J. Phys. Earth, **21**, 191-212, 1973

FAULTING MECHANISM OF THE GIFU EARTHQUAKE OF SEPTEMBER 9, 1969, AND SOME RELATED PROBLEMS

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(Received July 24, 1973)

The faulting process of a moderate-size shallow earthquake on inland Japan, the central Gifu earthquake of September 9, 1969 ($M=6.6$), has been investigated by synthesizing all available seismic and geodetic data.

The focal mechanism solution based on data from Japanese and WWSSN stations and the spatial distribution of aftershocks indicate that the earthquake was caused by left-lateral strike-slip motion along a vertical fault plane with dimensions of 20 by 10 km striking in the N30°W direction. The strong-motion records from five JMA stations within a distance of 80 km are compared with the synthetic seismograms computed from dynamic dislocation models. The comparison yields estimates for the seismic moment, average fault displacements, rise time, and rupture velocity. The pattern of vertical tectonic movements from pre- and post-earthquake leveling data along two nearby routes is generally consistent with that derived from the corresponding static models, but there is some possibility that displacements over the northwestern part of the fault might be considerably larger than the average. The strain steps that have been recorded during the earthquake on 23 strain meters at ten crustal movement observatories are not always consistent with theoretically expected values.

In relation to the faulting process, pre-earthquake data from leveling and tiltmeter observations are also examined from the viewpoint of earthquake prediction, and tectonic implications of the earthquake are discussed.

1. *Introduction*

The Gifu earthquake of September 9, 1969, with a magnitude of 6.6, occurred in the midst of a belt-like seismic region across central Japan, extending from the Hokuriku to Mikawa districts, along which a number of great earthquakes have taken place since the Nobi earthquake in 1891. From a geological point of view, the fracture pattern in this region, including many conjugate sets of strike-slip faults such as the Atera, Neo-dani, and Atotsugawa faults trending predominantly in the NNW-SSE and NE-SW directions, seems to suggest that the region had been subjected to Quaternary crustal deformations mainly due to horizontal tectonic compression in an E-W trend (SUGIMURA and MATSUDA, 1965; MATSUDA, 1966, MURAI, 1970; HUZITA *et al.*, 1973). The focal mechanism of the large earthquakes (ICHIKAWA, 1971) indicates predominant strike-slip components and the E-W pressure, which gives support to the geological evidence, and also, the mechanism of microearthquakes seems consistent with these features (MIKI *et al.*, 1965; WATANABE and NAKAMURA, 1967; YAMADA *et al.*, 1972). The Gifu earthquake took place under these circumstances, and among the great earthquakes in this region, the most extensive seismic and geodetic observations were made after the 1969 earthquake.

The purpose of the present paper is to elucidate the dynamical faulting process of this earthquake by synthesizing all available seismic and geodetic data, including spatial distribution of aftershocks, the radiation pattern of *P*-wave first motions from Japanese and WWSSN stations, strong motions at nearby JMA stations, vertical tectonic movements from pre- and post-earthquake leveling surveys and strain and tilt changes at intermediate distances. In relation to the faulting process, tectonic implications of the earthquake are discussed, and pre-earthquake data from leveling and tiltmeter observations are also examined from the viewpoint of earthquake prediction.

Table 1 lists the thirteen earthquakes that have occurred in this region since 1891 with magnitudes greater than 6.0 (e.g., USAMI, 1966). In Fig. 1 the focal mechanisms of some of the earthquakes are schematically illustrated; the solutions for earthquakes No. 6–11 are based on ICHIKAWA's analysis (1971) and Nos. 12 and 13 are from recent data (OOIDA and ITO, 1972; YAMADA and FUJII, 1973).

Table 1. List of earthquakes in the region concerned.

No.	Date			Earthquakes	Location		M
					λ	φ	
1	1891	10	28	Nobi	136°.6	35°.6	8.4
2	1900	3	22	Sabae	136.2	36.0	6.6
3	1909	8	14	Anegawa	136.3	35.4	6.9
4	1933	9	21	Noto	137.0	37.1	6.0
5	1934	8	18	Hachiman	137.0	35.7	6.2
6	1945	1	13	Mikawa	137.0	34.7	7.1
7	1948	6	28	Fukui	136.2	36.1	7.3
8	1952	3	7	Daishoji-Oki	136.2	36.5	6.8
9	1961	8	19	Kitamino	136.8	36.0	7.0
10	1963	3	27	Echizen-Misaki	135.8	35.8	6.9
11	1969	9	9	C. Gifu	137.1	35.8	6.6
12	1971	1	5	Atumi-Oki	137.2	34.4	6.1
13	1972	8	31	E. Fukui	136.8	35.9	6.0

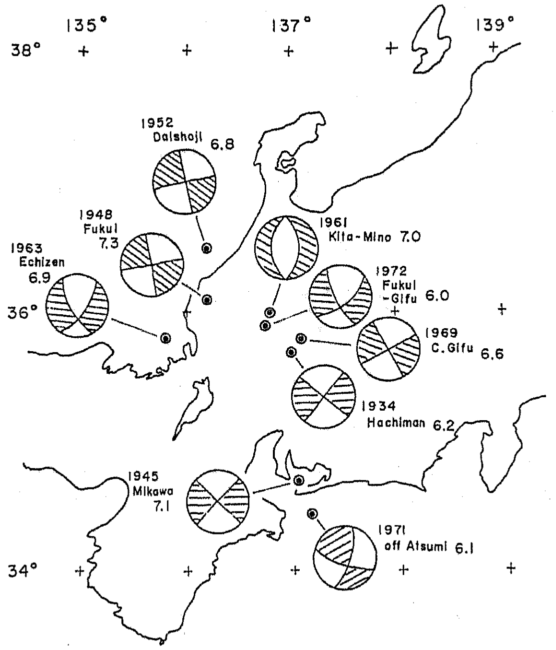


Fig. 1. Location and focal mechanism of large earthquakes in the region concerned. Most of the focal mechanism solutions are from Ichikawa (1971).

