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FAULT DYNAMICS OF THE 1995 HYOGO-KEN-NANBU EARTHQUAKE DERIVED FROM STRONG MOTION RECORDS

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ABSTRACT

Focal area of the 1995 Hyogo-Ken-Nanbu Earthquake was estimated roughly by using the map of active faults and the information of the locations of main and after shocks. And the rupture direction and length of the faults were determined by the acceleration records along the focal area. Finally, the direction and the length of the faults were checked by using the loci of the displacement at the several stations. Result of examination are described as follow. The faults related to this earthquake consist of two main faults as the Nojima fault and the Suma (Suma-Egeyama) fault and a sub-fault under the Akashi channel. The total length of the faults is approximately 30km.

KEYWORDS

Hyogo-Ken-Nanbu Earthquake, strong acceleration records, loci of displacement, fault location, directivety, fault rupture direction, fault rupture velocity, integration of accelerogram.

INTRODUCTION

5:46:51 a.m. (Japan Standard time: JST=UTC+9hr) on January 17, 1995, M 7. 2 (defined by the Japan Meteorological Agency) earthquake attacked Hanshin-Awaji area in Japan. M_w is estimated 6.9 by USGS and Harvard University. After Prof. Hiroo Kanamori of Earthquake Laboratory of California Institute of Technology (Caltech), an earthquake of M_w 6.9 is almost the same scale of the 1989 Loma Prieta earthquake. A large number of houses and office buildings were destroyed or severely damaged. Total victims for this earthquake are over 6300. To investigate the damage, it is necessary to clear the location of the faults related this earthquake. Here, the faults location are clarified based on the strong motion records.

STRONG MOTION RECORDS AND MAXIMUM ACCELERATIONS

JR, Japan Railway Companies, have been using accelerometers as alarm seismometers for train operation. At the time of the 1995 Hyogo-Ken-Nanbu earthquake, these alarm seismometers displayed their functions well. Most of them can record and print out not only the strength of earthquake motion (the maximum value of vectorial sum of horizontal components) for alarm, but also maximum accelerations of each components. The characteristics of alarm seismometer is high cut with elimination by 12 dB/OCT of frequency component over 5 Hz. Besides, this type of seismometer has a function to record waveforms with high cut characteristics of elimination by 12 dB/OCT over frequency component of 10 Hz. Low frequency components under 0.1 Hz was eliminated by 6 dB/OCT for both alarm and waveform record. The maximum accelerations observed at various places, mainly along the JR lines, are summarized in Fig. 1.

