5. Correlation Analysis of Damage Rate to Houses and Buried Pipes with Permanent Ground Displacements and Strains

In this chapter, the correlation of the damage rate to houses, buried pipes, etc., with the permanent ground displacements as well as with the permanent ground strains, which are calculated from the measured displacements, is discussed.

5.1 Correlation of damage rate to houses and buried pipes, with the magnitude of permanent ground displacements

As mentioned in Chapter 2, severe damage was caused to houses and buried pipes in Noshiro City during the 1983 Nihonkai-Chubu earthquake. In this section, the correlation between the magnitude of permanent ground displacements and the damage rate to houses and buried pipes is examined.

The permanent horizontal ground displacements were measured at about 2,000 points in Noshiro City, while the damage to the houses and buried pipelines was thoroughly investigated by the city government.[3] These data were arranged for the correlation analysis using the following procedure:

(i) The area of Noshiro City, where the permanent ground displacements were measured, was divided into 100 m square cells, as shown in Figure 5-1. The mean value of the absolute amplitudes of the permanent ground displacements measured within each cell was calculated, disregarding the directions of the displacement vectors.

(ii) In cases in which the amplitudes and directions of displacement vectors in the adjacent cells are similar, they were combined to form one block, from which one mean value of the ground displacements was calculated. The reason for this was that by doing so the number of samples of damage to houses and buried pipes, included in one block would be increased, thereby improving the reliability of the results of the correlative analysis between the damage rate and the permanent ground displacements.

(iii) The rate of damage to buried pipes was calculated as a number of damage points per one km in each cell or block, and the rate of damage to houses was obtained as a ratio of the number of damaged houses to the total number of houses, as shown in the following:

$$\text{Rate of damage to houses} = \frac{n_1 + 0.5n_2}{N}$$

where,

- N : Total number of houses in each cell or block
- n_1 : Number of totally destroyed houses in each cell or block
- n_2 : Number of partially destroyed houses in each cell or block

Figure 5-2 shows the mean values of the permanent ground displacements calculated in the cells or blocks. In the unshaded area, no displacement measurements were conducted.

The relationship between the rate of damage to houses and the magnitudes of the permanent ground displacements is shown in Figure 5-3. To assure the reliability of the result, the data for blocks or cells containing less than 75 houses (N) were excluded. A certain high correlation can be recognized between

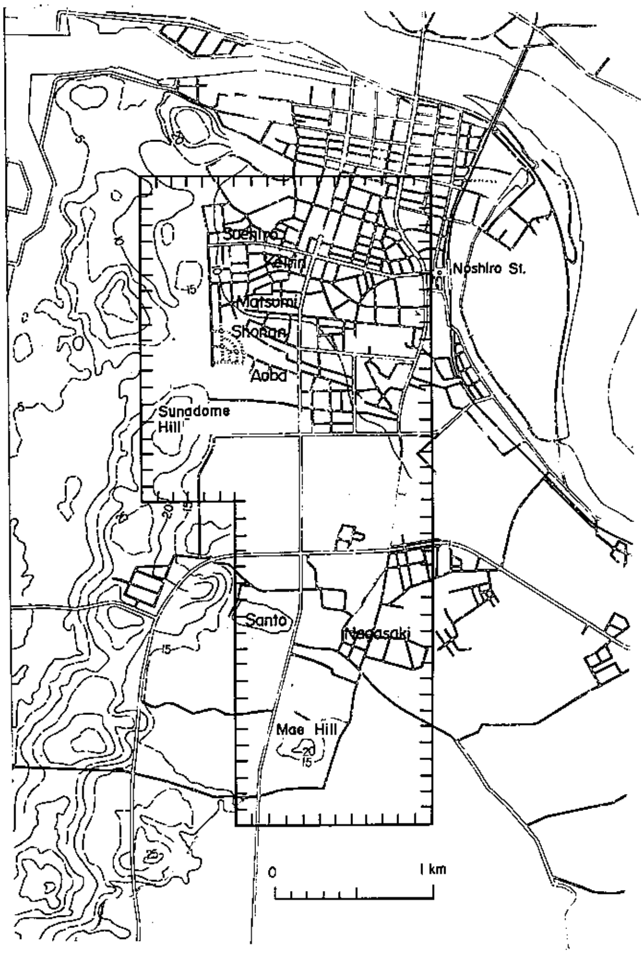


Fig. 5-1 Square cells for analysis on quantitative relationship between permanent ground displacements and damage rates to houses and buried pipes

