Observation of Earthquake Strong-Motion with Deep Boreholes
—— An Introductory Note for Iwaki and Tomioka Observation Station in Japan ——

by

Research Committee on Earthquake Observation
with Vertical Instrument Array in Rock

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SUMMARY

Vertical instruments arrays for observation of earthquake strong-motion have been established at Iwaki and Tomioka, which are about 200km distant from Tokyo. Several accelerometers are arranged vertically from bedrock to ground surface at each station. The bedrocks, of which shear-wave velocity is about 3 km/s, are located at 920m in depth for Tomioka station and at 310m in depth for Iwaki station. Objectives of observation at these stations are to make clear the characteristics of earthquake ground motion at bedrock and to estimate the amplification of seismic-wave amplitudes in surface layers. Details of observation systems, results of geophysical logging, and some observed accelerograms are discussed in the text.

1 OBSERVATION ARRAYS

(i) Site Selection

Tomioka and Iwaki in Fukushima prefecture were selected as observation sites (Fig.1). Station code of the former is TMK and that of the latter is IWK.

We intend to observe seismic ground motion in the hard rock of which shear-wave velocity is larger than 1200 m/s at IWK station, and in rock layers of which shear-wave velocities are 600 m/s in the upper layer and 1200 m/s in the lower layer at TMK station. Main conditions for selecting observation sites are as follows. (1) The observaton sites are located in or near the high seismic activity region. (2) Geological structure of the observation sites should be as simple as possible. (3) Thickness of alluvium or delluvium that overlies the rock layer should be very thin.

(ii) Vertical Arrays and Sub-arrays

Geological structure and location of accelerometers at IWK and TMK stations are shown in Fig.2.

The main observation station, IWK, consists of seven observation points. Six points are arranged at GL-330m, GL-200m, GL-130m, GL-70m, GL-20m and at GL. And another accelerometer is installed at GL, on the top of the alluvial

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layer. The main TMK observation station consists of six observation points at GL-950m, GL-660m, GL-251m, GL-100m, GL-6m and at GL. Two other observation points are installed to form a horizontal triangle array of which sides are about 150m. The seismometers of two points are set up at GL-6m and GL-4m respectively at the top of the Neogene sedimentary rock.

(iii) Site Description

Fig.3 and Fig.4 show the detailed underground structures at IWK and TMK, which were known from the result of PS-log, formation density log, electric log and surface seismic prospecting. The geophysical loggings were carried out at the deepest borehole. Fig.5 shows the explosion seismic prospecting across TMK station. This result (Vp) is consistent with the velocity obtained by 'S-log in Fig.4. The distance of IWK and TMK is about 30km. The Palaeogene and Neogene sedimentary rock layers are on the bedrock at TMK, while the Palaeogene sedimentary rock layer is on the bedrock at IWK. Therefore, level of bedrock at TMK is about 600m deeper than that of IWK.

2 OBSERVATION SCHEME

(i) Operating System

Location and Geological conditions for the main observation stations of IWK and TMK were explained in the above section. Sub-stations are constructed at Kodamagawa (KDG) for IWK station, and at Idegawa (IDG) and Hokidaira (HKD) for TMK station. Accelerometers of sub-stations are installed on the outcrop of the rock layer which corresponds to the bedrock at the main stations respectively. Control and monitering center (CMC) to operate these stations was established in the laboratory of Kajima Institute of Construction Technology in Chofu city, suburb of Tokyo. The CMC and the observation stations are connected by public telephone lines, so as to check the functions of instrumentation system of the stations, and to transmit the observed records from the stations to the CMC without visiting the site.
Fig.6 shows the rough schematic block diagram of this system.

