# Control of Train Operation on the New Tokaido Line on the Occasion of Earthquake

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The New Tokaido Line is located along the coast of the Pacific Ocean where the activity of earthquakes has been comparatively high in Japan. Because of high speed, long braking distance and frequent service of the train operations, provision against earthquakes has to be seriously considered.

Train operation is regulated in case of earthquakes as follows: running trains are stopped immediately in the event of an earthquake and the train speed is resumed to the normal condition after safety of the track is confirmed. For this purpose, alarm seismographs and communication facilities have been set at 25 transformer substations; and two types of seismographs act automatically in case the horizontal acceleration of the ground exceeds 40 gal and 80 gal respectively. At this time, the electric power supply to the train is cut automatically and their action is communicated to the Centralized Traffic Control Office. Since November 1965, the total number of actions of the seismographs has reached 28. Furthermore, in order to record the ground acceleration during an earthquake, SMAC Type strong motion seismographs have been set near the alarm seismographs.

We are making efforts to improve the method for control of train operation on the occasion of earthquake by examining the frequency and magnitude of earthquakes recorded by means of the instruments and observing the response and damage of tracks and structures.

Thirty-five records of strong motion seismographs have been obtained, though unusually heavy earthquakes have not been experienced as yet. We have studied the relation between magnitude, distance from epicenter and acceleration of different sites in places where frequent records of acceleration have been obtained. It is found that the period and amplitude of acceleration of ground vary in wide range corresponding to topographic and soil conditions.

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Synopsis

On the occasion of earthquakes, running trains on the New Tokaido Line are stopped automatically by cutting the electric power supply and applying the emergency brake. For this purpose, alarm seismographs which act in case the horizontal acceleration of ground exceeds 40 gal were set at 25 substations.

Furthermore SMAC Type strong motion seismographs were installed to record the ground acceleration. We are making efforts to improve the method for control of train operation in case of earthquake, by examining the magnitude, the distance from epicenter and the acceleration of grounds.

## 1. General

The New Tokaido Line is located along the Pacific Ocean Coast where the activity of earthquakes has been comparatively frequent in Japan. Because of the high speed of 210 km/h, the long braking distance and the frequent service, provisions must be made for earthquakes. To consider speed only, if the train traveling at a speed of 210 km/h stops in an emergency on a level track, its braking distance is nearly 2.1 km and the time required to stop is about one minute.

Present knowledge concerning the forecast of earthquakes or the effects of earthquake on structures and train operation with high speed, is not adequate for the conditions we must face. The practical method of control of train operation in case of earthquake practised on the New Tokaido Line is described below.

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2. The present situation to control train operation on the occasion of earthquake

In order to control train operation on the occasion of earthquake, alarm seismographs (AJT-2 Type) and communication facilities were installed at 25 substations as shown in Fig. 1. The alarm seismograph employs the inverted pendulum, the period of which is 0.1 sec. in horizontal vibrations. In order to secure nearly equal accuracy in all horizontal directions, 10 electric contacts are installed around the pendulum. When the pendulum is vibrated and gets in touch with one of these contacts, an electric circuit is made and the electric power supplied to the train is cut automatically. The alarm seismograph is enclosed in a steel box and fixed on a concrete footing in a prefabricated booth.

The numerical value of acceleration to generate the action of the alarm seismograph has been set at 40 gal. The reasons are as follows:

1) Damage of structures due to earthquakes is recognized to occur by the acceleration of 40 gal and over.

2) On the occasion of unusually severe earthquakes, it is desirable to stop trains before the principal portion begins. But the duration time and acceleration of preliminary tremor seem to be from 0 sec. to 30 sec. and seem to be of about one-tenth the magnitude of the principal portion. Also, if acceleration of alarm seismograph corresponds to the preliminary tremor of a severe earthquake, it would be impractical, as it would act by weak earthquakes or artificial shocks.

3) If the set value is smaller than 40 gal, the accuracy of the seismograph would be insufficient for practical use.

When an alarm seismograph acts, the electric power supply to the train between adjacent substations is cut automatically and at the same time emergency brakes are applied to the trains in operation. Their actions are communicated to the Centralized Traffic Control Office in Tokyo. CTC forwards the seismic information to the motorman of the train by the announcement of the Meteorological Agency and Track Maintenance Office.

When considerable damage is thought possible, structure and track inspectors of Track Maintenance Office have to patrol to confirm the condition of the structures and tracks. Their verified conditions are communicated to the CTC, from where orders to the motorman is issued.

