3. Permanent Ground Displacements in Niigata City during The 1964 Niigata Earthquake

On June 16, 1964, the Niigata earthquake with a magnitude of 7.5 occurred. Its epicenter was located near Awashima in the Japan Sea off Niigata City. The Niigata earthquake caused serious damage to many structures in the coastal area of the Japan Sea, from Niigata through the Yamagata and Akita Prefectures. In Niigata City in particular, which is located about 50 km from the epicenter, buildings, bridges, oil storage tanks, lifeline facilities, etc., were extensively damaged.

The maximum acceleration recorded in the basement of a four story concrete building in Niigata City was about 160 gal, suggesting that the earthquake motion was not particularly strong, and that most of the damage was caused by liquefaction rather than by ground motion.

It was reported that liquefaction occurred mostly in reclaimed former channels of the Shinano and Tsusen Rivers in Niigata City.[1]

In this chapter, the permanent ground displacements measured by aerial photograph survey in Niigata City will first be discussed. The causes of the permanent ground displacements and their causal relationship with the damage to structures will also be studied.

3.1 Method of measurement

Figure 3-1 shows the area in Niigata City where the permanent ground displacements were measured. The measurement method was the same as that for the Noshiro City discussed in Section 2.1. 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.

Datum points were selected on the tops of the stable sand dunes northwest of the city, as shown in Figure 3-1. No sand boiling, cracks, etc., were observed in the vicinity of the datum points during or after the earthquake and the datum points can be considered to have not been affected by the earthquake.

The measurement accuracy was estimated by almost the same procedure as that for the Noshiro City, i.e. ±72 cm horizontally and ±66 cm vertically.* However, as the datum points selected were on the sand dunes in the northwestern area, the

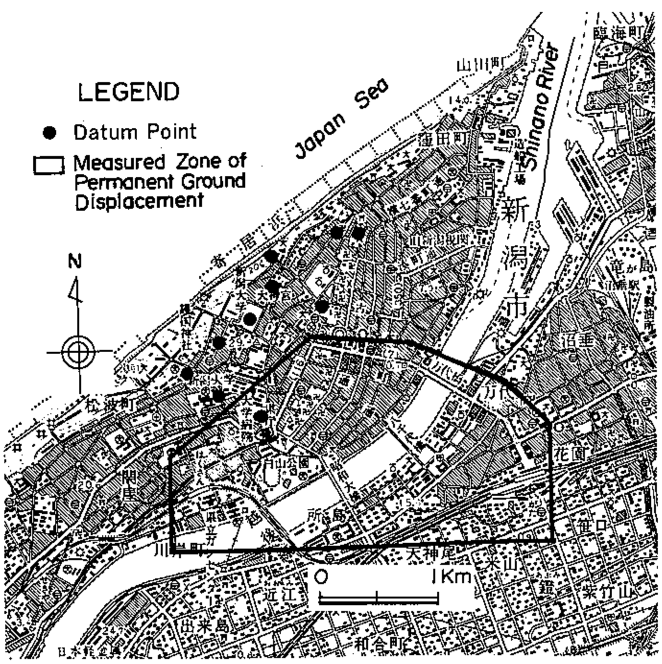
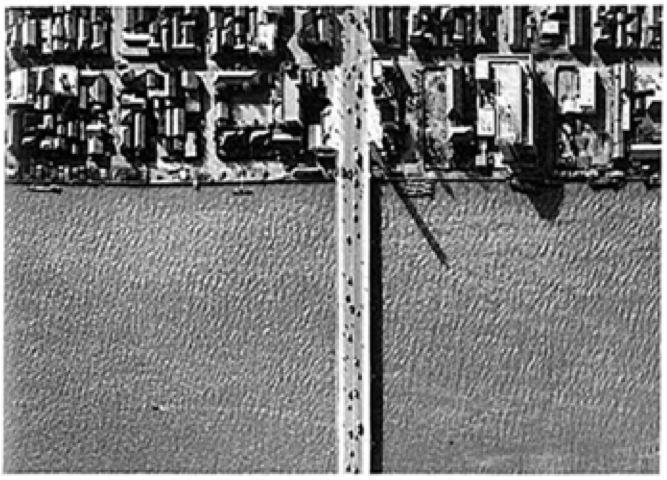


Fig. 3-1 Measured area and datum points for aerial survey

* Appendix II



(a) Before the earthquake

(b) After the earthquake

Photo 3-1 Aerial photographs and measurement points

measurement accuracy may be slightly lower near Niigata Railway Station (See Figure 3-3), which is somewhat distant from the datum points.

The points at which the permanent ground displacements were measured were selected on manholes, the corners of drainage channels, etc. The total number of points was about 400. Photo 3-1 shows one example of the aerial photographs taken before and after the earthquake in the vicinity of the left bank of the Bandai Bridge.

3.2 Permanent ground displacements and earthquake damage

3.2.1 Measured permanent ground displacements

Figure 3-2 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.[8]

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.

On the other hand, the permanent ground displacements on the right bank from the Echigo Railway Bridge to the Showa Bridge were small and non-uniform in direction. No sand boiling or cracks were observed in this area. The permanent ground displacements were also small in the vicinity of Nishibori Street and Higashibori Street, which were constructed by reclaiming old canals with sandy soil. However, ground failures such as sand boiling and cracks were observed in this area.

By referring to the old water front line of the Shinano River and the coast circa 1600, shown in Figure 3-3, it can be concluded that the location of the former river channel mostly coincides with the areas where large ground displacements occurred. Namely, the area on the left bank from the Showa