(ii) Instrumentations

The specifications of accelerometers and observation equipments are shown in Table 1. The sensor unit is composed of three components of NS, EW and UD. Data of about five seconds are always stored in the delaying circuit. Seismic wave informations from sensors are recorded by the analog data recorder and the digital cassette recorder. Automatic Gain Control (AGC) has ranges down to 1/3 and 1/10, so that destructively intense ground motion can be recorded with no saturation. The trigger levels of recorders at main stations are adjusted at 0.3 Gal for the deepest observation points (GL-330m for IWK, GL-950m for TMK) and the sensitivity of all accelerometers are arranged at 50 Gals in full scale, in consideration of the results of preliminary observation. Trigger level and sensitivity of instruments at sub-stations are shown in Table 1.

3 RECORDED EARTHQUAKES

(i) Analyzed Earthquakes

Routine observation started on August, 1981 at IWK and on August, 1982 at TMK. Number of observed earthquakes is 100 and 81 up to July 1983 for IWK and TMK, respectively. Accelerograms for 28 earthquakes observed at IWK and 29 earthquakes at TMK are analyzed to study vertical distribution of maximum amplitudes and response spectra. Location of epicenters and magnitudes for analyzed earthquakes are shown in Fig.7. With regard to the earthquakes represented by the shaded circles in Fig.7 some discussions will be given below.

(ii) Vertical Distribution of Maximum Accelerations

The distribution of maximum acceleration with depth was worked out for the earthquakes that gave larger acceleration than 0.5 Gal for all three components, NS, EW and UD of the deepest sensor. The result of the NS component is shown in Fig.8. The outstanding characteristic exhibited in Fig.8 can be pointed that the amplification of the acceleration is observed only in the soft thin layer, which is found in the uppermost part of the vertical array site. This result is obtained from the observed accelerograms for the earthquakes of which magnitudes are less than 6. This means that the results are derived from the seismic time histories composed mainly of short-period waves. In the future investigation, the acceleration amplification with depth should be studied using earthquake records of larger earthquakes (M>6) which are expected to be including much longer wave component.

(iii) Response Spectra

With regard to the six earthquakes that gave good records at both stations response spectrum analysis was carried out. In Fig.9 the response spectra calculated from the records of deepest seismometers (NS component) at both stations are compared for all these six earthquakes. It is noticed firstly for the case of the two events, EQ.3 and EQ.5, the spectra of the both stations are showing quite a same shape. The EQ.5 has an extremely large epicentral distance (R) and EQ.3 has a very large focal depth (D). In both cases the wave paths of these earthquakes must have shown a fairly large incident angle. Secondly, all other earthquakes did not give much difference in magnitude, epicentral distance and forcal depth. In spite of it, there are considerable difference in shape between the spectra of the two stations. This difference may suggest a lateral inhomogeneity of the crustal structure around these stations. On the other hand, Fig.10 shows the response spectra calculated from the records of two different earthquakes, of which hypocenter located close to each other, obtained by the same seismometer installed at the deepest point of TMK station. This shows that even the records of the earthquakes, of which hypocenter are located so closely, can give quite different response spectra.

(iv) Recorded Earthquakes of Sub-station

Two earthquakes (EQ.6 on July 2, 1983 and EQ.8 on July 23, 1982) has been observed simulteneously at IWK station and KDG sub-station up to July 1983. Maximum acceleration values of the records are shown in Fig.11. Maximum ac–

celerations observed at KDG are smaller than those at the deepest point of IWK for EQ.6, while the former are larger than the latter for EQ.8.

4 CONCLUDING REMARKS

At IWK station 100 earthquakes were recorded since August 1981, and at TMK station 81 earthquakes since August 1982. About 20 percents of these earthquake records have been filed in the form of digitized events. It has already carried out somewhat analysis with these digitized data. Active research works are now being carried on among our research group using these data with many subjects, for example the evaluation of damping of seismic waves in rock medium.

