NEW AUTOMATIC TRAIN STOPPING SYSTEM DURING EARTHQUAKE

by

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SYNOPSIS

The fundamental model of a new automatic train stopping system during earthquake has been worked out. This system is based on the following two ideas. The one is setting the seismic detection points away from the railway line toward the expected foci. The other is prediction of the amplitude of subsequent maximum motion from waveform of preliminary tremor. The tripartite network observing system with a mini- computer on line will make it possible to estimate approximately the focus and the magnitude in an early stage.

INTRODUCTION

Strenuous efforts have been rendered by JNR to assure the safety of running trains in the event of a large earthquake. The efforts include establishment of a system for automatically halting the train within fifty kilometers centered around the line for the sake of safety, when a seismic acceleration of more than forty gals is detected on the ground along a railway line. Detectors for this purpose were initially installed along the Tokaido SHINKANSEN and they have proved effective in detection of more than fifty earthquakes in the last ten years. Commonly, however, such a value of acceleration occurs even in an earthquake of considerable magnitude, several seconds before a seismic motion of maximum acceleration takes place (See Fig. 1). Such a system should be so modified as to be able to stop running trains still earlier, because forty gals acceleration is an inappropriate value at which it is too late to make the train speed decrease before a deformation and a destruction of railway structure occur.

For instance, consider the route of a high speed railway line now being under construction in the northeastern region of Japan. Most of large earthquakes causing havoc in this region are known to originate from the Pacific Ocean. Now for the sake of prolonging further such a time margin of several seconds, the following two methods are being considered.

1) If the seismic detection points are set off the line toward the foci, the time differences in wave propagation between the line and the detection points will give a sufficient time for the train to be safely decelerated before a large earthquake hits. Further, since a felt earthquake in a wide area can be considered a strong earthquake, deceleration of train when tremors of relatively small amplitudes reach in an early stage will make a successful counterplan for a large earthquake, if seismographs are set at a large number of points. However, detection of an earthquake at many spots takes some time; accordingly instruments have to be set in a well-considered arrangement.

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2) Earthquake damage does not generate generally at the stage of preliminary tremor, but occurs at the time of maximum motion or later. Except near the source region, therefore, proposition of some time margin corresponding to S-P will be effective to allow a train to decelerate before a maximum motion hits. For example, such S-P time as 15 to 25 seconds at the damaged sites was observed in the 1968 Tokachi-oki Earthquake which originated from the Pacific Ocean. Now prediction of the amplitude of subsequent maximum motion from waveform of preliminary tremor, which is associated with the source mechanism and so on, would be difficult. However, the data on amplitude or period in time domain will provide clues to it. Also using a mini-computer on line, it will be possible to estimate approximately the focus and the magnitude in a very short time. We have hastened this study under from this point of view.

RELATIONSHIP BETWEEN EARTHQUAKE MAGNITUDE
AND PERIOD OF INITIAL MOTION OF P WAVE

Relationship between the magnitude M and the period T of the initial motion of P wave has been investigated by many researchers. Kasahara (1957) studied the period of the initial motion by performing Fourier transformation on the initial motion in the horizontal seismograms recorded by a long period seismograph, and showed the following equation (1) from the data on large earthquakes of magnitude $M > 5$.

$$\log T = -2.59 + 0.51 M \qquad (1)$$

Terashima (1968) also studied the similar period by performing the same transformation or by reading the apparent period. His result is shown as the equation (2) for the microearthquakes of magnitude $0 < M < 3$.

$$\log T = -1.79 + 0.47 M \qquad (2)$$

He found that the two equations above stated had both almost the same inclinations. Then from the result of the statistical treatment of the data which were used to obtain equations (1) and (2), he showed that these two equations could be reduced to one equation as follow,

$$\log T = -1.40 + 0.30 M. \qquad (3)$$

From equation (3) or Fig. 2, we can know that the period T of the initial motion and the magnitude M are linear and the period T of more than one second will be needed for our purpose.

