CONSIDERATIONS ON EARTHQUAKE FORCE EVALUATION

by

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1. Introduction Since the time when the strong earthquake observations started in the United States in 1932, taking the lead of all other countries, it has become soon be noted that the recorded maximum acceleration on the strong motion accelerograms showed fairly a large figure exceeding general presumption for relating the ground acceleration to the seismic intensity.

The start of the strong earthquake observation project in Japan, though it has delayed greatly from that of the USA, supported by eager efforts of those concerned, number of strong motion accelerographs (SMAC) has increased rapidly, especially after 1964, when the first excellent SMAC record was obtained in Niigata City where very heavy building damage was experienced because of the attack of the Niigata earthquake of June 16, 1964. Presently more than 700 SMAC are installed throughout the whole Japan yielding a great many valuable strong motion records, taking the advantage of the large seismic activity in and around Japan.

With respect to these many strong motion records, obtained in Japan, it was also noticed since in its early stage that the recorded maximum acceleration on SMAC showed exceedingly larger figure than the acceleration expected from the largeness of the earthquake damage to buildings, showing something similar nature found in the USA.

Strong earthquake motions registered by these strong motion accelerographs are the only reliable informations which would announce us what is the earthquake force that causes sometimes very heavy catastrophe. The informations included in the strong motion accelerograms, however, are given in an implicit form, therefore, it was called upon great many interpretations[1,2] on these accelerograms with the intension of extracting the most effective characteristics included in these accelerograms by which the earthquake destruction could be related to the earthquake forces.

2. Maximum acceleration related to the seismic intensity In Japan since the effective imprementation of the strong earthquake observation projects in 1957, fairly a large number of records have been accumulated. The maximum accelerations read out from these records were related to the seismic intensity at the location where the records were observed. Result is reproduced in Fig. 1. The maximum accelerations in Fig. 1 were provided from the "Strong Motion Earthquake Records in Japan, Vols. 1-12 (1970)", but only those which were recorded on the ground or on the ground floor of the buildings. The intensity scale is given in JMA Scale (Japan Meteorological Agency Scale with degree zero for unfelt earthquake up to VII of the most catastrophic). In the figure it is also indicated a Modified Mercalli Scale for reference. Solid circle indicates that plot has duplicated more than three times, while open circle shows that it is only one plot or maximum two plots.

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Table 1 Earthquake that gave large maximum accelerations

Earthq. No.	Location of Epicenter	Date		Magni-tude	Depth km	Observation Station	max Acceleration g [*]	Intensity (JMA Scale) at observa-tion station	Duration time larger acc.	total t
1	South of Hokkaido	1962 IV	23	7.0	60	kushiro	E 0.38 (0.23)	IV	5.5 sec	11 sec
2	Off Ibaragi Pref.	1964 II	5		60	Tōkai-mura	N 0.194(0.11)	III	5.3	20
3	Niigata	1964 VI	16	7.7	40	Niigata	E 0.159(0.155)	V	4.0	30
4	Off Ibaragi Pref.	1964 XI	14		50	Tōkai-mura	E 0.22 (0.21)	III	0.6	40
5	Matsushiro	1966 IV	5	5.4	0	Hoshina	E 0.52 (0.21)	V	1.3	2.8
6	E. part of Hokkaido	1967 XI	11		20	Kushiro	E 0.23 (0.19)	IV	0.7	1.5
7	Off Ibaragi Pref.	1967 XI	19		40	Tōkai-mura	N 0.48 (0.27)	III	0.9	5.0
8	Hyuganada	1968 IV	1	7.5	30	Hosozima	E 0.26 (0.16)	IV	2.7	15
9	Tokachi-oki	1968 V	16	7.9	0	Hachinohe	N 0.23 (0.18)	V	11	40
	〃	〃 〃	〃	〃	〃	Muroran	N 0.21 (0.15)	IV	17	36
10	Higashi Matsuyama	1968 VII	1	6.1	50	Tokyo	E 0.18 (0.15)	IV	2.5	6.5
11	Ehime Pref.	1968 VIII	6	6.6	40	Uwajima	0.44 (0.37)	V	4.5	12
12	Hidaka-sankei	1970 I	21	6.8	60	Hiroo	E 0.44 (0.41)	V	3.5	15
13	Kashimanada	1970 II	4	4.8	40	Tōkai-mura	E 0.17 (0.13)	III	0.7	1

