2 . Permanent Ground Displacements in Noshiro City 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. Figure 2-1 shows the epicenter of the earthquake and the recorded maximum horizontal acceleration. A maximum horizontal acceleration reached over 200 gal in Akita City . The aftershock epicenters' area, shown in the figure, was considered to represent the earthquake fault zone.

Noshiro City, where most of the urban area is built on the sand dune along the Japan Sea coast and the alluvial plane of the Yoneshiro River, suffered 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 cracks, subsidences, bulging, etc., were also seen in the damaged area.[(2),(3)]

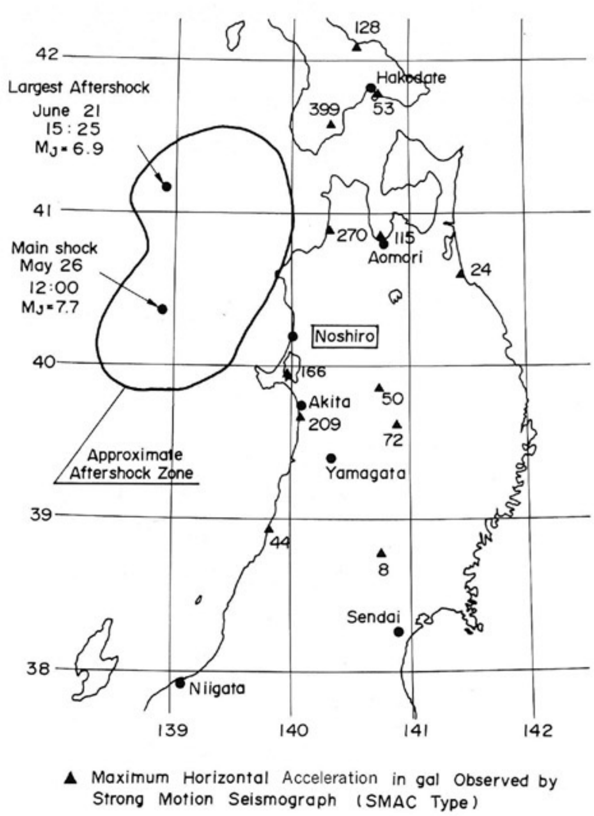


Fig. 2-1 Epicenter and maximum horizontal acceleration during the 1983 Nihonkai-Chubu earthquake

In this chapter, the results of the measurements of the permanent ground displacements in Noshiro City and the relationship between the permanent ground displacements, the damage to the structures, and the ground failures are described, followed by a consideration of the causes of the permanent ground displacements based on the geological and topographical conditions.

2 . 1 Method of measurement

Permanent ground displacements induced by the

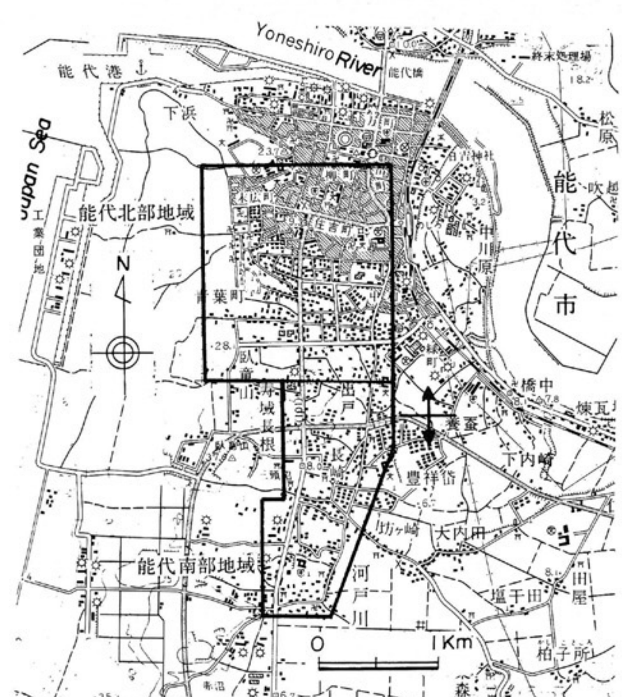


Fig. 2-2 Measured area of permanent ground displacement in Noshiro City

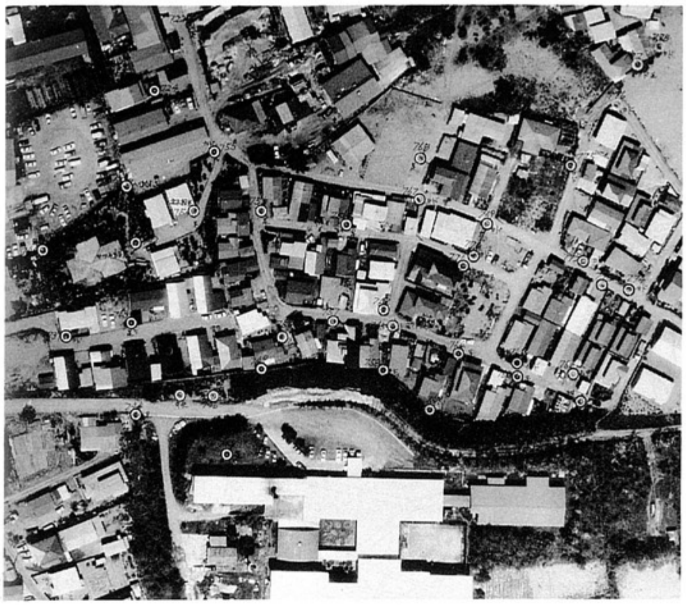
Photo 2-1 Bird's-eye view of Noshiro City and measured area (Courtesy of the Noshiro City Government)

earthquake were measured from aerial photographs taken under the same conditions 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. The scale of both photographs is 1 : 8000.

Figure 2-2 and Photo 2-1 show the measured area of the permanent ground displacement in Noshiro City. The displacements were measured mainly in the areas where damage to houses and buried pipes and ground failures such as cracks and subsidences were observed.

To measure the permanent ground displacements using pre- and post-earthquake aerial photographs, it was necessary to select datum points which were considered to be unaffected 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 no 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 must be conducted on points which are



(a) Northern slope of the Mae Hill

(b) Near a graveyard in Aoba-cho

Photo 2-2 Examples of aerial photographs used for measurement

fixed on the ground surface and which can be found in both the pre- and post-earthquake photographs. Manholes, 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 2-2 shows examples of the aerial photographs and points of measurement on the northern side of Mae Hill and near the graveyard in Aoba-cho where the permanent ground displacements were dominant as shown in Figures 2-3 and 2-4.

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.*

2 . 2 Permanent ground displacements and earthquake damage

2 . 2 . 1 Measured permanent ground displacements

Figures 2-3 and 2-4 show 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.

