Permanent ground displacement induced by soil liquefaction during 1983 Nihonkai-Chubu and the 1964 Niigata earthquakes

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ABSTRACT: Permanent ground displacements caused by liquefaction during the 1983 Nihonkai-Chubu and the 1964 Niigata earthquakes were measured by pre- and post-earthquake aerial survey, and the causes of the ground displacements based on the geological and the topographical conditions, are discussed.

1 PERMANENT GROUND DISPLACEMENT DURING THE 1983 NIHONKAI-CHUBU EARTHQUAKE

The Nihonkai-Chubu earthquake, with a magnitude of 7.7, occurred in the Japan Sea about 90 km west of Aomori Prefecture on May 26, 1983, causing severe damage to the coastal area of the Tohoku region. Fig. 1 shows the epicenter of the earthquake and the recorded maximum horizontal acceleration.

Permanent ground displacements were measured in Noshiro City (Fig. 2), where most of the urban area is built on the sand dune along the Japan Sea coast and alluvial plane of the Yoneshiro River and caused severe damage to houses, buildings, and lifeline facilities. Numerous sand volcanoes were found in the area where the heavy damage was concentrated, showing that the ground was considerably liquefied. Other ground failures such as

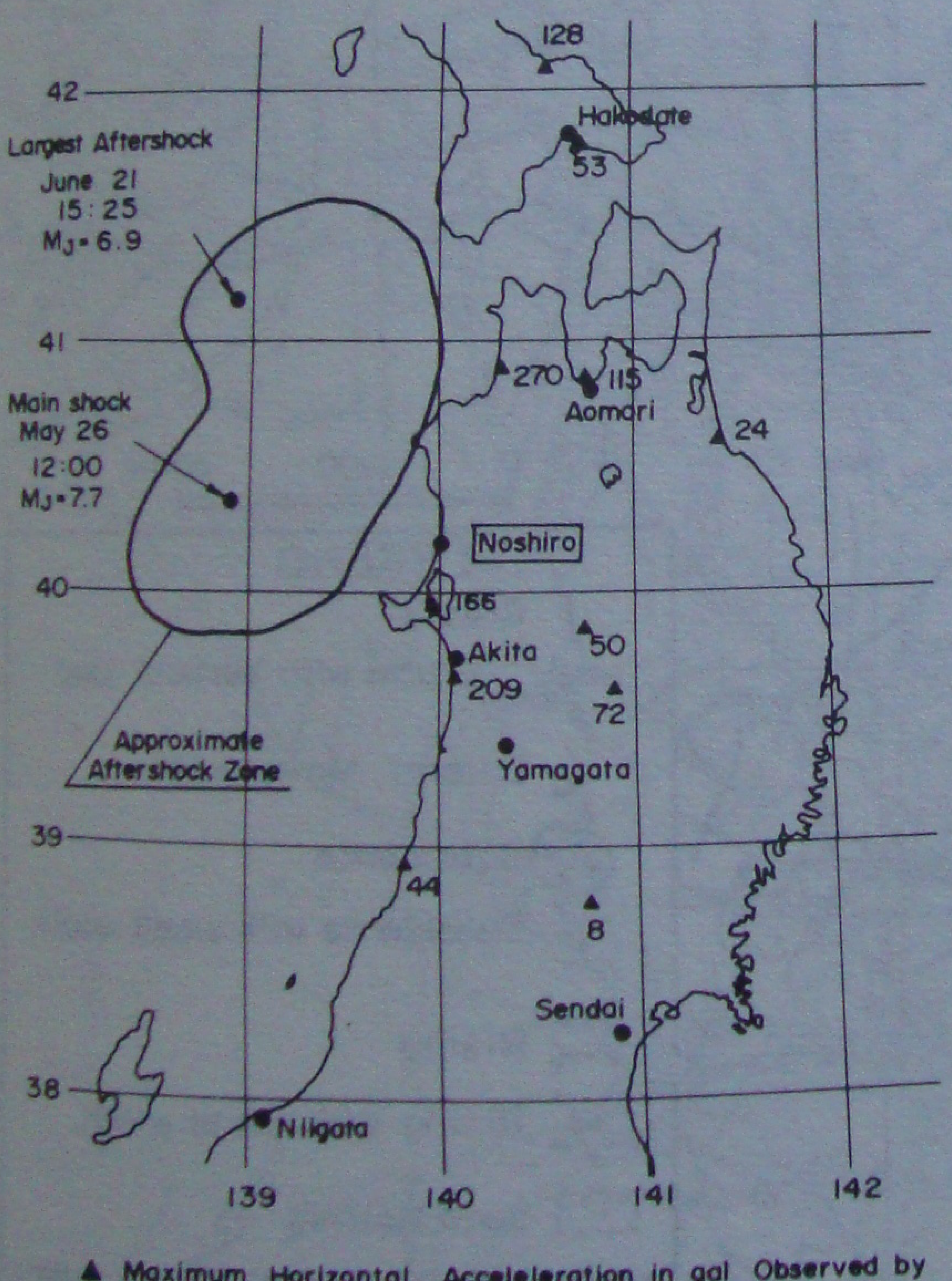


Fig. 1 Epicenter and maximum horizontal acceleration during the 1983 Nihonkai-Chubu earthquake

Fig. 2 Measured area of permanent ground displacement in Noshiro City

cracks, subsidences, bulging, etc., were also seen in the damaged area.

1.1 Method of measurement

Permanent ground displacements induced by the earthquake were measured from aerial photographs taken with a same reduction scale of 1:8000 before and after the tremor. The pre-earthquake aerial photograph used for the survey was taken in 1981, two years before the earthquake, and the post-earthquake photograph was taken a week after its occurrence.

To measure the magnitudes of the permanent ground displacements, it was necessary to select datum points which were considered not to be moved by the earthquake. In principle, most of the datum points in this survey were selected from triangulation points in the periphery of the area to be measured. All the selected triangulation points were located on the stable tops of either hills or sand dunes, where no ground failures, including liquefaction, or damage to structures were found. It can be assumed that no permanent ground displacements were caused by the earthquake in the neighborhood of the triangulation points.