When it is ascertained that no serious damage has occurred, electric power supply is restored after a safety delay period of 5 minutes. Then the first train is operated at a speed of 30 km/h, paying attention to the condition of the track and structure. Inspectors travel with the train for this check. After safety of the line is confirmed, the speed of train is raised gradually in the order of 70, 160, and 210 km/h. Normal operations are then continued.

Moreover, an alarm seismograph similar to AJA-2 which acts by the horizontal acceleration more than 80 gal will be set at 25 substations before December 1968. The action of these seismographs is communicated independently to the CTC, and the train dispatchers are able to catch immediately information about the earthquake.

It is important that trains in operation are stopped immediately when an unusually severe earthquakes occurs.

## 3. General situation of past earthquakes along the line

### 3.1 Intensity of earthquakes

Earthquakes occurred from 1921 to 1966 along the line, of which those ranging from IV to VI in the Japanese Seismic Intensity scale are summarized in Table-1.

Relation between the intensity scale and acceleration is as follows.

| | | | |
|---|---|---|---|
| Intensity Scale (JMA) | IV | V | VI |
| Acceleration (gal) | 25-80 | 80-250 | 250-400 |

The annual mean number of earthquakes whose intensity scale is IV and V are respectively 2.1 and 0.5, considering the whole line from Tokyo and Osaka.

The magnitude and number of earthquakes which occurred along the line and was assumed to have influenced the service, are shown in Fig. 2. The general tendencies seem to be as follows.

$$5.9 < M < 6.9 \qquad N = 10^{-0.182M + 0.541}$$
$$6.9 \leqq M < 8.3 \qquad N = 10^{-0.661M + 3.381}$$

Where, N is average annual number of the earthquakes whose magnitude exceeds M, and M is magnitude.

3.2 Data of earthquakes since the opening of the line

The total number of earthquakes which occurred along the line from November 1964 to May 1968 was 95. The number which resulted in the shut down of electric power or the speed reduction of trains was 26, and the details are shown in Table-2. Up to date, the No.9 earthquake is the only one which inflicted damage on the line. The total cost for repair due to the earthquake damage was 38 million yen. The kinds of damage were settlement of tracks, displacement of concrete walls and opening of joints in the culverts. Their numbers were respectively 15 (max 0.8 cm), 2 (max. 0.5 cm) and 4 (max. 5 cm).

4. Study on the record of SMAC type strong motion seismograph

Since October 1966, SMAC (B2) type strong motion seismographs which act on over 5 gal vertical acceleration have been installed on the same 25 concrete footings as the alarm seismographs and at two other sites. The object is to examine the sensitivity of the alarm seismograph and measure ground motion at different sites in case of earthquake.

The acceleration of ground in case of earthquake will vary depending on the magnitude, the epicentral distance, topography, and ground condition. In order to improve the alarm seismograph, we paid attention to the records of SMAC on the line, although there was no severe earthquake.

We studied the amplitude and period of maximum horizontal acceleration and the mean value of three waves near the maximum acceleration in the NS and EW direction. Fig.3 shows the relation between amplitude, period and epicentral distance. In Fig.3(a), (b), it is recognized that acceleration decreases with the epicentral distance, except at Shirobori and Atami. The reason why the amplitude at Shirobori and Atami is comparatively large is assumed to be that both places are on the inclined rocks or talus where the period ranges from 0.7 sec to 0.2 sec.

In Fig.3, (c) and (d) are plotted with examples of comparatively small epicentral distances. From the figures, the effect of epicentral distance is not found. The site where a comparatively large amplitude appears is the point near the epicenter and on the hard ground. However, attention should be paid to the soft ground (as at Iwabuchi) which shows such large amplitude and period in spite of long epicentral distance as shown in Fig.3(e).

In order to find differences in ground conditions, six locations having many seismic records were selected. The ground conditions at these places are as follows.

Shin-yokohama: The surface is a diluvium layer, about 2 m thick, under which there exists a tertiary shale deposit.

Hiratsuka: Alluvium sand

Moritogawa: Thick alluvium sand and gravel

Shirobori: Rock or talus

Atami: Rock or talus

Iwabuchi: Soft surface layer, about 11 m thick, of alluvium clay and sand, under which diluvium sand and gravel are deposited.

