.4962
2.0	0.9631	0.9533	0.9408	0.9245	0.9025	0.8714	0.8232	0.7336	0.6651	0.5214
2.2	0.9757	0.9681	0.9581	0.9446	0.9257	0.9980	0.8531	0.7655	0.6959	0.5449
2.4	0.9845	0.9788	0.9711	0.9602	0.9444	0.9201	0.8791	0.7945	0.7244	0.5669
2.6	0.9904	0.9863	0.9805	0.9720	0.9590	0.9383	0.9014	0.8208	0.7509	0.5878
2.8	0.9942	0.9914	0.9871	0.9806	0.9703	0.9529	0.9204	0.8445	0.7755	0.6075
3.0	0.9966	0.9947	0.9917	0.9869	0.9789	0.9646	0.9363	0.8658	0.7982	0.6263
3.2	0.9981	0.9968	0.9948	0.9913	0.9852	0.9738	0.9496	0.8847	0.8191	0.6442
3.4	0.9989	0.9982	0.9968	0.9944	0.9898	0.9808	0.9605	0.9015	0.8384	0.6614
3.6	0.9994	0.9990	0.9981	0.9964	0.9931	0.9862	0.9693	0.9163	0.8560	0.6778
3.8	0.9997	0.9994	0.9989	0.9978	0.9954	0.9902	0.9764	0.9293	0.8722	0.6935
4.0	0.9999	0.9997	0.9994	0.9986	0.9970	0.9931	0.9821	0.9406	0.8869	0.7086
4.2	0.9999	0.9998	0.9996	0.9992	0.9981	0.9952	0.9865	0.9504	0.9003	0.7231
4.4	0.9999	0.9999	0.9998	0.9995	0.9988	0.9968	0.9900	0.9589	0.9124	0.7371
4.6	0.9999	0.9999	0.9999	0.9997	0.9993	0.9978	0.9926	0.9660	0.9233	0.7505
4.8	0.9999	0.9999	0.9999	0.9999	0.9996	0.9986	0.9946	0.9721	0.9331	0.7634
5.0	0.9999	0.9999	0.9999	0.9999	0.9997	0.9991	0.9961	0.9773	0.9419	0.7757

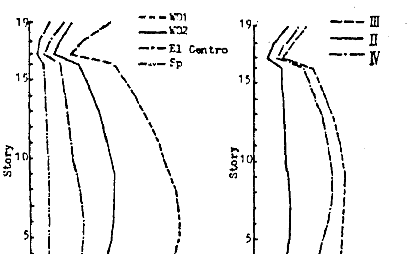


Fig.16 Envelops of Interstorey Drifts