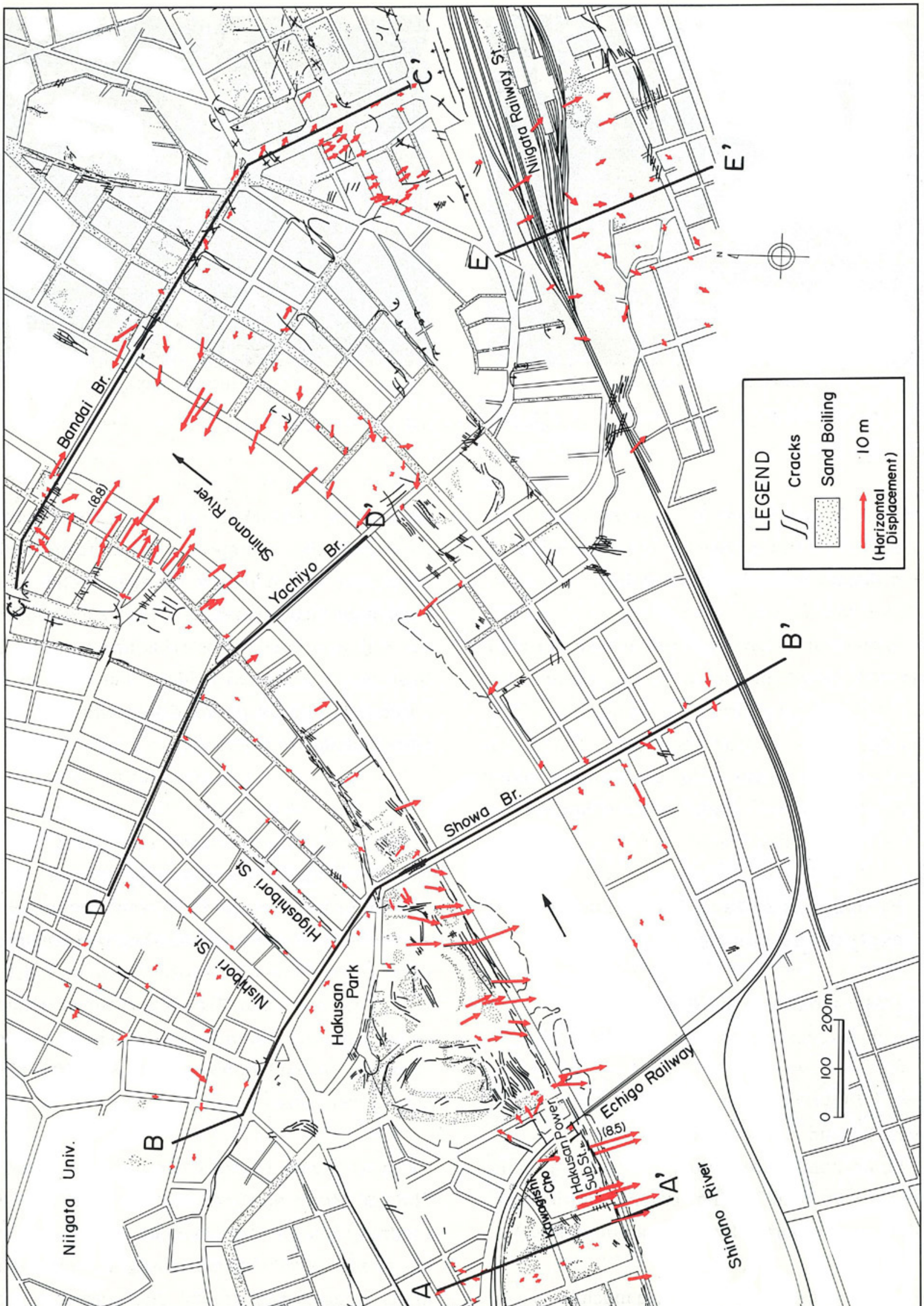


Fig. 3-2 Permanent horizontal ground displacements in Niigata City during the 1964 Niigata earthquake

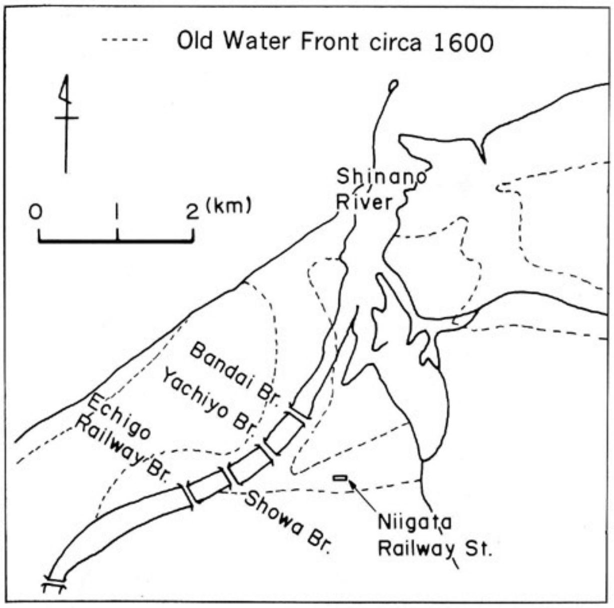
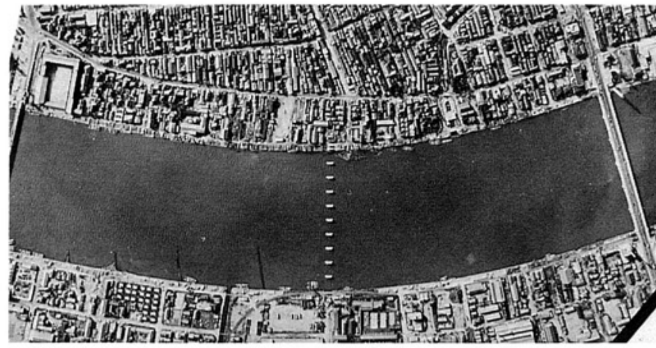


Fig. 3-3 Waterfront line of Niigata City circa 1600

Bridge to Kawagishi-cho and the areas on both banks from the Yachiyo Bridge to the Bandai Bridge are on the former river channel. As opposed to this, the area on the right bank from the Echigo Railway Bridge to the Showa Bridge and the area of Nishibori Street and Higashibori Street are located outside the former river channel.*

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.** From Figure 3-3 it can be seen that the area near Niigata Railway Station is also located on the former river channel.

As mentioned above, the permanent ground displacements measured along the Shinano River were over 8 m. The points at which these displacements were measured, were located well away from the river bank and can be considered to



(a) Before the earthquake (1962)

(b) After the earthquake (1971)

Photo 3-2 Aerial photographs for the measurement of river width

have not been affected by the local ground displacements caused by the collapse of the revetment of the river. This means that the ground displacements occurred over the entire area along the Shinano River basin and that the river width was largely reduced by the earthquake.

To verify this fact, an aerial photograph survey was performed, 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 by the aerial photograph taken before the earthquake. Photo 3-2 shows a part of the two aerial photographs used for the measurement and Figure 3-4 the results.

Between the Bandai Bridge and the Yachiyo

* The sand boiling, cracks, etc., which occurred near Nishibori Street will be described in 3.3.4.

** The permanent ground displacement in the area near Niigata Station will be studied in 3.3.3 in connection with the soil conditions.

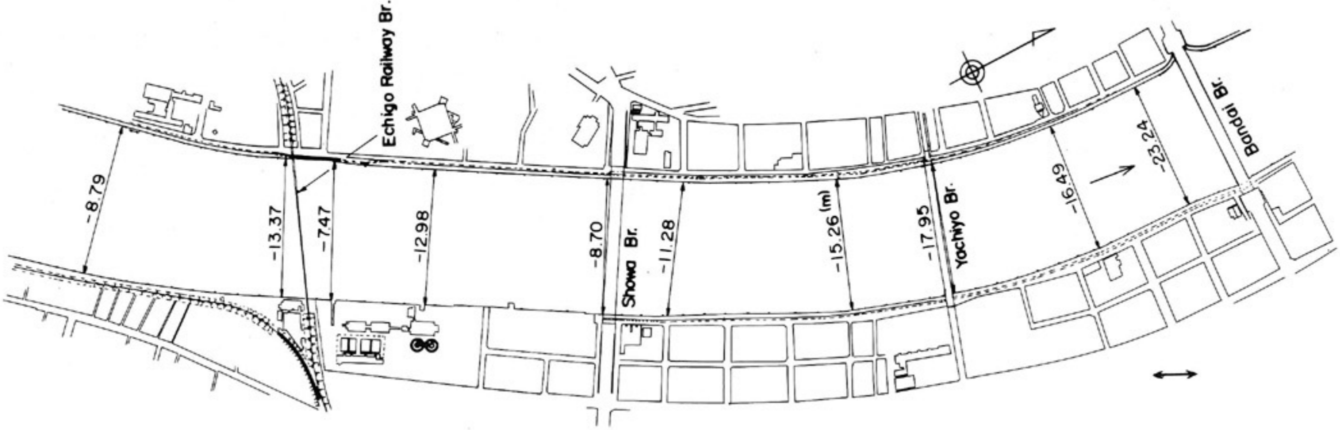


Fig. 3-4 Reduction of river width during the Niigata earthquake (m)

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.

The measured contractions in the river width are somewhat larger than the sums of the permanent ground displacements, shown in Figure 3-2, on both banks of the river. However, taking into account the fact that the new revetment was constructed after the earthquake by driving steel sheet piles in front of the collapsed revetment, it can be concluded that the reductions of the river width coincide quantitatively with the permanent ground displacements measured on the river banks.

Photo 3-3 shows the left bank of the Bandai Bridge in 1971 by which time the revetment had been completely restored. By comparing this photograph with the one shown in Photo 3-1 (a), which was taken two years before the earthquake, 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 displacements were reduced because of the rigidity of the Bandai Bridge, a stone masonry arch bridge.