* Appendix I

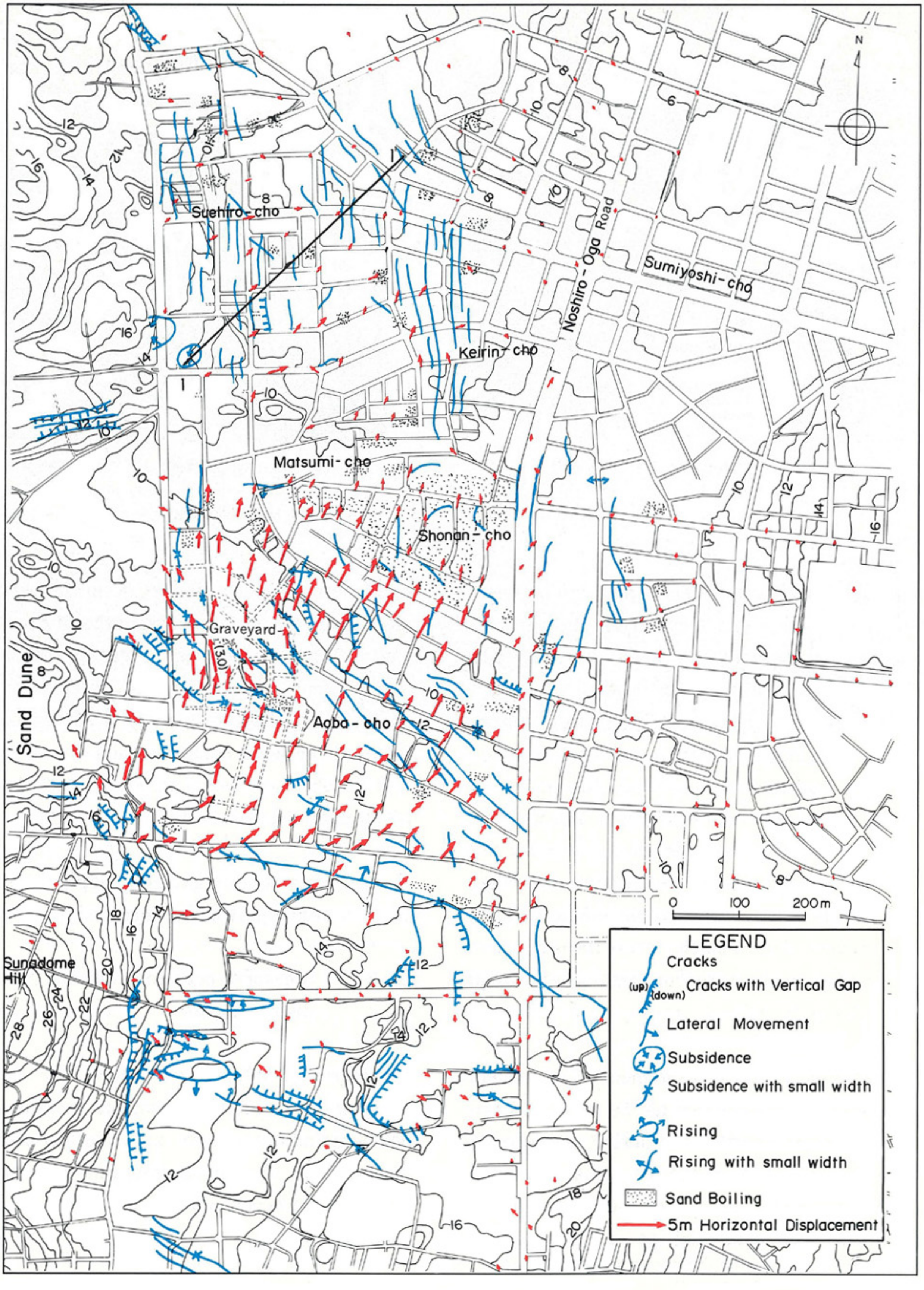


Fig. 2-3 Permanent horizontal ground displacements in the northern part of Noshiro City

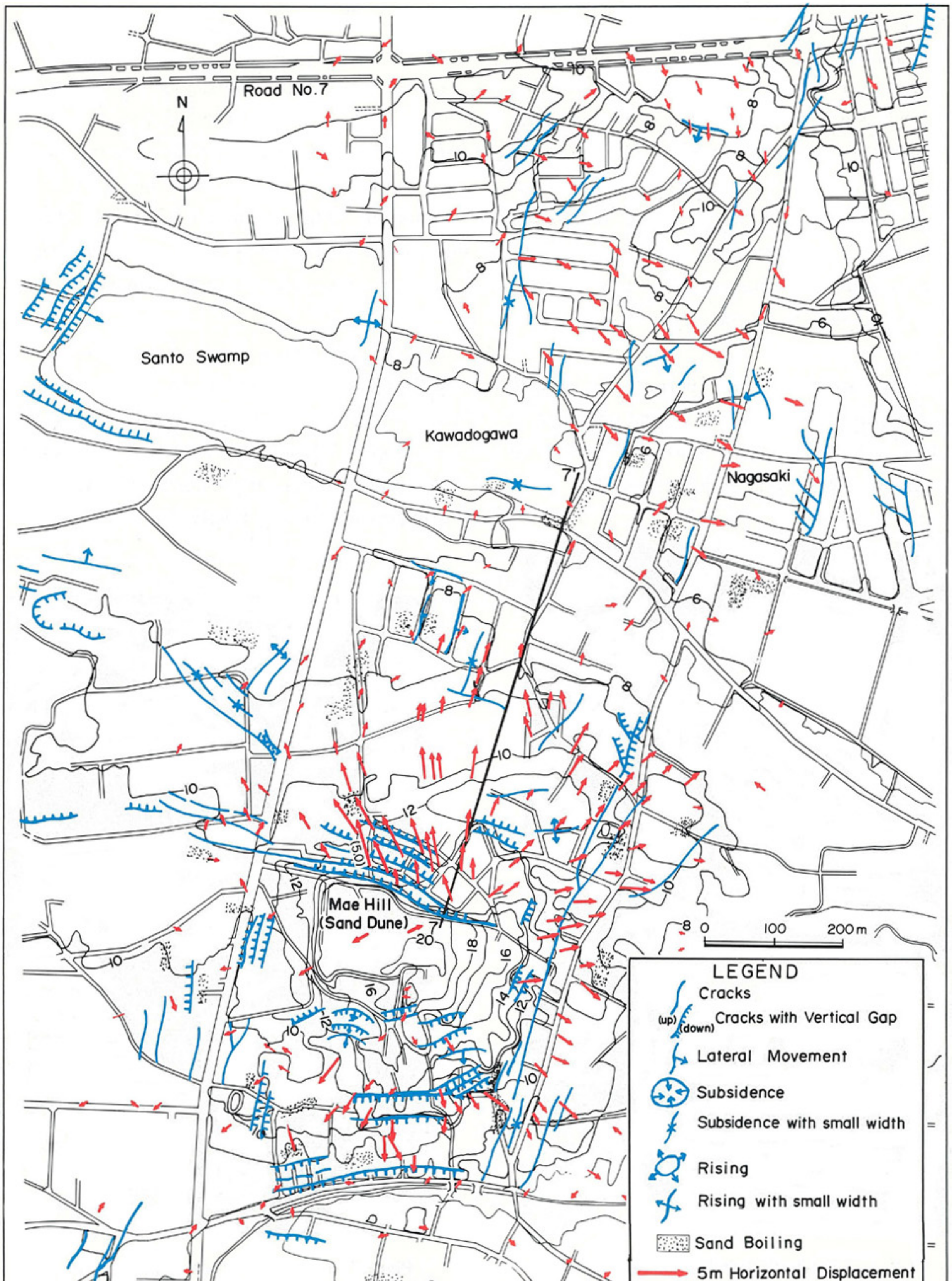


Fig. 2-4 Permanent horizontal ground displacements in the southern part of Noshiro City

In the northern area, as shown in Figure 2-3, 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 1 km in a northerly or northeasterly direction. The maximum horizontal displacement in the northern area reached about 3 m, on the slopes 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.

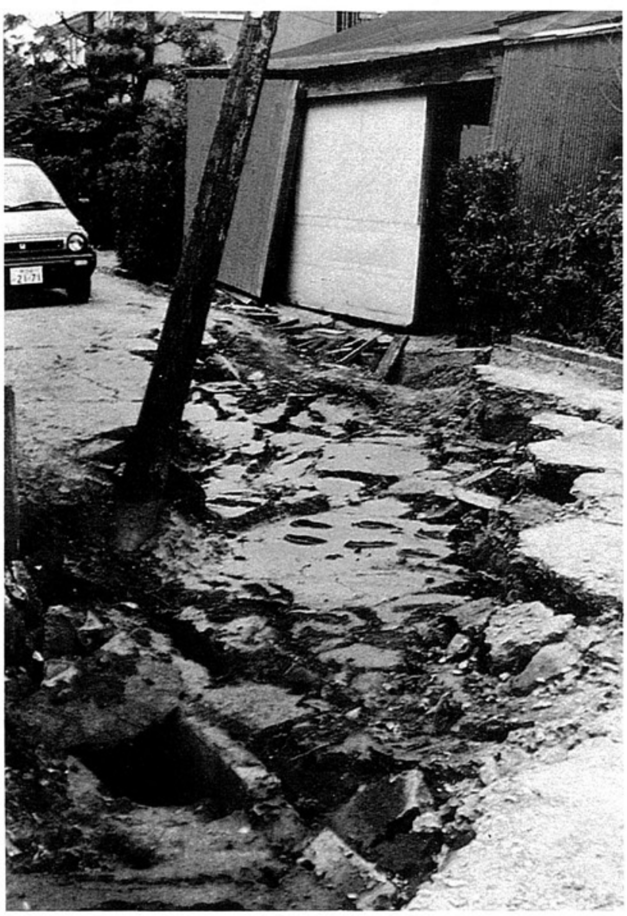


Photo 2-3 Cracks with subsidence on road in Aoba-cho (Courtesy of the Noshiro City Government)

In the southern area, as shown in Figure 2-4, 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.

