A STUDY OF THE VARIABILITY IN kth PEAK GROUND MOTIONS IN A GEOLOGICALLY SIMILAR ENVIRONMENT USING ACCELEROGRAMS FROM THE 1971 SAN FERNANDO EARTHQUAKE

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SUMMARY

This paper considers the analysis of uncertainties in primary and non-primary peak ground motions due to local effects using data from the 1971 San Fernando earthquake. It is shown that these peaks show logarithmic standard deviations of the same order as the more commonly used parameters PGA and RMS, with a corresponding reduction in uncertainty when distance and embedment effects are removed.

INTRODUCTION

In seismic hazard analysis, the specification of the level of ground motion at a site is generally made through the use of an attenuation equation for some ground motion parameter (usually PGA). These equations are for the most part logarithmic regressions of the parameter that express its median value as a function of distance, magnitude and, occasionally, site geology. The observed values of the ground motion parameter show a large scatter about the predicted median line. Many efforts have been made in the past to measure the residuals about the regression curve (see for example Joyner & Boore, 1981). McCann and Boore (1983) have studied the variability of two RMS measures and also of PGA for a group of records that were obtained during the 1971 San Fernando earthquake. The uncertainty in ground motion was analyzed by studying the residuals about a regression with distance for one set of data and the corresponding residuals for another set consisting of 3 distinct clusters of accelerograms in the Los Angeles area. They found that the RMS acceleration is not a more stable ground motion parameter when compared to the PGA. By analyzing the residuals of these two ground motion parameters in the presence or absence of variables like instrument embedment depth and other local effects, they estimate that the uncertainty in ground motion prediction can be reduced by as much as a factor of 1.3 or so. The primary objective of this paper is to extend the work of McCann and Boore to include the analysis of the uncertainty in the prediction of the non-primary excursions in an acceleration time history.

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BACKGROUND

In a previous report (DeHerrera & Zsutty, 1982) the authors have presented a simple model to calculate the expected value and standard deviation of the kth largest peak as a function of two parameters: λ, whose reciprocal is essentially an RMS-like measure and N, the number of peaks. In the context of this model, a peak is defined as the largest absolute excursion between two zero crossings in a time history. It is implicitly assumed that such a time history has a mean value of zero during the strongest part of the motion. It was observed that the kth peak was well predicted by knowledge of either λ or the largest peak. It is therefore desirable to carry out an analysis of the residuals of the kth peak in order to see what kind of statistical stability this parameter possesses.

DESCRIPTION OF DATA USED

The data base used is essentially the same one as used by McCann and Boore (1983), which in turn includes groupings delineated by Hanks (1975). There are, however, two exceptions:

a. Corrected accelerograms (volume 11, Cal Tech EERL) were used for all computations and extraction of peaks.

b. EERL record K159 (Los Angeles, 750 S. Garland Ave.) was excluded since it was not in the original data base used by DeHerrera & Zsutty (1982).

The distance R is taken to the closest point of rupture on the fault, and the local geology is categorized in accordance with the procedures described by Boore, Oliver, Page and Joyner (1978). Tables 1 and 2 show the two different sets of data, together with the observed 1st, 2nd, 5th, 10th and 20th largest peaks in the accelerogram, together with the number of "exponential peaks" N and the exponential distribution parameter $1/\lambda$.

UNCERTAINTY IN THE k^{th} PEAK

In order to gage the uncertainty in the kth peak and compare it with that of other published ground motion parameters, it is convenient to work with the base 10 logarithm of the parameter. A least squares fit is made to the data with a function of the form

$$\log_{10} X'_k = A_k + B_k \log R$$

where X'_k is the median estimate of the kth peak, R is the previously defined distance to the closest point of rupture to the fault, and A_k and B_k are regression constants. Several groupings of data were performing the regressions: Large structures (soil sites), and small structures (soil sites, rock sites and combined rock & soil sites). The resulting expressions' regression coefficients and the corresponding residuals for the random variables $\log_{10} (X_k)$ are given on Table 3.