RELATIONSHIP BETWEEN MAXIMUM MOTION AND
PRELIMINARY TREMOR WITH AMPLITUDE

For the comparison between the maximum motion and the preliminary tremor with amplitude, the horizontal seismograms being recorded at the JMA stations were read. Effective number of earthquakes is 192, and the number of seismograms is 282 for strong motion seismographs and is 503 for JMA electromagnetic seismograph. The stations distribute in the Pacific Ocean side of the northeastern region. The epicentral distribution of the earthquakes used is shown in Fig. 3, and the numbers of seismograms being adopted for every intensity and station

are shown in Table 1. The reason for using two kinds of seismograms is that the one takes records of large amplitudes and the other does ones with clear preliminary tremor.

Outstanding results of analysis are shown in Fig. 4. In this figure, M_0 is the maximum amplitude, P_3 is the maximum amplitude of which time interval is 3 seconds from the onset of P wave, and P_m is the maximum amplitude in preliminaly tremor. The upper two are for all earthquakes and the lower two are for the earthquakes of the intensity more than four. M/P_3 has a peak value of about five, but it may be difficult to predict with high probability the amplitude of the maximum motion from the amplitude of preliminary tremor. M/P_m has a sharp peak value, but these values frequently appear at the end part of the preliminary tremor. This method is not useful for us because it takes too long time to stop a train. Lower two figures show the same tendency as upper two.

EARTHQUAKE OBSERVATION ON TRIAL AND THE TRAIN STOPPING SYSTEM WITH COMPUTER

To put such a system into practice, earthquake observation on trial is required together with an analysis of the past seismograms. We have not sufficient data to work out an appropriate judgment system in a short time. The purpose of this observation is as follows ;

1) Many earthquakes of different magnitudes must be observed from the initial motion of P wave to coda by seismographs of the same characteristics. We have to know the nature of waveform in relation to the source mechanism or the source region.

2) It is indispensable to know the focus in a short time, and to know the differences between an earthquake and a ground noise. Finally we must raise the accuracy of prediction of the amplitude of maximum motion from the preliminary tremor.

Considering the above metioned matters, we are now tentatively observing earthquake motions near the seaside of the region as stated before by tripartite network method with about 25 kilometers separation of the points. Wire - tele-metering method is adopted from the observation points to the recording center, and the seismographs, mainly velocity type and partially displacement and acceleration type, are all installed on the rock in the tunnels. In this equipment, the storage or the calculation of the seismic data to be used for the prediction system in a short time is done in the mini-computer on line. Analysis of the recorded data for raising the accuracy of prediction is done after rerecording the magnetic tapes which have been recorded through a delay circuit of thirty seconds. The overall frequency range of the seismographs is about 20 to 0.1 Hz. Identification of a seismic wave from a ground noise must be made under consideration of the differences between them in the frequency range, the duration, the spatial simultaneity, the arrival time, the sense and the amplitude of the initial motion and so on.

CONCLUDING REMARKS

The fundamental model of a new automatic control system of train speed during earthquake has been worked out. Detective seismographs at many spots are set off the railway line toward the foci, and prediction of the amplitude of maximum motion from waveform of preliminary tremor has been studied. Using a mini-computer on line, it is possible to estimate the focus and the magnitude in an early stage. Then the judgement about whether an earthquake affects the safety of the line or not will be possible with some techniques mentioned above. Concerning some earthquakes of maximum amplitudes too small for such a judgement, it is expected to find a practical way out of the difficulty by train speed control such as reacceleration after deceleration.

ACKNOWLEDGEMENT

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2) Terashima T., 1968, Magnitude of Microearthquake and the Spectra of Microearthquake Waves, Bulletin of International Institute of Seismology and Earthquake Engineering, Vol. 5, pp. 31 - 108.

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Table 1 The numbers of seismograms being adopted for every intensity and station.

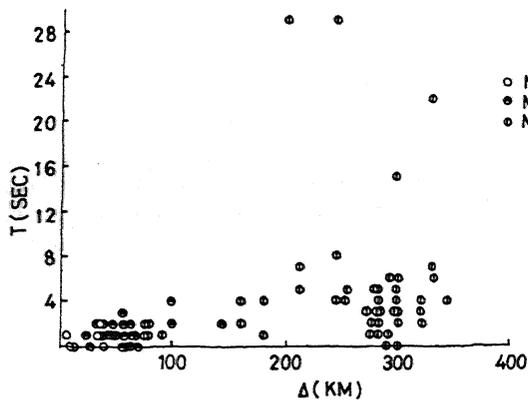| SITE No. JMA INTENSITY	1	2	3	4	5	6	7	8	9	10
0	1	4	3	31	16	18	24	20	16	3
x		5	4		1	3	3	4	2	1
1	1	11	18	16	16	25	31	20	16	3
2	11	27	25	18	24	11	23	14	14	9
3	7	17	19	9	14	14	6	10	14	9
4	4	9	12	6	6	5	3	4	5	2
5		1	1				1			