2. *Focal Mechanism*

The focal mechanism of the present earthquake has been determined by the JMA (Ichikawa, personal communication, 1969) using *P*-wave data from JMA stations. In this paper, additional data from university stations inside Japan and from WWSSN stations are incorporated. For teleseismic distances the Jeffreys-Bullen velocity profile is applied, and an average crustal structure in Southwest Japan is taken into account for Japanese stations. Figure 2 shows the radiation pattern projected onto the lower hemisphere of the Wulff net, where solid and open circles indicate stations with compression and dilatation, respectively. In Fig. 3 are shown some examples of long-period seismograms at the WWSSN stations, which suggests a rather complicated initiation of fracture. The focal mechanism yields two possible solutions for the choice of the fault plane. The strikes of the first and second nodal planes in the N30°W and N60°E directions agree with those for other large earthquakes in this area as well as with the two trends of major geological faults. Both the solutions indicate strike-slip motion along a vertical fault plane.

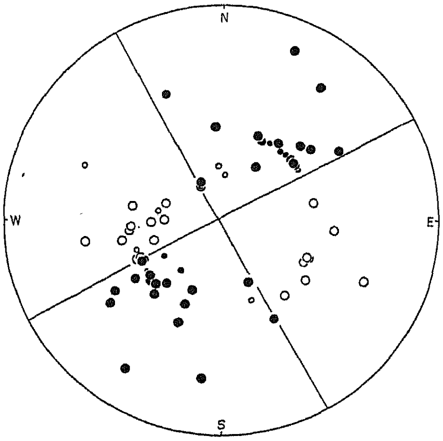


Fig. 2. Radiation pattern of P wave first motions projected onto the lower hemisphere. Solid and open circles indicate compression and dilatation.

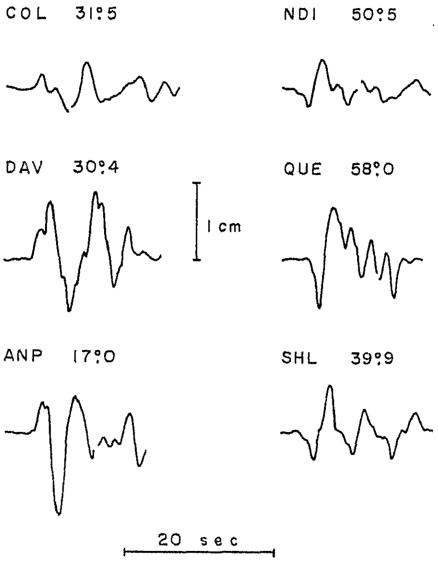


Fig. 3. Examples of long-period seismograms at WWSSN stations.

3. *Spatial Distribution of Aftershocks*

Extensive observations of aftershocks were made by several organizations right after the main shock (AFTERSHOCK RESEARCH GROUP, 1970; KAMINUMA, 1970; AOKI *et al.*, 1970; WATANABE and KUROISO, 1970; SASAKI *et al.*, 1970), and some of them continued until one year later (ITO, 1971). Some of the observations clearly indicate that the aftershock zone gradually spreads out as the time goes on, and therefore the zone in an early stage of activity may

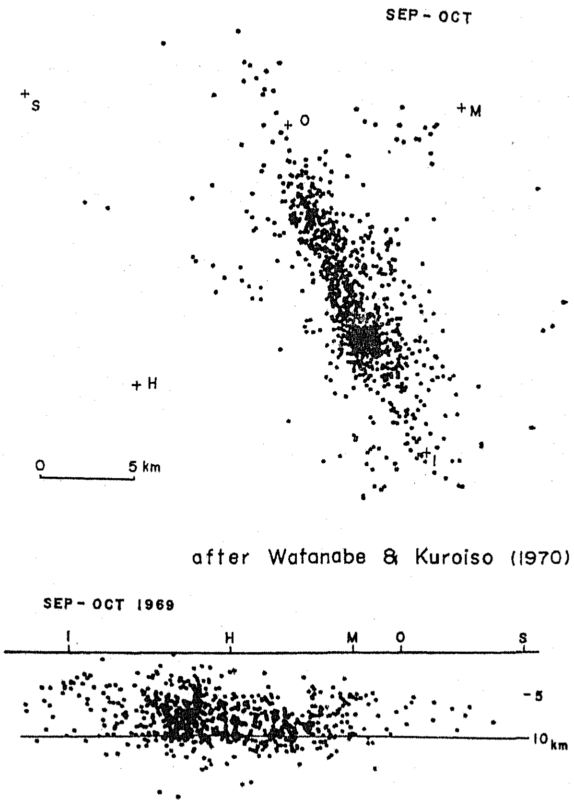


Fig. 4. Spatial distribution of aftershocks, after WATANABE and KUROISO (1970).

represent the fault area of the main shock. Figure 4 shows the spatial distribution of aftershocks with magnitudes greater than 1.5 that occurred between September 22 and October 31 (WATANABE and KUROISO, 1970). Most of the epicenters are concentrated in a belt-like area extending for about 20 km and striking in the N30°W direction, which agrees with the strike of the first nodal plane derived from the focal mechanism. For this reason, we consider the first nodal plane to be the fault plane. The location of the main shock, which may be regarded as the initiating point of fracture, lies in the most dense portion of aftershock epicenters, as suggested by re-examination of data (ITO, 1971). Most of the focal depths range between 2 and 12 km. Since no clear evidence of fault breaks was traced on the ground surface (MATSUDA and TSUNEISHI, 1970), it appears that the fault plane does not reach the surface.

It may be reasonable to infer from these data that the main shock was caused by left-lateral strike-slip motion along a nearly vertical fault plane with dimensions about 20 by 10 km and a strike of N30°W. In later sections, a more detailed rupture process is theorized on the basis of the above model.

4. *Dynamic Ground Displacements*

Strong-motion seismographs at several JMA stations have recorded ground motions with relatively long periods from the Gifu earthquake. The natural period of the seismographs is 6 sec for the horizontal, and 5 sec for the vertical components, and other constants are the damping of about 0.6 and the magnification nearly equal to 1. Since it is expected that the ground motions recorded in the near-field will provide useful clues to the rupture process, the records from five nearby stations within 80 km from the epicenter—Gifu, Takayama, Nagoya, Iida and Fukui, as indicated by solid circles in Fig. 5—are analyzed here. Figure 6 shows some examples of the strong-motion records obtained at the Gifu ($\Delta=51$ km) and Takayama ($\Delta=44$ km) stations.