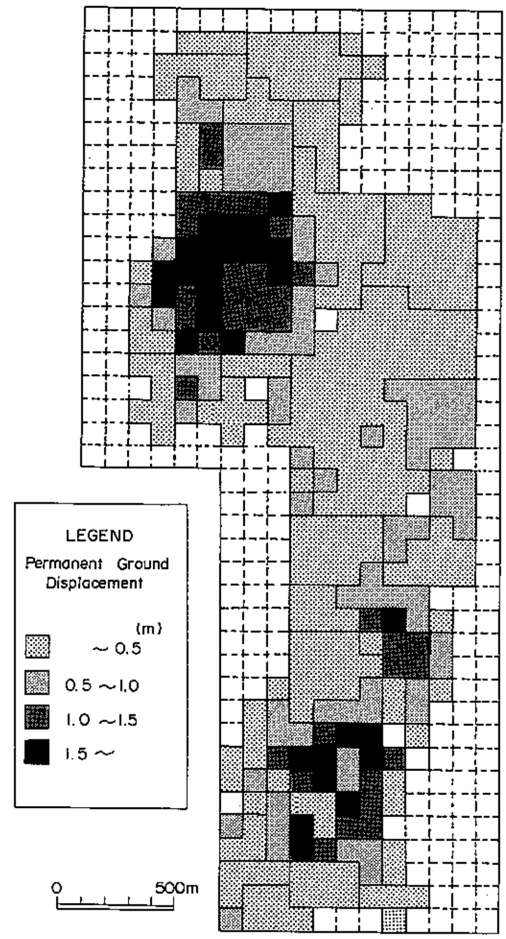


Fig. 5-2 Mean values of the magnitude of permanent ground displacements calculated in cells or blocks

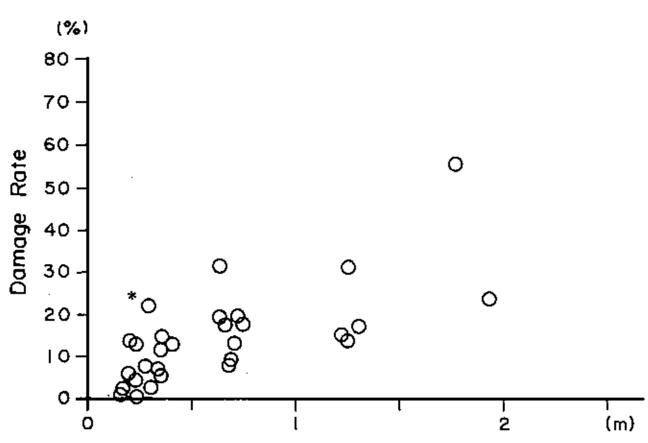
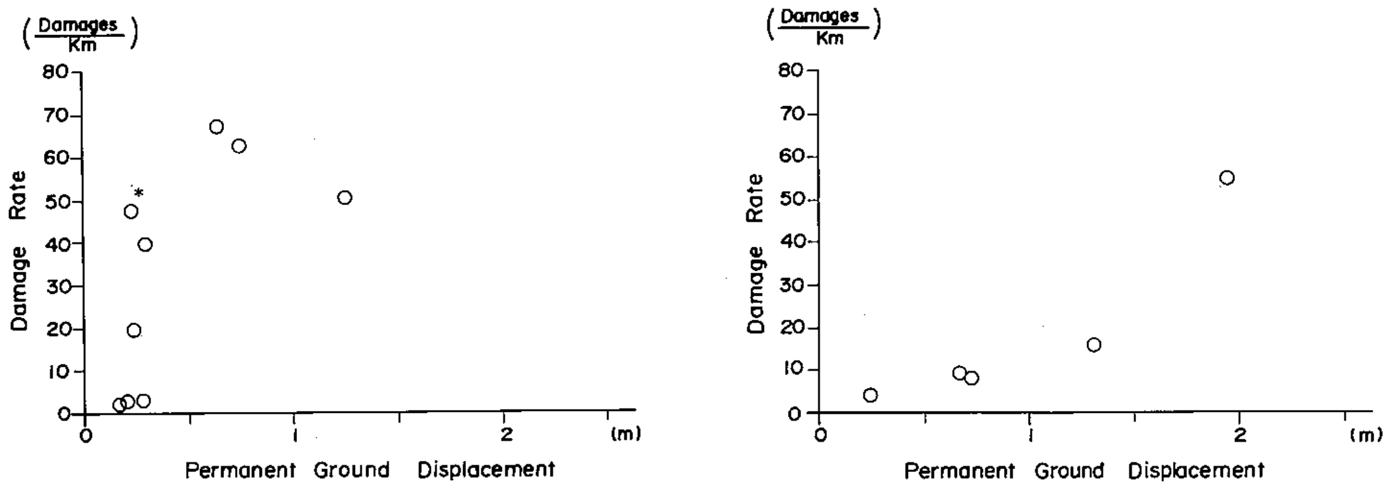