The most interesting result from the above mentioned regressions is that there seems to be an initial decrease in the logarithmic standard deviation of the residuals as the index "k" increases, suggesting that there is an optimal peak (not the largest X_1, nor the twentieth largest X_{20}) from the standpoint of minimizing the uncertainty in hazard estimation. It should be noted, however, that the logarithmic standard deviations given on Table 3 are not significantly different from those computed by McCann and Boore.

LOCAL COMPONENT OF GROUND MOTION VARIABILITY

The occurrence of an earthquake and its effects at a particular site involve several physical mechanisms that contribute to the overall scatter shown by ground motion parameters. These mechanisms act at the seismic source, the transmission path and finally at the local site itself. The local contribution to the uncertainty can be estimated by analyzing records that are obtained from accelerograms located in close proximity to each other. Hanks (1975) identified three such groups of recordings from the San Fernando earthquake. These records share essentially the same azimuth, propagation path and gross geologic features. Figure 1 shows the location of these three areas in Los Angeles. McCann and Boore (1983) regressed PGA and RMS against H, the instrument depth below grade, and found the contribution to the uncertainty from this effect. A similar analysis was performed by the authors on the parameters X_k, k=1,2,5,10,20 and $1/\lambda$ using the same area groups. The median values for the above six parameters were computed for each area group and are shown on Table 4. The three area groups were merged into one and regressed against the variable H, obtaining an estimate of logarithmic standard deviation due to local effects. Table 5 presents the results of this last regression.

SINGLE EVENT LOCAL PEAK PREDICTIONS FROM AN EXPONENTIAL MODEL

Previous work by the authors (1979, 1982) has shown that an exponential model provides a way to make estimates of the expected kth peak and its standard deviation. In those studies the data was not separated into individual earthquakes. It was decided to see how well the observed peaks compare with the calculated expected kth peak. By plotting $1/\lambda$ against $1/\lambda \ln N$ (Figure 2), a value of $\ln N^* = 4.87$ is obtained. Recalling that the expected value of the kth largest extreme from an exponential sample of size N is given by

$$\bar{X}_k = \frac{1}{\lambda} \sum_{z=k}^{N} \frac{1}{z}$$

the residuals (logarithmic) can be easily computed from knowledge of the actual observed X_k. It was found that using $\ln N^* = 4.87$ and the average value of $1/\lambda = 28.2$ cm/sec2 , the residuals were almost the same as those calculated from the deviations of the least square lines associated with the merged area group.

DISCUSSION AND CONCLUSIONS

The main objective of this paper has been to study the variability shown by the non-primary peaks. The data indicates that such variability is of the same order as that exhibited by the more traditional ground motion parameters PGA and RMS, and that local effects can influence 20-30 % of the total logarithmic variance.

ACKNOWLEDGEMENTS

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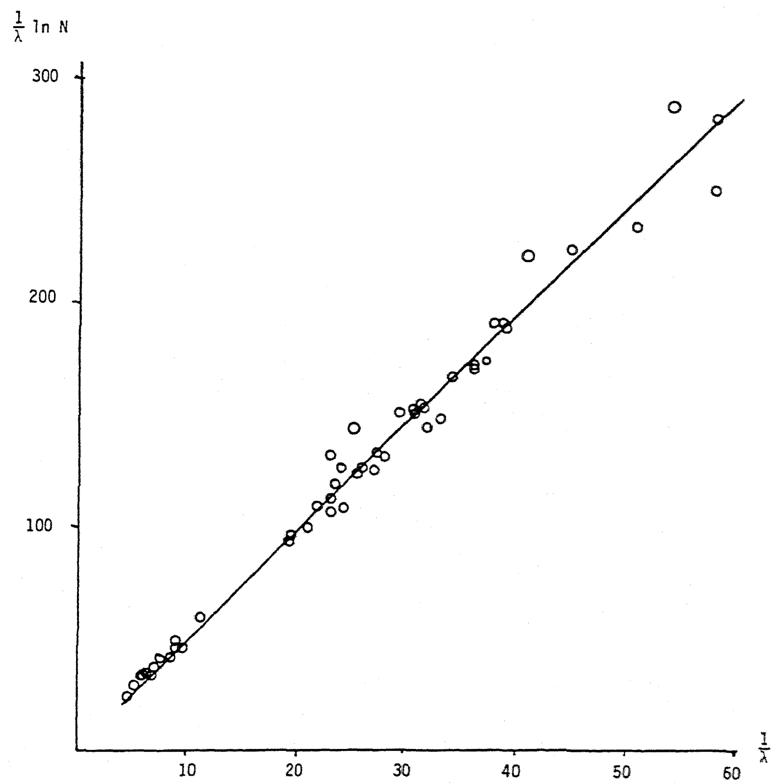