We calculate here theoretical ground displacements and synthetic seismograms appropriate to the above five stations, in comparison with the obtained records, to estimate dynamic fault parameters. To compute the near-field displacements, the formulations given by MARUYAMA (1963) and HASKELL (1969), which are appropriate to dynamic dislocations in an infinite medium, are used, and simple corrections for the free surface are applied. These expressions are not exact for a semi-infinite case, but proved to give good approximations at least for direct body waves, in view of a complete theory including body and surface waves in a half-space that have recently been derived (KAWASAKI *et al.*, 1972; SATO, 1972).

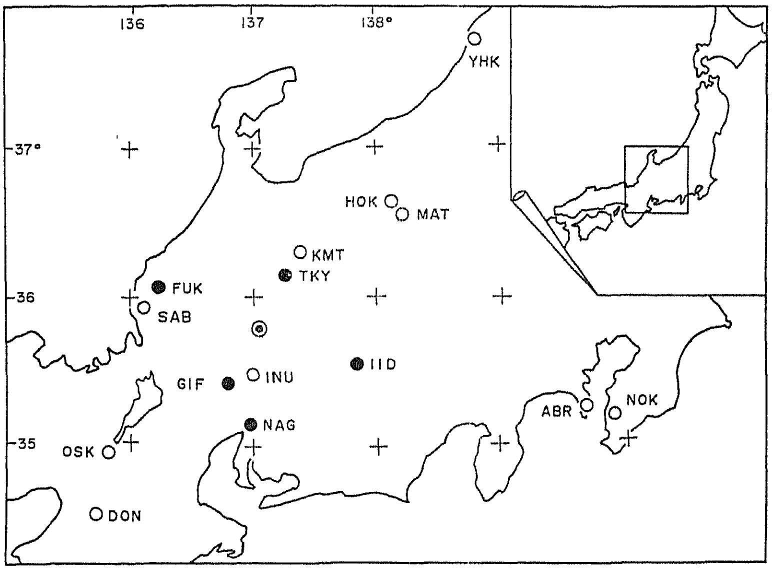


Fig. 5. Location of the epicenter (double circle), JMA stations with strong-motion seismographs (solid circle), and crustal movement observatories (open circle) where strain steps have been recorded.

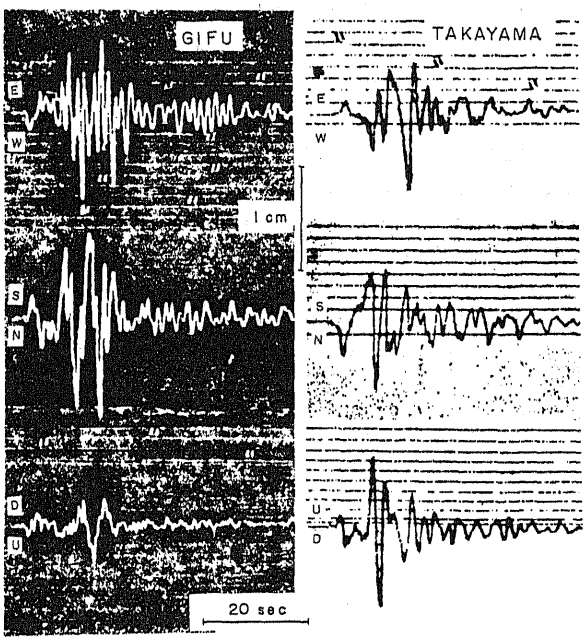


Fig. 6. Examples of strong-motion records.

The location of the main shock with respect to the aftershock zone suggests bilateral fracture propagation with somewhat longer extension to the northwest as compared to the southeast side. However, an idealized bilateral fracture propagated simultaneously over some depths may not be realistic, and radial faulting initiating from the hypocenter was found to be most reasonable in the case of the San Fernando earthquake (MIKUMO, 1973). For this reason, we assume here a radial mode of fracture, which stops at the edge of the fault plane. The rupture velocity v is assumed to take values between 2.0 and 3.0 km/sec, while the compressional velocity in the surface layer near the epicentral area is taken to be 5.5 km/sec from recent explosion seismic observations (AOKI *et al.*, 1972), and the corresponding shear velocity is assumed to be 3.2 km/sec. The rise time τ of fault displacements is assumed to be between 0.2 and 3.0 sec. The method employed in numerical calculations to get the theoretical displacements is similar to that described in MIKUMO (1973), and the corresponding synthetic seismograms are calculated by convolving the displacements with the impulse response of the strong-motion seismographs used.

Figure 7 compares two components of the records obtained at Gifu with the synthetic seismograms with several assumed rise times and rupture velocities. The comparison shows that general features of the first 10 sec of the records including both direct P and S waves may be explained by some of the synthetic seismograms, if high frequency components involved in the records were filtered out. Large amplitudes after 15 sec may be due to the arrival of surface waves, which cannot be explained by the present approximate theory. Although it is rather difficult to discriminate the best correspondence from the seismograms, the uppermost traces with $\tau = 1$ sec and $v = 2.5$ km/sec appear to closely approximate the records. In Figs. 8(a) and (b), similar records obtained at four stations are displayed, together with the synthetic seismograms computed for Model A with a constant fault displacement and the same parameters as estimated above. The lowest traces are from an alternative model described below. Again, the computed traces from Model A may give fairly good explanations for the first 10–15 sec of all the records. The maximum amplitudes on the recorded and computed seismograms are directly compared in Fig. 9, which yields the seismic moment of 3.5×10^{25} dyne·cm. Since we have estimated the fault dimensions for Model A as 18 by 10 km, the average