This project is jointly founded by six electric power companies in Japan, that is, Tohoku Electric Power Company, Tokyo Electric Power Company, Chubu Electric Power Company, Hokuriku Electric Power Company, Chugoku Electric Power Company and Japan Atomic Power Company. For the purpose of giving the most effective excutions of this project, a research committee inscribed on the title was formed. The members of this committee are S. Omote (committee chairman, Professor, Kyushu Sangyo Univ.), Y. Ohsaki (ex-professor, Univ. of Tokyo), Y. Ohsawa (Professor, Earthquake Research Inst., Univ. of Tokyo), E. Shima (Professor, E.R.I., Univ. of Tokyo), S. Yoshikawa (Professor, Disaster Prevention Research Inst., Kyoto Univ.), M. Watabe (Director, I.I.S.E.E., Building Research Inst.) and Y.Kameda (Director, Kajima Institute of Construction Technology). And the committee secretaries are T. Ohta (Chief research engineer, K.I.C.T.) and N. Adachi (Senior research engineer, K.I.C.T.).

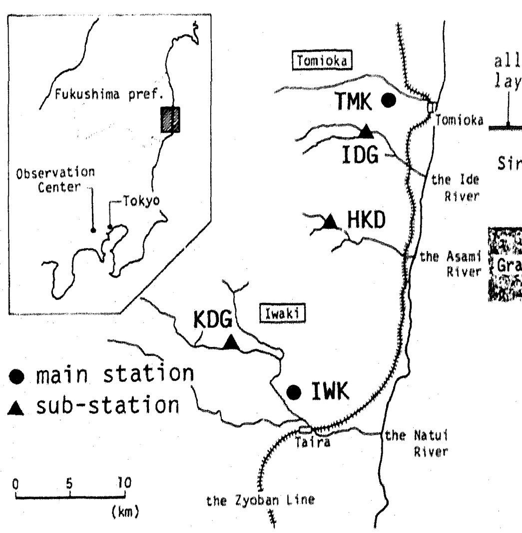

Fig.1 Location of Observation Stations

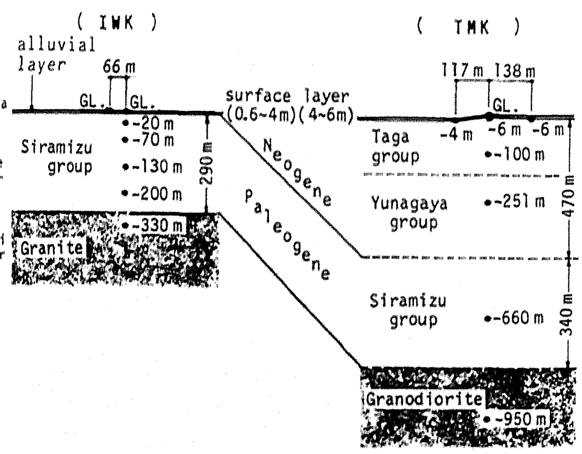

