Paper No. 854. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

SEISMIC DAMAGE TO CIVIL ENGINEERING STRUCTURES BY THE 1994 FAR-OFF SANRIKU EARTHQUAKE

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ABSTRACT

The 1994 Far-Off Sanriku Earthquake with a magnitude of 7.5 in the JMA (Japan Meteorology Agency) scale, occurred at 21:19 on December 28, 1994, causing grave damage to the Hachinohe region, 200km west of the epicenter. Among the various types of damage concerning civil engineering structures, several noteworthy phenomena were observed, such as cause of soil liquefaction and its countermeasures, damage due to the vertical component of seismic force, effectiveness of seismic countermeasures at water supply facilities in Hachinohe City. In addition, the effects of connection plate between beams of a bridge in order to prevent them from falling, small tsunami contrary to large and shallow earthquake at great water depth, very little damage to the reservoirs of flammables,etc.were notable.

KEYWORDS

The 1994 Far-Off Sanriku Earthquake; low-angle thrust; seismic intensity; liquefaction; vertical seismic force; water supply; seismic device; tsunami; flammables

The 1994 Far Off Sanriku Earthquake

A large shallow earthquake with a magnitude 7.5 occurred on December 28, 1994, at latitude of 40.43° N and longitude of 143.75° E. This earthquake and largest aftershock(M6.9) caused severe damage in Hachinohe city, Aomori , Japan. The seismic intensity in Hachnohe city was 6 in JMA scale , those of Aomori, Mutsu and Morioka cities were 5. The source mechanism is low-angle thrust. The fault parameter and total seismic moment are estimated by Kosuga, et. al.(1995). After them , the total seismic moment is 2.1×10^{21} dyne cm, strike is 177 degrees and dip angle is 30 degrees.
Fig.1 shows the locations of epicenters of main shock and largest-after shock. Fig. 2 shows the recorded acceleration seismograms and its Fourier spectrum during the Far off Sanriku earthquake of 1994 at Hachinohe Meteorological observatory.

Outline of damage

The Sanriku Eq. including the maximum aftershock on 7 January in 1995, claimed 3 deaths, 783 injuries and grave damage of 75.5 billion yen(about 755 million US dollars) to many social facilities. The damage was concentrated in structures and facilities on relatively good ground(max. acc.675 gal) as terraces and volcanic deposits on the paleozoic layer in Hachinohe City. Damage on the alluvium layers, even on soft ground(observed max.acc.200 gal), along the Mabechi and the Niida Rivers, was relatively light. Other damage due to the Sanriku Eq. has many particular characteristics. This paper will report several noteworthy points among these.

Liquefaction and its countermeasures

Although the phenomenon of liquefaction due to this earthquake was observed at some places, as shown in Fig.3, the one at Hachinohe Port was generated over a wide area and on a large scale, mainly at the 2nd industrial port which was newly reclaimed after the 1968 Off Tokachi Earthquake(hereinafter Tokachi Eq.). The bedrock at the 2nd port submerges at a steep angle from the old coastline to the north-west offshore, shown in Fig.2(Sakajiri and Sasatani,1994). The liquefaction caused small movement forward of quays, settlement of aprons, sand boil and so on, from No.1 to No.4 wharf.At the 1st port and the fishery port, the influence of liquefaction was relatively small and sand boil, fissures of pavement,etc.were observed in places.

Among the liquefaction phenomena at the 2nd port, several noteworthy facts were found at No.3 wharf. On the top of wharf, big silos and a plant of Tohoku Grain Terminal Co.Ltd.(TGT)(Photo.1) and a small park are situated along the Mabechi River(Fig.3). The ground of the silos and the plant was improved 10m below with sand compaction method in the 1st construction stage and with gravel drain method in the 2nd stage. The improved ground of the plant was quite sound except for a slight settlement (Photo.2), though a bit of boiled sand on the natural ground of the same area was observed. At the small park and its parking area neighboring to the plant a lot of boiled sand was found throughout the site (Photo.3), contrasting the other side of a fence. From a series of phenomena including other examples, it was confirmed that ground improvements with dewatering can be effective in preventing soil liquefaction or reducing its influence,

Figure 4 shows the geologic column of both sites,where we can not find a bedrock under very thick sedimentary layers up to 80m. It is suggested that the phenomenon of liquefaction is strongly related to the existence of the thick or soft sedimentary layers which accumulate seismic energy and amplify the strain of upper layers (Shioi,1980). At observation point MTS in Fig.2, the predominant period of the ground is 2.5-3 second (Sakajiri and Sasatani,1994) and severe liquefaction is reported. Since the depth of the bedrock at TGT is presumed to be more than 200m, a fairly long period is considered. At 1st industrial port where sedimentary layers are relatively thin, a few small sand boils were found on some reclaimed grounds near the shore.