Figure 2: Graphical determination of ln N*

SMALL BUILDINGS ON SOIL SITES

EERL#	R	X1	X2	X5	X10	X20	1/λ	N
G107	22.00	107.30	83.50	78.70	62.80	48.30	24.30	88
D058	23.00	207.00	176.00	168.80	157.60	106.90	50.50	106
J141	27.00	145.50	107.70	86.90	48.80	33.70	22.20	144
G114	32.00	136.20	121.10	81.10	72.20	61.60	24.10	188
F103	41.00	120.50	110.40	85.70	80.60	69.00	23.10	300
N191	54.00	40.10	29.20	22.30	18.70	16.00	6.00	248
O205	59.00	28.40	22.90	20.40	18.40	15.30	5.40	276
P222	62.00	25.90	25.40	22.60	21.80	16.50	6.00	222
F101	91.00	37.50	33.60	29.80	26.40	22.40	9.40	114

N = 9

SMALL BUILDINGS ON ROCK SITES

EERL#	R	X1	X2	X5	X10	X20	1/λ	N
G106	18.40	188.60	173.30	133.20	81.30	74.90	36.70	114
O198	19.40	176.90	172.30	102.40	81.10	61.20	31.30	138
J144	21.00	346.20	345.80	216.70	155.20	105.80	54.40	198
J142	24.00	168.20	123.30	106.20	97.80	67.00	25.10	304
J143	24.00	119.30	104.90	79.40	67.60	52.10	23.00	138
D056	26.00	309.40	204.40	172.70	130.50	80.50	41.40	214
M184	59.00	57.20	39.80	37.10	33.80	25.10	9.10	266
F102	64.00	24.60	21.90	16.20	13.60	11.10	4.60	184

N = 8

SMALL BUILDINGS: ALL SITES (SOIL & ROCK)

EERL#	R	X1	X2	X5	X10	X20	1/λ	N
G107	22.00	107.30	83.50	78.70	62.80	48.30	24.30	88
D058	23.00	207.00	176.00	168.80	152.60	106.90	50.50	106
J141	27.00	145.50	107.70	86.90	48.80	33.70	22.20	144
G114	32.00	136.20	121.10	81.10	72.20	61.60	24.10	188
F103	41.00	120.50	110.40	85.70	80.60	69.00	23.10	300
N191	54.00	40.10	29.20	22.30	18.70	16.00	6.00	248
O205	59.00	28.40	22.90	20.40	18.40	15.30	5.40	276
P222	62.00	25.90	25.40	22.60	21.80	16.50	6.00	222
F101	91.00	37.50	33.60	29.80	26.40	22.40	9.40	114
G106	18.40	188.60	173.30	133.20	81.30	74.90	36.70	114
O198	19.40	176.90	172.30	102.40	81.10	61.20	31.30	138
J144	21.00	346.20	345.80	216.70	155.20	105.80	54.40	198
J142	24.00	168.20	123.30	106.20	97.80	67.00	25.10	304
J143	24.00	119.30	104.90	79.40	67.60	52.10	23.00	138
D056	26.00	309.40	204.40	172.70	130.50	80.50	41.40	214
M184	59.00	57.20	39.80	37.10	33.80	25.10	9.10	266
F102	64.00	24.60	21.90	16.20	13.60	11.10	4.60	184