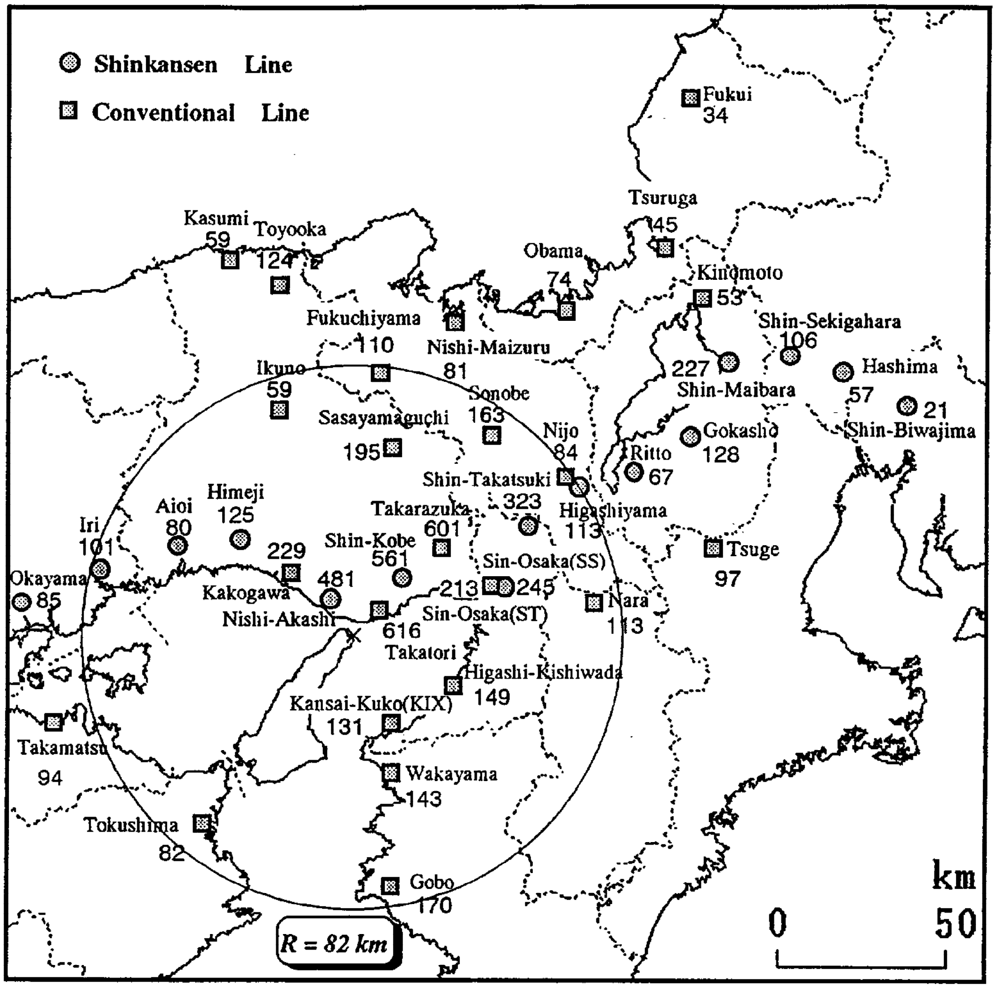

Fig. 1 Maximum Accelerations along the Japan Railways

Seismometers installed along Shinkansen line can record waveform from P wave arrival because they are digital recording type seismometer with delay device. On the contrary, alarm seismometers for the conventional lines are analog recording type seismometer (FM record, S/N ratio is over 56 dB) without delay device, and can record only the waveform after the signal exceed certain trigger levels. However the Hyogo-Ken-Nanbu earthquake was multiple and caused by the movements of a few faults with time lag, the alarm seismometers also succeeded to record the waveform before the main movement.

ACTIVE FAULTS IN FOCAL REGION OF THE HYOGO-KEN-NANBU EARTHQUAKE

A part of fault related the Hyogo-Ken-Nanbu Earthquake appears at ground surface of northwestern part of Awaji Island for about 9 km long. This fault corresponds to the Nojima Fault. At Nojima-Hirabayashi of Hokudan-Cho, the maximum displacements of 1.7 m for horizontal and 1.3 m for vertical components were comfirmed by Suzuki *et* *al.*,1995. Although in Kobe side no surface fault is comfirmed, the deformation caused by the earthquake is suddenly changed at foot of Hachibuse-Yama. It suggests a fault through this area, corresponding to the Suma Fault. Fig. 2 shows distribution of active faults near the focal region from *Active Faults in Japan* (1991) with strong motion sites mentioned in this paper.

JMA, Japan Meteorological Agency, estimated the epicenter (start point of rupture) at the north end of the Nojima fault in Akashi Strait at first. But JMA move the location of epicenter to relatively east from the first epicenter. According to Fig. 3, Geological Map in Akashi Strait investigated with sonic wave (Izaki *et al.*, 1962), the first JMA epicenter correspond to joining point of the Nojima and F1 faults, the second JMA epicenter correspond to joining point of F4 and F5 faults. F4 fault connects to the Suma Fault through F2 fault. A suspension bridge, Akashi-Strait Bridge, is under construction. The main tower in Awaji side (2P) is on the crust block surrounded by F1, F4 and F5 faults. F1 fault is running between 2P and 1P, the other side main tower. F5 fault is running between 2P and 2A, the anchorage in Awaji side. F4 fault connects the Suma Fault through F2 fault.