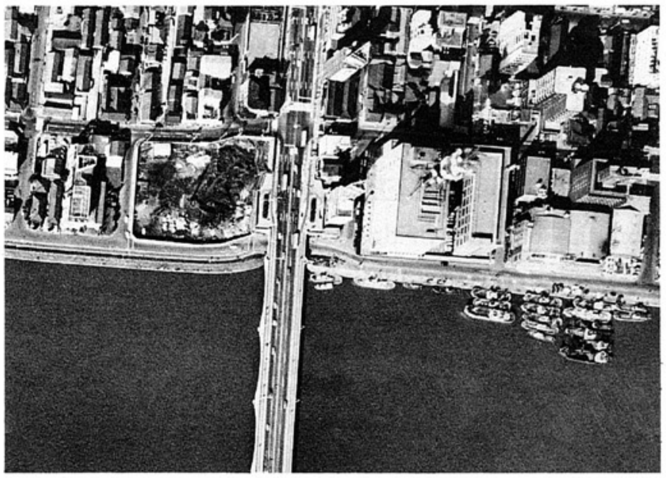


Photo 3-3 Revetment near Bandai Bridge on the Shinano River

3.2.2 Damage to revetment, bridge piers, foundation piles, etc.

Numerous reports have already been prepared on the damage caused to various structures by the 1964 Niigata earthquake. In this section, the causal relationship between the damage and the measured permanent ground displacements is examined by quoting from these existing reports.[(1),(8),(9),(10),(11),(12)]

(1) Damage to Shinano River revetment

As mentioned in the previous section, horizontal ground displacements of above 8 m occurred in the area along the Shinano River toward the center of the river, and the river width was reduced by as much as 23 m. According to the references,[(1),(9),(10)] it was reported that the revetment of the left bank between the Bandai Bridge and the Echigo Railway bridge, which consisted of steel sheet piles of 8 m length, collapsed toward the river and the revetment line developed a zigzag shape with considerable subsidence and tilting.*

Photo 3-4 shows one example of such damage on the left bank near the Bandai Bridge. A building actually slipped into the river because of the ground displacements toward the river. Severe damage was also reported to the wooden pile revetment on the left bank upstream of the Echigo Railway bridge.

On the right bank, from the Bandai Bridge to about the midpoint between the Yachiyo Bridge and the Showa Bridge, the revetment, constructed of steel sheet piles and wooden piles, slid horizontally and was submerged to a depth of 1.2 to 1.5 m. Photo 3-5 shows the horizontal movement of the river bank as viewed from upstream of the right bank near the Yachiyo Bridge.

No damage was reported to the right bank revetment upstream of the Showa Bridge, where the permanent ground displacement was small.

From the result above-mentioned, it can be concluded that the damage to the revetments of Shinano River occurred in the area where permanent ground displacements were observed.

(2) Damage to the Hakusan power substation

According to reference (1), it was reported that at the Hakusan power substation, located on the riverside at Kawagishi-cho, as shown in Figure 3-5, "an area of 300 m width and 100 m length slid about 7 m toward the Shinano River." It was also reported that a steel tower for electric cables in the substation also moved towards the river, loosening the cables

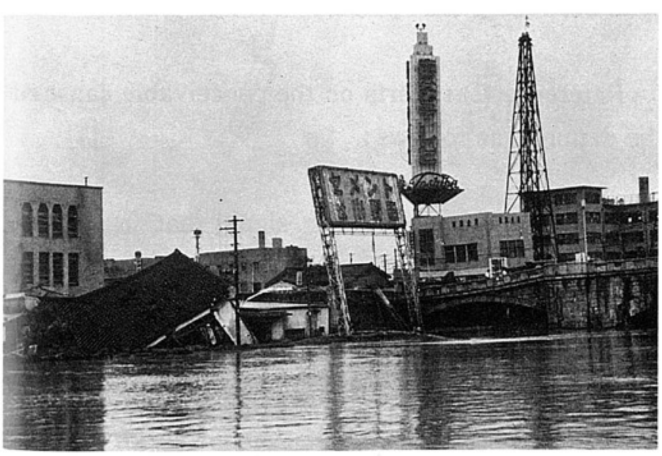


Photo 3-4 Displacement of a building toward the river on the left bank near Bandai Bridge

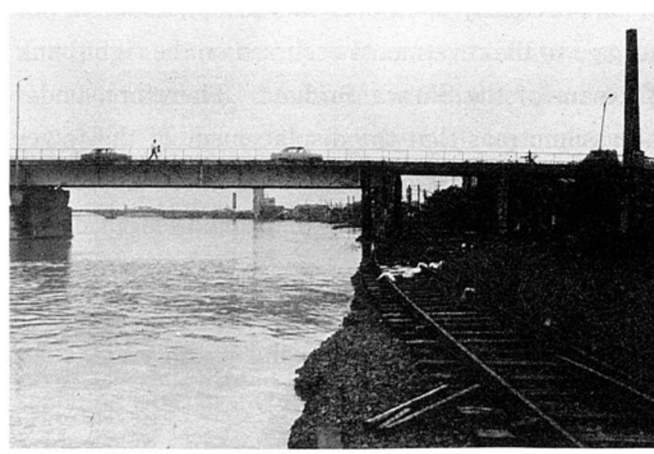


Photo 3-5 Horizontal displacements of right bank near Yachiyo Bridge

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* An eye witness at the left bank near the Showa Bridge during the earthquake reported that he had observed the successive collapse of the revetment after the earthquake motion had ended.[(10)]

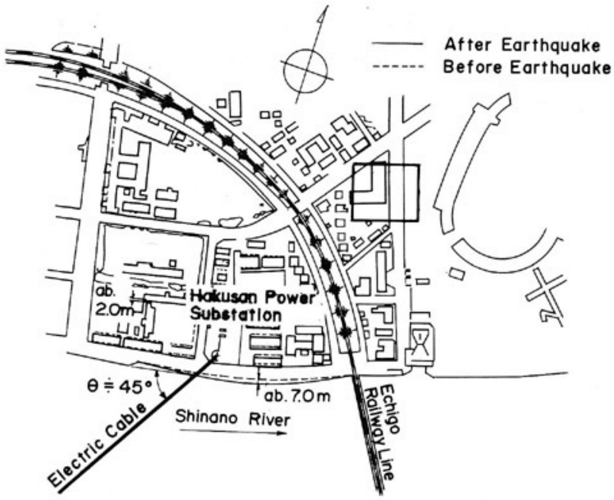


Fig. 3-5 Displacements of Hakusan power substation(1)

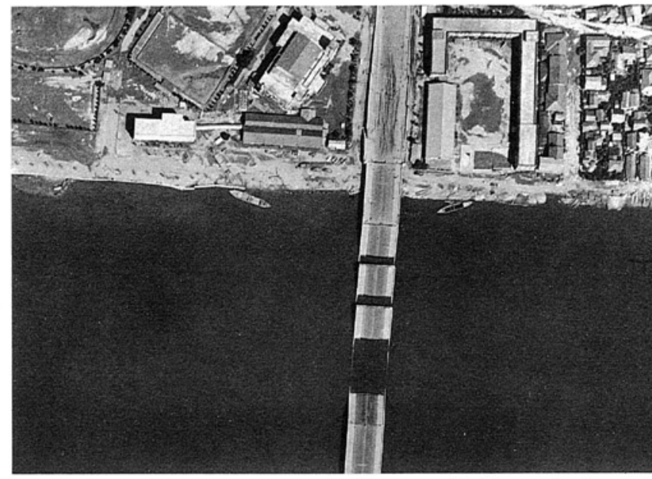


Photo 3-6 Collapse of Showa Bridge during Niigata earthquake

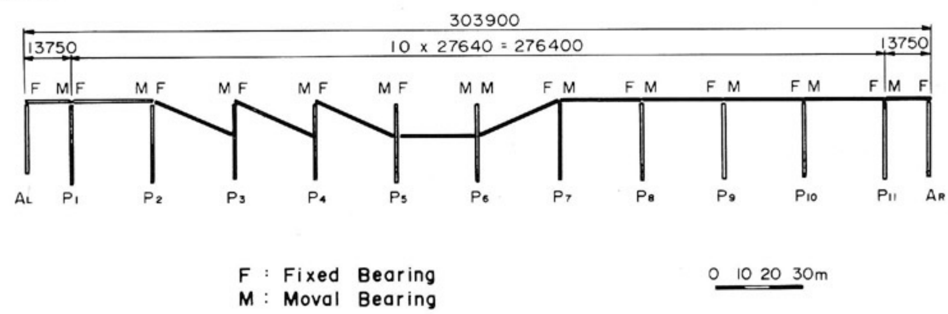


Fig. 3-6 Collapse of Showa Bridge during Niigata earthquake(1)

crossing the Shinano River, the restoration of which required shortening of the cables by about 4 m.