N = 17

LARGE BUILDINGS ON SOIL SITES

EERL#	R	X1	X2	X5	X10	X20	1/λ	N
H115	15.00	220.60	192.70	152.70	125.70	108.80	44.90	148
O233	15.40	243.30	242.10	224.70	178.10	120.60	57.90	134
F088	16.50	265.70	225.10	177.90	138.60	89.20	57.70	80
G108	21.00	198.00	169.20	112.10	97.20	70.10	35.70	120
H121	22.60	119.40	114.90	87.30	69.40	55.10	23.50	152
D057	23.00	148.20	144.60	100.40	85.40	62.10	33.20	86
D062	26.50	130.30	128.20	108.10	97.80	67.20	32.40	118
F086	33.00	104.60	82.00	64.60	53.30	36.60	19.50	120
H118	36.00	33.70	28.90	27.40	23.80	21.40	7.50	212
P231	37.00	41.30	37.20	27.20	23.90	18.60	8.00	158
S267	37.00	61.50	55.80	43.60	34.50	26.50	11.40	198
O204	58.00	26.00	23.70	18.30	17.20	14.10	5.20	210
N196	58.00	35.00	32.50	31.10	28.40	22.70	8.60	184
H124	58.00	34.90	23.70	22.10	19.40	17.70	6.40	202
M180	66.00	29.90	27.40	20.80	18.80	15.50	5.70	236
F087	70.00	28.20	27.30	24.20	19.20	17.10	5.90	264
P220	78.00	34.30	30.60	27.20	20.90	16.10	6.60	218
O206	93.00	43.90	29.70	24.70	21.40	18.20	6.50	242

N = 18

Table 1: Data sets used in this study

Table 2: Area local data sets used in this study

AREA 1 DATA

EERL#	R	X1	X2	X5	X10	X20	1/λ	H	N
E075	46.00	133.80	127.20	95.80	88.20	54.80	29.30	4.60	116
F083	46.00	161.90	155.00	113.70	96.50	74.50	34.10	1.50	134
J148	46.00	112.00	101.00	93.90	77.90	65.00	28.10	3.00	106
P217	46.00	108.30	105.80	80.00	63.70	44.60	23.30	3.00	110
S265	46.00	125.20	105.80	93.50	71.30	56.40	25.50	16.80	136
S266	46.00	153.60	147.70	91.70	86.20	59.90	30.90	3.00	128

N = 6

AREA 2 DATA

EERL#	R	X1	X2	X5	X10	X20	1/λ	H	N
C054	48.00	147.10	134.10	86.80	54.20	34.40	27.70	6.10	90
F089	48.00	139.00	112.40	85.70	68.40	56.60	25.80	.01	120
F098	48.00	236.40	167.70	117.50	104.80	84.40	38.60	1.00	134
G112	48.00	101.90	90.90	75.60	55.10	37.80	21.30	15.00	110
K157	48.00	168.30	154.70	80.50	67.50	50.80	27.40	7.50	122
R253	48.00	242.00	202.30	123.90	104.20	77.30	38.50	1.80	142

N = 6

AREA 3 DATA

EERL#	R	X1	X2	X5	X10	X20	1/λ	H	N
D059	45.00	147.10	146.10	101.10	87.80	72.90	31.00	13.60	136
R249	45.00	84.20	83.60	66.70	54.20	43.90	19.40	14.20	126
I134	45.00	97.90	95.70	80.40	61.30	48.50	22.70	11.30	110
I131	45.00	184.30	137.80	119.50	102.50	74.60	35.90	.01	118
N188	45.00	126.50	125.40	107.80	99.30	81.30	30.70	4.00	160

N = 5

COMBINED AREA DATA (AREAS 1, 2, 3)