The measurement of the permanent ground displacements was conducted on points which are fixed on the ground surface and which can be found in both the pre- and post-earthquake photographs. Manholes,

Fig. 3 Permanent horizontal ground displacements in the northern part of Noshiro City

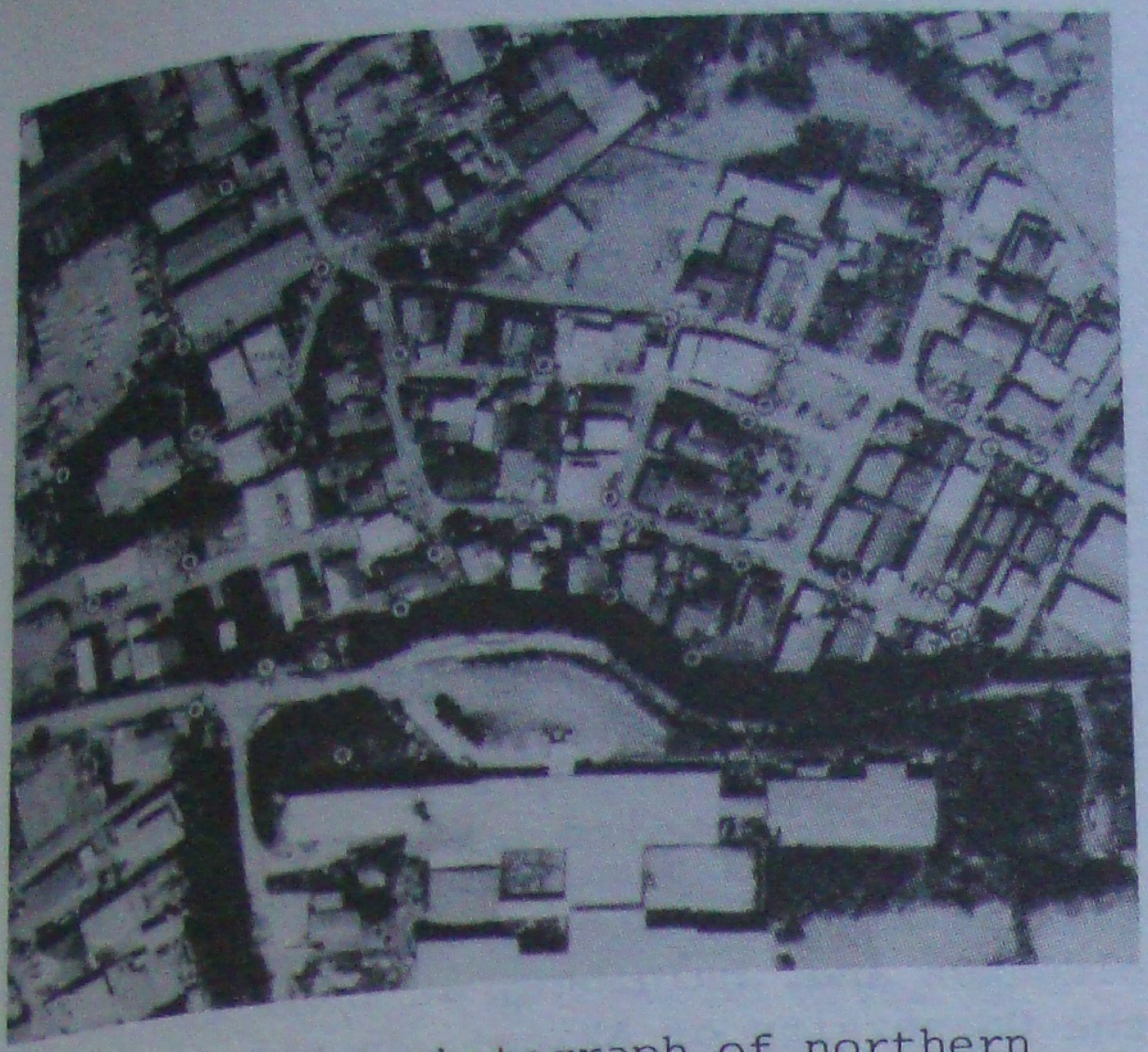


Photo 1 Aerial photograph of northern slope of the Mae Hill

Photo 2 Cracks in the road leading to the graveyard in Aoba-cho

Fig. 4 Permanent horizontal ground displacements in the southern part of Noshiro City

cadastral boundary stones, bases of light poles, corners of drainage channels, etc., were preferentially selected, but in areas where measurement points such as these could not be found, the roofs of houses, which were confirmed not to have been damaged, were secondarily selected. A total of about 2,000 points was selected. Photo 1 shows one example of the aerial photographs and points of measurement on the northern side of Mae Hill where the permanent ground displacements were dominant as shown in Fig. 4.

The accuracy of the measurement of permanent ground displacements depends on the reduced scales of the pre- and post-earthquake aerial photographs, human error in reading the coordinates of the measurement points, etc. The accuracy of the measurement was estimated as ±17 cm in the horizontal direction and ±28 cm in the vertical direction in the northern area of the city, and ±16 cm and ±20 cm in the southern area. Furthermore, in a part of the southern area, in order to verify the results of aerial survey, a traverse survey and a plane table survey were conducted and it was confirmed that the obtained results agree well with those of the aerial photograph survey.

1.2 Measured permanent ground displacements and ground failure

Figs. 3 and 4 show some parts of the permanent horizontal ground displacements measured in the northern and southern areas of Noshiro City, respectively. It can be seen that a large ground displacement occurred along the gentle slopes of the sand dunes.

In the northern area, as shown in Fig. 3, permanent ground displacements were dominant in the western half on the west side of the Noshiro-Oga Road, which is gently sloped, and forms the transition area between the sand dunes and the alluvial plane. The displacements started from halfway down the sand dune, Sunadome Hill, and extended for about 800 m in a northerly or northeasterly direction. The maximum horizontal displacement in the northern area reached about 3 m, in the graveyard of Aoba-cho.

On the other hand, the permanent ground displacements in the eastern half on the east side of the Noshiro-Oga Road, which is located mostly on the alluvial plane, were very small, at less than 1.0 m.

In the southern area, as shown in Fig. 4, a large displacement occurred on the slope of Mae Hill, a sand dune about 10 m higher than the surrounding area. On the northern slope of the hill, the displacements started from near the top and extended horizontally for more than 400 m in a northerly direction. The maximum horizontal displacement exceeded 5.0 m and the direction of the displacement was almost parallel to that of the slope.

The displacements on the southern slope of Mae Hill extended horizontally for about 300 m from the top to near the road running east-west at the toe of the slope. The displacements on the eastern slope also extended to near the north-south road, where the ground surface was mostly flat.

Figs. 3 and 4 also show ground failures such as sand volcanoes, cracks, subsidences and, bulgings, as investigated by the University of Akita. In the northern area, as shown in Fig. 3, the ground failures were concentrated in the western part (Aoba-cho, Matsumi-cho, etc.), where the permanent ground displacements were large. Photo 2 shows one example of cracks in the road leading to the graveyard in Aoba-cho, where the maximum horizontal displacement was 3.0 m.

On the eastern side of the Noshiro-Oga Road, where the permanent ground displacements were very small, very few ground failures were found.

In the southern part, as shown in Fig. 4, many cracks and subsidences were also found around Mae Hill, where displacements exceeding 5.0 m occurred.