The amplitudes and periods measured at these sites are plotted in Fig.4 and Table 3. Predominant periods of microtremor, measured by velocity seismographs, in February 1968, are also shown in these figures. By the results of these measurements, we can qualitatively conclude:

1) Acceleration of ground is related mainly to the degree of the magnitude and the distance from epicenter. Comparatively large acceleration appears in waves of short periods except in Iwabuchi.

2) The period of acceleration tends to be short when the ground is hard. The range is wide and leans to the long period when the ground is soft.

3) There seems to be no tendency that periods of acceleration appear near the predominant period of microtremors and acceleration near the period is comparatively large.

It is difficult to find mentionable results from these weak earthquakes. Because the phenomena of earthquakes are very complicated and range widely, further intensive investigation of severe earthquakes should be done.

## 5. Conclusion

The problems raised in our effort to study further, to ensure safety of operation and to develop structural design in the future are as follows.

1) Possibility of strong earthquakes which would produce damage on the line heavy enough to interfere with the operation of high speed trains.

2) Investigation of practical physical measures to stop trains immediately in the event of severe earthquakes.

3) Relationship between damage to tracks and structures and the magnitude or intensity of earthquakes.

Acknowledgements

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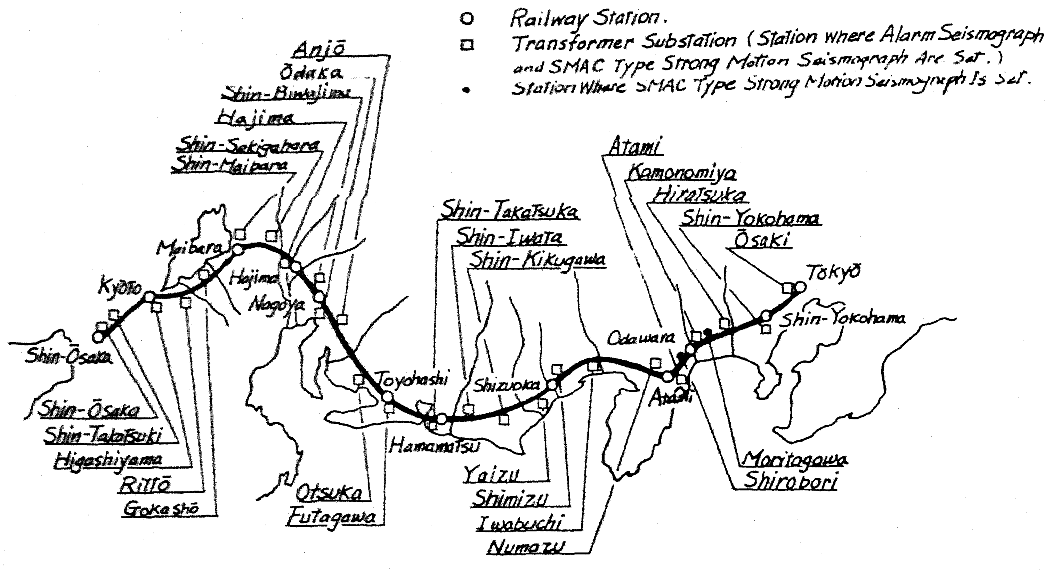



Fig.-1. Station Where Alarm Seismograph and SMAC Type Strong Motion Seismograph Are Set Along The New Tōkaido Line.