As previously mentioned, neither liquefaction nor damage to the revetments occurred on the right bank upstream of the Showa Bridge.* Therefore, under the assumptions that the displacement of the tower on the right bank was zero and the cable crosses the river at an angle of 45°, the shortened length of the cable is calculated as 5.3 m from the permanent ground displacement of 7.5 m in the vicinity of the steel tower on the left bank, and roughly coincides with the reported value.

(3) Collapse of Showa Bridge

The collapse of Showa Bridge was one of the worst instances of damage to structures during the Niigata earthquake. As shown in Figure 3-6 and Photo 3-6, five simple steel girders of about 28 m span between piers P_2 and P_7 collapsed.

Reference (1) reports on the conceivable cause of the damage, as follows:

(i) There were obvious signs that a violent collision had occurred between the girders themselves and between the girders and the abutment on the left bank. From the above, it can be conjectured that a large horizontal force had been exerted on the girder from the abutment of the left bank, and this is considered to have been one of the causes of the collapse.

* On the right bank upstream of the Echigo Railway Bridge, permanent ground displacement was not measured since this area had little damage.

(ii) There were also signs that the bridge pier foundations on the left bank had moved toward the center of the river. In particular, pier P_6 had tilted considerably toward the right bank. It may be considered that such movement of the bridge pier foundations also contributed to the collapse.

(iii) Because of the flexibility of the pile bent piers, a large relative displacement occurred between adjacent piers due to differences of the earthquake motion and of the friction of the shoe, resulting in the collapse of the bridge.

Figure 3-7 shows the deformation of the steel pipe piles of pier P_4, that were extracted after the

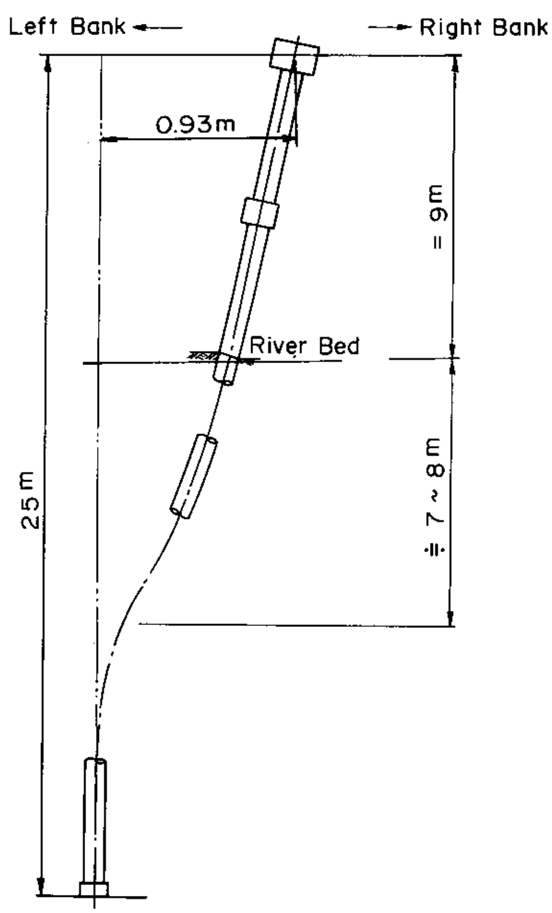


Fig. 3-7 Damage to steel pipe piles of pier P_4 of Showa Bridge[1]

earthquake.[1] The piles were bent toward the right bank at a position 7 to 8 m below the river bed. As will be mentioned in 3.3.2 it is assumed that in the left bank area near the Showa Bridge, a soil layer with a thickness of about 10 m liquefied (see Fig. 3-12 (b)), causing a large ground displacement toward the river. The damage to the steel pipe pile of the piers can be explained well by this assumption.

Regarding the collapse of the Showa Bridge, reliable eyewitnesses reported[9] that the collapse of the bridge started somewhat later, maybe 0-1 minute, after the earthquake motion had ended. As mentioned earlier, the damage to the revetment of the left bank of the Showa Bridge also started after the eorthquake motion. If the direct cause of the collapse was the inertia force of the earthquake motion, as mentioned above in item (iii), the damage should have occurred during the main tremor, so it is not rational to consider the inertia force as the main cause of the collapse.

By taking into consideration the permanent displacements measured on the left bank of the Showa Bridge, the reported damage to the pier pile, the assumed liquefied layer shown in Figure 3-12 (b) and the statements of the witnesses, the following can be concluded as the more rational cause of the collapse. That is, the sandy soil layer liquefied during the main earthquake motion, and slid due to the large reduction of shearing resistance. The sliding continued even after the earthquake motion until the excess pore water pressure dispersed, the permanent ground displacements on the left bank reaching several meters, substantially deforming the bridge pier and causing the collapse of the bridge.

(4) Damage to the retaining wall of access road on the left bank of the Showa Bridge

According to reference (1), large openings were found between the joints of the retaining wall of the access road to the Showa Bridge. As shown in Figure 3-8, the sum of opening of joints over the total of length of the retaining wall, about 100 m, was approximately 1.2 m. Figure 3-8 also shows the permanent ground displacements in the proximity of the access road. From the figure, it can be seen that the permanent ground displacement in the direction of the bridge axis was very small at the starting point of the access road, because the ground displacement vector was almost perpendicular to the axis of the access road. The amplitude of the ground displacement vector at the end of the access road, that is near the bridge abutment, was about 2.0 m, and the displacement component in the direction of the bridge axis was about 1.6 m, which mostly coincided with the sum of the openings of the retaining wall.

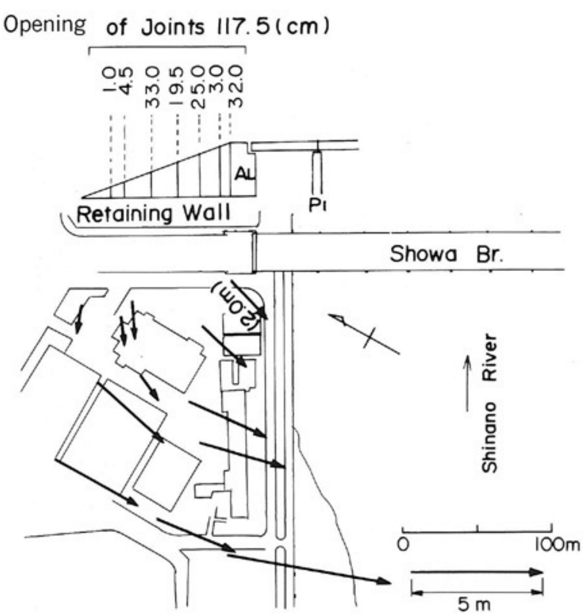


Fig. 3-8 Damage to retaining wall of access road of Showa Bridge[1]

It can also be seen from the results shown in Figure 3-8 that the permanent ground displacements near the bridge abutment were smaller than those in the area distant from the bridge. This is due to the fact that the abutment resisted the ground displacement because of its stiffness, as in the case of the abutment of the Bandai Bridge mentioned earlier.