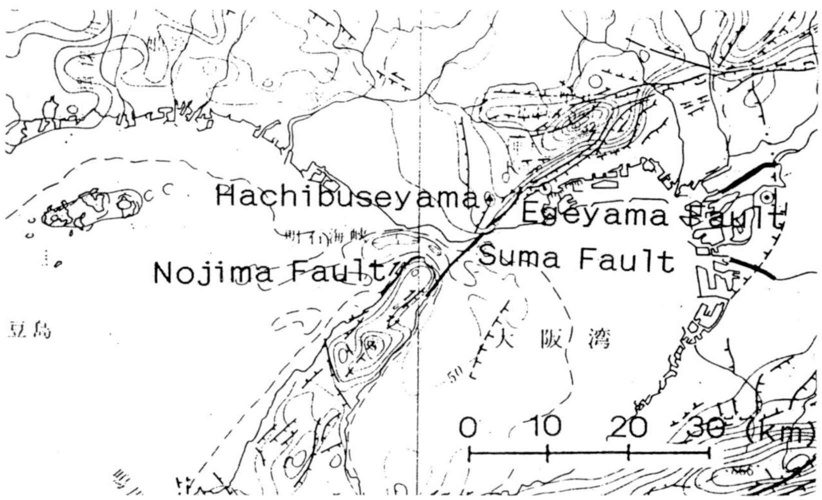

Fig. 2 Active Faults in Hanshin-Awaji Area

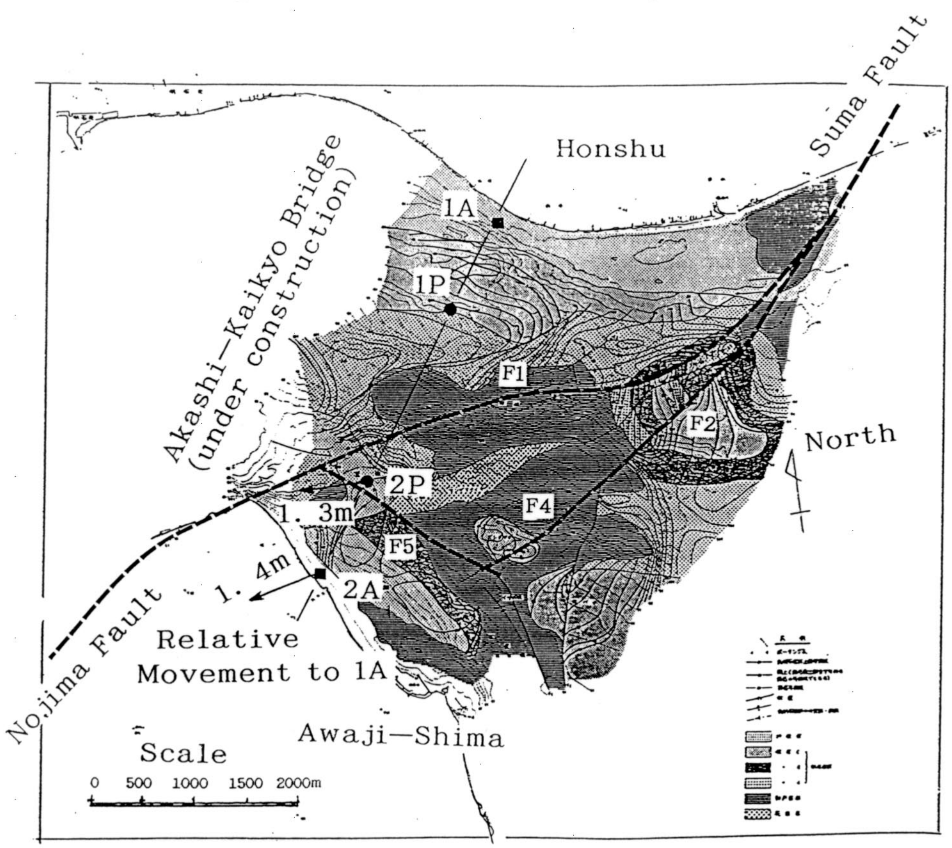

Fig. 3 Faults at Akashi Strait and Movement of Foundation of Akashi-Kaikyo Bridge

According to GPS measurement by the Maritime Safety Agency, relative movements of 1P, 2P and 2A to the anchorage of Kobe side 1A show no displacement, 1.3 m to West direction and 1.4 m to W20S direction, respectively. This fact indicates that F1 fault moved mainly, and F5 fault slightly moved with F1 fault movement.

ESTIMATION OF FAULT LENGTH BASED ON THE STRONG MOTION RECORDS

Fig. 4 show the accelerograms of Takarazuka station (JR conventional line), Nishi-Akashi station (JR Shinkansen line) and Kobe Marine Meteorological Observatory of JMA (KMO). Fig. 1 shows locations of these stations on the distribution map of active faults around the epicenter. Nishi-Akashi station is situated 8 km perpendicularly sideways from the fault line, while Takarazuka station and KMO are on the extension of the fault line.