From the figures, it can be seen that the horizontal directions of the permanent ground displacements are mostly perpendicular to those of the ground cracks.

1.3 Study on the causes of the permanent ground displacements

Many sand volcanoes were found in the areas where the permanent ground displacements were large, as shown in Figs. 3 and 4. The liquefaction of soil layers can therefore be assumed to be one of the main causes of the permanent ground displacements.

Fig. 5 shows one example of the subsurface soil conditions along a section line, shown in Fig. 3 (7-7'), and the estimated liquefied soil layers. The liquefied soil layers were conjectured by calculating the Factor of Liquefaction Resistance F_L proposed by Iwasaki et al. The soil layer with F_L less than 1.0 was considered to have been liquefied.

From the figure it can be found that a liquefied layer with a thickness of 2-5 m exists under the sloped ground surface.

Near the toe of the slope where the liquefied layers become thinner and the ground surface is flat, the permanent ground displacements become smaller. Therefore, the gradient of the ground surface and the thickness of the liquefied layer can be considered as the influential factors for the magnitude of the displacement.

2 PERMANENT GROUND DISPLACEMENT DURING THE 1964 NIIGATA EARTHQUAKE

On June 16, 1964, the Niigata earthquake with a magnitude of 7.5 occurred in the Japan Sea about 50 km off Niigata City. In the area along the Shinano River in Niigata City, buildings, bridges, oil storage tanks, lifeline facilities, etc., were extensively damaged by soil liquefaction.

The measurement method was almost the same as that for the Noshiro City discussed in 1.1. The pre-earthquake photograph was taken in 1962, two years before the earthquake and the post-earthquake photograph was taken four hours after the earthquake. The scales of the two photographs were 1/11,000 and 1/12,500, respectively. The measurement accuracy was estimated as ±72 cm horizontally and ±66 cm vertically.

2.1 Measured permanent ground displacements and earthquake damage

Fig. 6 shows the horizontal vectors of the permanent ground displacements, measured by the aerial photograph survey along with the ground failures, such as sand boiling, cracks, subsidences, etc., which were reported by Niigata University.

The permanent displacements are much larger on the left bank of the Shinano River from the Showa Bridge to the Hakusan power substation in Kawagishi-cho, and on both banks from the Bandai Bridge to the Yachiyo Bridge. The maximum horizontal displacement is 8.5 m in the proximity of the Hakusan power substation and 8.8 m on the left bank near the Bandai Bridge. The directions of the horizontal vectors of the displacements are almost perpendicular to the river.

The magnitude of the permanent ground displacement in the area near the Niigata Railway Station is 2 to 3 m, smaller than that along the Shinano River, but it is notable that the direction of the displacement was not toward the river but toward the station.

As mentioned above, the permanent ground displacements measured along the Shinano River were over 8 m. This means that the river width was largely reduced by the earthquake. To verify this fact, an aerial photograph survey was performed,

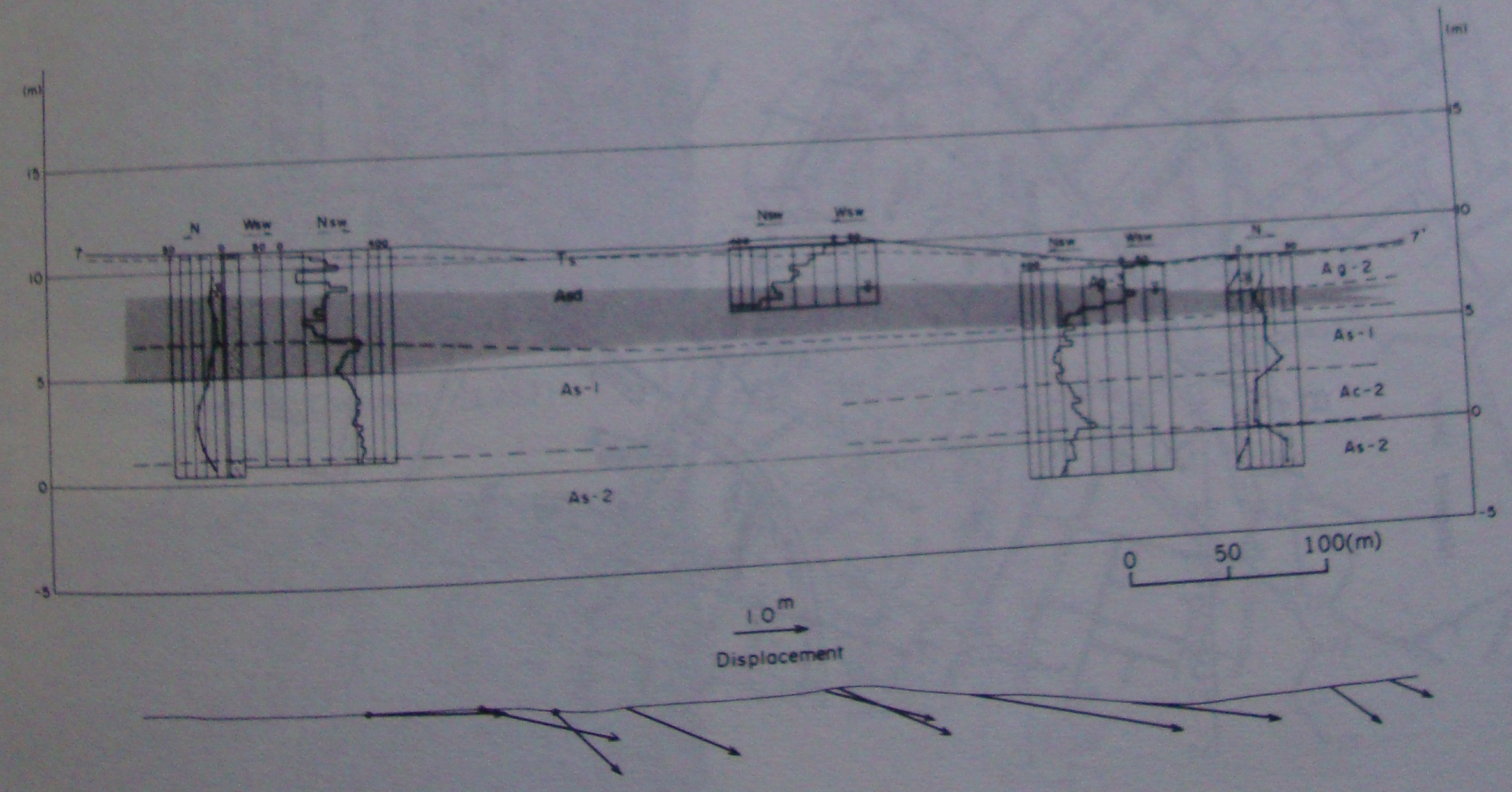


Fig. 5 Soil layer profiles and estimated liquefied layer (Section 7-7')