Photo 2-4 A vertically split tree due to liquefaction in Aoba-cho (Courtesy of the Noshiro City Government)

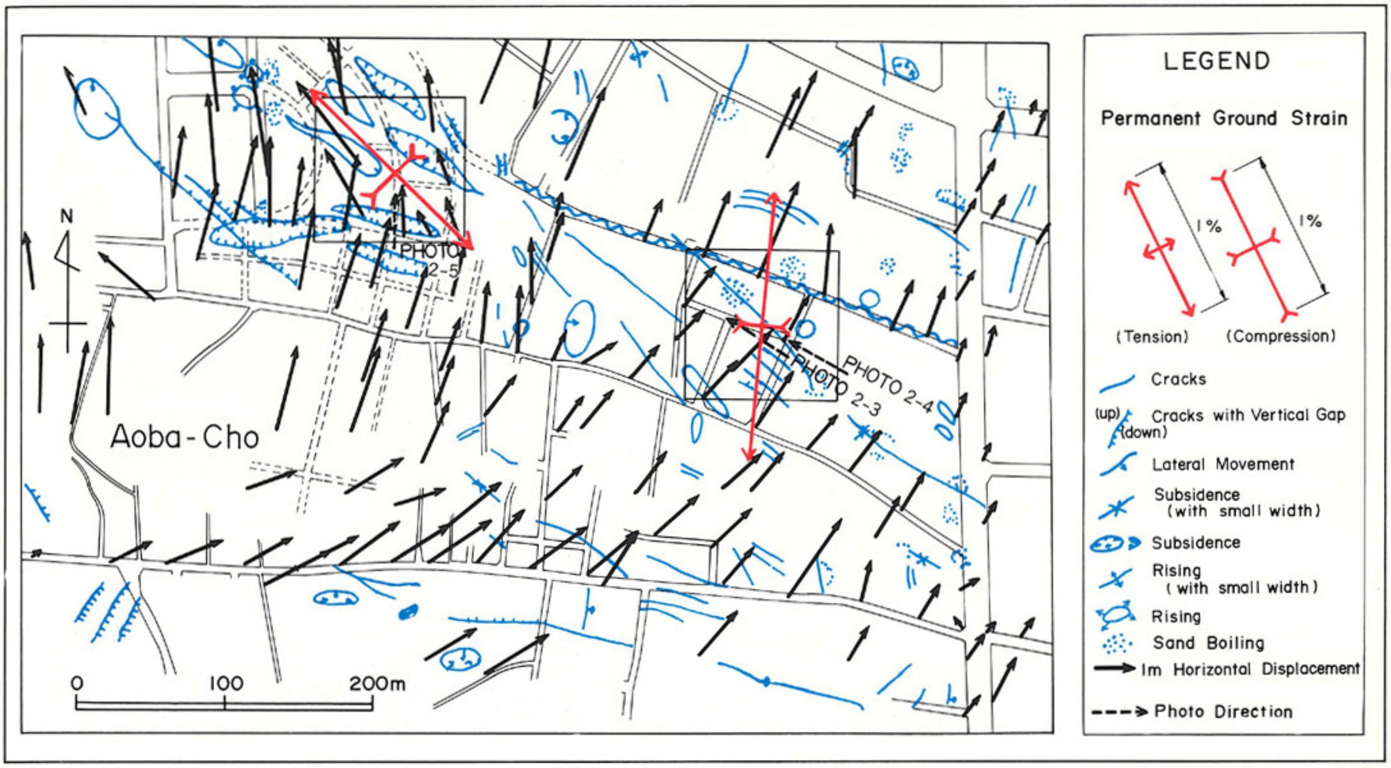


Fig. 2-5 Locations of photos 2-3, 2-4, and 2-5, and horizontal displacements in the surrounding area in Aoba-cho

Photo 2-5 Cracks in the road leading to the graveyard in Aoba-cho (Courtesy of the Noshiro City Government)

In addition to the displacements around Mae Hill, another slide was found in the southern part, commencing near Road No. 7 in the southeasterly direction and extending for about 300 m distance.

2.2.2 Ground failures and permanent ground displacements

Figures 2-3 and 2-4 also show ground failures such as sand volcanoes, cracks, subsidences and, bulgings, as investigated by the University of Akita.[3] In the northern area, as shown in Figure 2-3, the ground failures were concentrated in the western part (Aobao-cho, Matsumi-cho, etc.), where the permanent ground displacements were large.

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

Photos 2-3 and 2-4 show wide cracks and subsidences on a road, and a tree split by the ground