Fig. 1 The relation between epicentral distance Δ and time difference T from 40 gals to maximum acceleration by the SMAC accelerograms.
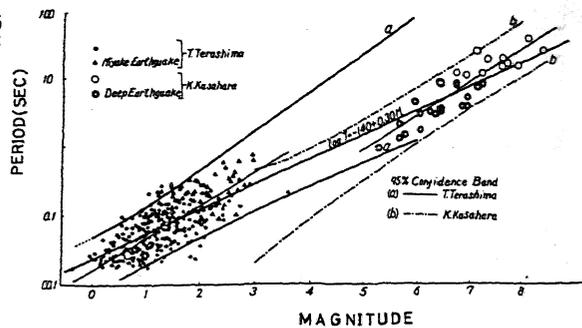

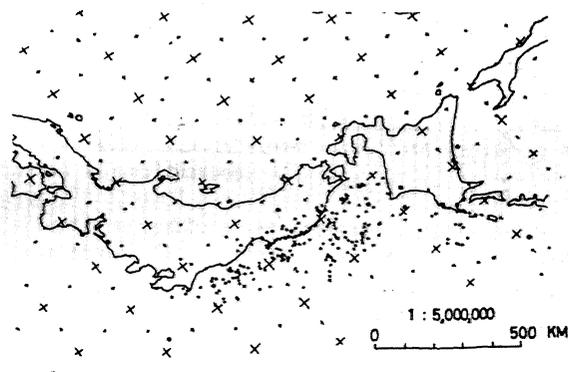Fig. 2 The comparison of the relations between M and T (after Terashima).

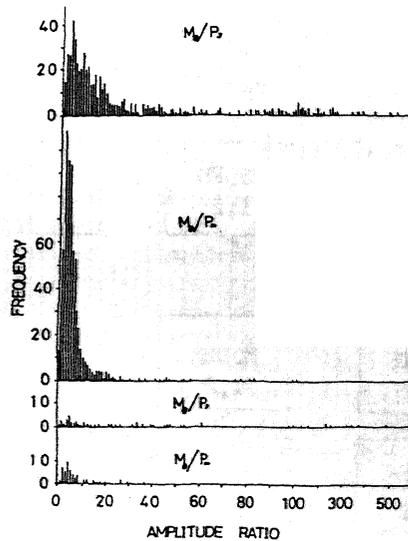Fig. 3 The epicentral distribution of the analysed earthquakes.

Fig. 4 The histogram of the amplitude ratio M_a/ P.