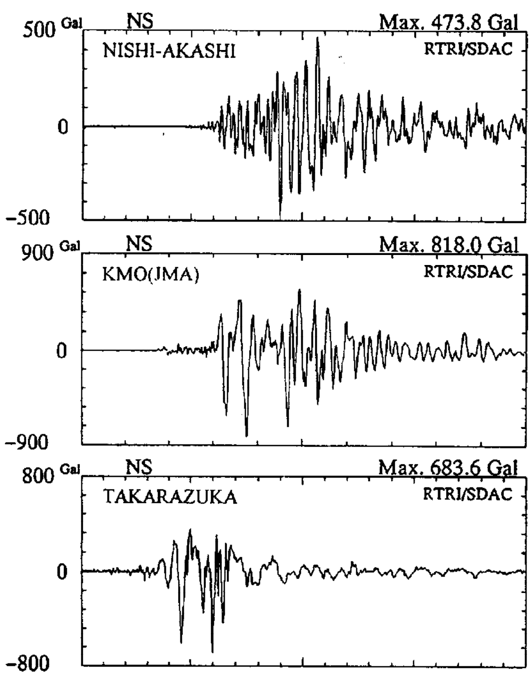

Fig. 4 Examples of Accelerogram

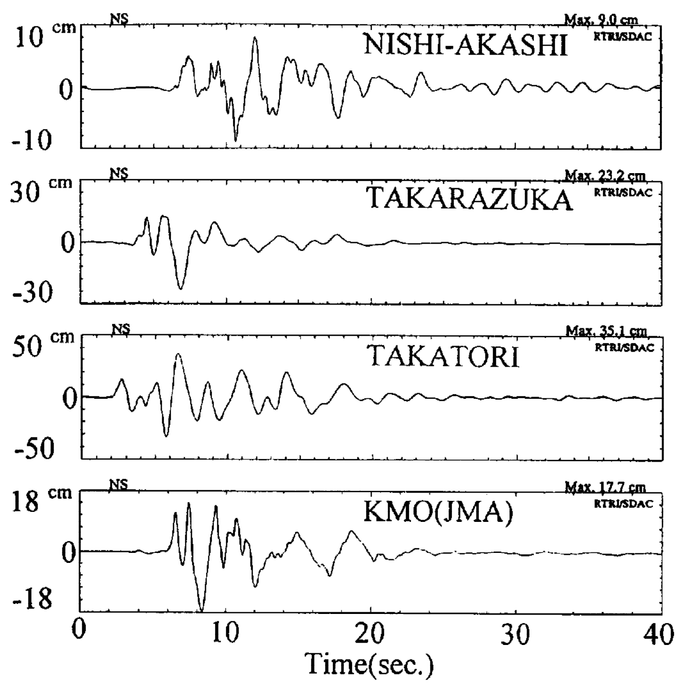

Fig. 6 Double Integrated Displacement Waveforms

At Takarazuka station, on the extension of the fault line, the maximum acceleration is large but the earthquake motion continues very short. Besides, at Nishi-Akashi station, separated sideways from the fault line, the earthquake motion continues rather long. By the precise observation of the record of Takarazuka station, it is possible to confirm that high frequency waveform is seen on the accelerogram with gentle change. The motion characteristics of accelerogram at Nishi-Akashi station is relatively constant, which is an intermediate characteristics of low frequency and high frequency waveforms at Takarazuka station. Thus, the low frequency part is due to the fault motion going away from Takarazuka, and the high frequency part shows the fault motion coming toward Takarazuka. That is to say at first, the fault motion propagated as going away from Takarazuka and after that , propagated as coming toward Takarazuka. The waveform shows that the earthquake motion continuation time for the former is 6.0 sec. and that for the latter is 2.0 sec. arriving after 1.5 sec. of the former (see Fig.4 to refer).

Assuming that Takarazuka station lies on the extension of fault line, the relationship of the locations of the fault and observatory can be shown as Fig. 5.