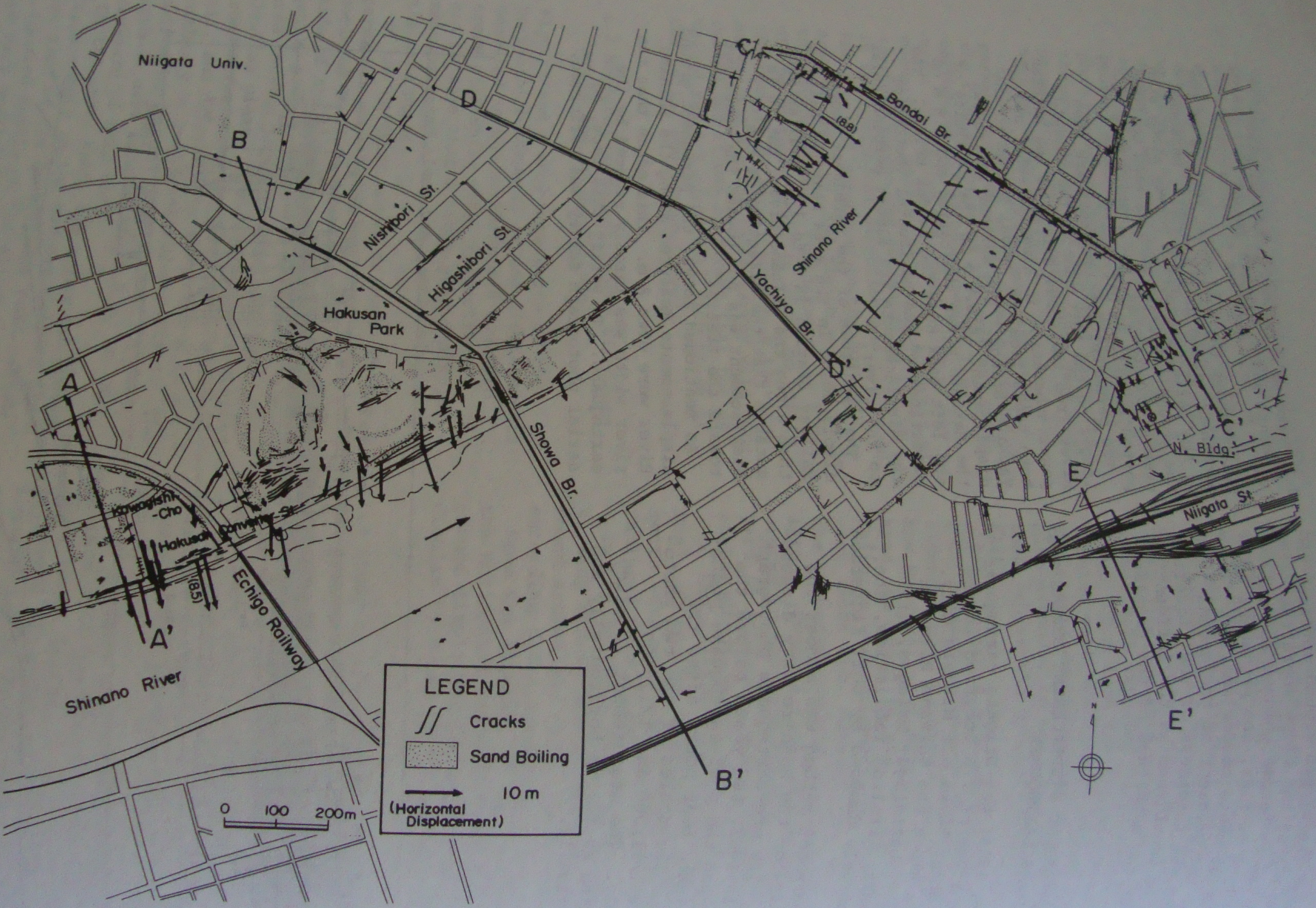


Fig. 6 Permanent horizontal ground displacements in Niigata City during the 1964 Niigata earthquake

paying attention to the river widths before and after the earthquake. The width reduction was obtained by subtracting the river width measured from the aerial photograph taken in 1975, by which time the revetment had been completely restored, from that measured from the aerial photograph taken before the earthquake.

Fig. 7 shows the reduction of the river width. Between the Bandai Bridge and the Yachiyo Bridge, where large permanent ground displacements occurred on both banks, the river width was reduced by 16 to 23 m, while between the Showa Bridge and Kawagishi-cho, where large permanent ground displacements occurred only on the left bank, the river width was reduced by 7 to 13 m.

Photo 3 shows the left bank of the Bandai Bridge before and after the earthquake. Photo (a) was taken in 1962, two years before the earthquake, while photo (b) was taken in 1971 by which time the revetment had been completely restored. By comparing these photographs it can be seen that the revetment, which was straight before the earthquake, became curved at the bridge abutment after the earthquake. This shows that in the vicinity of the abutment, the permanent ground