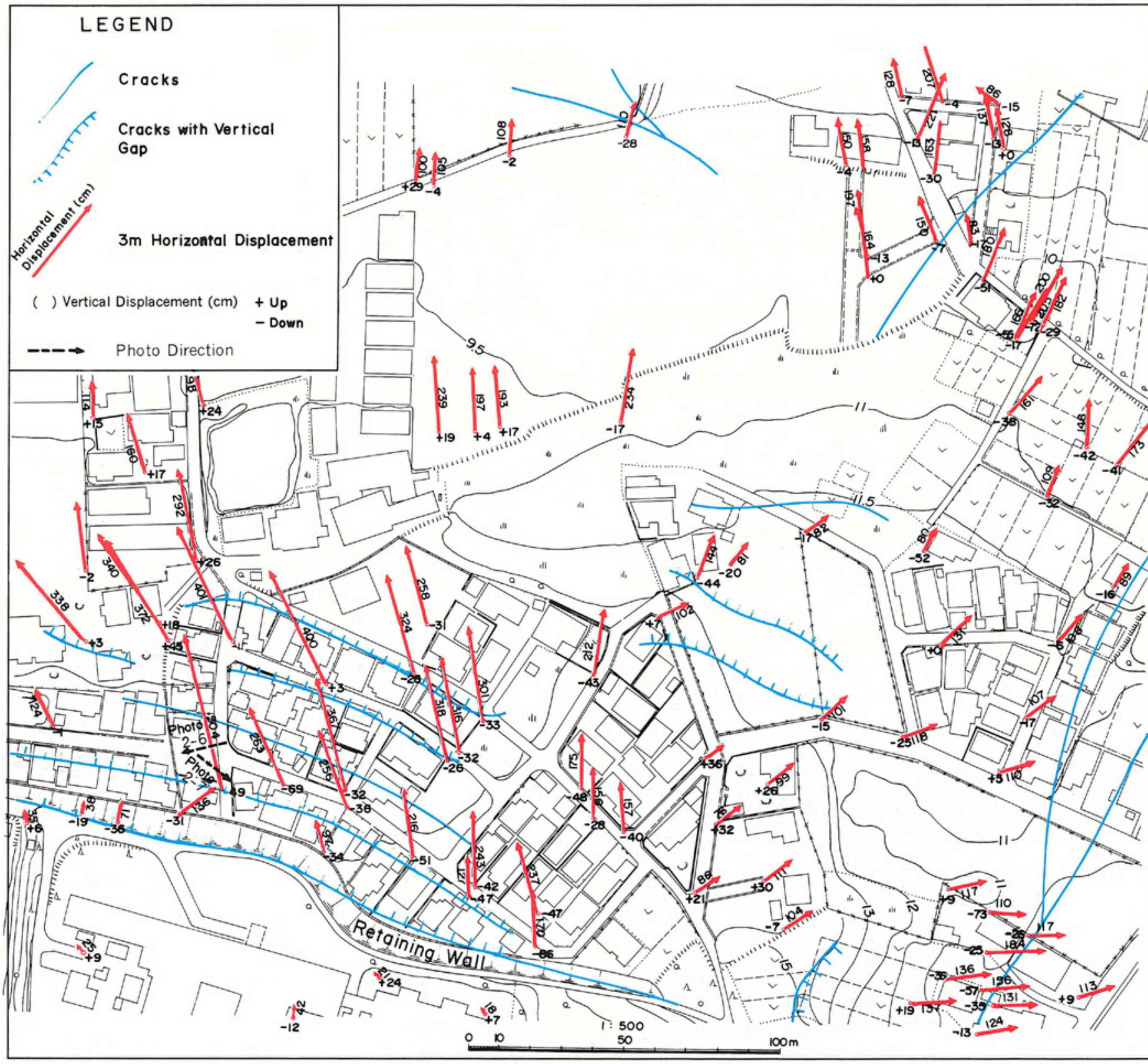


Fig. 2-6 Locations of photos 2-6 and 2-7, and the horizontal displacements on the northern slope of Mae Hill

displacement in Aoba-cho. The locations and the directions of the two photographs are shown in Figure 2-5 along with the horizontal vectors of the permanent ground displacements in the surrounding areas. Sand volcanoes were found around the split tree.

Figure 2-5 also shows the permanent ground strains calculated from the measured displacements by a method to be outlined in Chapter 5. A large tensile strain of 1.7 % was calculated in the vicinity of the cracks and the split tree. It is noteworthy that the direction of the tensile strain coincides with those of the splitting of the tree and the ground cracks.

Photo 2-5 shows another example of a ground failure, in the graveyard in Aoba-cho, where the permanent ground displacement was 1.5 to 2.5 m and the tensile strain of the ground, 1.5 %, as shown in Figure 2-5.

In the southern part, as shown in Figure 2-4, large cracks and subsidences were found around Mae Hill, where displacements exceeding 5.0 m occurred. Details of the permanent ground displacements and ground failures on the northern slope of the hill are shown in Figure 2-6. The region shown in Figure 2-6 corresponds to Photo 2-2 (a). Many cracks and subsidences were seen on the upper parts of the slope.

Photo 2-6 Undulating ground on the northern slope of Mae Hill
(Courtesy of Prof. Y. Mori, Nihon Univ.)

Photos 2-6 and 2-7 show some examples of ground failures on the northern slope of Mae Hill. The locations and the directions of photographs are shown in Figure 2-6. From Photo 2-6, which was taken in a northeasterly direction toward Mae Hill, it can be seen that the ground surface was undulated. Most of the houses in this area were severely damaged, making them uninhabitable. Photo 2-7 shows one example of the cracks found in this area with subsidences which ran parallel to the retaining wall, shown in Figure 2-6.

Figure 2-6 also shows the vertical displacements subsidence and rising of the ground surface.* It shows that the ground subsided near the top of the sand dune, while the ground heaved at the bottom of the slope. The maximum subsidence was about 90 cm below the retaining wall near the top.

From the above result, it can be concluded that the ground failures were mainly concentrated in the areas where the permanent ground displacements were large, and the directions of the ground cracks were almost perpendicular to those of the permanent

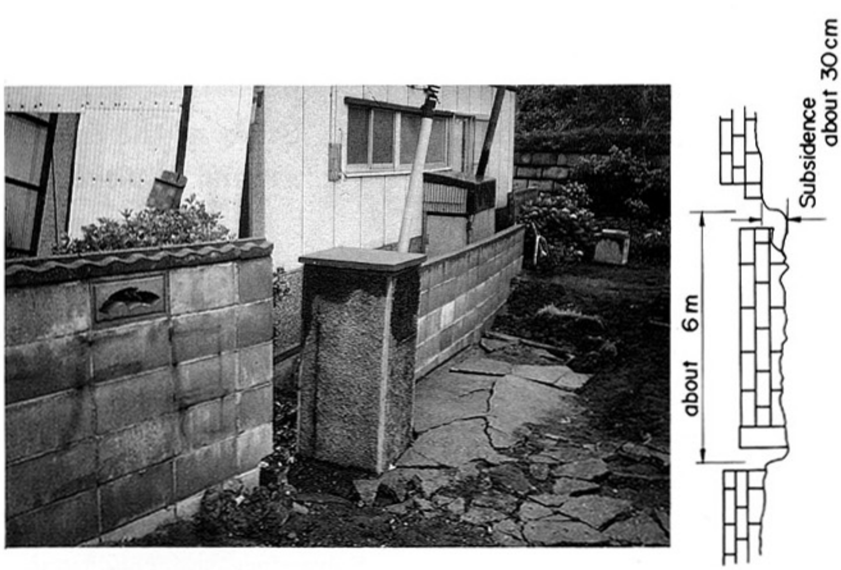


Photo 2-7 Cracks with subsidence on the northern slope of Mae Hill
(Courtesy of Prof. Y. Mori, Nihon Univ.)

* Some attention should be paid to the accuracy of ±20～30 cm in the vertical measurements. (Appendix I).

horizontal ground displacements.

The quantitative correlation between the permanent ground displacements and the ground failures will be discussed in Chapter 5.

2 . 2 . 3 Damage to houses and buried pipes, and permanent ground displacements

Noshiro City suffered severe damage to houses, lifeline facilities, etc., during the earthquake. In this section, the relationship between the permanent ground displacements and the damage to houses and buried pipes is briefly discussed.

Figure 2-7 shows the distribution of damage to water pipelines in Noshiro City. The pipelines consist of cast iron pipes, asbestos-cement pipes, polyvinylchloride pipes, and concrete pipes with diameters ranging from 50 to 450 mm. The water supply pipes were distributed throughout all areas of the urban district, but the damage to them was mainly concentrated in the areas where the permanent ground displacements were large. Most of the damage to water pipes was caused in the area between Aoba-cho and Keirin-cho in the northern part of the city, as well as in the area between Mae Hill and Road No. 7 in the southern part. However, very little damage was found in the area east of Noshiro-Oga Road.

Figure 2-8 shows the distribution of damage to gas pipes, which include both low and medium pressure lines. The low pressure lines consist of screw jointed cast iron pipes and polyvinylchloride pipes, which were installed only in the northern part of the city. The medium pressure lines consist of 80 mm diameter arc-welded steel pipes.

The distribution of the damage to the low pressure lines is similar to that of the damage to the water supply pipes. The damage was much more severe in the area west of the Noshiro-Oga Road, Aoba-cho, Keirin-cho, etc. On the east side of the road, little damage was found to the buried gas pipes.

The medium pressure lines were damaged in the southern part of the city. The failure process of the medium pressure gas pipe will be investigated by numerical analyses in Chapter 6.

Figure 2-9 shows the distribution of damage to houses, most of which were one or two-storied wooden structures. It was reported[3] that the damage to houses was caused mainly by nonuniform subsidences, cracks, and bulging of the foundation ground. The distribution of damage to houses mostly coincides with that of the permanent ground displacements.

From the above discussion, it can be concluded that the damage to buried pipes and houses has a close correlation with the permanent ground displacements. A more detailed and qualitative analysis of the relationship between the damage and the ground displacements will be presented in Chapter 5.

2 . 3 Study of the causes of permanent ground displacements

Many sand volcanoes were found in the areas where the permanent ground displacements were large, as shown in Figures 2-3 and 2-4. The liquefaction of soil layers can therefore be assumed to be one of the main causes of the permanent ground displacements.