(5) Damage to substructure of the Yachiyo Bridge

Figure 3-9 and Photo 3-7 show the damage to the abutment and the piers of the Yachiyo Bridge on the left bank. The foundation of the abutment and piers P_1, P_2 had been constructed of RC piles with diameters of 300 mm. From the damage, it was conjectured that the foundation ground slid toward the river, as shown in the figure.[11]

Pier 2 was broken in the middle, the permanent deformation between the bridge seat center and the lower part of the pier being 1.1 m. Similar damage was reported to the abutment and the piers on the right bank. According to the results shown in Figure 3-2, the permanent ground displacements on both banks were 2 to 4 m towards the river, explaining the cause of damage to the abutments and the piers.

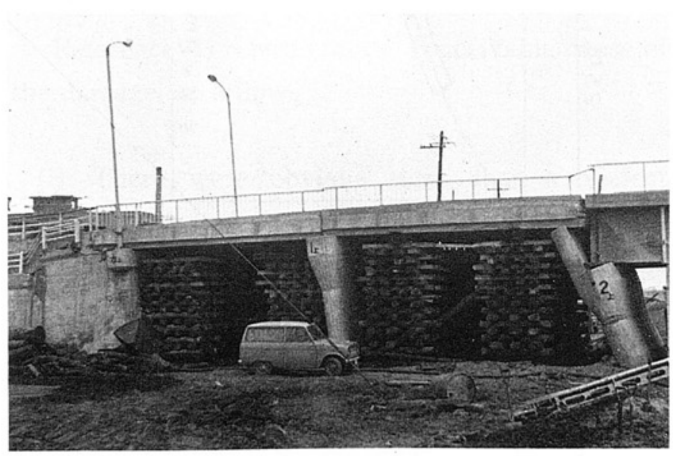


Photo 3-7 Damage to the abutment and the piers of Yachiyo Bridge on the left bank

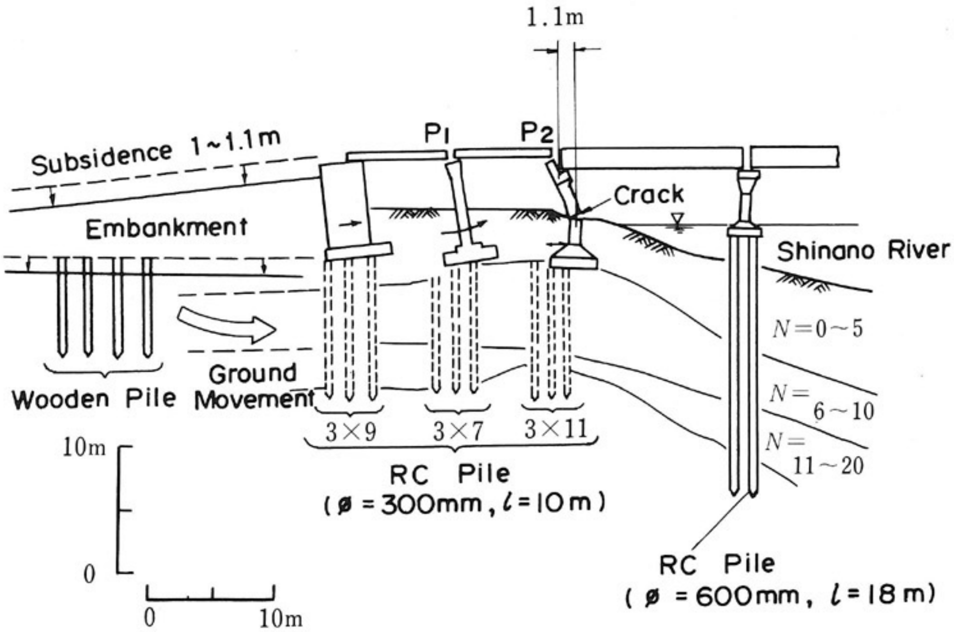


Fig. 3-9 Damage to the abutment and the piers of Yachiyo Bridge on the left bank(11)

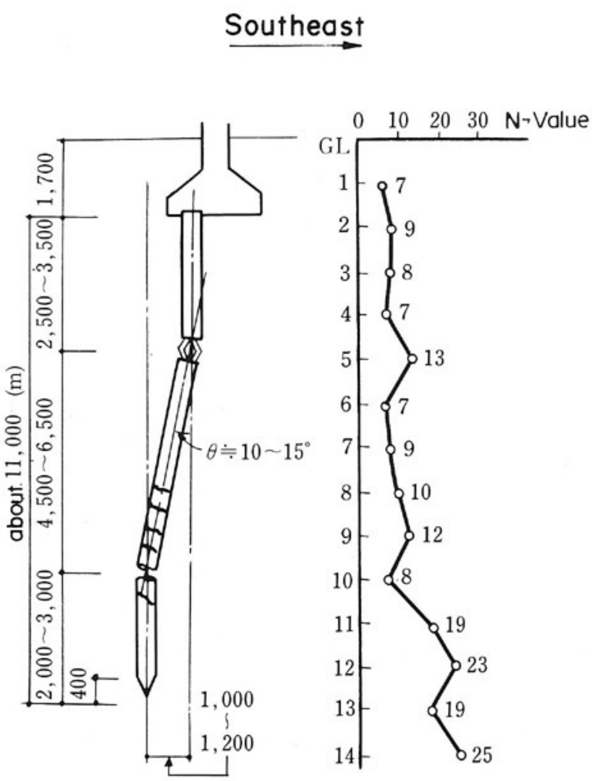


Fig. 3-10 Broken RC pile and soil condition(12)

Photo 3-8 Damage to RC pile
(Courtesy of Dr. S. Kawamura, et al.)

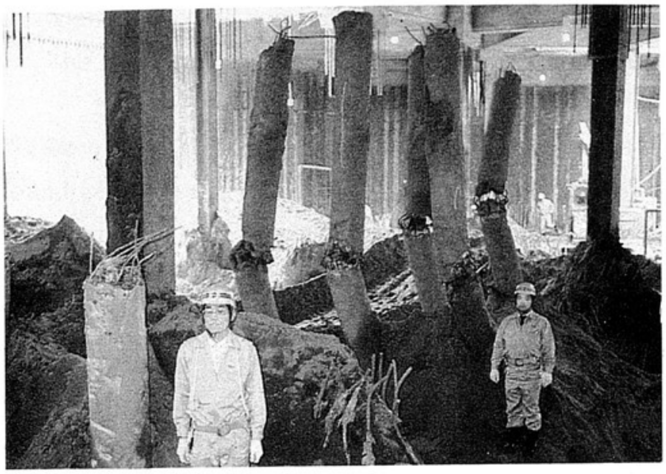


Photo 3-9 Damage to RC pile
(Courtesy of Dr. S. Kawamura, et al.)

(6) Damage to RC piles

When the piles of a building, located north of Niigata Railway Station were excavated for reconstruction in 1985, about twenty years after the earthquake, RC piles of 350 mm diameter and 11 to 12 m length were found to be broken. Kawamura and others[12] reported on the damage to the RC piles, as follows.

As shown in Figure 3-10 and Photos 3-8 and 3-9, 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 Figure 3-10.