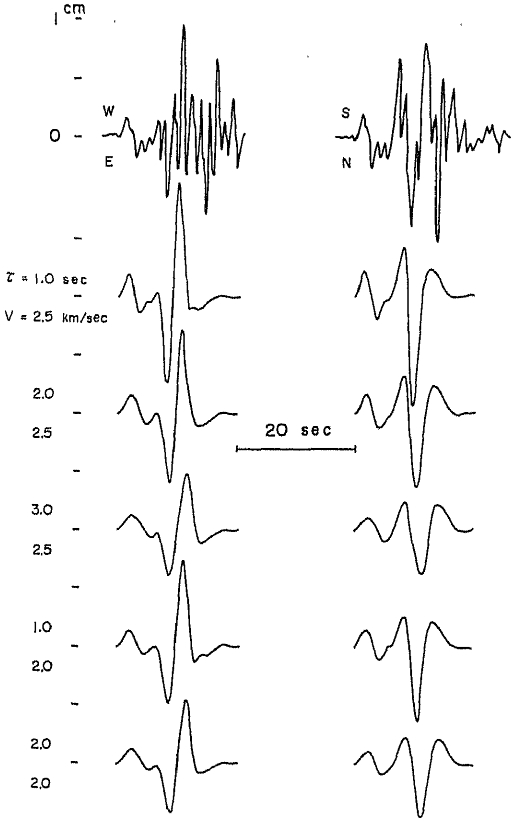
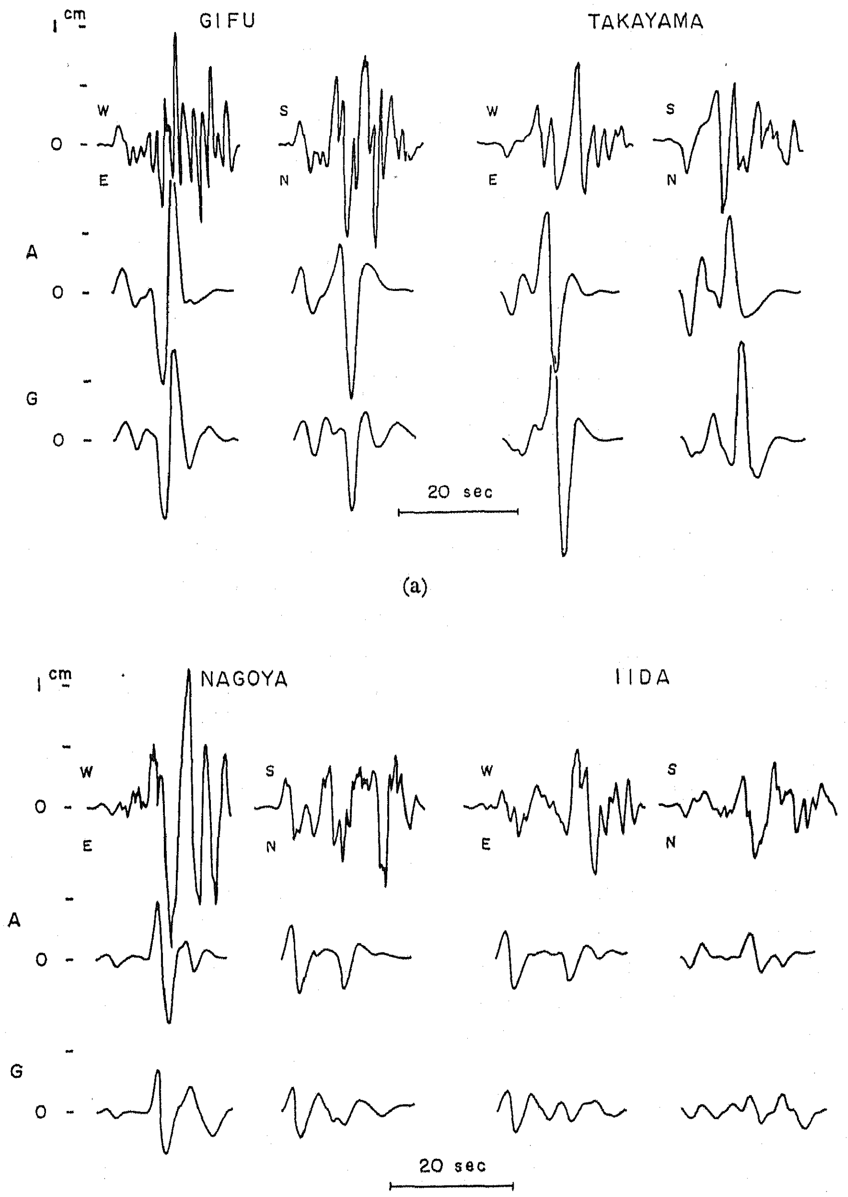


Fig. 7. Strong-motion records at Gifu and synthetic seismograms with various parameters.

fault displacement and the stress drop will be 64 cm and 15 bars, respectively, if the rigidity is taken to be 3×10^{11} dyne/cm^2.



(a)

(b)

Fig. 8. Strong-motion records and synthetic seismograms from two fault models.
(a) Gifu and Takayama (b) Nagoya and Iida

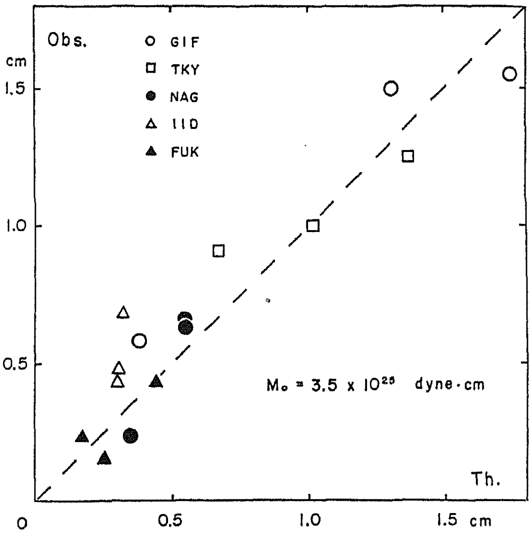


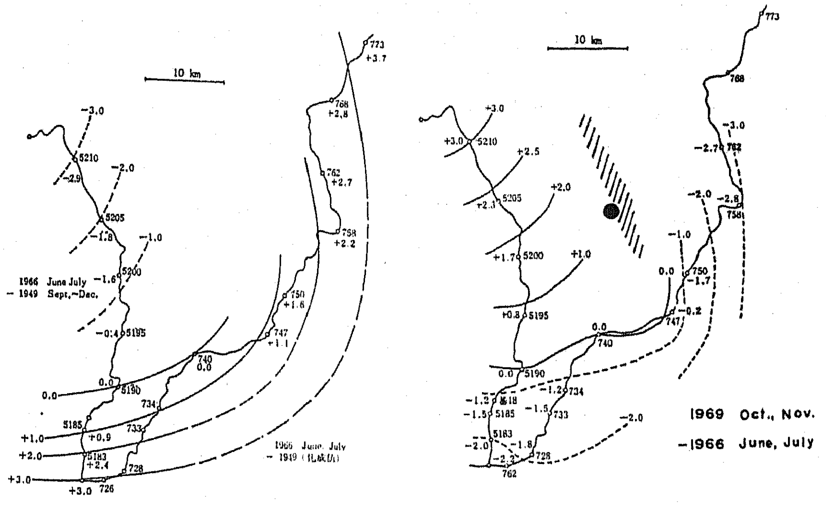
Fig. 9. Observed and theoretical amplitudes for five stations.