Subsurface soil conditions were investigated to examine the existence of liquefiable layers. The standard penetration test and the Swedish penetration test were conducted at 12 points and 134

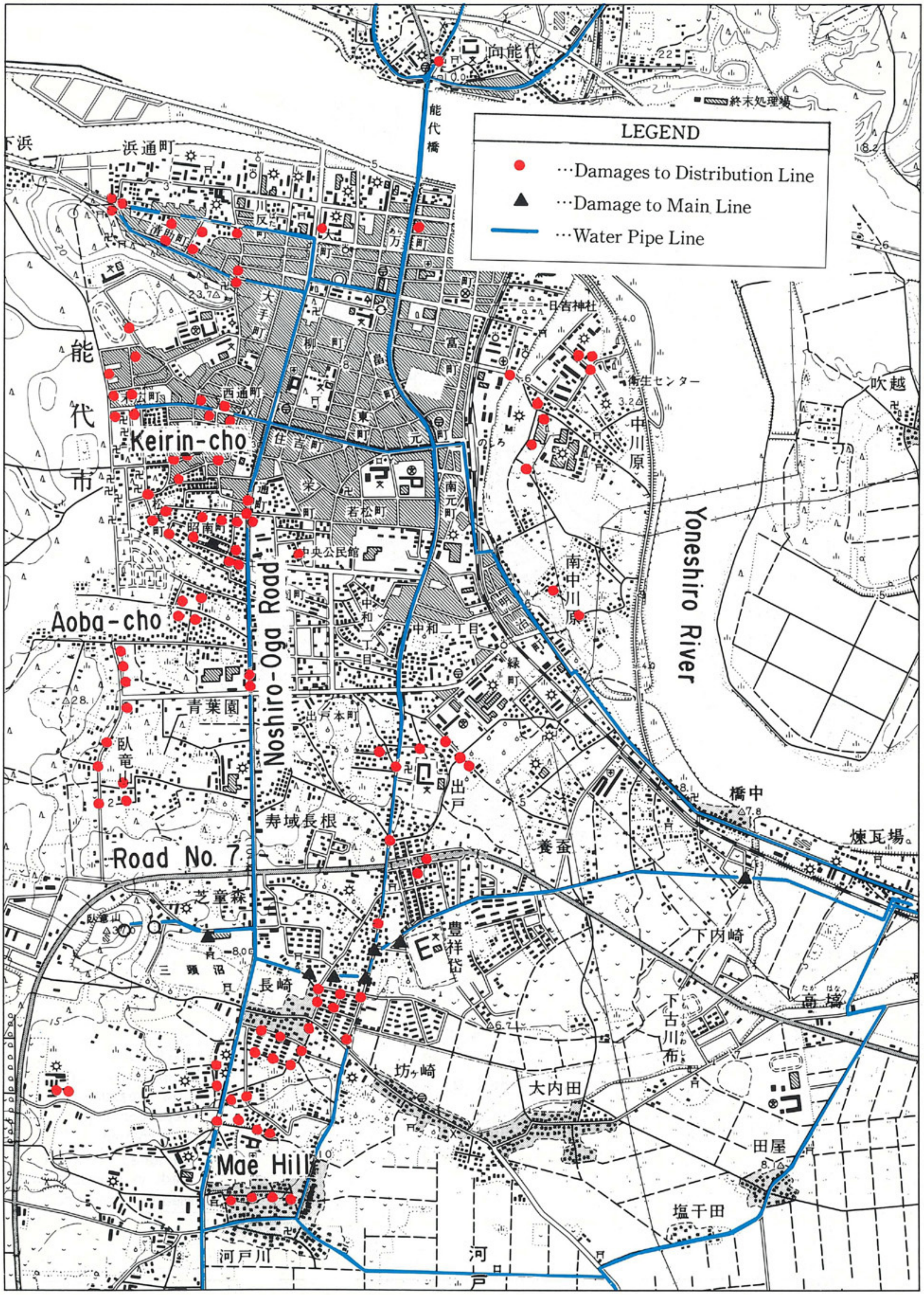


Fig. 2-7 Distribution of damage to buried water pipes in Noshiro City (Courtesy of the Noshiro City Government)

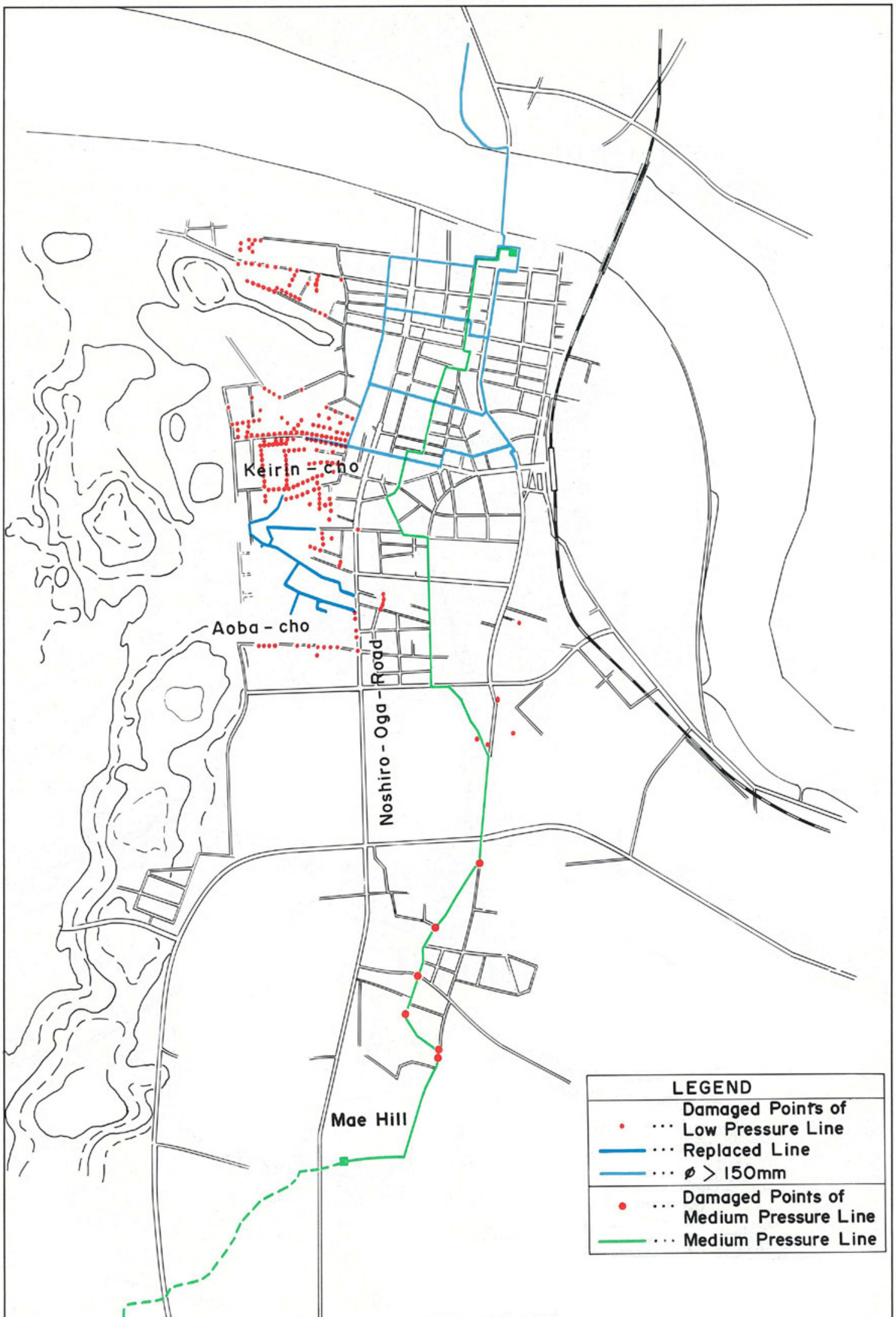


Fig. 2-8 Distribution of damage to buried gas pipes in Noshiro City (Courtesy of the Noshiro City Government)