Fig.2 Observation Points of Main Stations

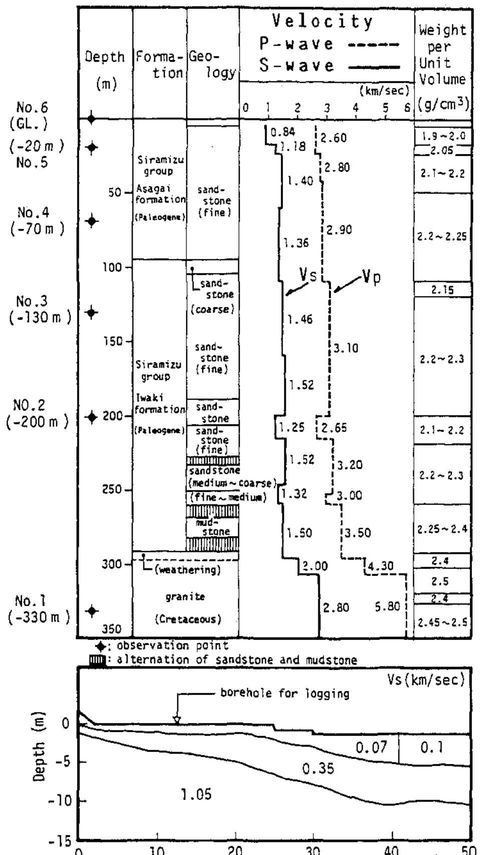

Fig.3
Results of Geophysical Logging and Observation Points of IWK

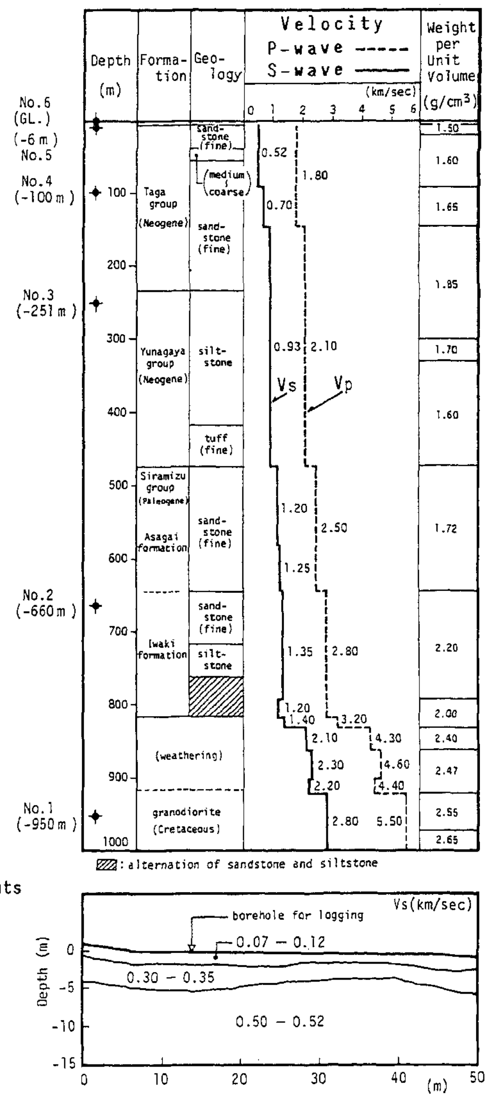

Fig.4
Results of Geophysical Logging and Observation Points of TMK

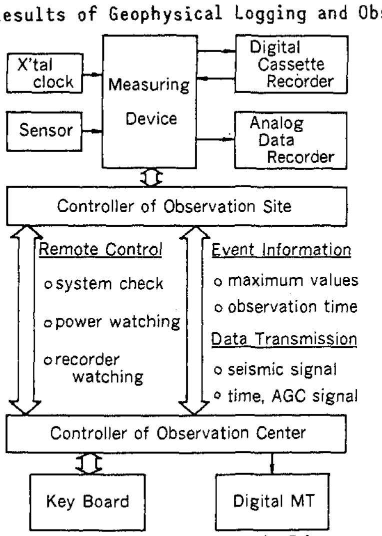

Fig.6 Schematic Block Diagram

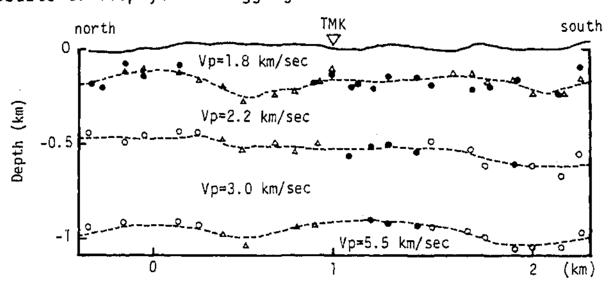

Fig.5 Results of Surface Seismic Prospecting in TMK

instruments	specifications
sensor	accelerometer ; servo type of velocity feed back
signal conditioner	0.005 – 500 Gal
delaying device	A/D converter ; 12bits 100 Hz or 200 Hz sampling delaying time ; 10.24 sec or 5.12 sec selectable
trigger,AGC	starter ;0.1~30 Gal selectable,AGC ; x1/3, x1/10
time code generator	clock ; x'tal clock+auto-calibrator by radio time signal time code ; slow code 30 sec frame, BCD code out put
analog data recorder	FM recording ; 14 channels
digital recorder	3M-type, 4 trucks, cassette MT
telemetering	public telephone line, 1200 bit/sec. PCM
power supply	surge absorbed AC line with battery of 6 hrs capacity
DSA-1 (sub-station)	500 Gal max., 2 Gal start, digital cassette recorder