*: E is E-W component, N N-S component and figures in bracket indicate max. acceleration of the other component

It can be noticed in the figure that there are not a few circles giving quite a large acceleration compared to the rated seismic intensity. In Table 1 some of these earthquakes are extracted together with necessary elements relating to the acceleration and intensity. Figures attached to each dot in Fig. 1 correspond to the Etq. No. in Table 1, and in this Table it is also tabulated such large earthquakes as also gave good acceleration records at the locations where large building destructions were observed.

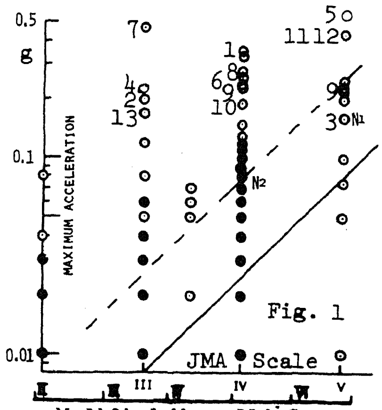


Fig. 1

With respect to these large accelerations observed in Japan, the largest acceleration appeared in one of the earthquake took place near Matsushiro[3] in the period of active Matsushiro earthquake swarm, (No.5 in Fig. 1). Maximum recorded acceleration exceeded 500 gals at Hoshina Station while almost no damage was reported excepting slight partial damage of a few wooden houses. In the case of Etq. No.1 in Table 1, the SMAC in Kushiro[4] (Hokkaido) recorded the maximum acceleration of 385 gals while no damage was seen with respect to any wooden houses in Kushiro City.

Recently, in 1970, a strong earthquake of magnitude 6.8 hit the south-east part of Hokkaido. In this case, a SMAC accelerograph in Hiroo[5] was incidentally installed almost just above the hypocentre, giving the maximum acceleration of 437 gals (No.12 in Fig. 1). While damage in Hiroo was only so slight as to be rated to Intensity V by JMA Scale. In the case of Etq. No.7, acceleration of 0.44g was observed at Tokai-mura, about 90 km distant from the epicentre, giving no damage at all around the observation station. Etq. No.11 also gave the maximum acceleration of 0.44g to the observation station at Uwajima, 36 km distant from the epicentre, accompanying only very slight damage.

In contrasting to these earthquakes above mentioned, we have several other earthquakes which gave fairly large damage for buildings in spite of their not so exceedingly large maximum accelerations. In the case of the Niigata earthquake[6] of 1964 large destructions were caused for many reinforced concrete buildings in the Niigata City but mainly because of the foundation failure due to liquifaction of under ground sand layer.

Observed maximum acceleration in the Niigata City was 159 gals (No.3 in Fig. 1).

In the case of the Tokachi-oki earthquake[7] of 1968 keen attention of construction engineers was focussed in the complete destruction caused to many reinforced concrete buildings in Hachinohe and other cities. Acceleration records obtained in the Hachinohe City, however, was not greater than 200 gals (No.9 in Fig. 1).

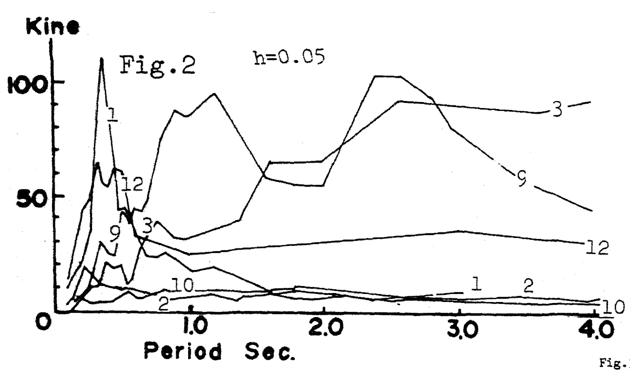
3. Velocity response spectrum of the recorded strong motion accelerograms

It is widely accepted that the earthquake force which is most directly related to the building destruction will be represented in terms of velocity rather than acceleration of the ground motion. In Fig. 2, velocity response spectrums of some of the selected earthquakes in Table 1 are reproduced[8] for the damping of 5 % critical. For reference, velocity response spectra of some of the famous American earthquakes[9,10] are reproduced in Fig. 3 to show in the same scale with Fig. 2 and for the same damping value.