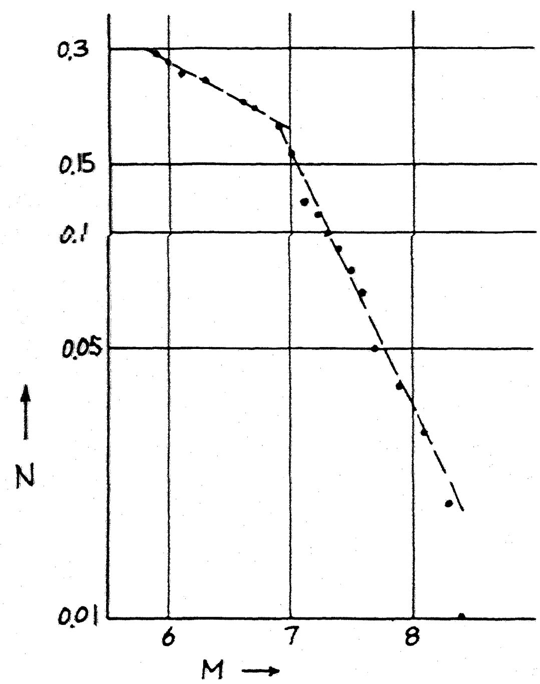
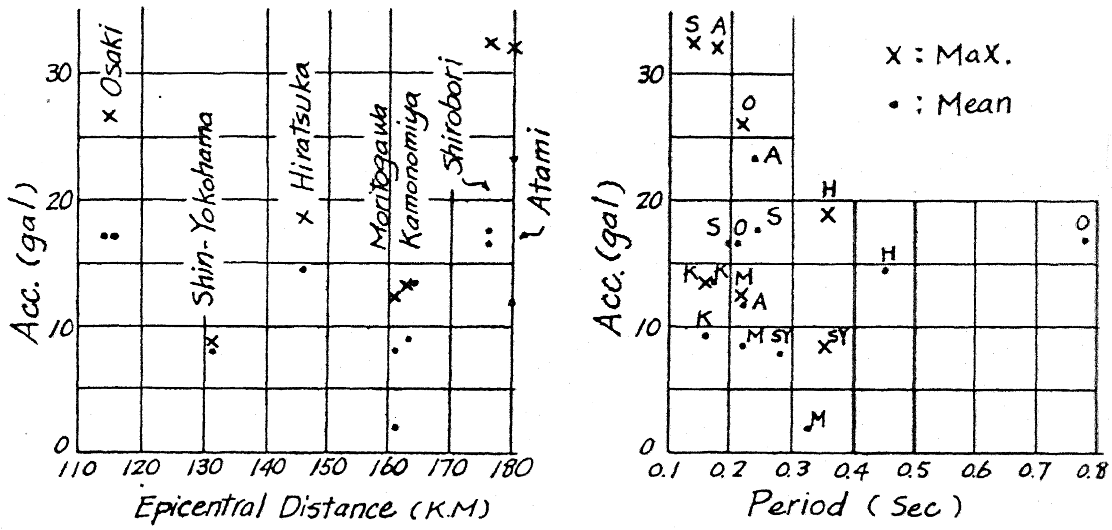
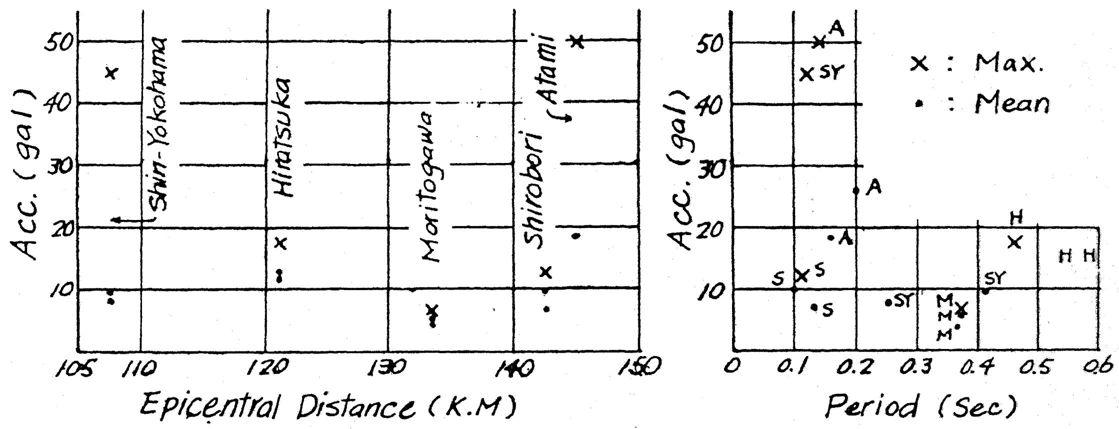