5. *Static Displacements*

Extensive leveling surveys were made one to two months after the Gifu earthquake along two routes surrounding the epicentral area from Seki (J 725) to Hagiwara (B.M. 767) and from Seki to Shiratori (B.M. 5212) (GEOGRAPHICAL SURVEY INST., 1970), while pre-earthquake measurements had been made in 1941 and 1966. The vertical tectonic movements derived from differences between the pre- and post-earthquake data (1966–1969) indicate a small uplift in the region northwest of the fault zone and subsidence in the southeast side, including a gentle southeastward tilt, as illustrated in Fig. 10(b) (GEOGRAPHICAL SURVEY INST., 1970).

In order to explain the pattern of the tectonic movements, we calculate theoretical, vertical displacements from some assumed fault models, using the formulations of MARUYAMA (1964) for static dislocations in a semi-infinite medium. The technique of numerical integrations is essentially the same as described in a previous paper (MIKUMO, 1973). The parameters specifying the fault orientation and dimensions are taken to be the same as in the dynamic model, as a first approximation. We assume that the fault displacement is constant with depth, because it is hard to estimate its depth variations from measurements in the case of a vertical fault plane.

Figure 11 gives the pattern of the theoretical, vertical displacements computed from Model A with a tentative dislocation of 0.5 m constant over all the fault plane. Thick and broken curves indicate contour lines of the uplift and subsidence, respectively, and light lines with dots show the leveling routes.



after Geogr. Survey Inst. Japan (1970)

Fig. 10. Elevation changes along two leveling routes, after GEOGRAPHICAL SURVEY INSTITUTE (1970).

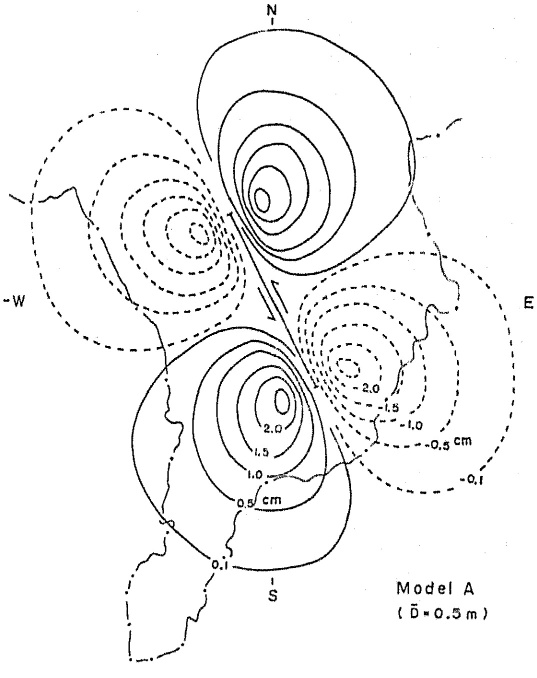


Fig. 11. Pattern of theoretical, vertical displacements from Model A.

The observed pattern shown in Fig. 10(b), in the southeast and part of the southwest region, appears to be accounted for by the above model, but the model does not explain well the observed uplift northwest of the fault zone. However, since the measured elevation changes include a uniform southeastward tilt over the region, we consider that real tectonic displacements by the earthquake would be those obtained by eliminating the uniform tilt from the 1966–1969 data. If the data compiled by TANAKA (personal communication, 1973) are reduced in that way, the tectonic displacements along the leveling routes are as shown in the uppermost trace in Fig. 15. A comparison of the trace with the corresponding theoretical displacements from Model A with $D=64$ cm indicates that the present fault model could give a good explanation to the measurements, at least to a first approximation.

For further discussion, we consider various models with different distributions of fault displacements in the direction of the fault length. Model B has the displacements decaying toward both ends of the fault, but does not yield appreciable difference from Model A in the general pattern of theoretical displacements. For Models C, D, E, F, and G, fault displacements are assumed to increase towards the northwest end of the fault, as shown in Fig. 12. The northwest area, particularly in Oku-Akegata Village, suffered heavy earthquake damage (MATSUDA and TSUNEISHI, 1970). It is to be noted that many grave stones there indicated counter-clockwise rotations and translations (NATSUDA and TSUNEISHI, 1970), suggesting large left-lateral ground displacements, although many others fell down, probably due to strong ground acceleration. We take these situations into the above models in a rather arbitrary way. The theoretical displacements from Models D and G given in Figs. 13 and 14 yield a similar pattern and may explain, to some extent, the measured uplift west of the fault zone. The corresponding displacements along the leveling routes are given in Fig. 15. Although the amounts of the measured uplift and subsidence are not large enough to discriminate these models, the pattern of Model A or G agrees fairly well with the observations. Figure 16 shows theoretical, horizontal displacements that would be expected from Model G. Unfortu-

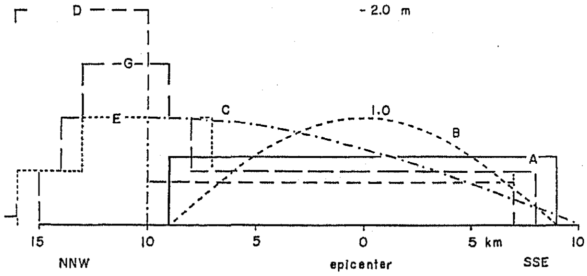


Fig. 12. Assumed fault displacements in the direction of the fault.