In the liquefaction at Hachinohe Port, various kinds of soil were boiled, including small gravel, silt and well-graded soil,as shown in Fig.5. Although liquefied ground became a force to push the wharves, it caused no severe damage to the structures on flat ground. Most of the buildings on the liquefied area are still being used after some repairing. The conveyor viaduct (Fig.1) from the TGT plant to the unloading berth, with a top heavy structure, was sound during the two big earthquakes in spite of passing a severely liquefied park, and continued to supply feed to cattle in the cold winter. Though the energy to induce liquefaction was enormous, it appears that the acceleration of the force to act upon structures was not so strong.

Vertical component of seismic force

Damage due to the Sanriku Eq. was concentrated in Hachinohe City and distributed densely on the diluvium terrace, volcanic sediments on the peleozoic layer of limestone, clay stone, sandstone and chart. This earthquake was predominantly shorter in period than the Tokachi Earthquake with almost the same epicenter and the magnitude 7.9. Figure 6 (Takita et al,1995) shows the spectrum of acceleration on the peleozoic clay stone 20m below Hachinohe Institute of Technology. From Fig.6, the predominant period seems to be 0.3

second for the horizontal direction. But for the vertical direction, it is difficult to determine the predominant period since high acceleration was distributed up to 8 Hz. Therefore, we cannot neglect the influence of the vertical component of this earthquake motion in order to analyze the damage to structures. Photo.4 shows cracks in some intermediate columns of the city hall, with heavier loads than edge columns. Photo.5 shows a big shear crack in a column on the porch of a high school, sustaining the overhanged portion of the building. Figure 7 shows failure and rehabilitation of the bank of railway,where another type of failure, slope sliding, occurred due to the Tokachi Eq. and had been repaired.

Seismic countermeasures for water supply

The water supply facilities in Hachinohe City were severely damaged by the Tokachi Eq.in 1968. Hachinohe Regional Water Works Enterprise(hereinafter HRWWE) has been making efforts to take seismic measures for their facilities based on this bitter experience. HRWWH devised an iron pipe with a new joint system shown in Fig.7, called a "seismic pipe". The seismic pipes are used for the trunk lines in the network 124km long(Fig.8) and received no damage from the 2 big earthquakes. HRWWE is building a loop circuit of the trunk line surrounding the center of the city. Furthermore, HRWWE took several seismic measures for purification and pumping stations such as strengthening of instruments, fixation of equipments and tool shelves, chemicals, protection of computers and so on.

The Sanriku Eq, halted water supply to about 30,000 houses after the main shock and about 5,000 houses after the aftershock. Damage was concentrated generally in branch lines, mainly vinyl chloride pipes, in the water supply network on relatively good ground, and its distribution corresponded with buildings and housings. Owing to the sound trunk line, the survey of damage and the repair work could start all together, using many control valves, and send water to the countryside. Water supply was recovered within 5 days after the main shock and 3 days after the aftershock, in spite of the very cold winter and the duration of the New Year vacation. Although the loop circuit was not yet completed, the completed portions became a big reservoir and supplied water to the water wagons at some points along the circuit, and to the trunk lines which had stopped due to disturbance of their natural springs by the earthquake. Indebted to other seismic countermeasures for the facilities taken, by HRWWE, damage to the water supply was limited and its influence to the citizen's lives during the New Year holidays also was minimized.

Miscellaneous

Among the notable phenomena, the connection plates between simple beams on the Ohhashi bridge near the center of the city prevented the girders from falling down into the river. The plates continuously connected whole girders and restricted the movement of the piers. Although the bridge was so damaged that some piers settled down and several parts of structures were broken, it maintained service under traffic control, just after the main shock.

The tsunami was very small, in spite of a large magnitude of 7.5, the shallow depth of the hypocenter, a large water depth of about 8,000m, the epicenter near that of the Tokachi Eq, with a tsunami moderate in scale, and so on. The reason probably depends on the property of the low- angle reversed fault.