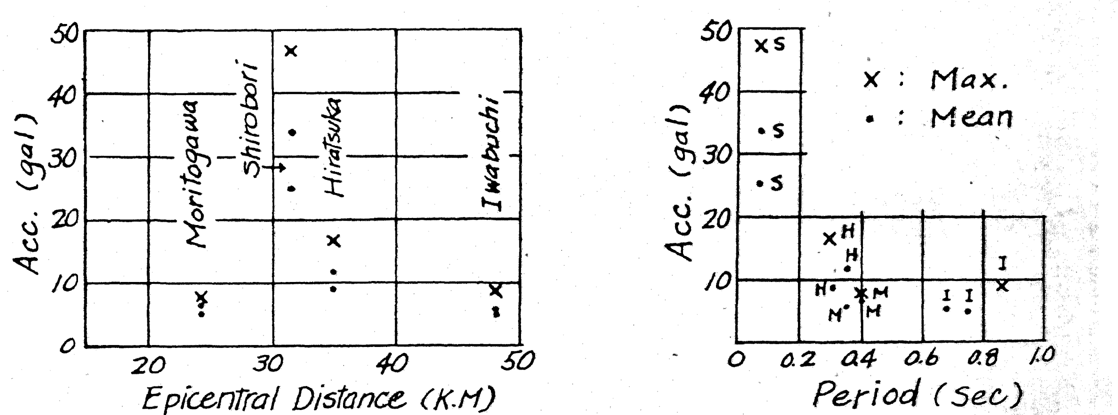

Fig-2 Relation Between Magnitude (M) and Average Annual Number (N) of Earthquakes Heavier than Magnitude M.




(a) Mt. Tsukuba-Earthquake (Mar. 19 1967 M = 5.4)

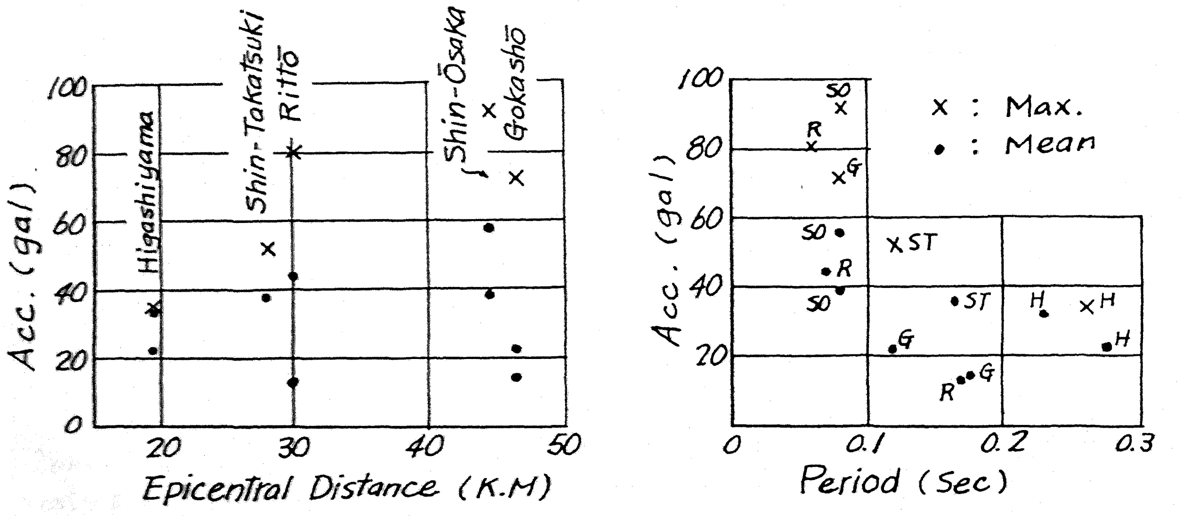



(b) Central Part in Chiba Pref. Earthquake (Nov. 10 1967 M ≑ 5.3)

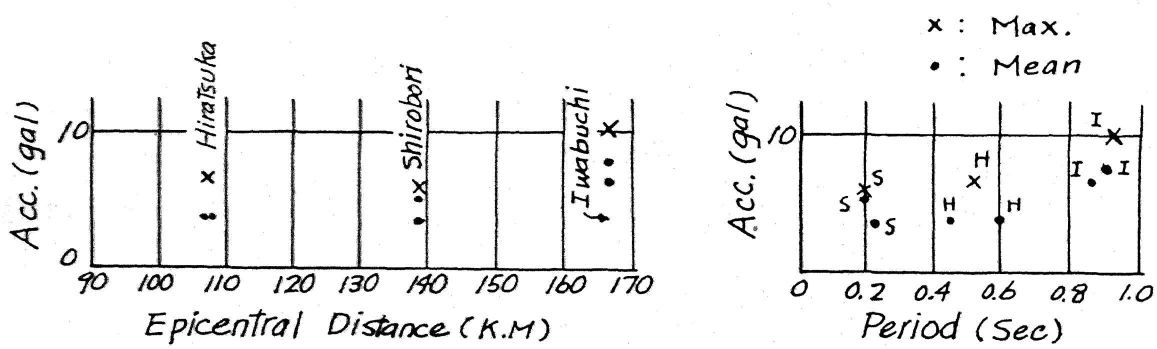



(C) West Part in Kanagawa Pref. Earthquake (Mar. 27 1967 M=4.4)