Figure 3-11 shows the permanent ground displacements near the building as measured by the aerial survey. The magnitude of the permanent ground displacement in this area is 1 to 2 m, and coincides well with the pile deformation. Furthermore, as shown in Figure 3-12, the direction of the ground displacement vector is southeasterly, that is, toward the Niigata Railway Station, and is

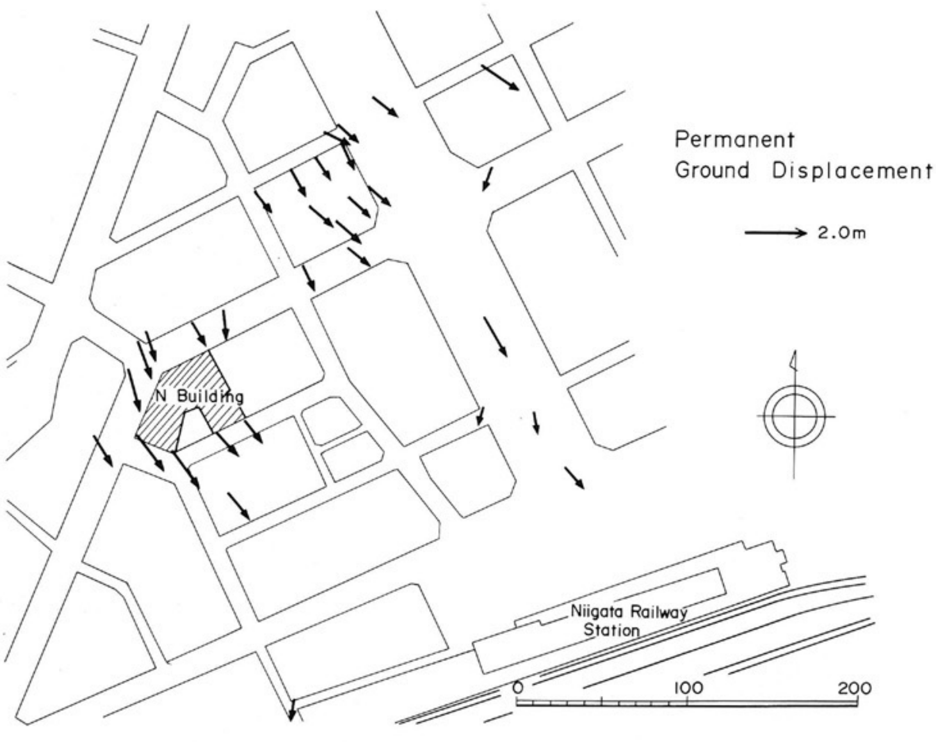


Fig. 3-11 Permanent ground displacements near the building where RC piles were damaged

almost the same as that of pile deformation shown in Figure 3-10. Therefore, it can be assumed that the permanent ground displacements were the cause of the damage to the piles, but the detailed discussions will be done by numerical analyses in Chapter 6.

As shown in Figure 3-10, the subsurface at the site of the building consists of a sandy layer with an N-value of 7~13 and a thickness of about 10 m. As discussed in the following section, it is assumed that the sandy layer liquefied and slid in the direction of Niigata Railway Station.

3 . 3 Study on the Causes of Permanent Ground Displacements

Figure 3-12 shows the subsurface soil profiles and permanent ground displacements along the five section lines shown in Niigata City. The section lines were drawn approximately parallel to the displacement vector as shown in Figure 3-2 and the horizontal displacements in Figure 3-12 show the component in the direction of the section lines. As previously mentioned, the ground displacements near the abutments of each bridge are considered to be reduced due to the resistance of the abutments, and so in the area of the river banks the displacements measured at the points somewhat distant from the bridge abutments which are considered to have been unaffected, are shown in the figure.

In each section line the liquefied soil layer was conjectured by using the Factor of Liquefaction Resistance F_L.* The soil layer with F_L less than 1.0 was considered to have been liquefied. Characteristics of the permanent ground displacements along each section line and the causes of the ground displacements are studied below.

3 . 3 . 1 Section A-A' (left bank in Kawagishi-cho)

In the area from the south side (right side in Figure 3-12 (a)) of the Echigo Line to the point about 100 m from the bank of the Shinano River, the permanent ground displacement is only about 1 m towards the river, but is suddenly increased to as large as 7 m near the bank. The ground surface and the upper surface of the liquefied layer in this area are flat, but the lower boundary face of the liquefied layer is sloped gently toward the river. The thickness of the liquefied layer in this area is more than 10 m.

In the area within about 70 m north (left in the figure) from the Echigo Line the direction of the ground displacements is away from the Shinano River. The soil layer profile shows that the lower boundary face of the liquefied layer falls toward the north in this area, and this is considered to be the cause of the ground displacement being in the opposite direction.

3 . 3 . 2 Section B-B' (Hakusan Park—Showa Bridge)

In Section B-B', the ground displacements in the area near the Hakusan Park are small and their directions are not uniform, as shown in Figure 3-2. The displacement increases to be 2 to 5 m in the area about 100 m from the left bank. On the right bank of the river, no large ground displacements can be found. From the soil layer profile it can be seen that the estimated liquefied layer is not thick near Hakusan Park and is mostly horizontal. On the other hand the liquefied layer is very thick, more than 10 m near the left bank and the lower boundary face of the

* This method requires the maximum acceleration on the ground surface. In this section, the maximum acceleration on the ground surface was assumed to be 159 gal, which was the value actually measured in the basement of a four story apartment building in Kawagishi-cho. The method is described in Appendix III.

liquefied layer is inclined towards the river. The thickness of the liquefied layer on the right bank is very thin.

From the result above-mentioned 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.

3.3.3 Section C-C' and Section E-E'(left bank of Bandai Bridge—Niigata Railway Station)

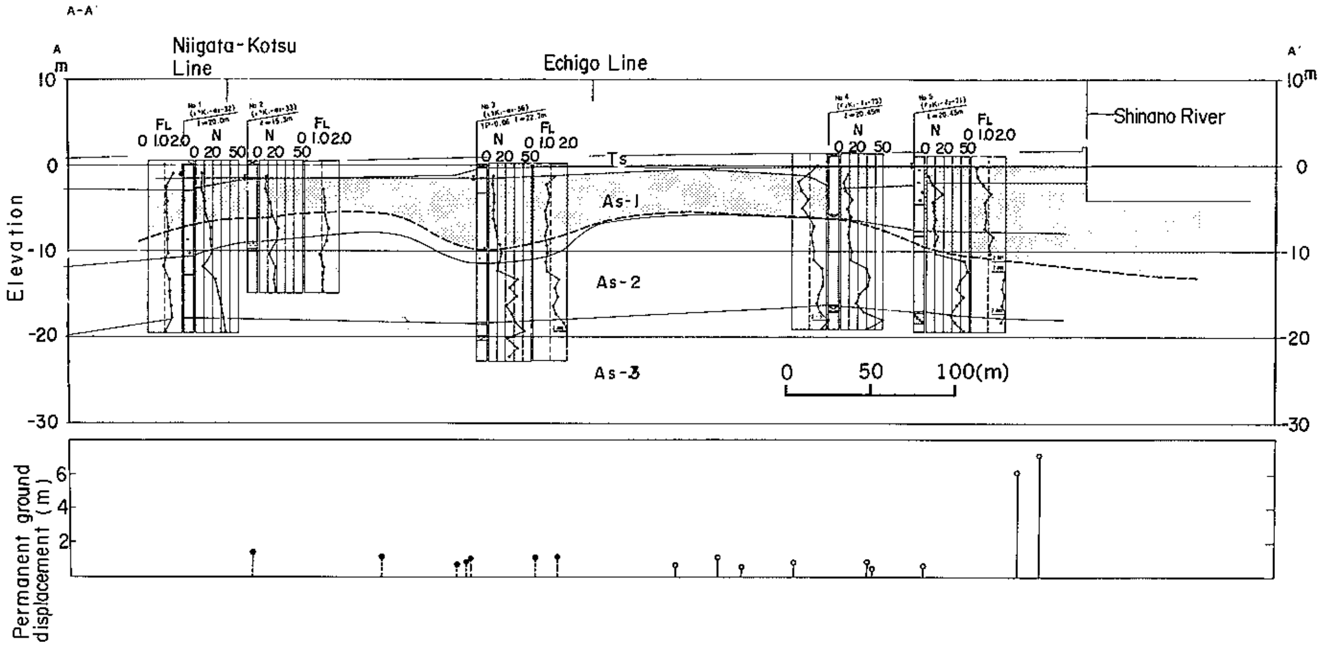
In Section C-C', large permanent ground displacements toward the river occurred on both banks. From the soil profile in this area, the depth of the liquefied layer increases suddenly toward the river center and the lower boundary face of the liquefied layer is sloped. In this case also the inclination of the lower boundary face of the liquefied layer and the topographical condition can be considered as the main causes of the permanent displacement.