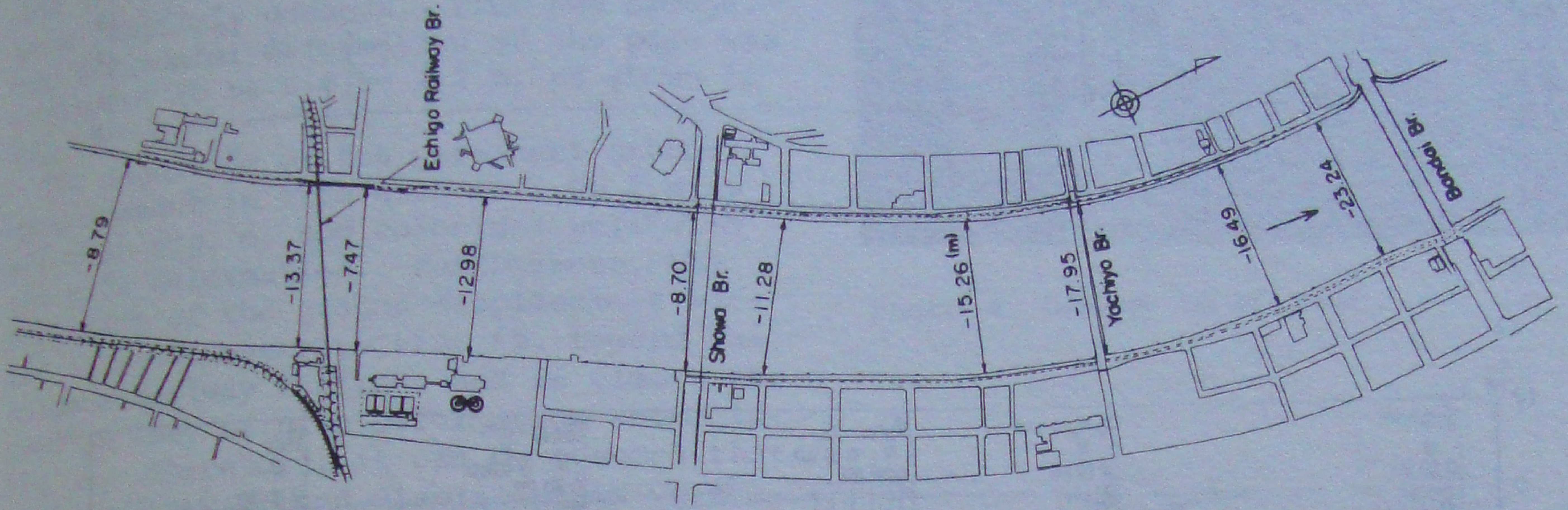
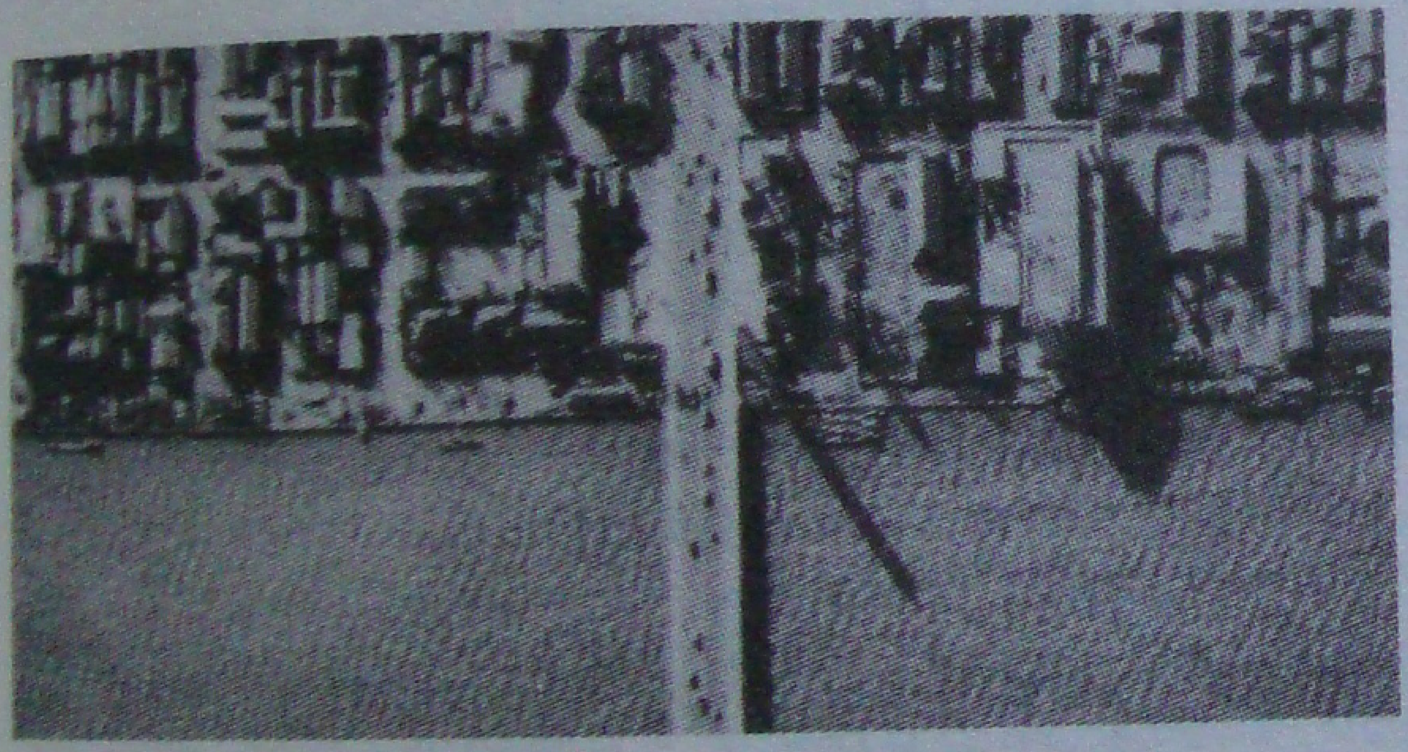
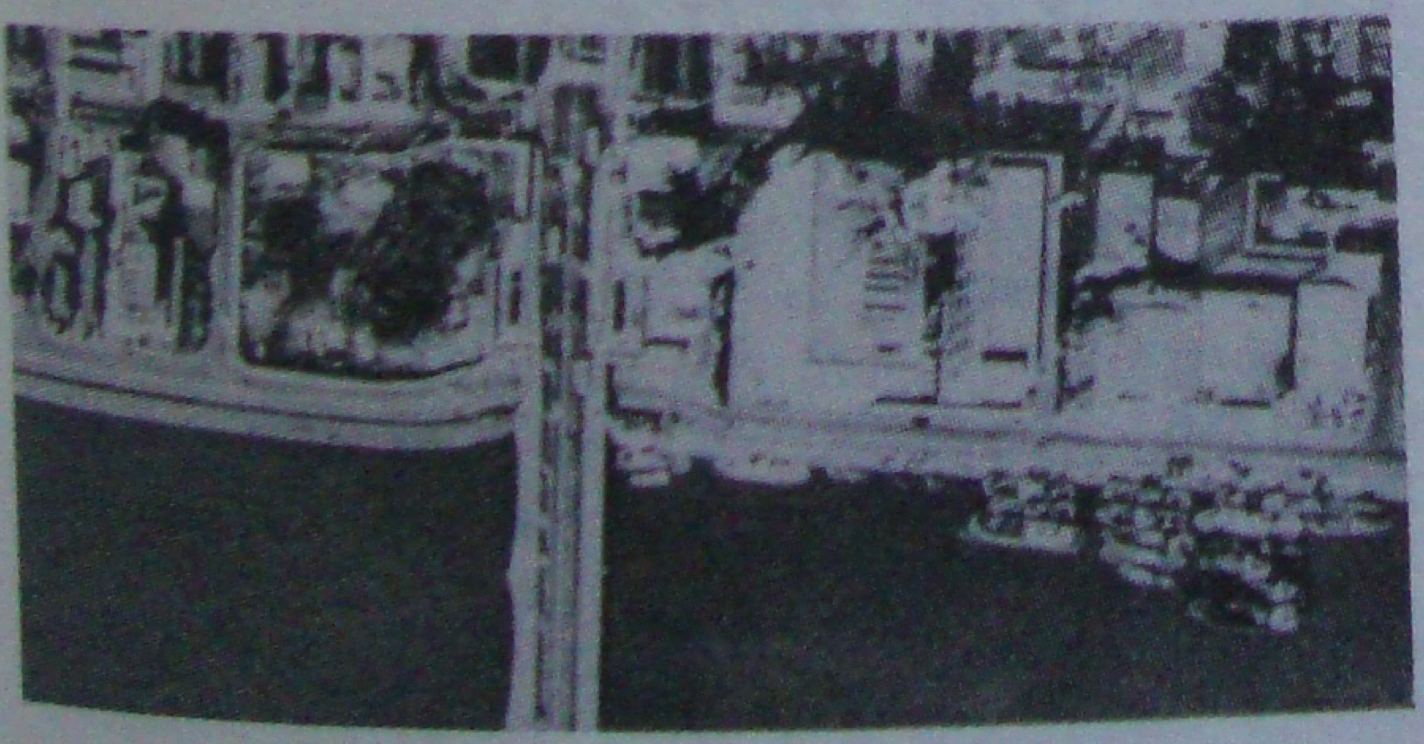