Fig-3 Relation between Epicentral Distance and Acceleration




(d) South Part in Kyōto Pref. Earthquake (June 21 1967 M=4.6




(e) Mt. Tsukuba Earthquake (Mar. 21 1967. M=5.1)

Fig-3 Relation between Epicentral Distance and Acceleration

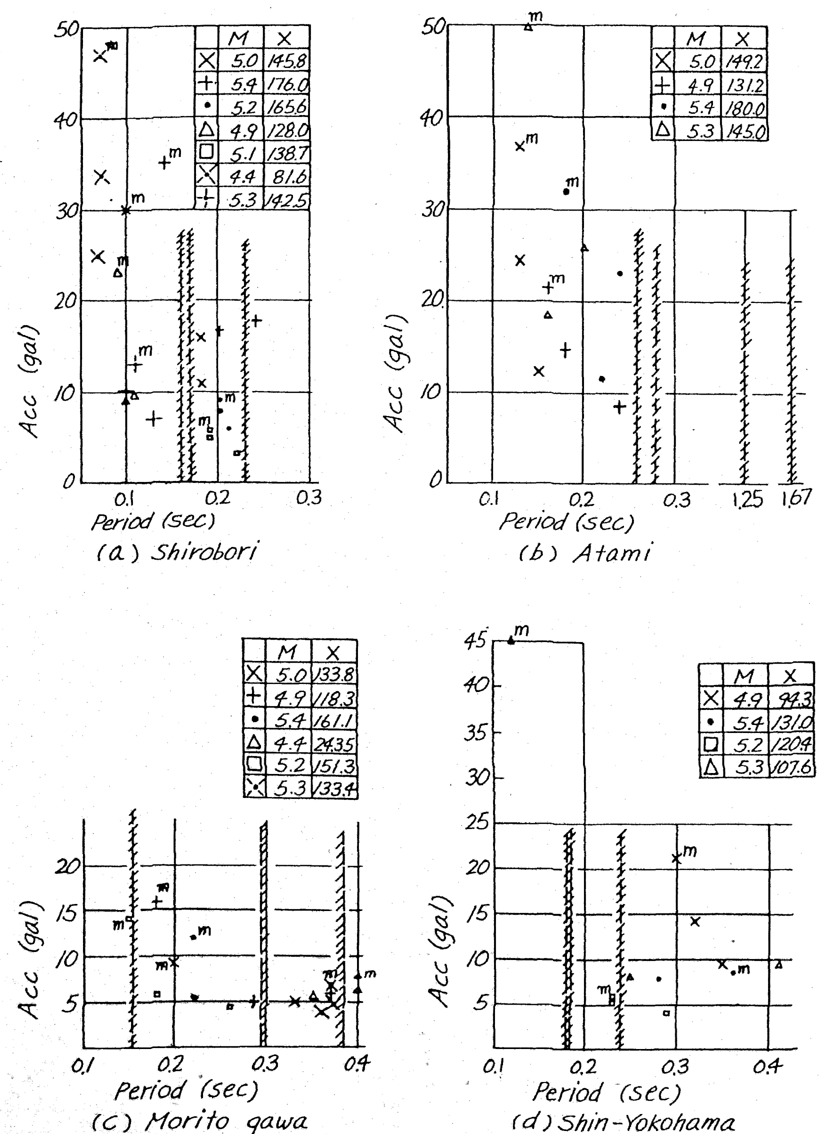
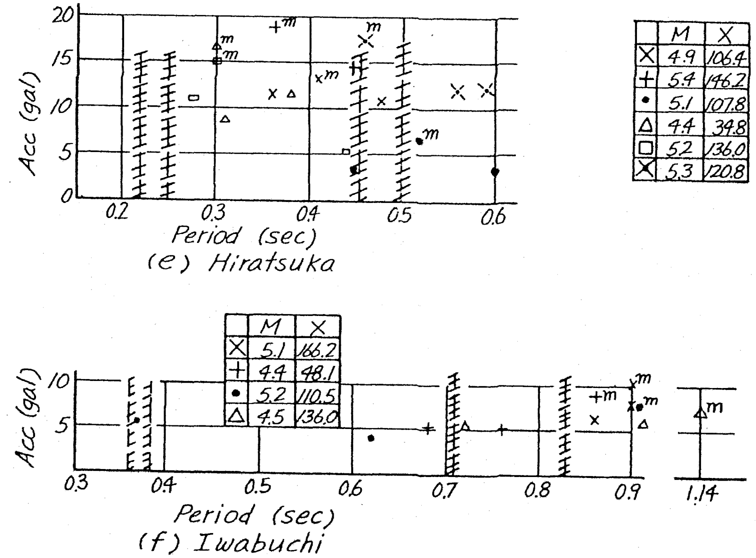