With respect to many cases the velocity response spectrum of such earthquakes that caused large destructions to buildings shows larger value covering the period range than that of such earthquakes as gave very large maximum acceleration but gave no or almost no damage.

Housner[11] is the first who proposed a measure for evaluating the earthquake force. The quantity, Spectrum Intensity SI of Housner, proved an excellent indicative for evaluating earthquake force, especially may be, for elastic structures. Housner and Jennings[12] proposed another measure of RMS, the root mean square, for strong phases of the ground accelerations on the seismograms.

Neumann[13] suggested that seismic intensity scale such as Modified Mercalli should be rated not by acceleration but by the ground velocity, because ground velocity would be effective more directly on the building damage. Blume[14] proposed a 9 digit representaion of the earthquake force for the nine different classes of period and for the intensity level from zero to nineth. Taking into considerations on the major influence on damage pattern by the variations in soil conditions, Seed[15] proposed structural damage potential indices.



Velocity response spectrum of earthquakes in Table 1

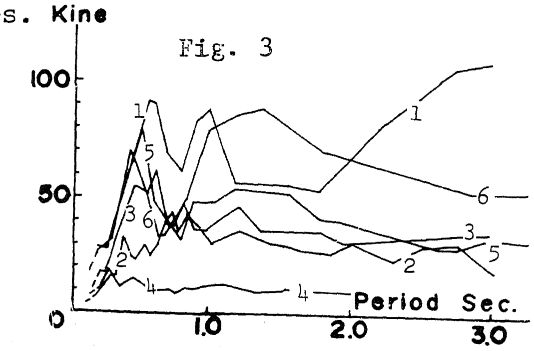


Fig.3 Velocity response spectrum of some of the American earthquakes
1 El Centro record, 1940 N-S
2 Taft record, 1952 N21E
3 Olympia, 1949 N80E
4 Golden Gate Park, San Francisco, 1957 S80E
5 Pacoima record, San Fernando E., S74E
6 Pacoima record, San Fernando E., S16E

4. Evaluation of an earthquake force In evaluating an earthquake force, it is quite reasonable to consider the Structure Damaging Potential advocated by Seed as an effective earthquake force for respective building, but, it seems that Spectrum Intensity of Housner will have wider applicability to express the largeness of an earthquake force that attacked the area under consideration.

However, again referring back to Fig. 2, it can be noticed that in general there is a definite nature to show larger Spectrum Intensity value for larger earthquake destruction but it does not necessarily true in all cases. For example there can be found no big difference in the value of Spectrum Intensity for two earthquakes, No.9 and No.12, the former accompanied by very heavy damage while the latter almost none.

Now consulting to the last column in Table 1 it can be found there is a big difference in the duration time of ground vibration of the two earthquakes. Etq. No.9 which gave large destruction gives definitely longer duration times. Therefore it is proposed in the present paper that the earthquake force could be defined in such a form as Const x V(v) x T(t), where V(v) is a function depending on velocity response spectrum and T(t) a function on duration time of larger amplitudes in the strong motion accelerograms.

In this paper, Spectrum Intensity of Housner was adopted as a functional form of V(v), while as to T(t), we applied a form of log t, because it is observed that the contribution of duration time to the earthquake force is fairly an insensitive character. In this way an earthquake force, EF, can be represented by

$$EF = F(x) \times SI \times \log t$$

where F(x) representing many factors other than herewith considered which may exert influences on earthquake force, for example, ground failure due to strong earthquake motion, vibrational and material characteristics of buildings under the attack of earthquake motions including the elasto-plastic[16] behaviors etc. For simplicity, however, as an first approximation, it may be allowed to put F(x) is almost unity. Under these conditions, in contrasting the (SI x log t) of the earthquakes above mentioned to the seismic intensity at their respective location, assuming that the intensity is representing an overall earthquake force, it was observed that the harmony between SI x log t and intensity was extreemly excellent.

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