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 figure (c)'). 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.

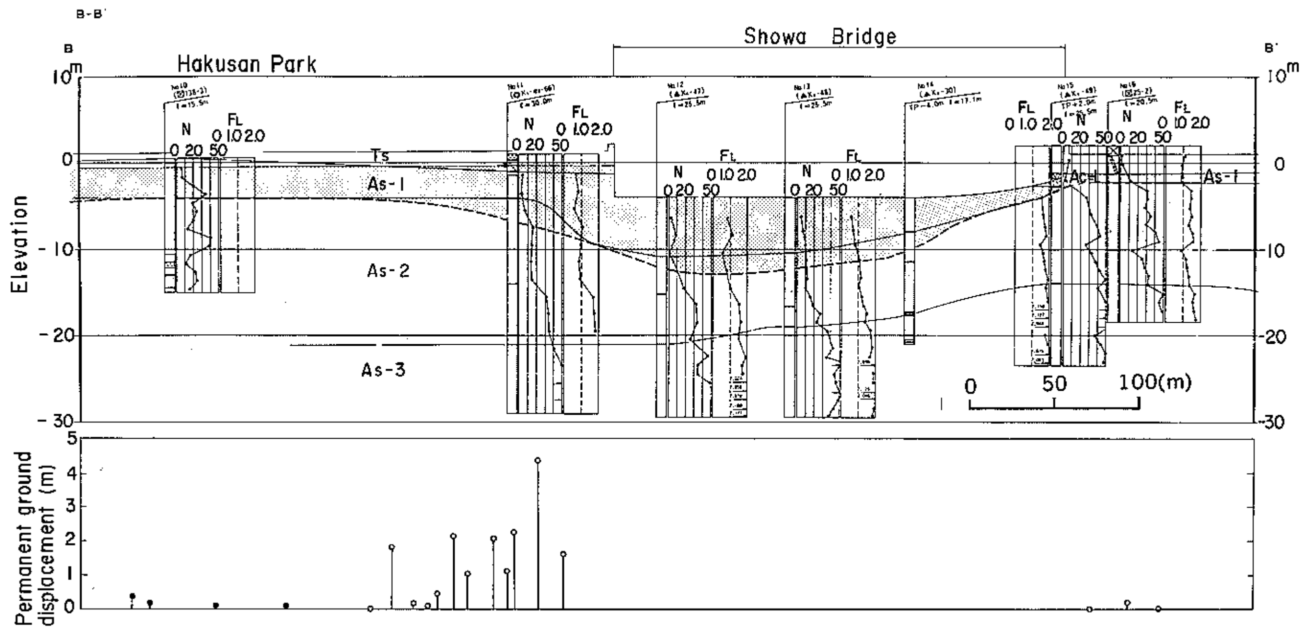
Along Section E-E', which is an extension of Section C-C', the permanent ground displacements are also in the direction away from the river. As shown in Figure 3-3, Niigata Railway Station was located on an old channel of the Shinano River and this is considered to be one of the reasons for the inclination of the lower boundary face of the liquefied layer.

3.3.4 Section D-D' (near Nishibori Street—left bank of Yachiyo Bridge)

As previously mentioned, in the areas near Higashibori and Nishibori Streets, very small permanent ground displacements occurred, although sand boiling and cracks were observed. The streets were constructed by reclaiming the old canals around 1955. Although the detailed soil condition of the reclaimed ground is unknown, the results of standard penetration tests conducted near the street indicate that the liquefaction resistance is comparatively high. Consequently, it may be assumed that only the reclamation material of the street liquefied, without causing a permanent ground displacement.



(a) Section A-A′



(b) Section B-B′

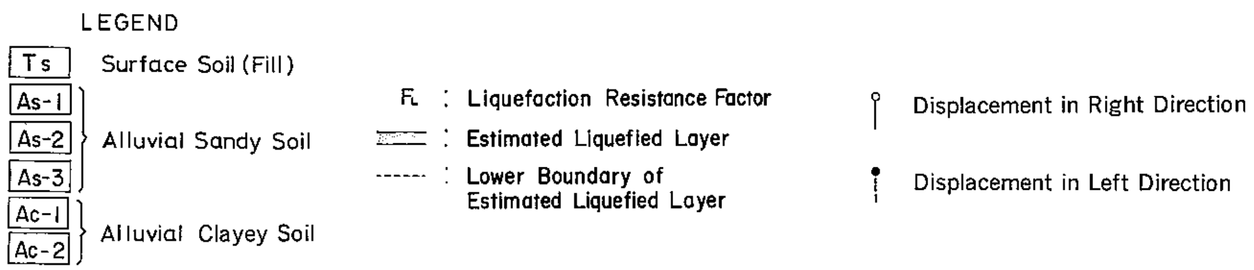
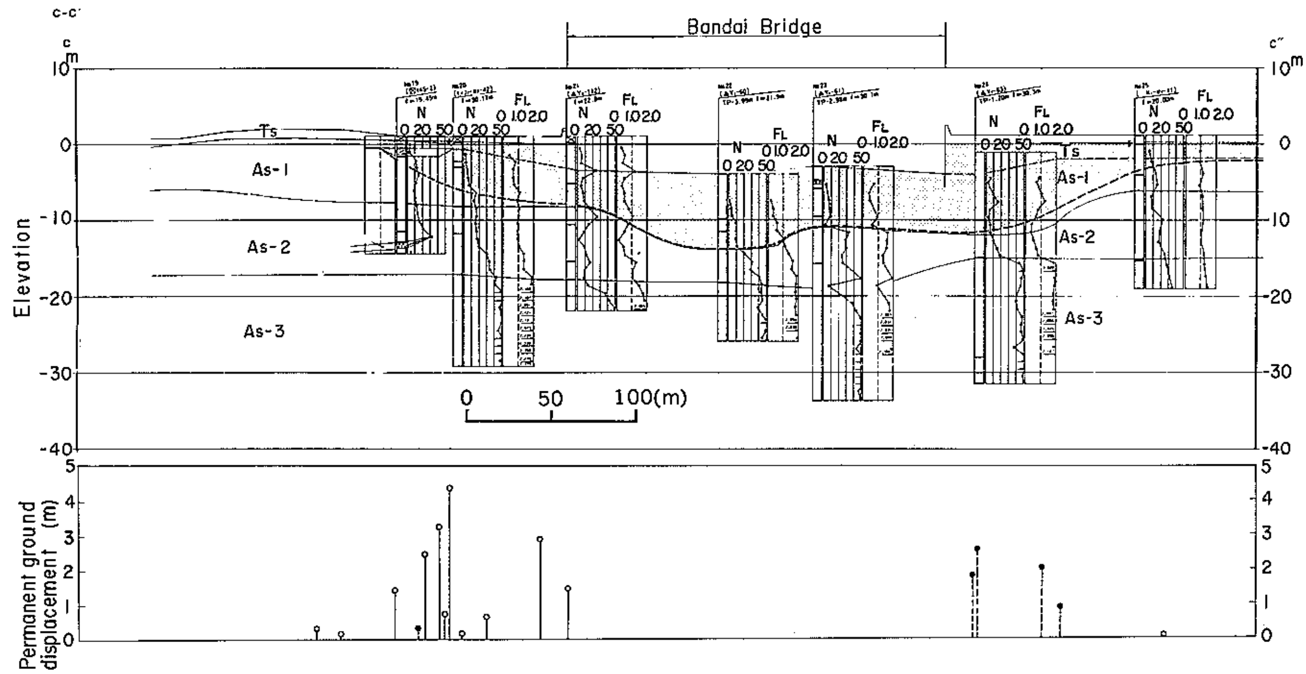
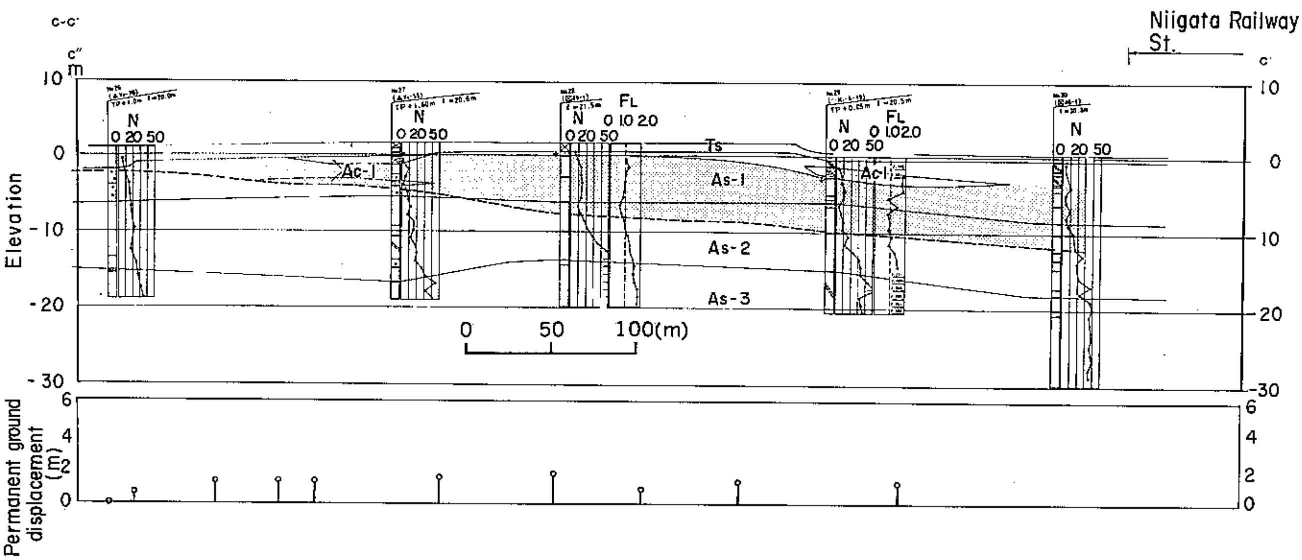