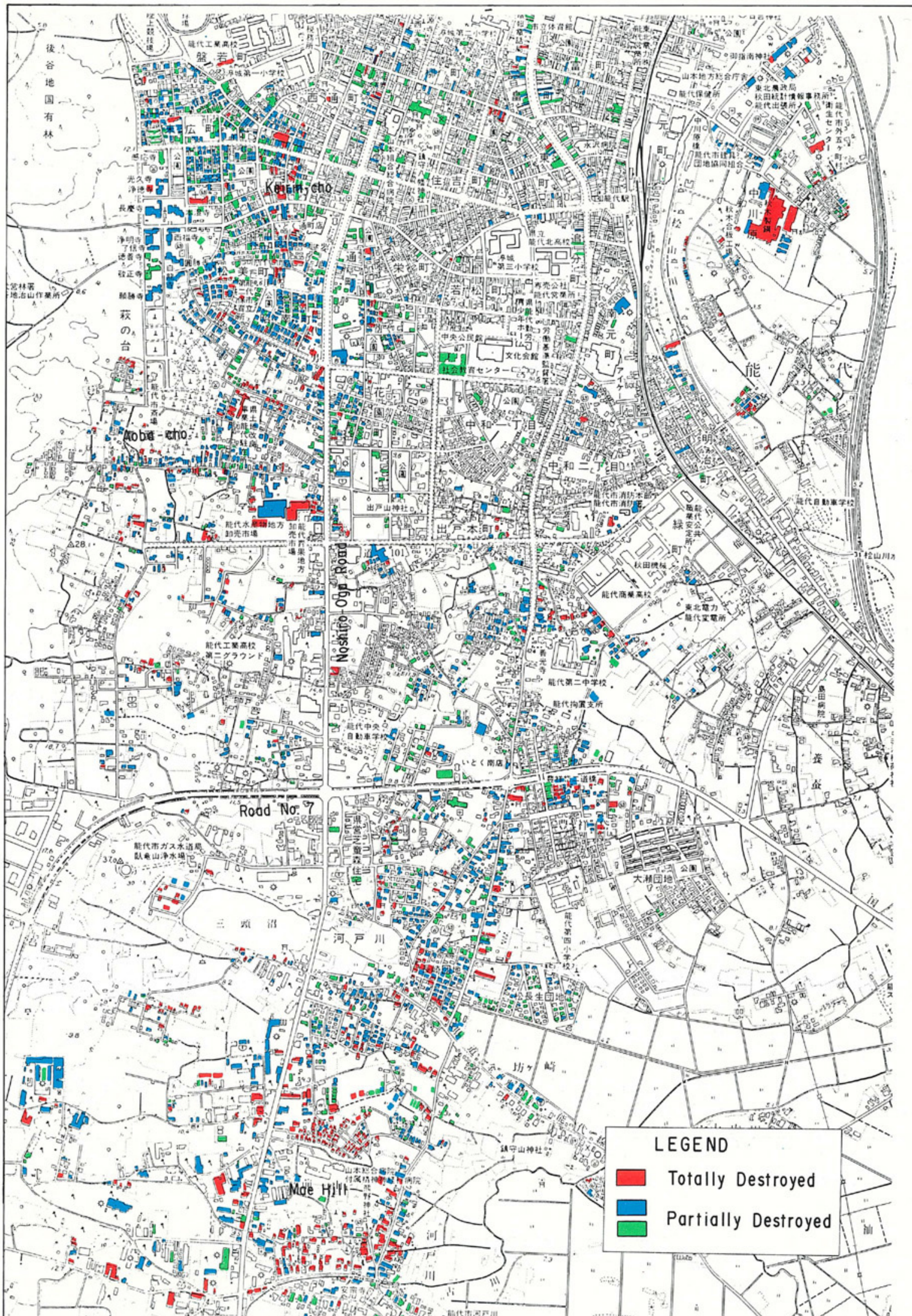
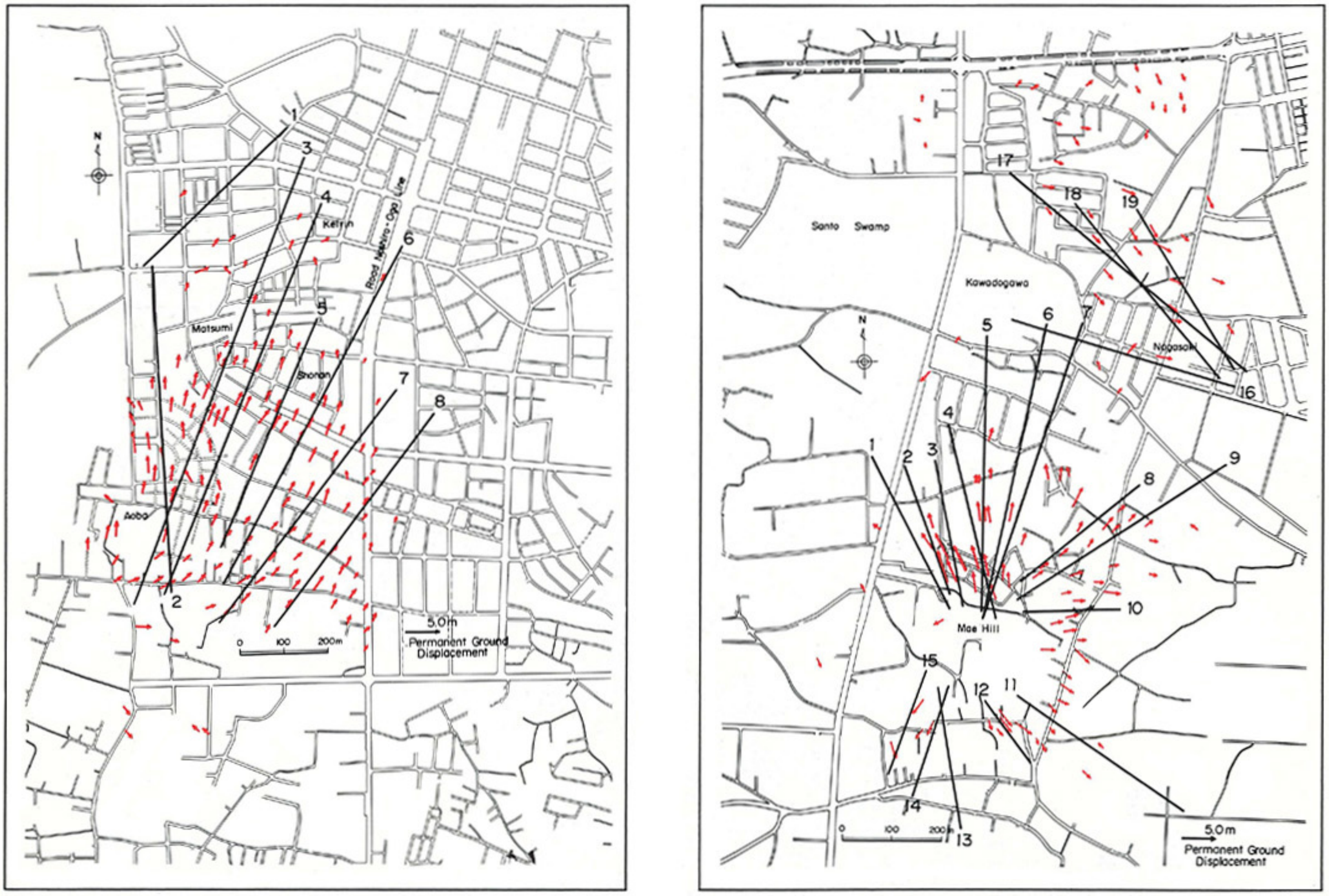


Fig. 2-9 Distribution of damage to houses in Noshiro City (Courtesy of the Noshiro City Government)

points, respectively, to cover all areas where permanent ground displacements were measured. Past boring data were also collected to supplement the above soil soundings.