Fig. 5-3 Relationship between the damage rate to houses and the permanent ground displacements

the displacement magnitude and the damage rate to houses, however, it should be noted that in some areas, even though the permanent displacement is small, the damage rate is comparatively high.

For example, the asterisk (*) in the figure shows the damage rate at Keirin-cho in the northern part of the city. In this area, the permanent ground displacement was small, but ground failures such as cracks, sand boiling, etc. (as shown in Figure 2-3) were found. This means that the houses can be damaged by local failures of the foundation ground, due to cracks, subsidence, and bulging without the large ground displacements due to the liquefaction over a wide area.



(a) Cast iron gas pipes

(b) Steel pipes

Fig. 5-4 Relationship between the damage rate to buried gas pipes (ϕ = 75~150 mm) and the permanent ground displacements

Figure 5-4 shows the damage rates to cast iron gas pipes (CIP) and steel gas pipes (SP) with diameters of 75 to 150 mm. A definite conclusion could not be reached because of an insufficient number of data, but it is clear that the damage rates to both types of pipes have a proportional relationship with the magnitudes of permanent ground displacements. It can also be seen from the figures that the damage rate to CIP is 2 or 3 times that of SP.

It should be noted that in some areas where the permanent ground displacements were small, the damage rate to CIP is very high. For example, the asterisk (*) in Figure 5-4 (a) shows the result in the Suehiro-cho area, which is also in the northern part of the city, as shown in Figure 2-3. In this area, although the permanent ground displacements were very small, less than 25 cm, the damage rate was very high, about 50 instances per km. As previously mentioned in the case of the damage rate to houses, the permanent ground displacements in this area were small, but ground failures due to liquefaction were observed as shown in Figure 2-3. This indicates that because the strength of cast iron pipes was generally low, the damage was caused by local ground failures induced by liquefaction, and/or by the relative displacements due to wave propagation, even though no large permanent ground displacements occurred.

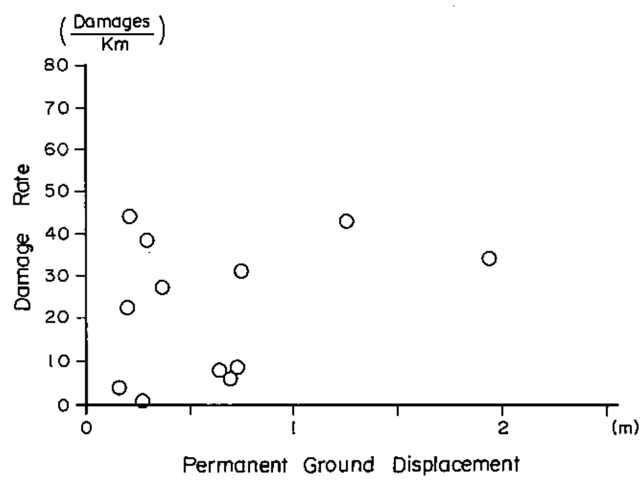


Fig. 5-5 Relationship between the damage rate to buried gas pipes and the permanent ground displacements (steel pipe, ϕ = 32~50 mm)