Fig. 7 Reduction of river width during Niigata earthquake (m)



(a) Before the earthquake (1962)



(b) After the earthquake (1971)

Photo 3 Left bank of the Bandai Bridge

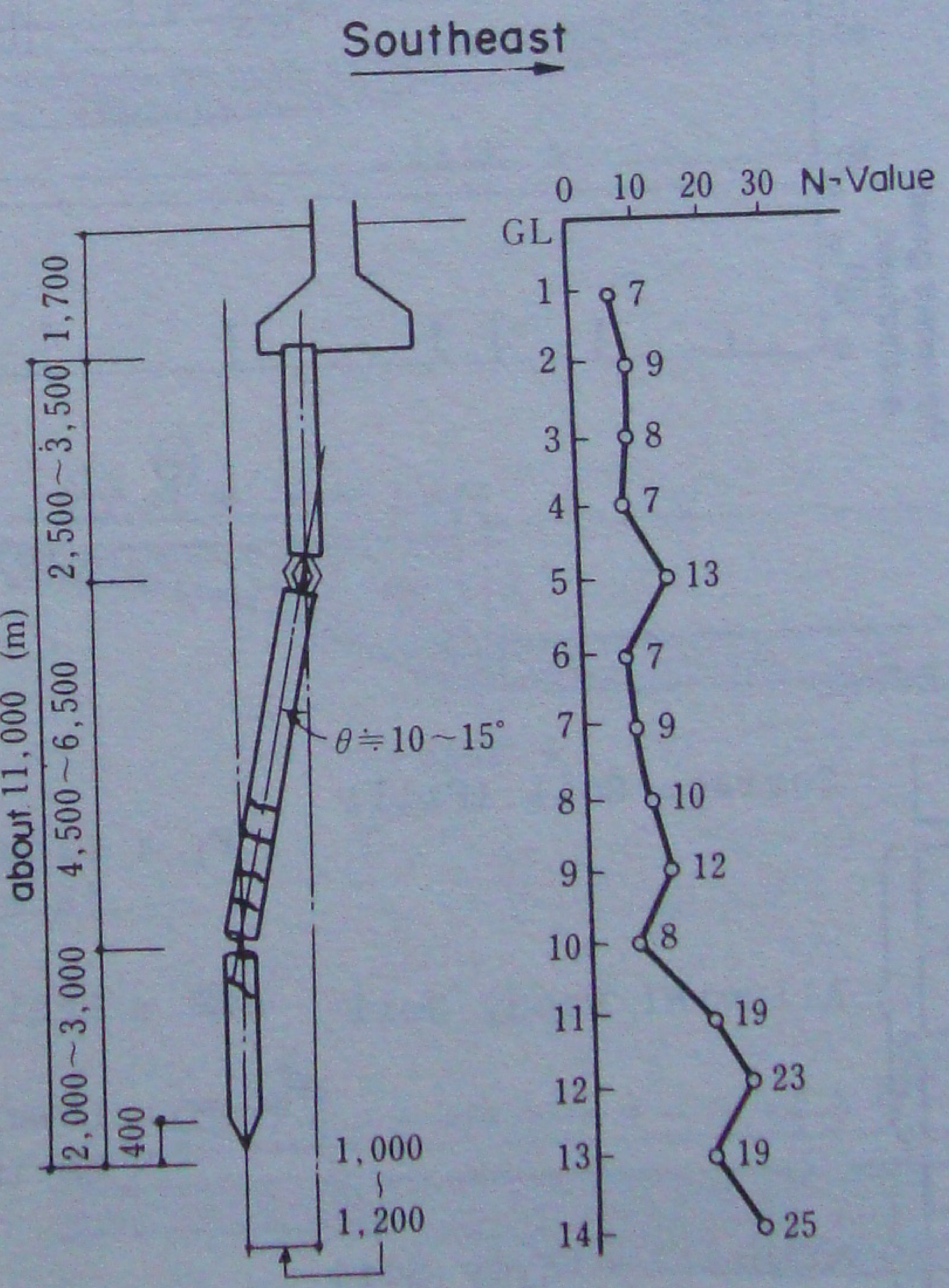
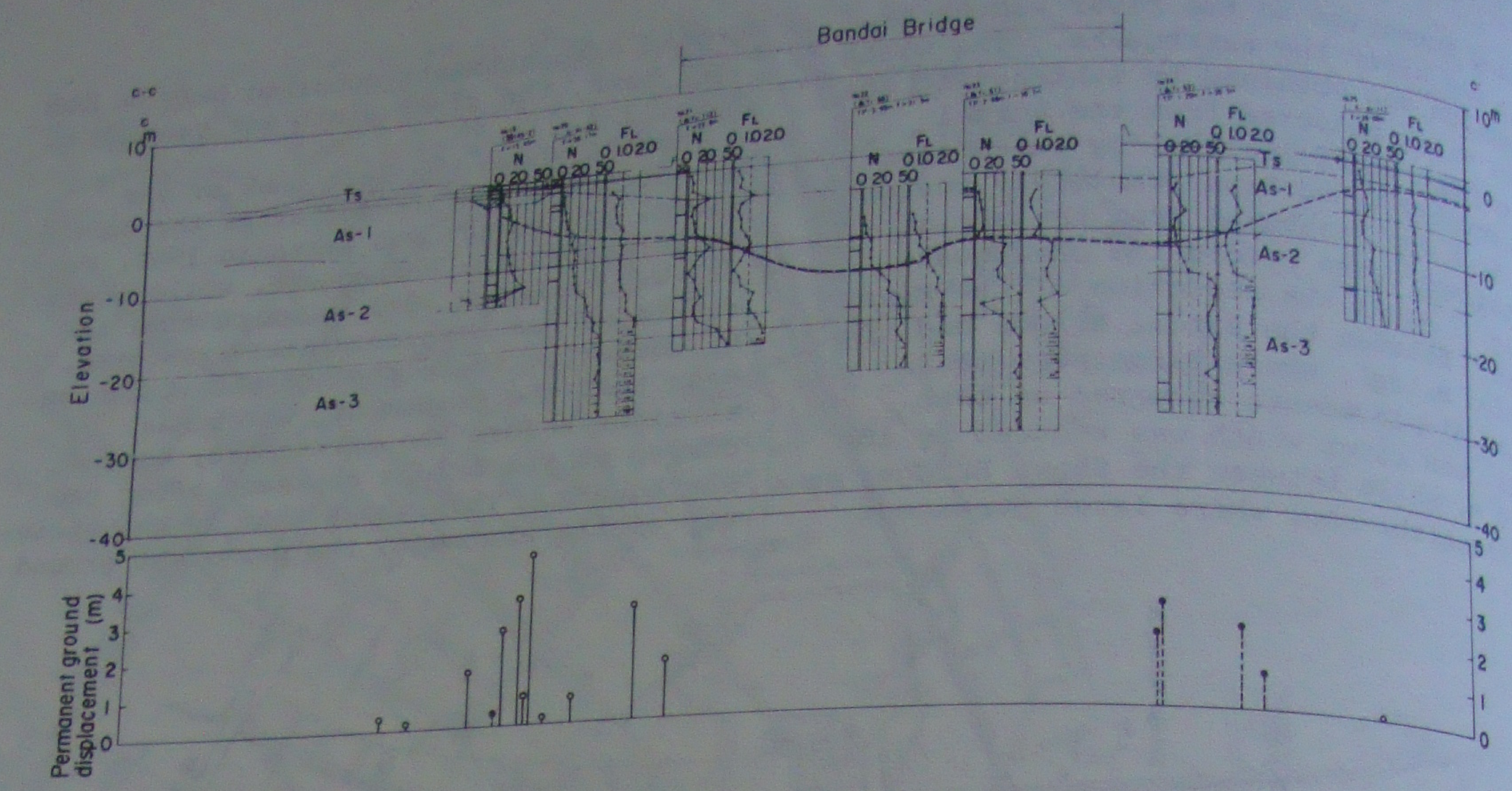
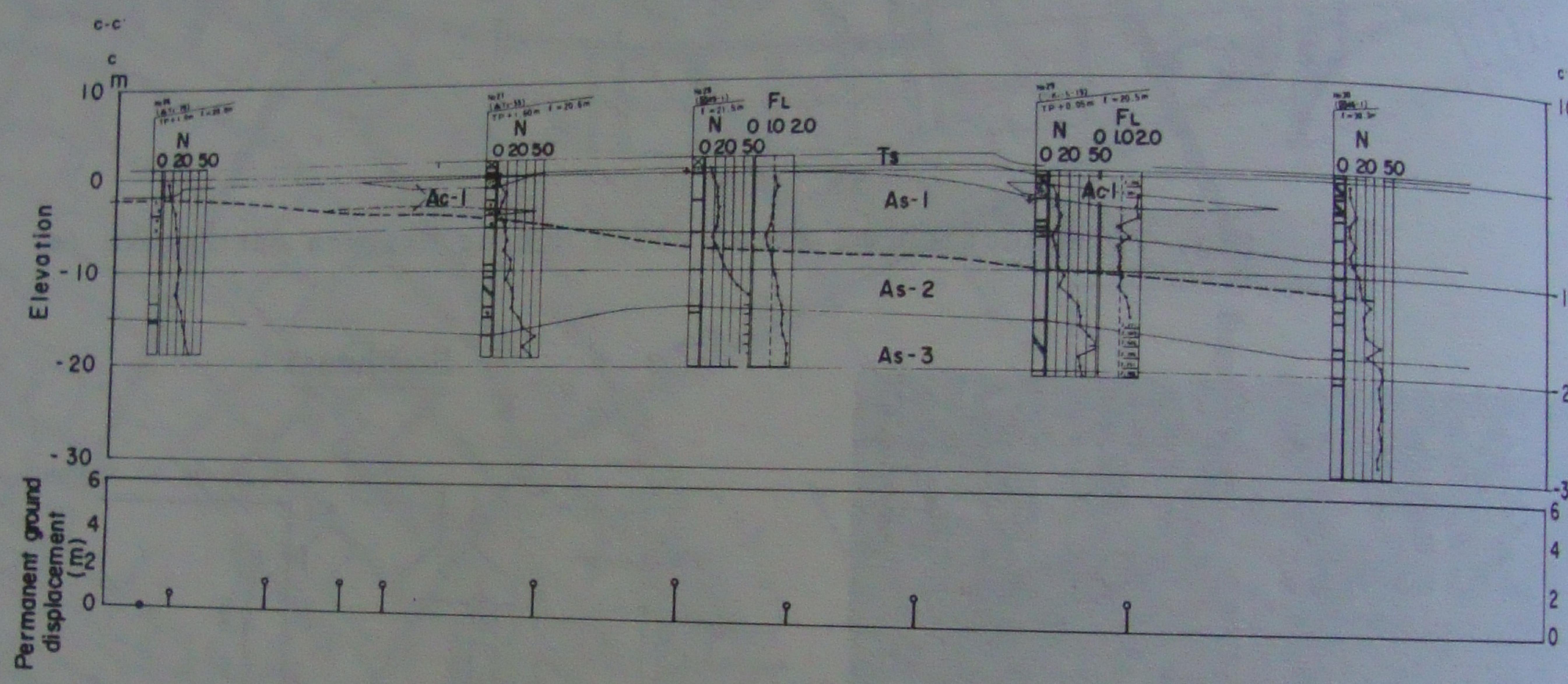


Fig. 8 Broken RC pile and soil condition



(a) Section C-C"



(b) Section C" - C'

LEGEND

Ts	Surface Soil (Fill)
As-1, As-2, As-3	Alluvial Sandy Soil
Ac-1, Ac-2	Alluvial Clayey Soil

F_L : Liquefaction Resistance Factor

▬ : Estimated Liquefied Layer

--- : Lower Boundary of Estimated Liquefied Layer

○ Displacement in Right Direction

● Displacement in Left Direction

Fig. 9 Soil layer profile and estimated liquefied layer displacements were reduced because of the rigidity of the Bandai Bridge, a stone masonry arch bridge.