EERL#	R	X1	X2	X5	X10	X20	1/λ	H	N
E075	46.00	133.80	127.20	95.80	88.20	54.80	29.30	4.60	116
F083	46.00	161.90	155.00	113.70	96.50	74.50	34.10	1.50	134
J148	46.00	112.00	101.00	93.90	77.90	65.00	28.10	3.00	106
P217	46.00	108.30	105.80	80.00	63.70	44.60	23.30	3.00	110
S265	46.00	125.20	105.80	93.50	71.30	56.40	25.50	16.80	136
S266	46.00	153.60	147.70	91.70	86.20	59.90	30.90	3.00	128
C054	48.00	147.10	134.10	86.80	54.20	34.40	27.70	6.10	90
F089	48.00	139.00	112.40	85.70	68.40	56.60	25.80	.01	120
F098	48.00	236.40	167.70	117.50	104.80	84.40	38.60	1.00	134
G112	48.00	101.90	90.90	75.60	55.10	37.80	21.30	15.00	110
K157	48.00	168.30	154.70	80.50	67.50	50.80	27.40	7.50	122
R253	48.00	242.00	202.30	123.90	104.20	77.30	38.50	1.80	142
D059	45.00	147.10	146.10	101.10	87.80	72.90	31.00	13.60	136
R249	45.00	84.20	83.60	66.70	54.20	43.90	19.40	14.20	126
I134	45.00	97.90	95.70	80.40	61.30	48.50	22.70	11.30	110
I131	45.00	184.30	137.80	119.50	102.50	74.60	35.90	.01	118
N188	45.00	126.50	125.40	107.80	99.30	81.30	30.70	4.00	160

N = 17

$$\log_{10} X'_k = A_k + B_k \log R$$

Large structures on soil sites (n=18)				Small structures on soil sites (n=9)			
k	A_k	B_k	σ	k	A_k	B_k	σ
1	3.90	-1.31	.154	1	4.11	-1.40	.185
2	3.95	-1.38	.145	2	3.92	-1.32	.203
5	3.77	-1.32	.144	5	3.86	-1.33	.192
10	3.64	-1.29	.136	10	3.58	-1.20	.218
20	3.38	-1.19	.111	20	3.30	-1.09	.223
1/λ	3.35	-1.40	.142	1/λ	3.33	-1.35	.209

Small structures on rock sites(n=8)				Small structures, soil&rock (n=17)			
k	A_k	B_k	σ	k	A_k	B_k	σ
1	4.40	-1.56	.205	1	4.29	-1.50	.183
2	4.49	-1.68	.176	2	4.23	-1.51	.182
5	4.16	-1.54	.188	5	3.99	-1.42	.178
10	3.84	-1.38	.190	10	3.68	-1.27	.191
20	3.69	-1.37	.145	20	3.44	-1.19	.181
1/λ	3.62	-1.56	.152	1/λ	3.42	-1.41	.175

Table 3: Results of regression analysis for various site configurations

Area 1			Area 2			Area 3		
k	X_k	σ_k	k	X_k	σ_k	k	X_k	σ_k
1	130.9	.08	1	164.8	.16	1	123.0	.16
2	121.9	.09	2	139.0	.14	2	114.8	.12
5	94.2	.06	5	93.3	.10	5	93.1	.12
10	79.8	.07	10	72.9	.14	10	78.3	.15
20	58.5	.08	20	53.8	.18	20	61.6	.13
1/λ	28.3	.07	1/λ	29.2	.11	1/λ	27.2	.13

Table 4: Median values from local area regressions

$$\log X_k = c_0 + c_1 H + c_2 d_1 + c_3 d_2 \pm \sigma_L$$

$d_1 = 1$ for area 1, $d_2 = 1$ for area 2; zero otherwise

k	c_0	c_1	c_2	c_3	σ_L
1	2.19	-1.2E-2	-1.2E-2	8.7E-2	.10
2	2.14	-9.2E-3	-5.3E-3	.05	.09
5	2.04	-8.1E-3	-2.1E-2	-2.7E-2	.07
10	1.99	-1.2E-2	-3.1E-2	-7.1E-2	.09
20	1.90	-1.2E-2	-6.7E-2	-.103	.11
1/λ	1.52	-1.0E-2	-1.6E-2	-4.1E-3	.07

Table 5: Regression against embedment depth H for various variables