Around Hachinohe several types of flammable storage reservoirs are situated such as a petroleum complex at the Hachinohe Port, underground storage caverns of 1,750,000kl at Kuji, 40km south of Hachinohe, and a group of 51 crude oil tanks with scale of 100,000kl at Mutsu-Ogawara, 60km north.In conclusion, there was no principal damage to the tanks and pipings such as fire, leakage and so on.Damage was limited to fissures in dikes and mounds, failure of tank roof seals, deformation of anchor bolts of water supply tank,etc. At the underground cavern, the acceleration was one third that of the ground surface and there was not any damage.

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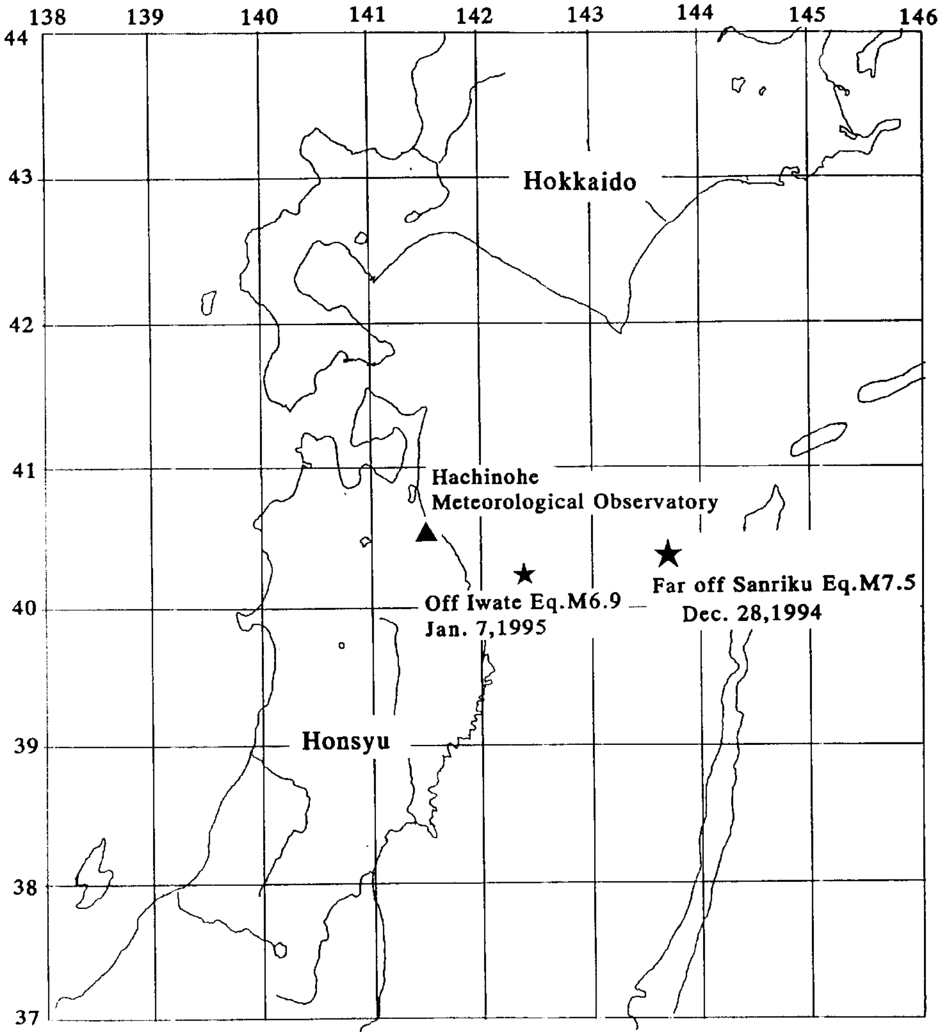