Fig-4 Acceleration of Ground




Note m : Maximum Amplitude
(symbol) : Predominant Period of Microtremor
M : Magnitude X : Epicentral Distance (K.M.)

Fig-4 Acceleration of Ground

Table-1 Number of Earthquakes heavier than Seismic Intensity IV

| Station / Seismic Intensity / Year | Tokyo | | | Yoko-hama | | | Mishima | | | Shizu-oka | | | Hama-matsu | | | Nagoya | | | Gifu | | | Kyoto | | | Osaka | | | Sum | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IV | V | VI | IV | V | VI | IV | V | VI | IV | V | VI | IV | V | VI | IV | V | VI | IV | V | VI | IV | V | VI | IV | V | VI | IV | V | VI |
| 1921 - 1930 | 13 | 9 | 1 | 4 | 4 | 0 | From 1930 2 | 0 | 1 | | | | 0 | 0 | 0 | From 1926 3 | 0 | 0 | 2 | 1 | 0 | 2 | 1 | 0 | 2 | 0 | 0 | 28 | 15 | 2 |
| 1931 - 1940 | 4 | 0 | 0 | 7 | 1 | 0 | 1 | 1 | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 1 | 0 | 0 | 15 | 4 | 0 |
| 1941 - 1950 | 1 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 4 | 1 | 0 | 3 | 2 | 0 | 6 | 0 | 0 | 3 | 0 | 0 | 24 | 4 | 0 |
| 1951 - 1960 | 4 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 15 | 0 | 0 |
| 1961 - 1966 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 8 | 0 | 0 |
| Sum | 22 | 9 | 1 | 22 | 5 | 0 | 6 | 1 | 1 | 3 | 0 | 0 | 1 | 1 | 0 | 10 | 1 | 0 | 6 | 3 | 0 | 12 | 3 | 0 | 8 | 0 | 0 | 90 | 23 | 2 |

Table-3 The range of records of accelerations

| Site | Range of Period (sec) | Range of Amplitude (gal) |
|---|---|---|
| Shirobori | 0.25 - 0.07 | 47 - 6 |
| Atami | 0.25 - 0.13 | 50 - 9 |
| Moritogawa | 0.40 - 0.15 | 16 - 4 |
| Shin-Yokohama | 0.41 - 0.23 | 45 - 4 |
| Hiratsuka | 0.60 - 0.27 | 19 - 3 |
| Iwabuchi | 1.14 - 0.37 | 10 - 5 |