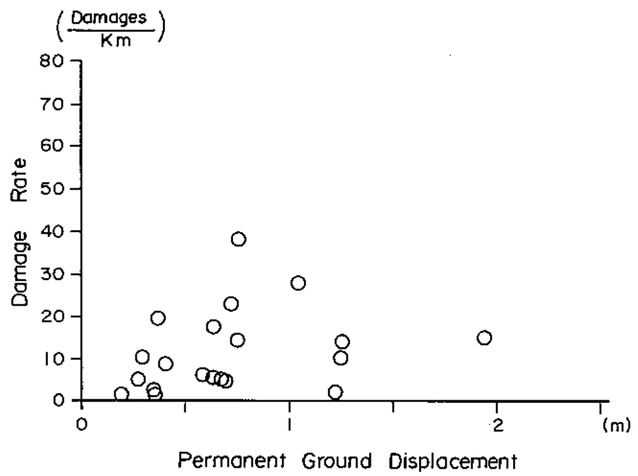


Fig. 5-6 Relationship between the damage rate to buried water pipes and the permanent ground displacements (asbestos cement pipe, ϕ =100~200 mm)

As shown in Figure 5-5, there is no distinct correlation between the damage rate to small diameter (32-50 mm) gas pipes and the magnitude of the permanent ground displacements. Most of the damage to small diameter gas pipes occurred at screw joints and T-shape joints. Since the strengths of these joints are generally low, damage could occur due to other causes, if not by permanent ground displacements, as in the case of cast iron pipes. These results show that the permanent ground displacement is not necessarily the only factor governing the damage to small diameter pipes.

A similar result was obtained in the case of asbestos cement water pipes of sizes between 100-200 mm. As shown in Figure 5-6,* no clear correlation can be found between the damage rate to these water pipes and the permanent ground displacements. It is also considered possible that these pipes may have been damaged by causes other than permanent ground displacements because of their low strengths.

5 . 2 Correlation of damage rate to buried pipes and ground cracks, with permanent ground displacements

5 . 2 . 1 Calculation of permanent ground strains

The strain generated in buried pipes by earthquakes depends on the relative displacement of the ground, that is, more on the ground strain than on the absolute amplitude of the displacement. In this section, the ground strain on horizontal plane is calculated from the permanent ground displacements by the following procedure, and its correlation with the damage rate to buried pipes, etc., is discussed.

(i) The displacement function in each square cell (200 m × 200 m, see Figure 5-7) is assumed to be linear, as follows. That is, the strains in a cell are assumed to be constant.

$$u=\alpha_1 x+\beta_1 y+\gamma_1$$

$$v=\alpha_2 x+\beta_2 y+\gamma_2$$

where,

x, y : Coordinates in the east-west and south-north directions

u, v : Components of ground displacements in the respective directions.

(ii) Six coefficients α_1, α_2, β_1, β_2, γ_1, and γ_2 are determined from the permanent ground displacements measured in a square cell using the Least Square Approximation. For the

* The damage rate to asbestos cement water pipes, as shown in Figure 5-6, was comparatively lower than that to the 75 to 150 mm dia. cast iron gas pipes shown in Figure 5-4(a),although the strengths of the water pipes were comparatively smaller than those of the gas pipes. This can be considered to be due to the fact that the damage to the gas pipes was detected much more accurately than that to the water pipes.