Fig.1 Location of the epicenters of main shock and the largest-after shock

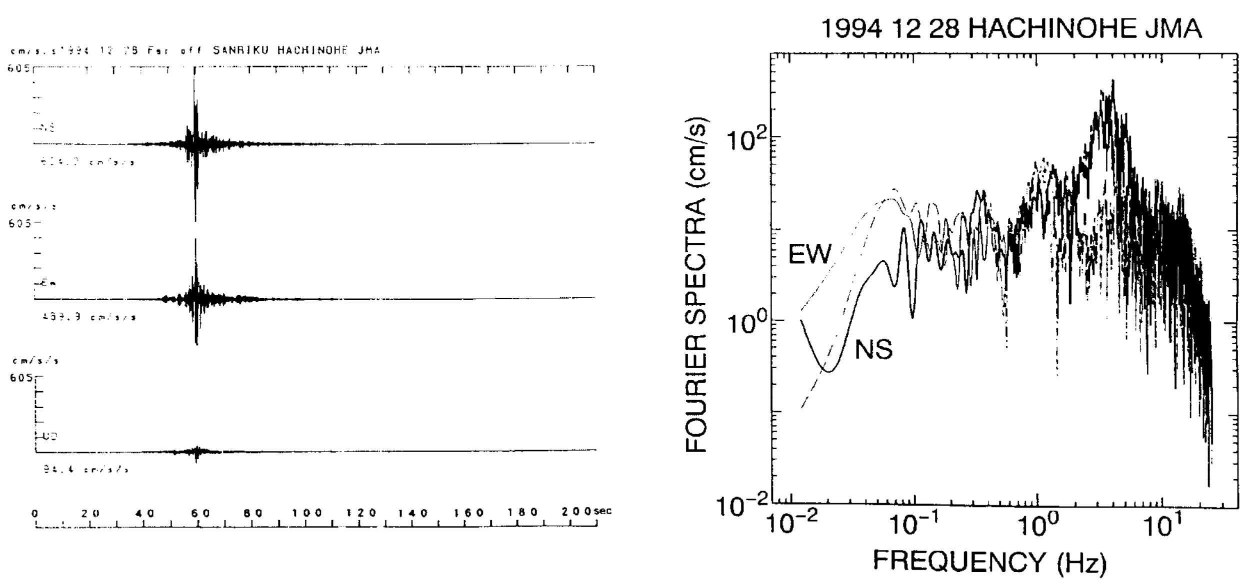

Fig.2 Acceleration seismograms and Fourier spectrum observed at Hachinohe Meteorological Observatory.