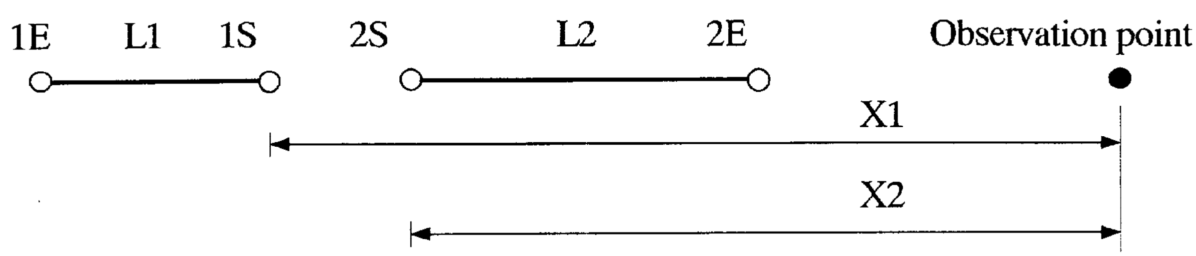

Fig. 5 Relationship between Faults and Observation Point

L1 and L2 are rupture lengths of Nojima and Suma faults, respectively. 1S and 1E are start and end of the ruptures for the Nojima fault, respectively. 2S and 2E are same meaning for the Suma fault. X1 and X2 are distances between start points of the Nojima and Suma faults, respectively, and Takarazuka station. T1 and T2 are the fault rupture duration times correspond to L1 and L2 observed at Takarazuka station. T1 and T2 become as follow.
$T1 = L1(1/Vr+1/Vs)$ and $T2 = L2(1/Vr-1/Vs)$, where Vr and Vs are the fault rupture velocity and S wave velocity, respectively. Therefore, $L1 = T1/(1/Vr+1/Vs)$ and $L2 = T1/(1/Vr-1/Vs)$. Difference of the outbreak times between 1S and 2S is assumed as t, then the difference of the arrival times of motion from 1S and 2S becomes as follow: $T12 = (X2-X1)/Vs+t$. Then, $t = T12 - (X2-X1)/Vs$. From waveform at Takarazuka, T1 = 6.0 sec, T2 = 2.0 sec and T12 = 1.5 sec. The velocities of S wave propagation and fault rupture, Vs and Vr can be assumed 4.0 km/s and 2.5 km/s respectively. Therefore, L1 = 9 km and L2 = 13 km are calculated.
The estimated length of L1 accord with the confirmed length of the Nojima Fault. Then the estimated length is relatively short but can be considered as proper. L2 fault seems to correspond to the Nojima fault and a part of the Egeyama Fault. Considering the distance of the direction of the fault at Akashi strait and the fact of occasion of small tsunami, the beginning of the fault is in Akashi strait and $X_1 - X_2 = 4$ km, then t is estimated 2.5 sec.

FAULT MOVEMENTS SEEN BY DISPLACEMENT LOCI OF SEISMIC MOTIONS

Integrating the acceleration records (Nakamura, 1980), waveforms expected to be observed by JMA V=1 strong-motion seismograph with To = 5 sec and h=0.552 can be obtained as shown in Fig. 6. The displacement loci in the horizontal plane at Nishiakashi, Takatori, Takarazuka and KMO are shown in Fig. 7.

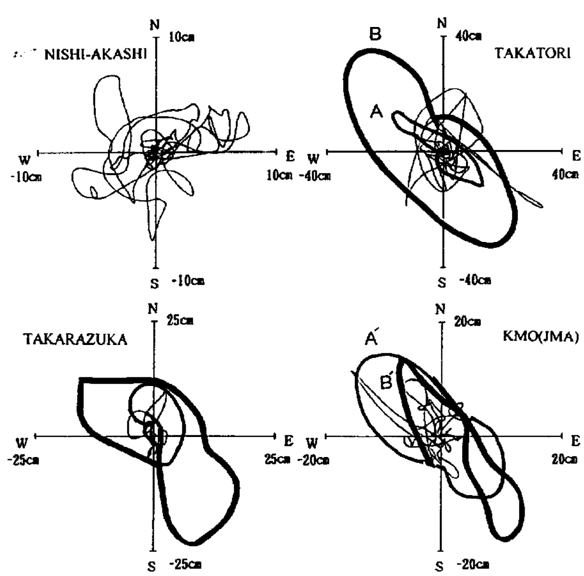

Fig. 7 Displacement Loci of Surface Ground in Focal Region

Displacement locus of seismic motions near the fault is expected to be perpendicular to the strike of the fault and the obtained loci at Takatori and KMO suggest the existence of faults striking WNW-ENE near the stations. Looking the loci in detail, two elliptic loci with different inclinations (A and B at Takatori and A' and B' at KMO) can be recognized. A and A' are shown with thin lines and B and B' with thick lines. The former are thought to correspond to Nojima Fault and the latter to Suma-Egeyama Fault.

