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STATISTICAL ANALYSIS OF PEAK ACCELERATIONS OF RECORDED EARTHQUAKE GROUND MOTIONS

地震記録最大加速度値の統計的解析

By Tsuneo KATAYAMA*
片 山 恒 雄

1. Data Set Used for Analysis

A strong-motion accelerograph usually records two horizontal and one vertical components of acceleration. Let the two horizontal peak accelerations be denoted by a_1 and a_2, and the vertical peak acceleration by a_V. Define the average horizontal acceleration, a, by

$$a = \frac{1}{2}(a_1 + a_2) \qquad (1)$$

Table 1 Distribution of Magnitude and Focal Depth of 46 Earthquakes

		Focal Depth (km)				Total
		0-29	30-99	100-199	200-500	
Magnitude	5.1-5.4	4	2	0	0	6
	5.5-5.9	4	3	1	0	8
	6.0-6.4	4	9	1	0	14
	6.5-6.9	4	6	1	0	11
	7.0-7.4	1	0	0	1	2
	7.5-7.9	1	4	0	0	5
Total		18	24	3	1	46

Table 2 Distribution of Average Acceleration Values for Different Ranges of Epicentral Distance

		Average Acceleration (gal)						Total
		0-9	10-49	50-99	100-149	150-199	200-	
Epicentral Distance (km)	0- 49	0	17	13	2	0	1	33
	50- 99	13	44	10	1	0	1	69
	100-149	9	38	6	1	1	0	55
	150-199	18	33	4	1	0	1	57
	200-	62	44	5	2	3	0	116
Total		102	176	38	7	4	3	330

A total of 330 pairs of a_1 and a_2, and 320 values of a_V were used for the present analysis. These peak acceleration values were obtained from 46 earthquakes during the period from 1963 to 1970 in Japan. Table 1 shows the numbers of earthquakes for different ranges of magnitude and focal depth. The distribution of average acceleration value, a, within the data set is shown in Table 2 for different ranges of epicentral distance.

2. Attenuation of Mean Peak Acceleration

The attenuation law of mean horizontal peak acceleration values was investigated by using 330 a-values described in the previous section. The following two types of attenuation law were assumed :

$$\log_{10}\bar{a} = A - B\log_{10}\Delta + CM \qquad (2)$$

$$\log_{10}\bar{a} = A - B\log_{10}(R + R_0) + CM \qquad (3)$$

in which $\bar{a}$ is the mean horizontal peak acceleration in gal, Δ is the epicentral distance in km, M is the earthquake magnitude, R is the focal distance in km, and A, B, C and R_0 are constants.

The result obtained by least squares fitting for Eq. (2)-type law was

$$\log_{10}\bar{a} = 0.982 - 1.290\log_{10}\Delta + 0.466M \qquad (4)$$

or $$\bar{a} = 9.60e^{1.073M}\Delta^{-1.290} \qquad (5)$$

with a standard error of estimation of 0.328 and a coefficient of multiple correlation of 0.708

Least squares fits for Eq. (3)-type law were carried out by varying the constant term R_0 between 5 and 40. However, no improvement was obtained in comparison with the simpler expression given by Eq. (2). The best fit in these cases was

$$\log_{10}\bar{a} = 2.308 - 1.637\log_{10}(R + 30) + 0.411M \qquad (6)$$

* Dept. of Building and Civil Engineering, Inst. of Industrial Science, Univ. of Tokyo.

or $\bar{a} = 203.3 e^{0.948M}(R+30)^{-1.637}$ (7)

with a standard error of estimation of 0.346 and a coefficient of multiple correlation of 0.667.