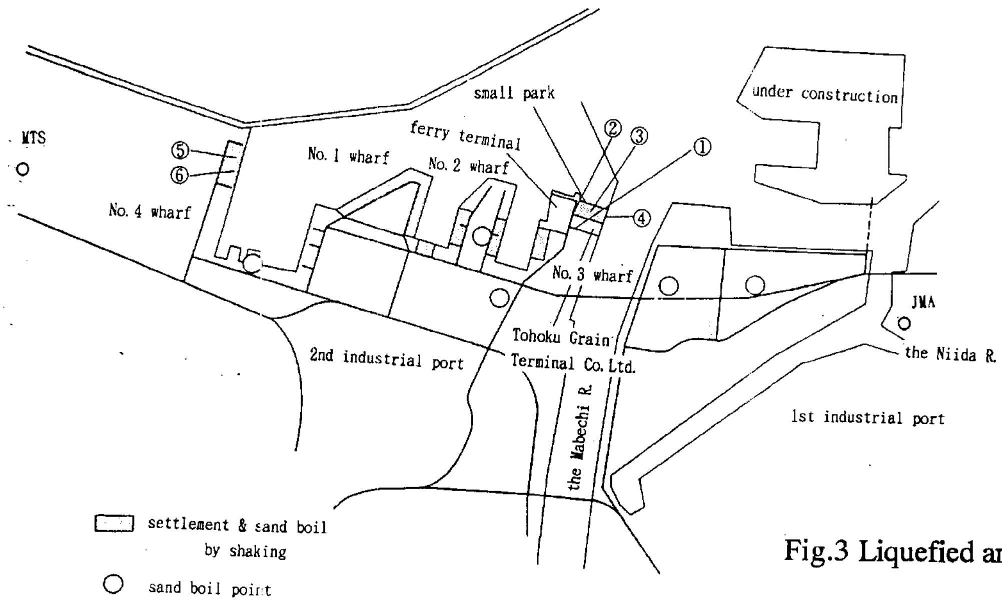

Fig.3 Liquefied area at Hachinohe Port

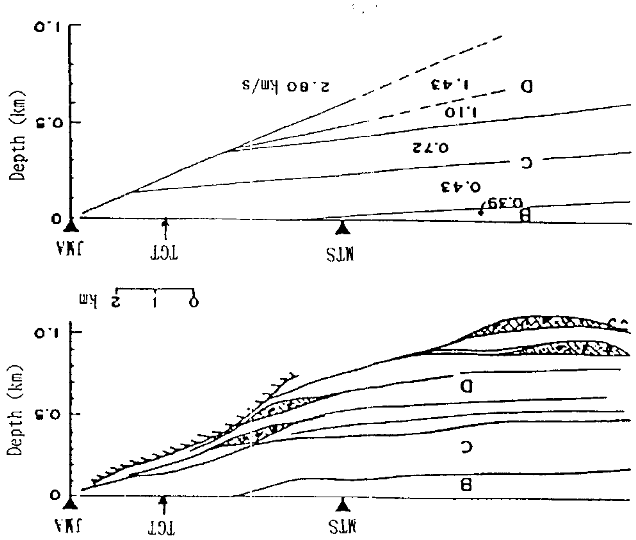

Fig.4Geologic section & velocity structure of Hachinohe Port

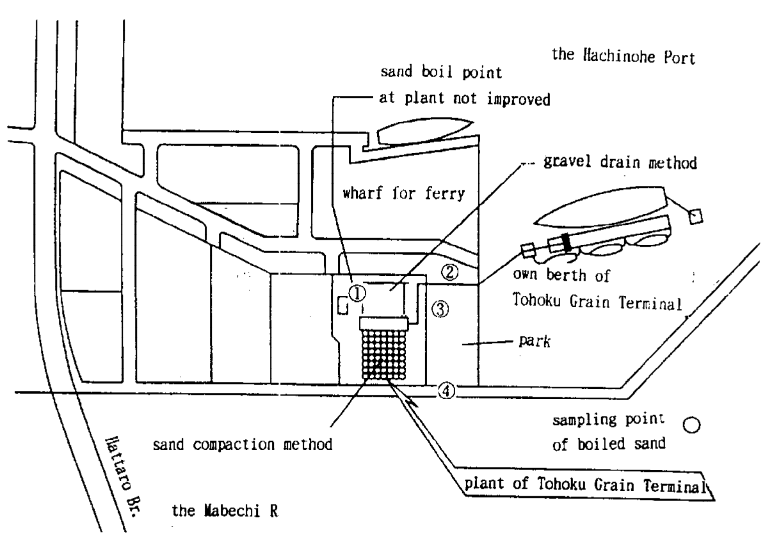

Fig.5 Disposition of No.3 wharf

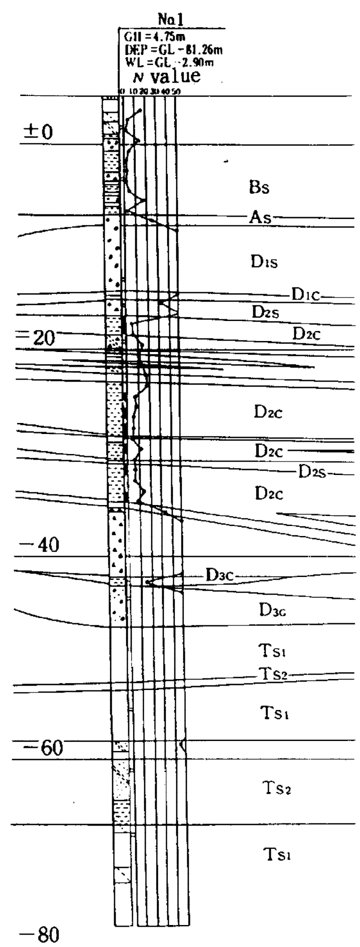

Fig.6 Geologic column

at the top of No.3 wharf

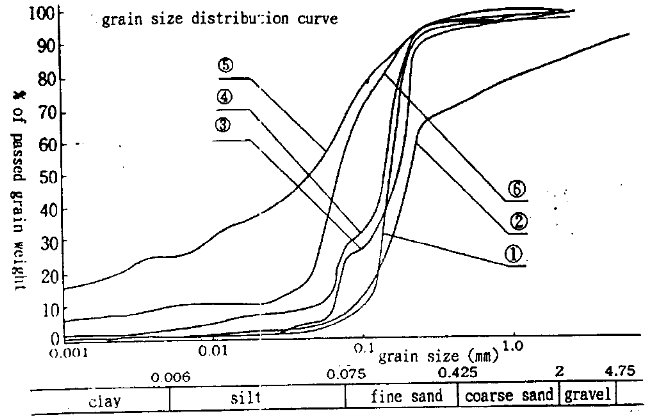