Kawamura, et al reported on the damage to the RC piles of a building (shown as N. Bldg. in Fig. 6) located north of Niigata Railway Station, which were found when the foundation was excavated for reconstruction in 1985, about twenty years after the earthquake.

As shown in Fig. 8 and Photo 4 the piles were found to be broken at two positions, 2.5 to 3.5 m from the upper end and 2.0 to 3.0 m from the bottom. Seventy four of the total of 304 piles were investigated and it was found that most of the piles were similarly damaged. From the damage, the horizontal deformation of the pile was estimated to be 1.0 to 1.2 m, as shown in Fig. 8.

The magnitude of the permanent ground displacement in this area is 1 to 2 m as shown in Fig. 6, and coincides well with the pile deformation. Furthermore, the direction of the ground displacement vector is southeasterly, that is, toward the Niigata Railway Station, and is almost the same as that of pile deformation shown in Fig. 8. Therefore, it can be assumed that the permanent ground displacements were the cause of the damage to the piles.

2.2 Study on the causes of the permanent ground displacements

Fig. 9 shows one example of subsurface soil condition and liquefied layers estimated by the Factor of Liquefaction Resistance F_L, along the section line C-C' shown in Fig. 6. The displacements in the figure show the horizontal component in the direction of the section line.

As mentioned previously, large permanent ground displacements toward the river occurred on both banks. From the soil profile in this area (Fig. (a)), the depth of the liquefied layer increases suddenly toward the river center and the lower boundary face of the liquefied layer is sloped. It can be assumed that the magnitude of the permanent ground displacements depends on the thickness and the inclination of the liquefied layer, and also on the topographical condition of the existing revetment.

About 300 m from the river toward Niigata Railway Station, permanent ground displacements of 1 to 2 m occurred in the direction away from the river (as shown in Fig. (b)). The ground surface in this area is flat, but the lower boundary face of the liquefied layer is estimated to be sloped with a small gradient of 2 - 3% toward Niigata Station. For this reason, the permanent ground displacements in this area were in the direction away from the river.

Photo 4 Damage to RC pile

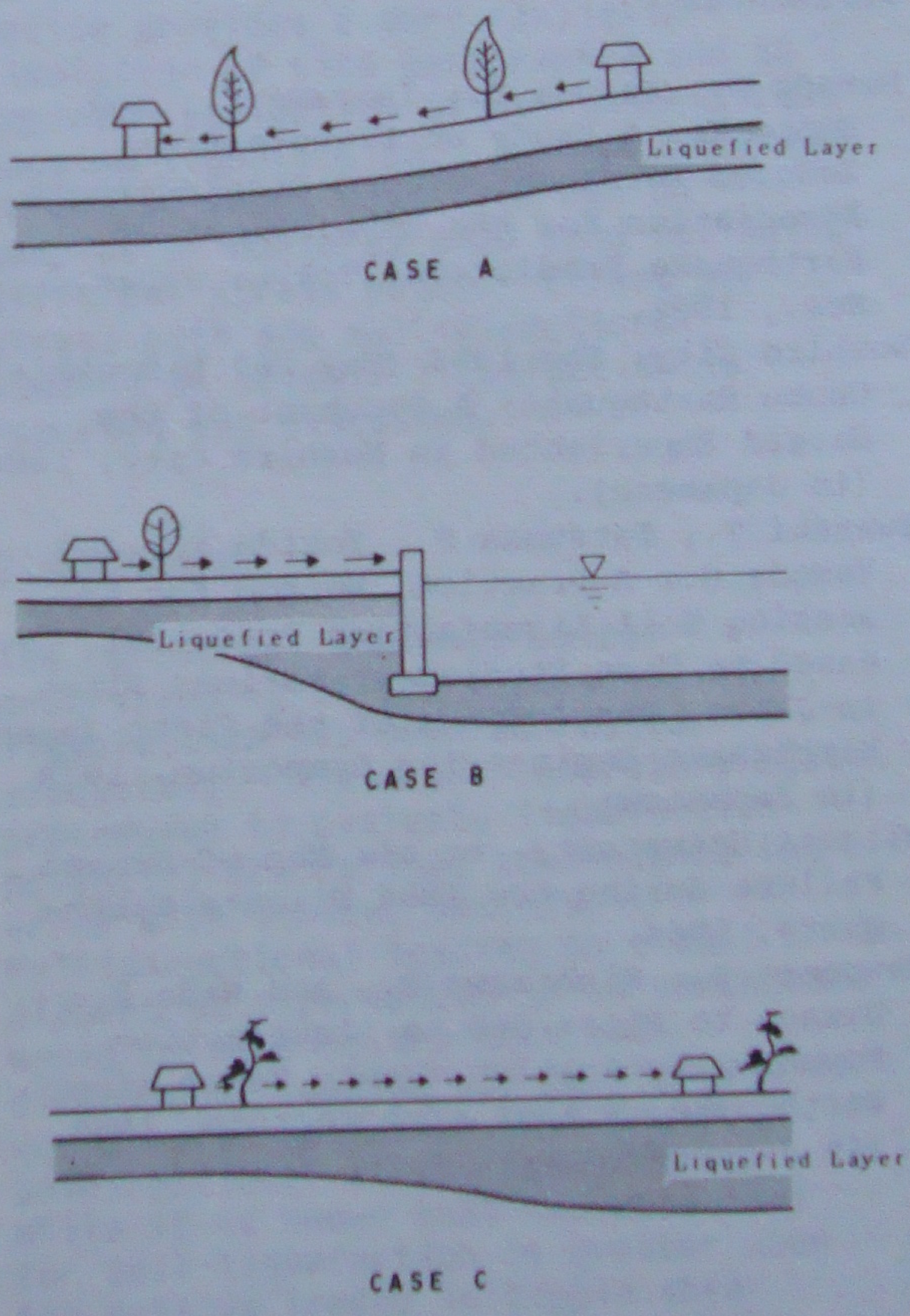


Fig. 10 Types of permanent ground displacements

3 CONCLUSION

The permanent ground displacements during the 1983 Nihonkai-Chubu and the 1964 Niigata earthquakes were measured by using pre- and post-earthquake aerial survey and the causes of the displacements were discussed by examining the geological and topographical conditions.

The types of permanent ground displacements caused by soil liquefaction during the two earthquakes can be summarized as shown in Fig. 10. Case A depicts the type of the displacements that occurred in Noshiro City; the ground surface is slightly inclined and the liquefied layer exists along the surface. Cases B and C depict the types found in Niigata City. Case B shows that the ground surface is flat on the land but has an abrupt vertical discontinuity at revetments of the river, and the lower boundary face of the liquefied layer is inclined towards the river center. Case C was found in the area around the Niigata Railway Station, where the ground surface is almost horizontal but the lower boundary face of the liquefied layer is inclined.

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