Scatter of data points about the estimating equation Eq. (4) or Eq. (5) is shown in Fig. 1 with lines representing one and two standard errors of estimation above and below the mean. Fig. 2 shows the distribution of

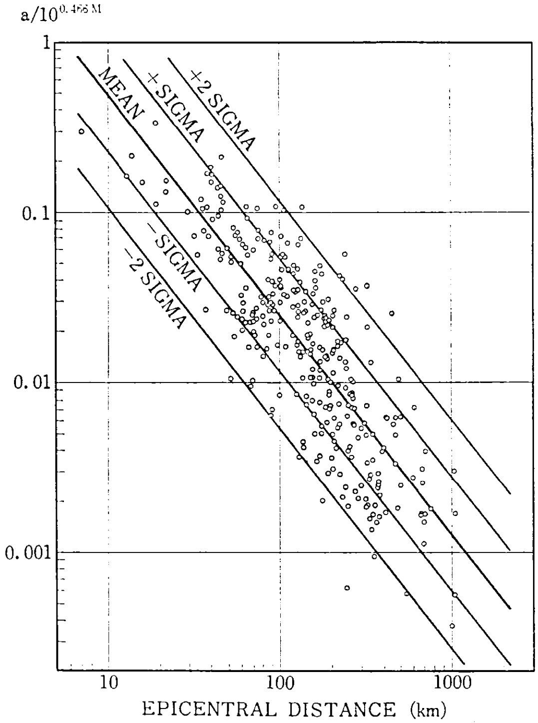

Fig. 1 Distribution of Original Data about Estimating Equation (4).

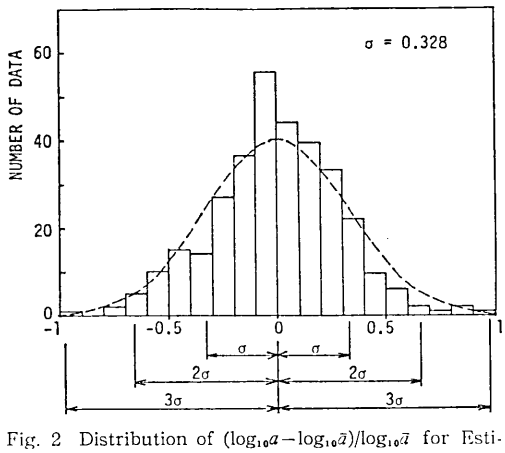

Fig. 2 Distribution of $(\log_{10}a - \log_{10}\bar{a})/\log_{10}\bar{a}$ for Estimating Equation (4).

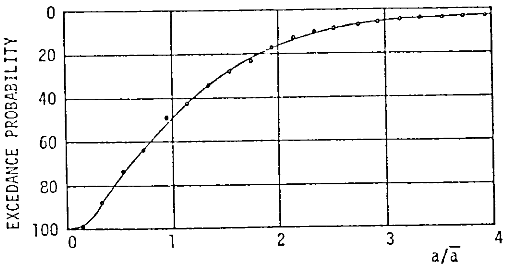

Fig. 3 Excedance Probability of $a/\bar{a}$ for Estimating Equation (4).

$$(\log_{10}a - \log_{10}\bar{a})/\log_{10}\bar{a}$$

when Eq. (4) or Eq. (5) is used as the estimating equation. Fig. 3 shows the excedance probability of $a/\bar{a}$. It can be seen that, if the mean horizontal peak acceleration is evaluated by Eq. (4) or Eq. (5), the probabilities for an extreme value to exceed the mean by 100% and 200% are about 15% and 5%, respectively.

Most of the past damaging earthquakes in Japan with epicenters on land had magnitude ranging from 6.5 to 7.5 and focal depth less than 10 km. By assuming $R=10$ in Eq. (6), the estimating equation for the mean epicentral acceleration becomes

$$\log_{10}\bar{a}_0 = -0.312 + 0.411M \quad (8)$$

from which the following values are obtained:

	Mean	Mean $+\sigma$
$M=6.5$	230 gal	510 gal
$M=7$	370 gal	810 gal
$M=7.5$	590 gal	1300 gal

Though it should be noted that the number of peak acceleration data for small epicentral distance is small, at least the mean values listed above show reasonable agreement with the maximum epicentral accelerations of past Japanese earthquakes estimated by post-earthquake surveys of damage (1).