Fig.7 Grain size accumulation curve of boiled sands

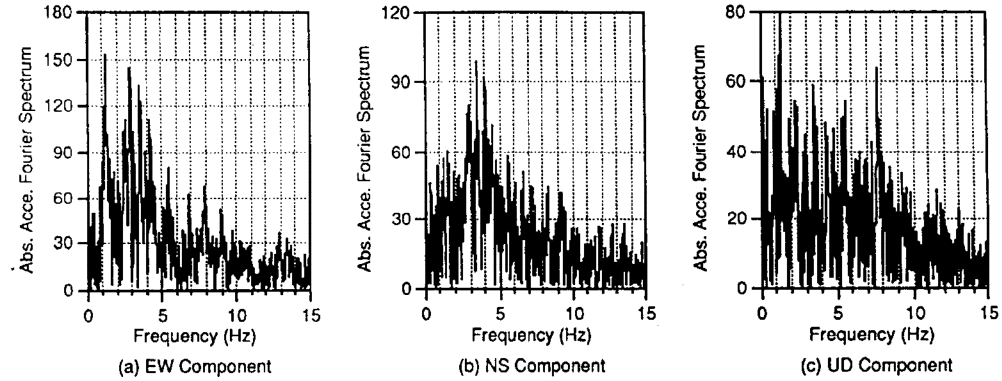

Fig.8 Fourier spectrum of the Sanriku Eq. at HIT

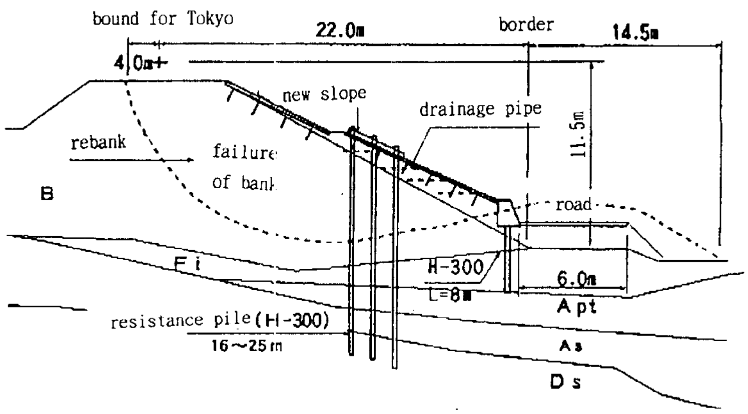

Fig.9 Failure & rehabilitation of bank of railway

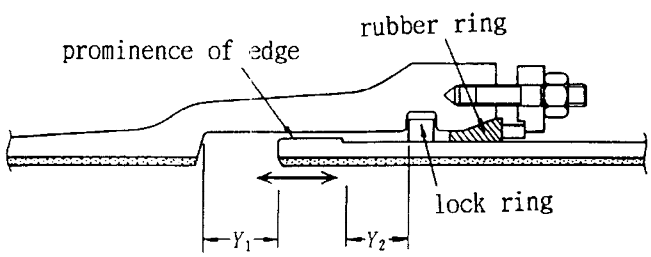

Fig.11 Detail structure of joint of seismic pipe

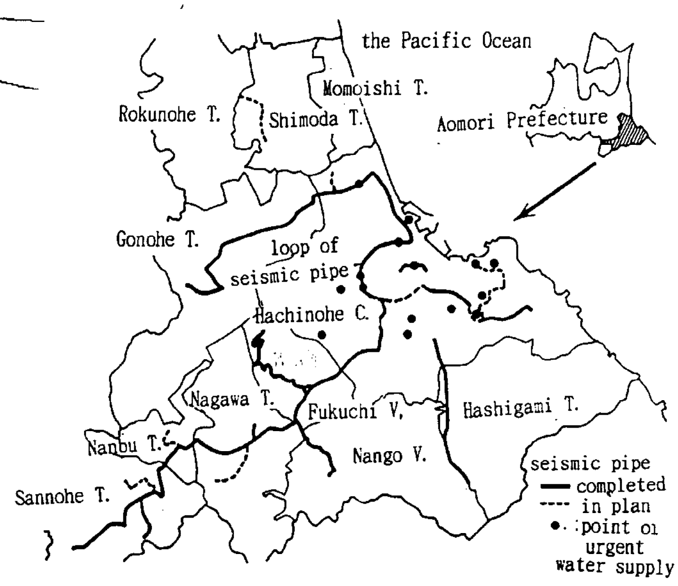

Fig.10 Seismic pipe in the main trunk line of HRWWE