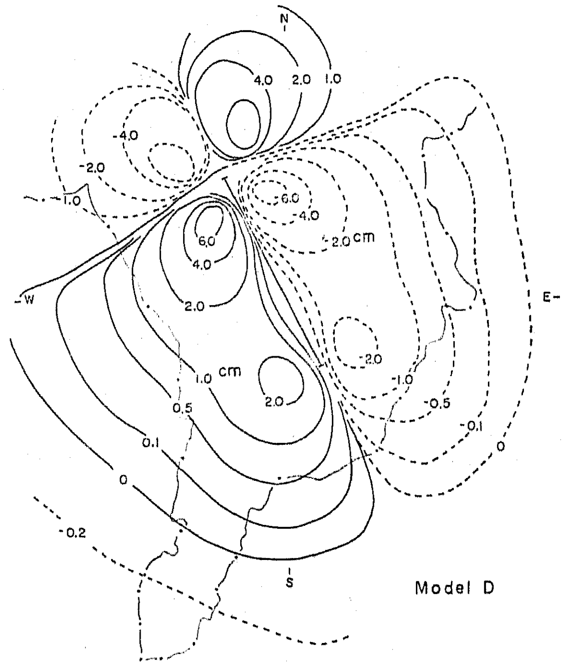


Fig. 13. Pattern of theoretical, vertical displacements from Model D.

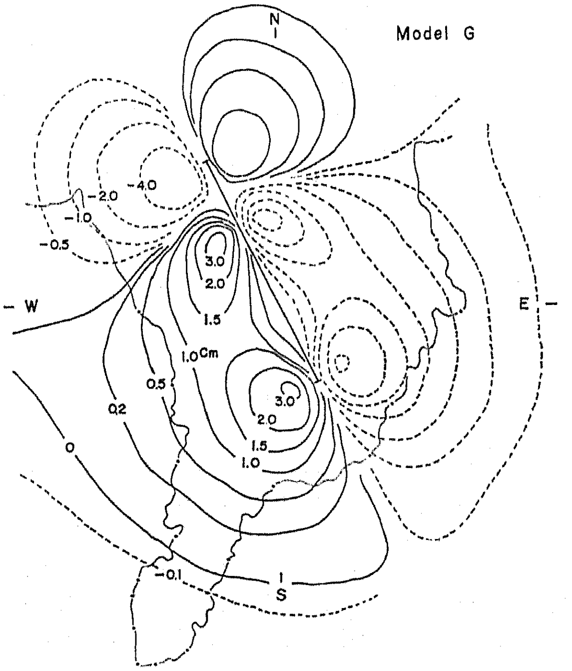


Fig. 14. Pattern of theoretical, vertical displacements from Model G.

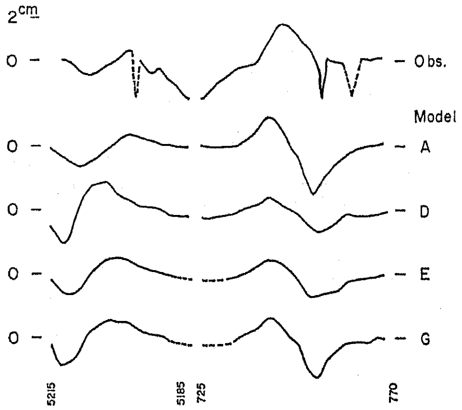


Fig. 15. Reduced vertical tectonic movement along the leveling routes and the corresponding theoretical displacements from various models.

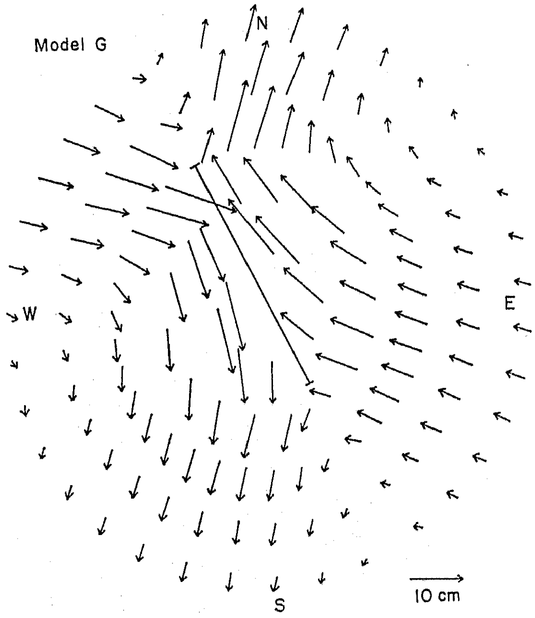


Fig. 16. Pattern of theoretical, horizontal displacements from Model G.

nately, however, there are no pre- and post-earthquake triangulation data to compare with the computed displacements.

The synthetic seismograms computed from Model G are also given in Figs. 8(a) and (b), in comparison with the strong-motion records at four stations. The comparison suggests that Model G could be an alternative model that explains reasonably well the dynamic ground motions as well as the tectonic movements.

6. *Strain and Tilt Changes*

During the Gifu earthquake, permanent strain steps were recorded on 19 strain meters at nine crustal movement observatories spread over central Japan (The Japanese Network of Crustal Movement Observatories, 1970). Further examinations of the records obtained at our stations revealed that

Table 2. Recorded strain steps and calculated strain changes.

Station	Comps.	Observed Strain Steps	Calculated Strain Changes	
			Model A	Model G
Inuyama	N-S	-1.37×10^{-7}	-3.90×10^{-7}	-4.10×10^{-7}
	NW-SE	−0.55	−1.47	−1.93
	E-W	0.15	0.87	0.88
Kamitakara	N-S	−(1.0)	−1.68	−2.14
	N45°E	−(1.0)	−2.04	−3.52
	N45°W	−(1.0)	0.25	0.61
Sabae	N-S	−0.31	−0.13	−0.25
	E-W	0.43	−0.88	1.41
	NW-SE	0.13	−0.53	0.67
Hokushin	N33°E	-40.0×10^{-9}	-7.65×10^{-9}	-8.90×10^{-9}
	N12°W	50.0	1.28	2.77
	N57°W	−20.0	−0.62	−1.82
Matsushiro	N-S	−4.0	1.69	3.72
	E-W	−4.0	−8.78	−12.11
Osakayama	N-S	−50.0	1.88	1.55
	E-W	−20.0	−7.15	−10.32
	S38°W	−20.0	−3.95	−7.70
Donzurubo	N4.5°E	0	−1.38	−2.47
	N40.5°W	0	0.85	1.22
	E4.5°S	−30.0	−2.60	−3.41
Aburatsubo	N22°E	−50.0	−0.38	−0.54
	N25°W	0	1.19	1.74
	N81°W	0	3.26	4.41
Nokogiriyama	N-S	0	−0.17	−0.18
	E-W	−3.0	2.44	3.30
	N45°W	2.0	1.82	2.57
Yahiko	N73°E	1.0	−1.49	−2.22
	N28°E	1.0	−1.84	−2.59
	N62°W	0	0.12	0.11

Remarks: Minus signs indicate compression.