Table 1 Specifications of Observation System

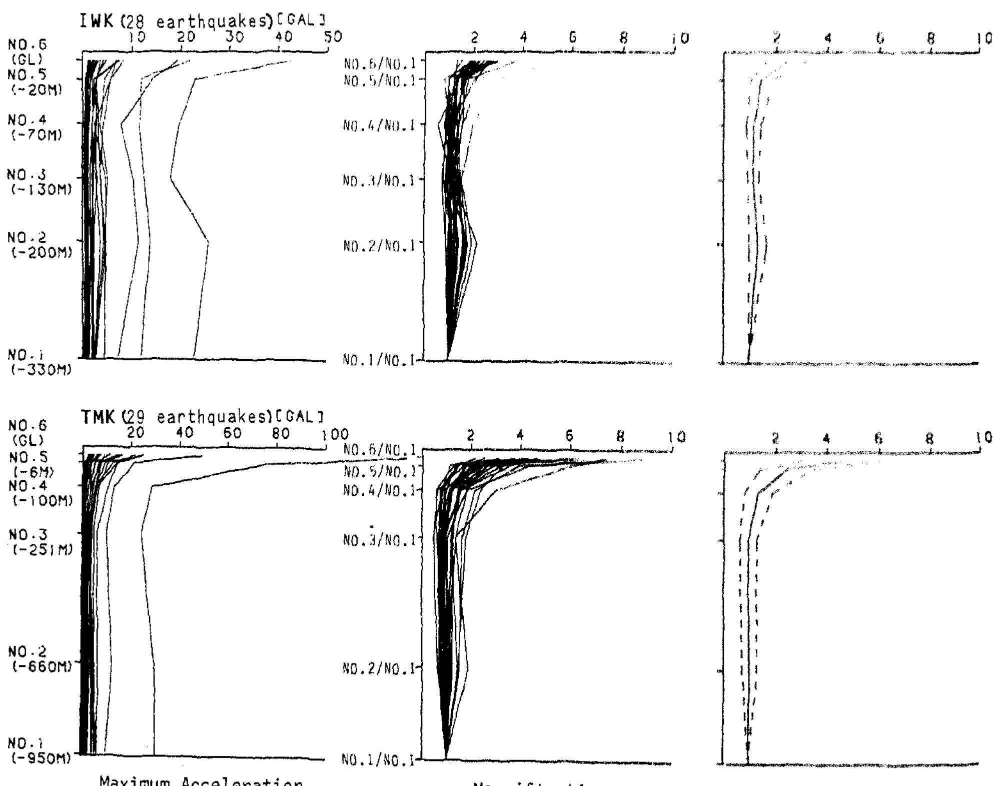

Fig.8 Vertical Distributions of Maximum Accelerations

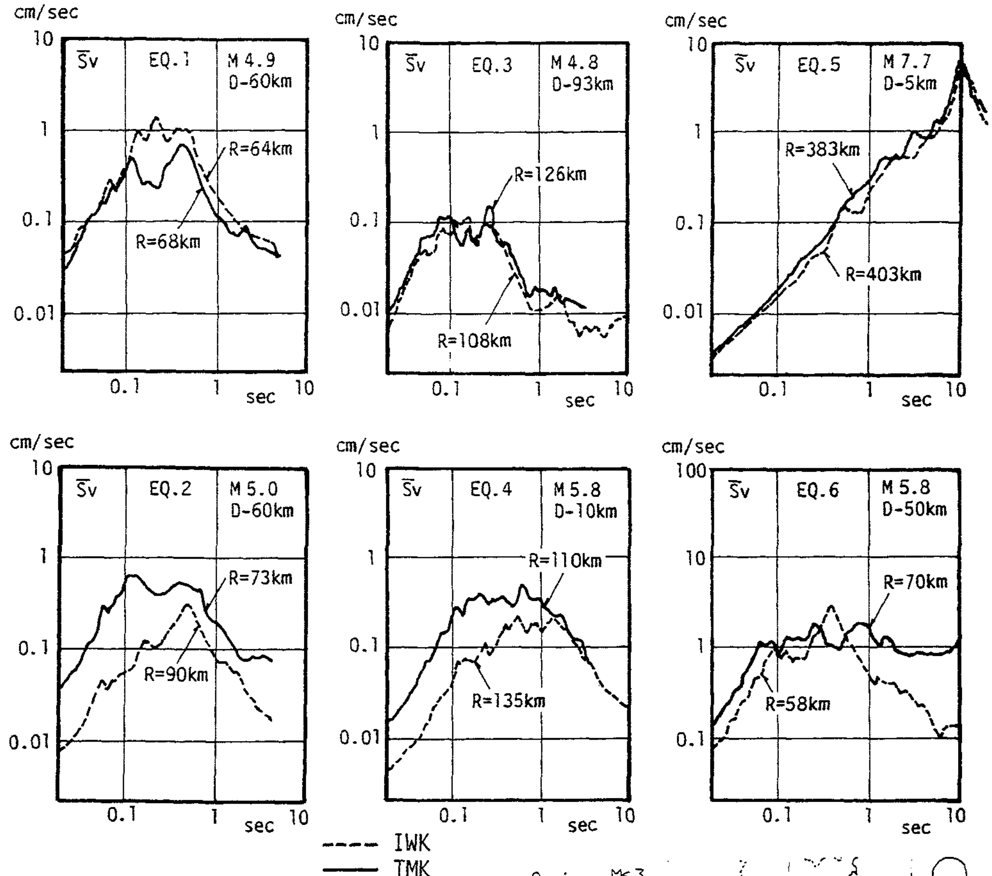