Based on the results of the soil condition investigation, soil layer profiles along 27 section lines, shown in Figure 2-10, were estimated. All section lines were drawn approximately parallel to the displacement vectors. The liquefied soil layers for each section were conjectured by calculating the Factor of Liquefaction Resistance F_L.*,** The soil layer with F_L less than 1.0 was considered to have been liquefied.

Figure 2-11 shows four examples of soil layer profiles and the estimated liquefaction zones, together with the permanent ground displacement vectors along each section. The horizontal displacements shown in the figure are the components of the displacement vectors in the direction of the section.



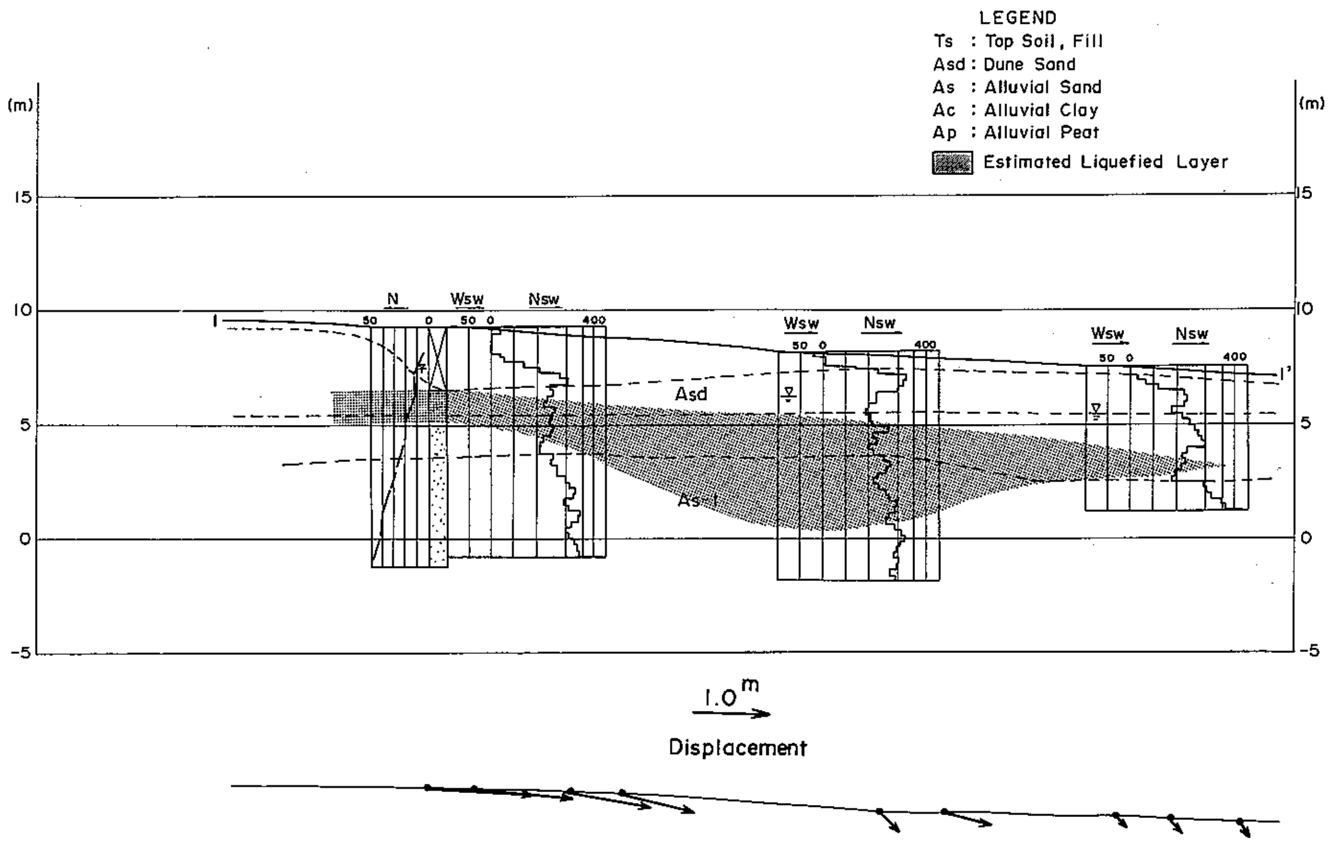
(a) Northern area in Noshiro City

(b) Southern area in Noshiro City

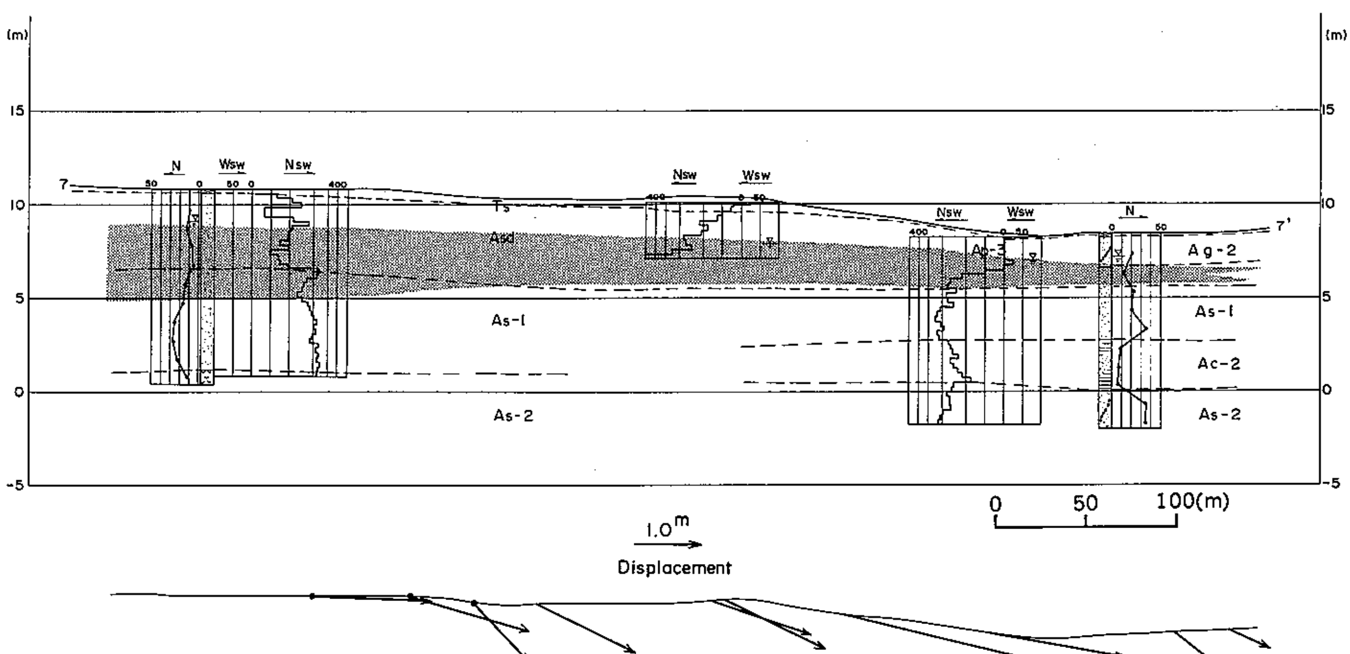
Fig. 2-10 Sections for soil layer profile drawings

* The details of the method are described in Appendix III.

** The maximum acceleration of the ground surface, which is necessary for calculating the Factor of Liquefaction Resistance, was assumed to be 250 gal with reference to the result shown in Figure 2-1.