Fig. 3-12 Soil layer profile and estimated liquefied layer



(c) Section C-C″



(c)′ Section C″-C′

LEGEND

Ts — Surface Soil (Fill)

As-1, As-2, As-3 — Alluvial Sandy Soil

Ac-1, Ac-2 — Alluvial Clayey Soil

FL : Liquefaction Resistance Factor

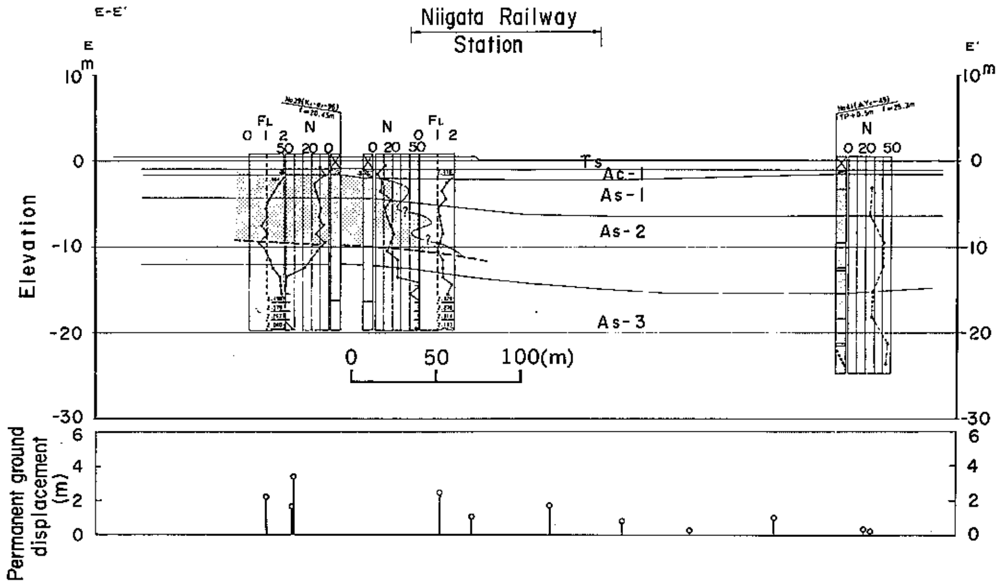
: Estimated Liquefied Layer

: Lower Boundary of Estimated Liquefied Layer

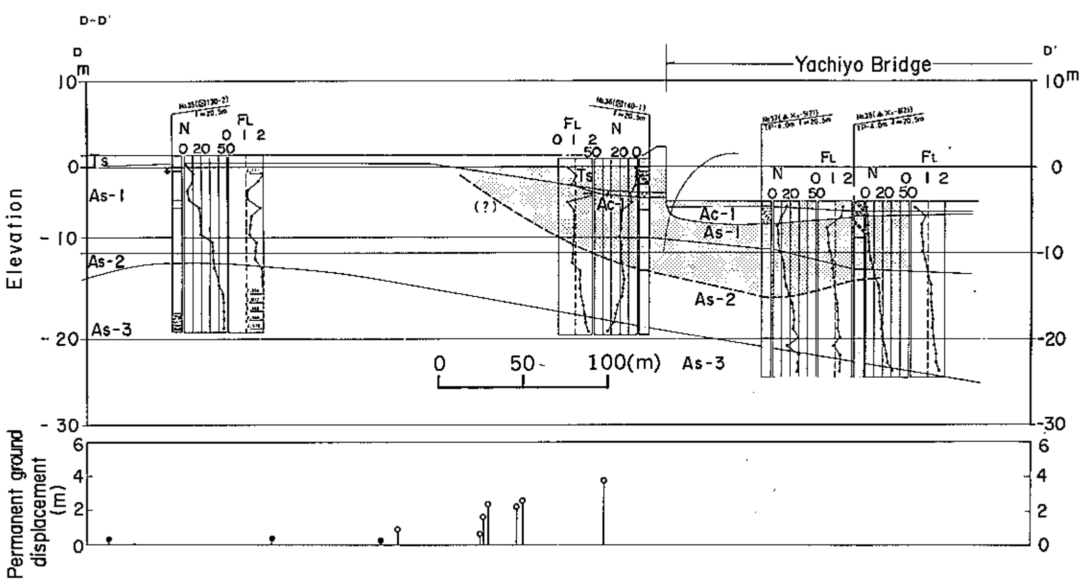
Displacement in Right Direction

Displacement in Left Direction

Fig. 3-12 Soil layer profile and estimated liquefied layer



(d) Section E-E′



(e) Section D-D′

LEGEND

Ts — Surface Soil (Fill)

As-1, As-2, As-3 — Alluvial Sandy Soil

Ac-1, Ac-2 — Alluvial Clayey Soil

FL : Liquefaction Resistance Factor

(shaded) : Estimated Liquefied Layer

------ : Lower Boundary of Estimated Liquefied Layer

Displacement in Right Direction

Displacement in Left Direction

Fig. 3-12 Soil layer profile and estimated liquefied layer