Fig.9 Comparison of Response Spectra at Bedrocks between IWK and TMK

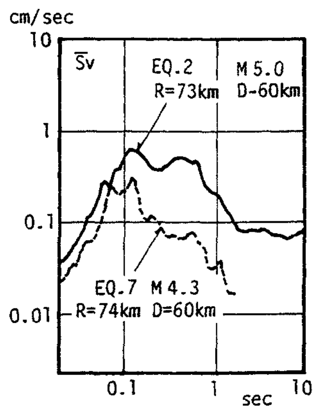

Fig.10 Comparison of Response Spectra at Bedrock in TMK between 2 earthquakes

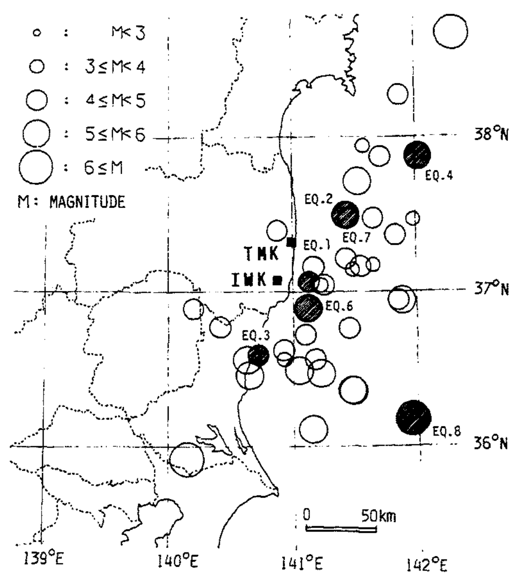

Fig.7 Distribution of Epicenters

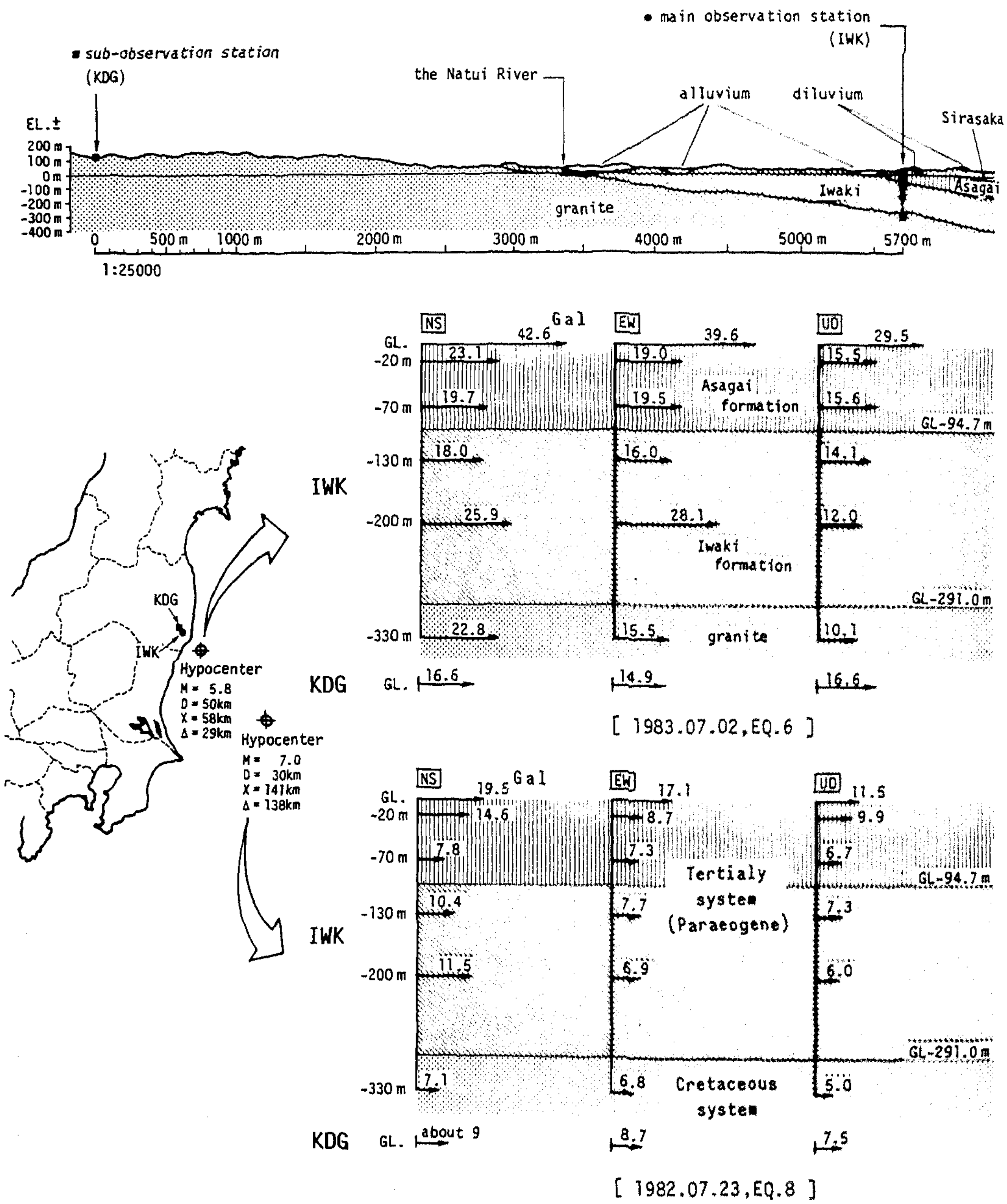

Fig.11 Comparison of Maximum Accelerations between *IWK and KDG*