Takarazuka lies on the extension of the fault group and displacement loci predominate in transverse direction to the fault group strike. The rupture times of each fault read by the turning points of the loci are T1 = 7.0sec, T2 = 2.5sec and T12 = 1.5sec, which differ slightly from the values obtained in the previous section. The values of this section, using the change points of displacement loci, are suspected more reliable than those of the previous section read only from the conspicuous phases of the acceleration wave forms.

KMO is situated at the eastern end of Egeyama Fault and although the movement eventually jumps here to another fault, the rupture becomes same as the values of Takarazuka, if the same situation with Takarazuka is taken for KMO. This suggests that the fault striking to Takarazuka stops around at KMO. Fig. 5 shows that the displacement wave forms at Takarazuka and KMO are very similar each other.

From the reading of Takarazuka and KMO, L1 = 11 km and L2 = 17 km. The difference of the origin times of the two faults is 2.5 sec, if X1-X2 = 4 km is assumed. Considering the surface extension of the Nojima Fault is about 9 km and the distance between off Suma and KMO is about 15 km, the fault length obtained here seems reasonable.

Displacement loci at Nishi-Akashi show very complicated forms, which reflects the combined movements of Nojima and Suma-Egeyama Faults as well as a short fault across the strait.

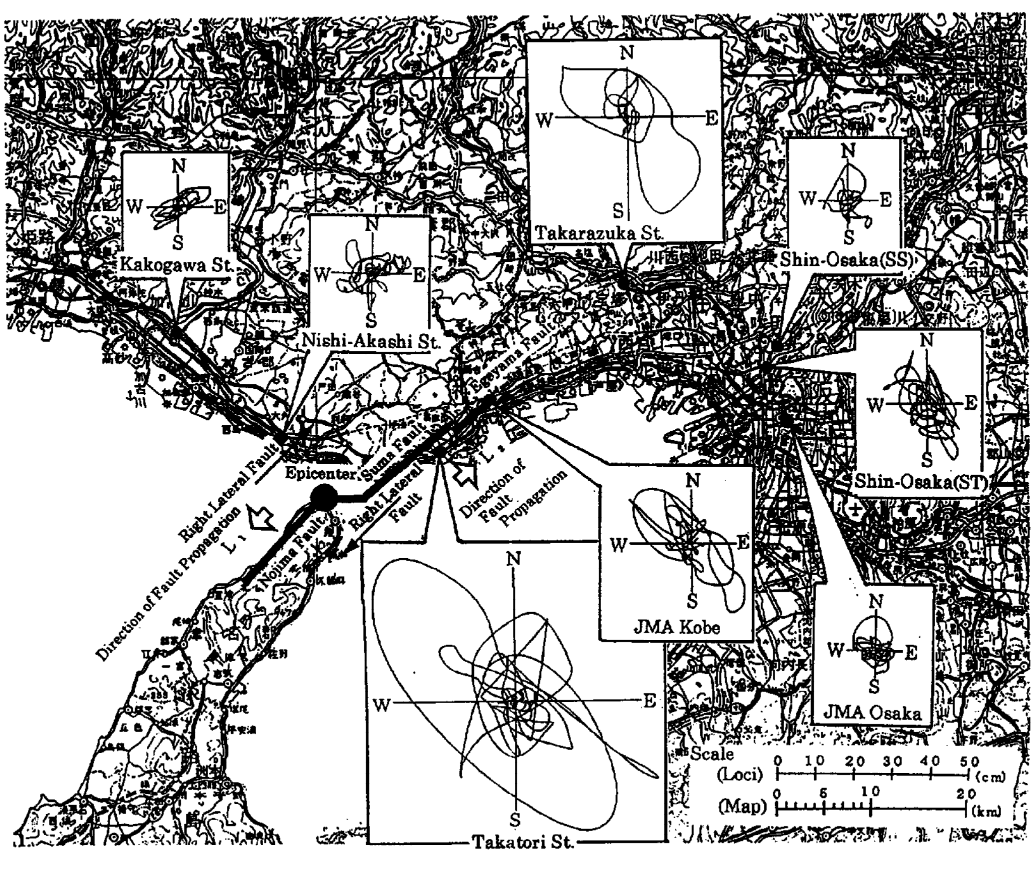

Fig. 8 Displacement Loci of Surface Ground, except JMA Osaka, on Map of Focal Region

In Fig. 8 displacement loci at different stations are illustrated using a same scale which show very large displacement loci at the stations east of the faults. At the eastern stations displacements transverse to the fault strike are large, suggesting these stations are not very far from the extension of the fault line. Displacement loci at Takatori show that loci corresponding to Suma-Egeyama Fault are appreciably longer than those corresponding to Nojima Fault. On the contrary, at KMO loci for the both faults are nearly same size, which also suggests KMO is situated at end of the fault.