Station	Comps.	Observed Tilt Steps	Calculated Tilt Changes	
			Model A	Model G
Kamitakara	N	24.0×10^{-8}	-1.52×10^{-8}	-1.07×10^{-8}
	E	−8.3	−1.73	−3.68
Kamioka	S45°E	341.0	0.47	0.92
Sabae	N	533.0	−0.18	−0.87
	E	−15.1	−1.55	−2.33

Remarks: Minus signs imply tilting toward the direction opposite that indicated.

similar strain steps were recorded on 3 strain meters at Sabae (SAB) and tilt offsets were also observed on 5 tiltmeters at three sites. The locations of all the observatories are given by open circles in Fig. 5, and the recorded amplitudes are tabulated in Table 2, where the given values except those from our observations are reproduced from the previous report (THE JAPANESE NETWORK OF CRUSTAL MOVEMENT OBSERVATORIES, 1970).

To compare with these observations, we calculated theoretical strain and tilt changes that would be expected from generation of faulting. The method of computation is the same as in the previous paper (MIKUMO, 1973). The results computed from Models A and G for each of the instrumental orientations at the above observatories are given in Table 2, and are compared with the recorded steps in Fig. 17. Solid and open circles correspond to the two models, triangles are the tilt steps, and crosses and four-dot symbols imply that the sense of the recorded steps is the reverse of that expected theoretically. We immediately notice rather scattered relations, but a closer examination shows that 13 observations may be approximated theoretically by either of the fault models. However, the other 14 observations are greater by one to two orders of magnitude than the expected values or recorded reverse signs. Some of the discrepancy may be attributed to the complex geological structure and topographic environments around recording sites, the effects of which are not introduced into the half-space model considered here. A second explanation of the departure would be local strain release secondarily induced by ground shaking, which is sometimes combined with variations in underground

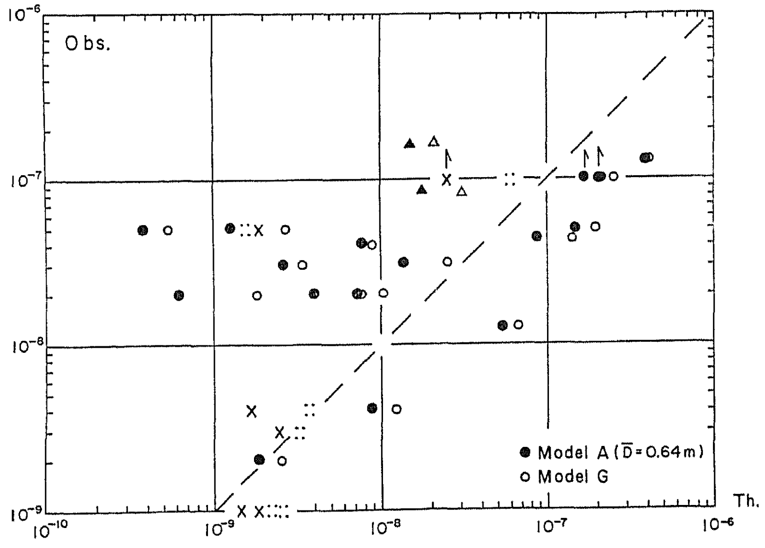


Fig. 17. Observed and theoretical strain steps.

water pressure (SHICHI *et al.*, 1970). The above two explanations are based on the standpoint that the recorded offsets are consequences of real changes of the strain field. Another explanation is that the instruments were seriously affected by strong ground motions upon the arrival of surface waves, rather than recorded strain changes. Some of the recorded steps, particularly of tilts, may be due to the instrumental effects.

Since we think that several factors could be involved in the records, it seems rather difficult to estimate the average fault displacement directly from regional distribution of the recorded strain steps, as in a previous work (THE JAPANESE NETWORK OF CRUSTAL MOVEMENT OBSERVATORIES, 1970).

7. *Some Related Phenomena*

Since there are a few reports that the Gifu earthquake had been preceded by some precursory phenomena, we shall examine these phenomena in relation to the faulting process discussed above.

Pre- and post-earthquake leveling data (GEOGRAPHICAL SURVEY INST., 1970, 1973) indicate little change of elevation between 1894 and 1941 and a gentle uplift between 1941 and 1966 prior to the earthquake, in the regions southeast and southwest of the fault zone (TANAKA, personal communication, 1973). During 1966–1969, the southeast side (B.M. 748–757) turned to slight subsidence, while the southwest side (B.M. 732–744) was more uplifted relative to B.M. 728, both of which may be due to the earthquake, and after the earthquake (1969–1972) both sides show rapid subsidence (TANAKA, personal communication, 1973). The northwest region, on the other hand, which had subsided during 1941–1966, turned to uplift between 1966–1969 (GEOGRAPHICAL SURVEY INST., 1970). One might think that the precursory gently uplift combined with the subsidence due to the earthquake as observed in the southeast side may well be accounted for by a dilatancy model (SCHOLZ *et al.*, 1973). However, the model seems to encounter some difficulty in explaining the increased uplift by the earthquake in the southwest side and also the change from the pre-earthquake subsidence to the post-earthquake uplift in the northwest side. This evidence suggests nonuniform pre-earthquake movement and the difficulty of predicting the direction of displacements that would be caused by an earthquake from pre-earthquake leveling surveys with intermittent periods.