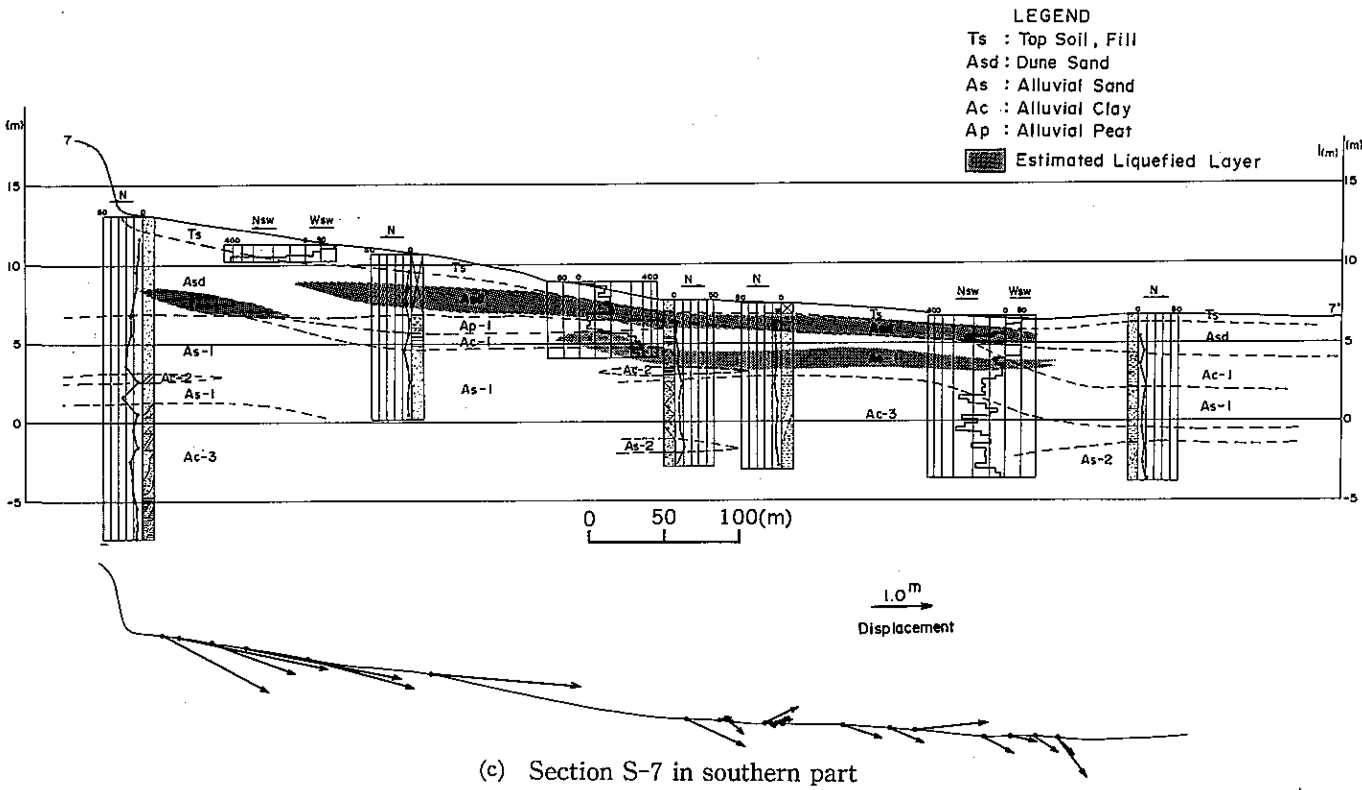


(a) Section N-1 in northern part

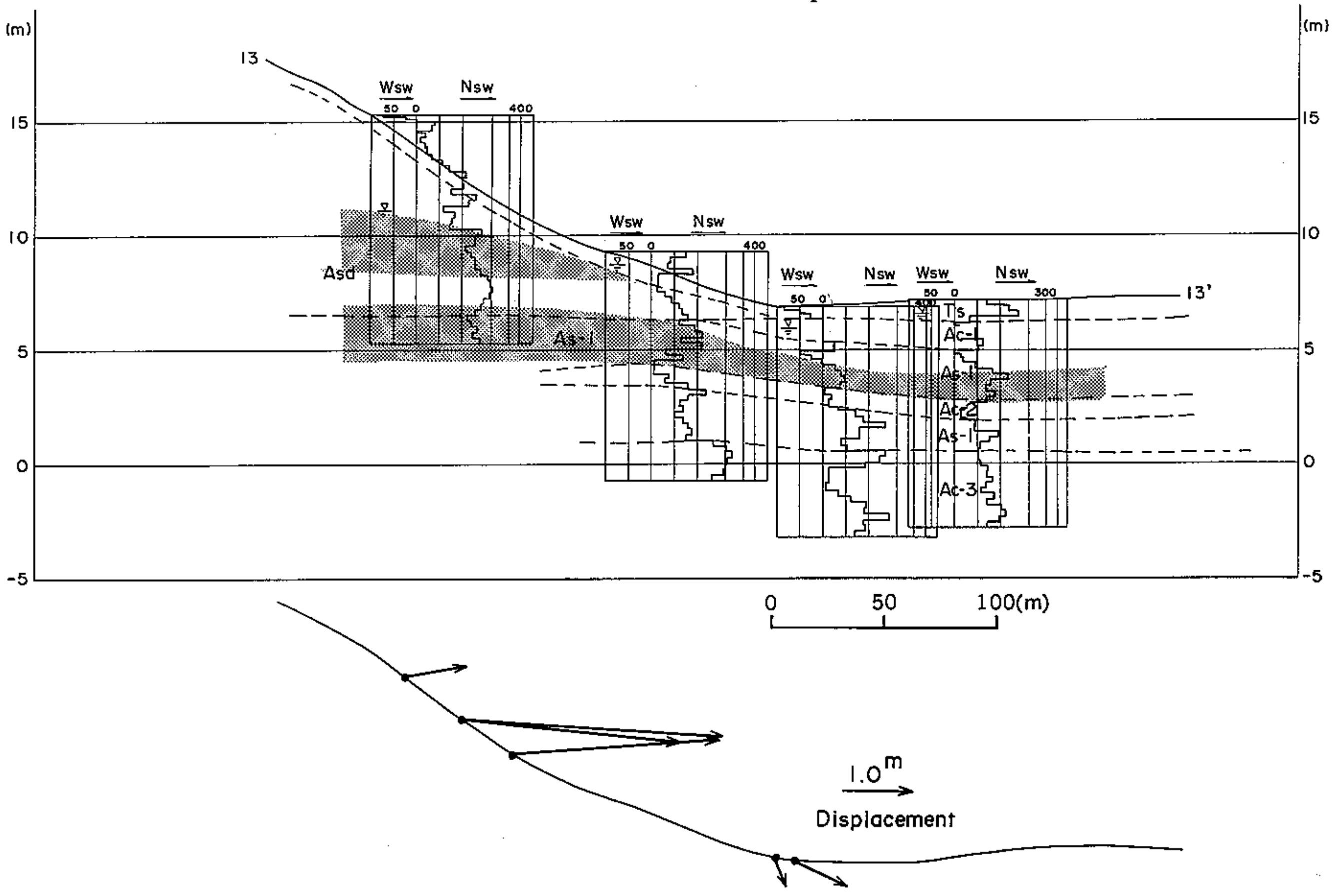


(b) Section N-7 in northern part

Fig. 2-11 Soil layer profiles and estimated liquefied layers



(c) Section S-7 in southern part



(d) Section S-13 in southern part

Fig. 2-11 Soil layer profiles and estimated liquefied layers

The liquefaction layers along sections S-7 and S-13 in the southern area are a little complicated, consisting of two or three layers, because silty layers, which have a higher resistance against liquefaction, exist between the sandy layers. However, along all sections,* liquefied soil layers with a thickness of 2 to 5 m underlie the gently sloped ground surfaces which have gradients of less than 6%. Hence, it can be easily concluded that the soil liquefaction was mainly responsible for the permanent displacements on the slope.

Generally speaking, the magnitude of the permanent ground displacement is larger where the liquefied soil layer is thick and the gradient of the slope is large. As shown by the soil profile and the liquefaction layer along the sections, the permanent ground displacements become much smaller near the toe of the slope where the liquefied layers become thinner and the ground surface is flat. 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. A quantitative analysis of these factors will be done in Chapter 4.

* Soil layer profiles along other section lines are shown in Appendix V.