Displacement loci of Takatori include portions showing curious movements along the fault strike after nearly linear back-and-forth movements. This comes after the movements corresponding to that of Suma Fault, suggesting a possibility to show the passing of the fault rupture. After this the movements become gradually linear and suggest the ground became plastic.

At KMO, 1.5 sec after the Suma Fault rupture started, rotation of the loci reversed its direction. This point is calculated about 10 km from the starting point of the rupture which nearly corresponds to the junction point with Egeyama Fault. Egeyama Fault is parallel with Suma Fault, separated somewhat to the south and KMO lies between the extension lines of the Suma and Egeyama Faults which explain the reverse rotation mentioned above reasonable.

CONCLUDING REMARKS

In conclusion, the movements of the faults are suspected as follow: the fault rupture, started under the sea bottom of the Akashi Strait near Ezaki Lighthouse, proceeded to WSW and due east . One rupture crossed the strait obliquely and continued to Suma Fault. Another rupture breaks about 11 km of Nojima Fault along the NW coast of Awaji Island. After about 2.5 sec from the initial break, the rupture reached Suma Fault off coast of Suma and a new big break started. This break proceeded ENE to Kobe 17 km and stopped at the eastern end of Egeyama Fault. This situation is shown in Fig. 8. Suspected fault position and the movements do not contradict with the damage situation in Kobe city. Aftershock distribution obtained by Disaster Prevention Research Institute, Kyoto University, shown in Fig. 9 shows aftershocks are few in the area where faults are located. Considering that in the area strongly ruptured by the main chock, aftershocks do not occur much, the locations of the fault suspected here are reasonable.

Result of examination are described as follow.

1) The faults related this earthquake consist of two main faults as the Nojima fault and the Suma fault, and a few fault under the Akashi channel between those two faults. The total length of the faults is approximately 30 km.
2) The main components of the earthquake displacement near the focal area is perpendicular to the fault plane.
3) The maximum velocity and displacement of the surface ground near the Suma fault exceeded 170 cm/s and 40 cm respectively.

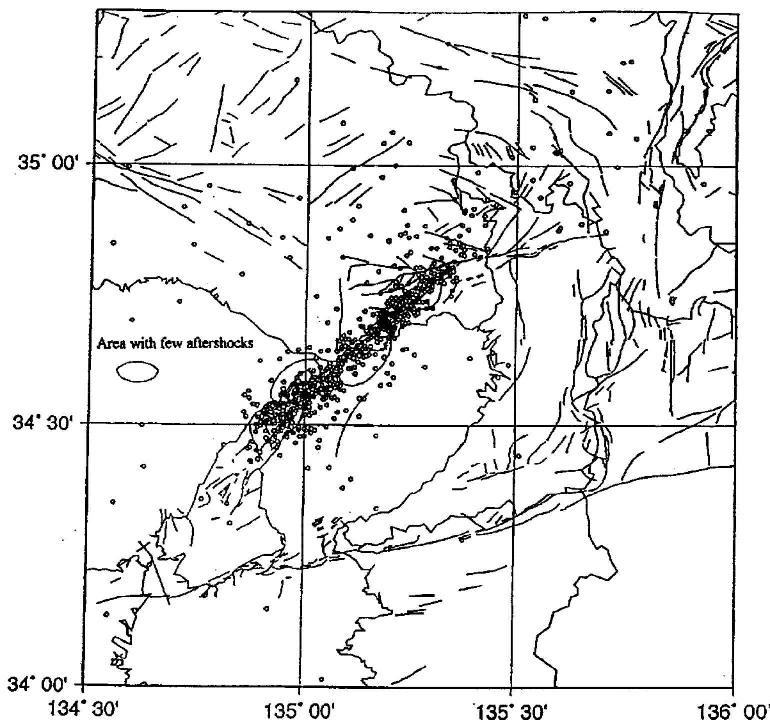

Fig. 9 Distribution of Aftershocks

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