Table-2 Earthquakes Which Influenced to the Train Operations

| No | Epicenter | Date | Seismic Intensity (J.M.A) | M | Circumstance of Operation |
|---|---|---|---|---|---|
| 6 | Middle Stream of The Tone River | '65. 1. 27 | III : Tōkyō, Yokohama<br>II : Shizuoka, Mishima | | Stoppage of Electric Supply (Tōkyō – Odawara) |
| 7 | South Part in Ibaragi Pref. | '65. 4. 6 | II : Tōkyō, Yokohama<br>I : Mishima | 5.5 | Stoppage of Electric Supply (Tōkyō – Odawara) |
| 9 | Suruga Bay | '65. 4. 20 | IV : Yokohama, Shizuoka, Mishima<br>III : Nagoya. Tōkyō<br>II : Gifu, Kyōto. Ōsaka | 6.5 | $8^h42^M$ Stoppage of Operation (Atami-Hamamatsu)<br>$14^h10^M$ Open (Shizuoka-Hamamatsu)<br>$15^h40^M$ Open (Atami-Shizuoka) |
| 11 | North Part in Chiba Pref. | '65. 5. 31 | III : Tōkyō<br>II : Yokohama | | Stoppage of Electric Supply (Tōkyō – Odawara) |
| 15 | Uraga Channel | '65. 7. 18 | I : Tōkyō, Yokohama | 4.4 | Stoppage of Electric Supply (Tōkyō – Yokohama) |
| 29 | Kameyama. Kyōto Pref. | '66. 3. 10 | III : Kyōto<br>I : Nagoya. Ōsaka | 4.6 | Action of Alarm Seismograph (Higashiyama, Shin-Takatsuki) |
| 32 | Off Ibaragi Pref. | '66. 4. 3 | III : Tōkyō<br>I : Yokohama | 5.8 | Speed Down (Tōkyō – Yokohama) |
| 34 | Near Mt. Ibuki | '66. 5. 26 | III : Nagoya. Gifu<br>I : Kyōto. Ōsaka | 5.1 | Action of Alarm Seismograph (Hajima. Maibara. Sekigahara) |
| 38 | North Part in Ōsaka Pref. | '66. 6. 29 | II : Ōsaka | 4.7 | Action of Alarm Seismograph (Shin-Ōsaka) |
| 39 | East of Mt. Ibuki | '66. 8. 3 | II : Nagoya<br>I : Gifu. Kyōto. Ōsaka | 4.6 | Action of Alarm Seismograph (Sekigahara. Maibara. Gokashō) (Ritto) |
| 40 | Central Part in Tōkyō Bay | '66. 8. 29 | II : Yokohama<br>I : Tōkyō. Mishima | | Action of Alarm Seismograph (Atami) |
| 42 | Between Ōsaka and Kyōto Pref. | '66. 10. 3 | II : Kyōto<br>I : Ōsaka | 3.8 | Action of Alarm Seismograph (Shin-Takatsuki) |
| 43 | Off Bōsō Pen. | '66. 10. 8 | III : Tōkyō<br>II : Yokohama | 4.9 | Speed Down (Tōkyō – Yokohama) |

Table-2 Earthquakes Which Influenced to the Train Operations

| No | Epicenter | Date | Seismic Intensity (J.M.A) | M | Circumstance of Operation |
|---|---|---|---|---|---|
| 45 | Down Stream of the Ōi River | 66.10.27 | III : Shizuoka<br>I : Nagoya. Mishima | 4.4 | Action of Alarm Seismograph (Shimizu) |
| 46 | North part in Chiba Pref. | 66.10.28 | II : Tōkyō, Yokohama, Mishima<br>I : Shizuoka | 5.0 | Action of Alarm Seismograph (Atami) |
| 47 | South part in Kyōto pref. | 66.11.4 | II : Kyōto | 3.6 | Action of Alarm Seismograph (Shintakatsuki) |
| 52 | East Part in Yamanashi pref | 67.1.5 | I : Tōkyō. Yokohama | 4.4 | Action of Alarm Seismograph (Kamonomiya) |
| 57 | Central Part in Chiba Pref. | 67.3.2 | III : Yokohama<br>II : Tōkyō<br>I : Shizuoka. Mishima | | Action of Alarm Seismograph (Ōsaki) |
| 61 | Off Boso Pen. | 67.5.16 | II : Mishima<br>I : Tōkyō. Yokohama | 4.5 | Action of Alarm Seismograph (Atami) |
| 64 | Central Part in Kyōto Pref. | 67.6.21 | III : Kyōto<br>II : Ōsaka, Nagoya | 4.6 | Action of Alarm Seismograph (Ritto, Shin-Takatsuki, Shin-Ōsaka) |
| 67 | South Part in Shizuoka Pref. | 67.8.2 | III : Shizuoka<br>I : Atami | 4.1 | Action of Alarm Seismograph (Yaizu) |
| 77 | Central Part in Chiba Pref. | 67.11.10 | III : Tōkyō. Yokohama | | Action of Alarm Seismograph (Ōsaki, Atami) |
| 80 | South Part in Kyōto Pref. | 68.1.20 | III : Kyōto<br>II : Ōsaka | 4.4 | Action of Alarm Seismograph (Shin-Takatsuki Shin-Osaka) |
| 81 | North Part in Chiba Pref. | 68.1.23 | II : Tōkyō. Yokohama<br>I : Mishima | | Action of Alarm Seismograph (Atami) |
| 86 | Central Part in Chiba Pref. | 68.3.7 | III : Tōkyō. Yokohama<br>I : Mishima | | Stoppage of Electric Supply (Tōkyō - Odawara) |
| 95 | Eastern Part in Shizuoka Pref. | 68.5.31 | I : Mishima | | Action of Alarm Seismograph (Atami) |