DISK   MT
PTR   ET

CPU
32K

TRANSMIS.
CONTROL
PART

TRAIN
CONTROL
CENTER

LAMP BELL
CONTACT O.P.
ET

PIO

EARTHQ.
SIGNAL

EARTHQ. LEVEL
SELECT. APPARATUS
TRIGGER SIGNAL

DATA   RECORDER
14 CH ✗ 3

LONG TIME
RECORDER
3 CH

AMP.
UNIT

DELAY
UNIT

D / A CONV.
UNIT

DELAY
UNIT

D / A CONV.
UNIT

TIME
CORDER

LOGIC
PART

LOGIC
PART

A / D CONV. UNIT

MODEM
1,2

MODEM
1,2

BUFFER AMP. UNIT

CRYSTAL
CLOCK

MODEM
1,2

MODEM
1,2

LOGIC
PART

LOGIC
PART

AMP.UNIT
LEVEL 1,2
VFB UNIT

AMP.UNIT
LEVEL 1,2
VFB UNIT

AMP.UNIT
LV 1,2,3,4
VFB UNIT

AMP.UNIT
LV 1,2

AMP.UNIT
LEVEL 4

PICK UP
3 COMP.
VEL.TYPE
OBS.PT.1

PICK UP
3 COMP.
VEL.TYPE
OBS.PT.2

PICK UP
3 COMP.
VEL.TYPE

PICK UP
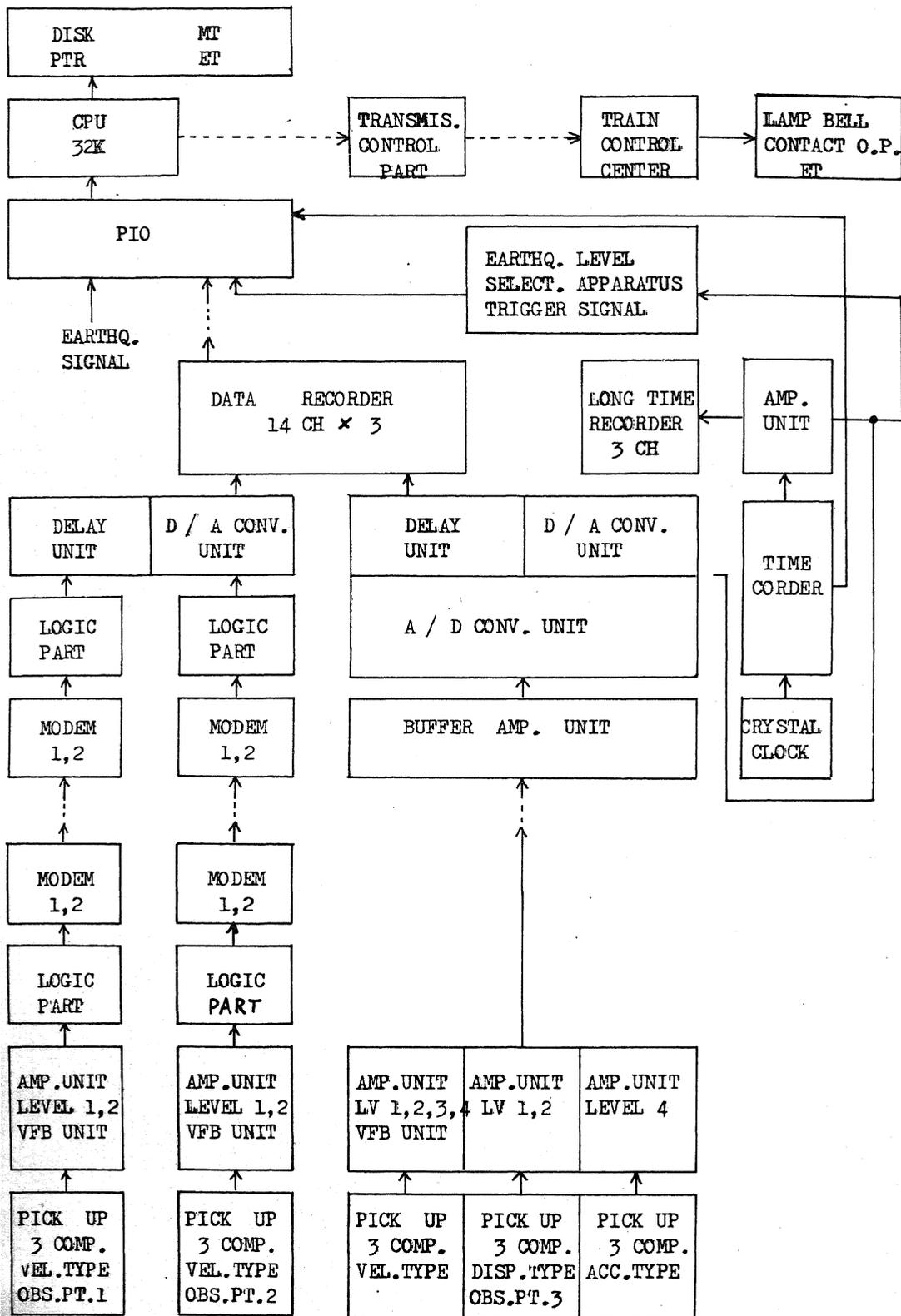3 COMP.
DISP.TYPE
OBS.PT.3

PICK UP
3 COMP.
ACC.TYPE

Fig. 5 The block diagram of the system for the earthquake observation and the train control on trial.