Continuous observations of crustal movements with tiltmeters and strain meters would provide another possibility of detecting some precursory phenomena. The rate of tilting derived from secular tilt movements observed by water-tube tiltmeters at Inuyama (48 km south of the epicenter) and Kamitakara (58 km northeast) shows appreciable changes about 10–11 months before the Gifu earthquake (SHICHI, 1973). The direction of tilting changed to N35°-

40°W and S60°-75°W at the two stations, respectively. On the other hand, calculations in the previous section show that generation of faulting from Models A and G should have produced changes in the direction of maximum tilt to N56°W and N57°W at Inuyama and S49°W and S74°W at Kamitakara. It is interesting that the observed changes are consistent with those expected from faulting, and hence would be regarded as significant precursory phenomena, if they are not due to meteorological disturbances. These might be interpreted as analogous to the so-called γ_1 phase or some progressing β_2 phase (FUJITA and FUJII, 1973).

Tiltmeter records obtained by horizontal pendulum instruments at our four sites at distances between 60 and 80 km are also examined to see if there are any short-term precursory phenomena just prior to the earthquake (KISHIMOTO *et al.*, 1973). A most careful examination appears to indicate some changes in the rate of tilting at the stations 5 to 10 days before the earthquake, but there is some doubt whether they are precursory phenomena, because the instruments used are sensitive to meteorological and other environmental disturbances.

8. *Discussion and Concluding Remarks*

The fault parameters for two probable models derived in the present study are summarized in Table 3. We think that these fault models provide some reasonable explanations for the general observed features of both the dynamic and static ground displacements, although we made simple assumptions for the medium propagated by seismic waves and for distribution of fault displacements. More complete analysis will be made in the future by improving these conditions, and this would yield some modifications in the derived parameters.

KANAMORI (1972) has estimated fault parameters for the present earthquake from long-period strong-motion records at a station about 170 km southwest of the epicenter. These are: $\bar{D}=63$ cm, $\tau=1.8$ sec, $v=3.0$ km/sec, and

Table 3. Fault parameters.

Fault plane	Kanamori	Model A	Model G
Strike		N27°W	N27°W
Dip		90°	90°
Fault Length L (km)	15	18	23
Fault Width W (km)	10	10	10
Seismic Moment Mo (dyne·cm)	2.25×10^{25}	3.5×10^{25}	5.0×10^{25}
Average Displacement $\bar{D}$ (m)	.63	0.6_4	0.7_2
Stress Drop σ (bars)		15	16
Rise Time τ (sec)	1.8	~1	~1
Rupture Velocity v (km/sec)	3.0	2.0~2.5	2.0~2.5

$Mo=2.25\times10^{25}$ dyne·cm, with $L=15$ km and $W=10$ km, which are somewhat different from our estimates. Our analysis based on more information from around of the epicentral area yields a somewhat detailed rupture process. There is a possibility that displacements across the northwestern part of the fault might be somewhat larger than the average, which could be interpreted as a result of complicated fracture propagation.

The tectonic implication of the Gifu earthquake is that it was caused by left-lateral strike-slip movement along a vertical fault in the N30°W direction, which may be due to horizontal compressional stresses of the S75°E-N75°W, similar to the case of large earthquakes in this region. There are striking active, geological faults in the region surrounding the epicentral area; the Atera fault running in the NNW-SSE direction with left-lateral slip at a rate of about 5 m/1000 years (SUGIMURA and MATSUDA, 1965; MURAI, 1970), the Neodani fault which was formed almost parallel to the above during the great Nobi earthquake in 1891 (MURAMATSU, 1963), and the Atotsugawa fault of the NE-SW trend with right-lateral offsets (MATSUDA, 1966). Although the presumed fault of the present earthquake runs parallel close to the Atera fault, it does not seem to have been affected by movements of the latter, since there was no evidence of slip motions along the Atera fault (MURAI, 1970; MATSUDA and TSUNEISHI, 1970; KASAHARA *et al.*, 1970) and because of low seismic activity there (e.g., IKAMI *et al.*, 1972). On the other hand, seismicity on the southwest side of the Neo-dani fault has been very high, whereas the northwest side was almost aseismic (MIKI *et al.*, 1965; WATANABE and NAKAMURA, 1967; OOIDA *et al.*, 1971). The Gifu earthquake took place in the aseismic area where only smaller geological faults appear, and may not be related to movements of these faults (MATSUDA and TSUNEISHI, 1970). It seems likely that large compressional stresses of the E-W trend, which might result from underthrusting of the Pacific Plate against the Asia Plate, caused the present earthquake in a region of local stress concentration which received some aftereffects of the great Nobi earthquake. The existence of the large-scale compressional stresses are confirmed from distribution of maximum shear strains (TANAKA, personal commnication, 1973) based on wide-area triangulations (1883–1909; 1948–1968).

Pre-earthquake leveling surveys and tiltmeter observations revealed some precursory phenomena. While leveling surveys made in 1966, more than two years before, and in 1969, two months after the earthquake, do not provide information on tectonic movements in progress between the two periods, precursory changes in the tilting direction seem to have occurred during the period. These observations are of some interest from the viewpoint of predicting the earthquake, but leave some questions about our assumption that the differences in the leveling data between 1966 and 1969 correspond directly to the static displacements caused by the earthquake. The measured tectonic movements might involve this type of pre-earthquake movements as well as after-slip movements as suggested by FUJITA and FUJII (1973).

We think that the results obtained in the present study add some knowledge to the faulting mechanism of the Gifu earthquake.

I am grateful to Drs. Masaji Ichikawa and Mamoru Katsumata of the Japan Meteorological Agency, for kindly supplying the seismic data, Drs. Minoru Tanaka and Hiroshi Sato of the Geographical Survey Institute of Japan, for kindly providing me the geodetic data. I wish to thank Professor Hiroo Kanamori of MIT and Dr. Ryuichi Shichi of Nagoya University for their unpublished results, and Dr. Hikaru Watanabe and Mr. Akio Kuroiso for permission to reproduce their results. My thanks are also due Mrs. Ritsuko Koizumi for assistance in the present work and Mr. Yoshinobu Hoso for drawing the figures.

The computations involved were made at the Data Processing Center, Kyoto University.

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