3. Scatter of Peak Acceleration Values in Two Horizontal Directions at a Site

The distributions of

$$\frac{a_1 - a}{a} \text{ and } \frac{a_2 - a}{a}$$

were studied for 330 pairs of a_1 and a_2. The

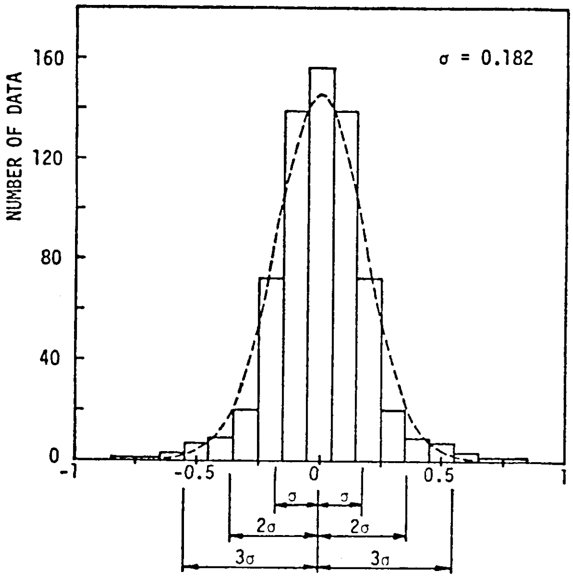

Fig. 4 Distribution of $(a_1-a)/a$ & $(a_2-a)/a$.
a_1 & a_2=Peak Accelerations in Two Horizontal Directions at a Site
$a=(a_1+a_2)/2$

result is shown in Fig. 4, from which it can be seen that the probability that a_1 or a_2 differs from the average value by more than ±40% is roughly 5%.

4. Ratio of Vertical to Horizontal Peak Acceleration

The distribution of the ratio between the vertical and the horizontal peak acceleration a_V/a was studied for a set of 320 data. The result is shown in Figs. 5 and 6. The mean ratio was found to be 0.43 and the standard deviation was 0.24. The probability that the maximum vertical acceleration exceed 50% of the maximum horizontal acceleration is seen to be about 20%. No definite relation was found between a_V/a and epicentral distance as seen from Table 3.

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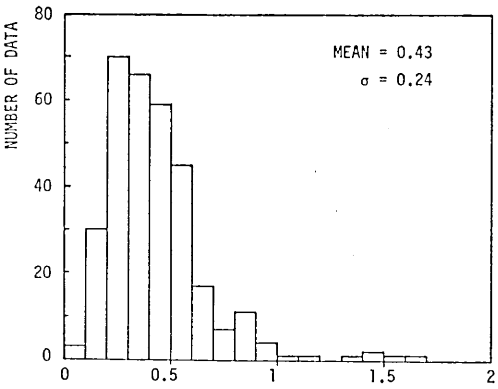

Fig. 5 Distribution of a_V/a.

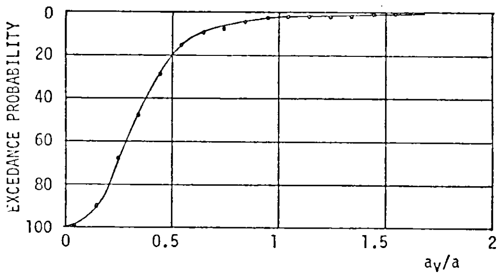

Fig. 6 Excedance Probability of a_V/a.

Table 3 Ratio Between Vertical and Horizontal Peak Acceleration Vs. Epicentral Distance

		$5.5 \leq M < 6.5$			$6.5 \leq M < 7.5$			Total Data Set		
		N	$\overline{a_V/a}$	σ	N	$\overline{a_V/a}$	σ	N	$\overline{a_V/a}$	σ
Δ (km)	0- 49	16	0.36	0.10	2	—	—	34	0.35	0.21
	50- 99	43	0.43	0.18	14	0.40	0.09	67	0.44	0.21
	100-149	21	0.42	0.23	25	0.38	0.15	53	0.40	0.20
	150-199	19	0.44	0.21	26	0.41	0.25	55	0.45	0.31
	200-	16	0.48	0.30	39	0.49	0.22	111	0.45	0.25
Total		115	0.43	0.21	106	0.43	0.20	320	0.43	0.24

Δ=Epicentral distance
N=Number of data
$\overline{a_V/a}$=Average ratio
σ=Standard deviation

Reference

1) S. Okamoto, An Introduction to Earthquake Engineering, University of Tokyo Press, 1973.