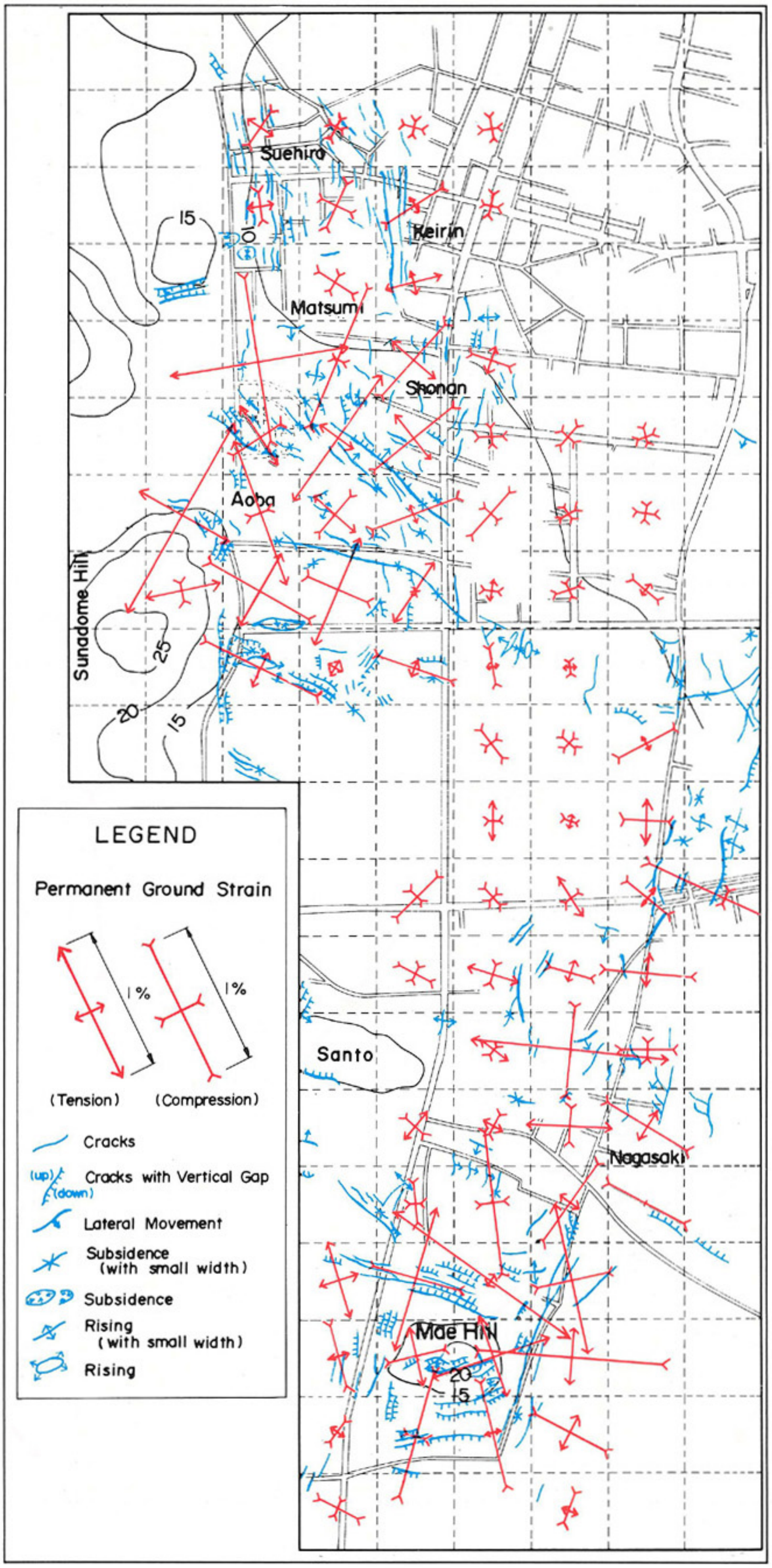


Fig. 5-7 Permanent ground strains and ground failures in Noshiro City

determination of ground strains, at least three displacement vectors are necessary in each square cell. The permanent ground strains on horizontal plane are obtained as the differentials of the displacement function.

Figure 5-7 shows the permanent ground strains in Noshiro City obtained by the above mentioned procedure, together with ground failures such as cracks, subsidences, etc. The maximum ground strain exceeded 1.5 % around Mae Hill in the southern part of the city as well as on the slope of Sunadome Hill in the northern part.

On the upper part of the northeastern slope of Sunadome Hill, a large tensile strain was caused along the approximate direction of the slope, while in the area near Shonan-cho and Matsumi-cho at the toe of the slope, a compressive strain was caused. A similar result can be found on the slopes of Mae Hill. On the upper parts of the slopes tensile strain was dominant, while compressive strain was notable in the lower parts of the slopes. As mentioned in Chapter 2, the sliding started from near the top of the sand dune and diminished at the toe of the slope. As a matter of course, the distribution of the calculated permanent strain on the slope coincided with the pattern of the sliding.

Ground failures such as cracks and subsidences were concentrated in the area where the permanent ground strains were dominant. It is worth noting that the directions of the principal tensile strain are roughly perpendicular to those of the cracks on the

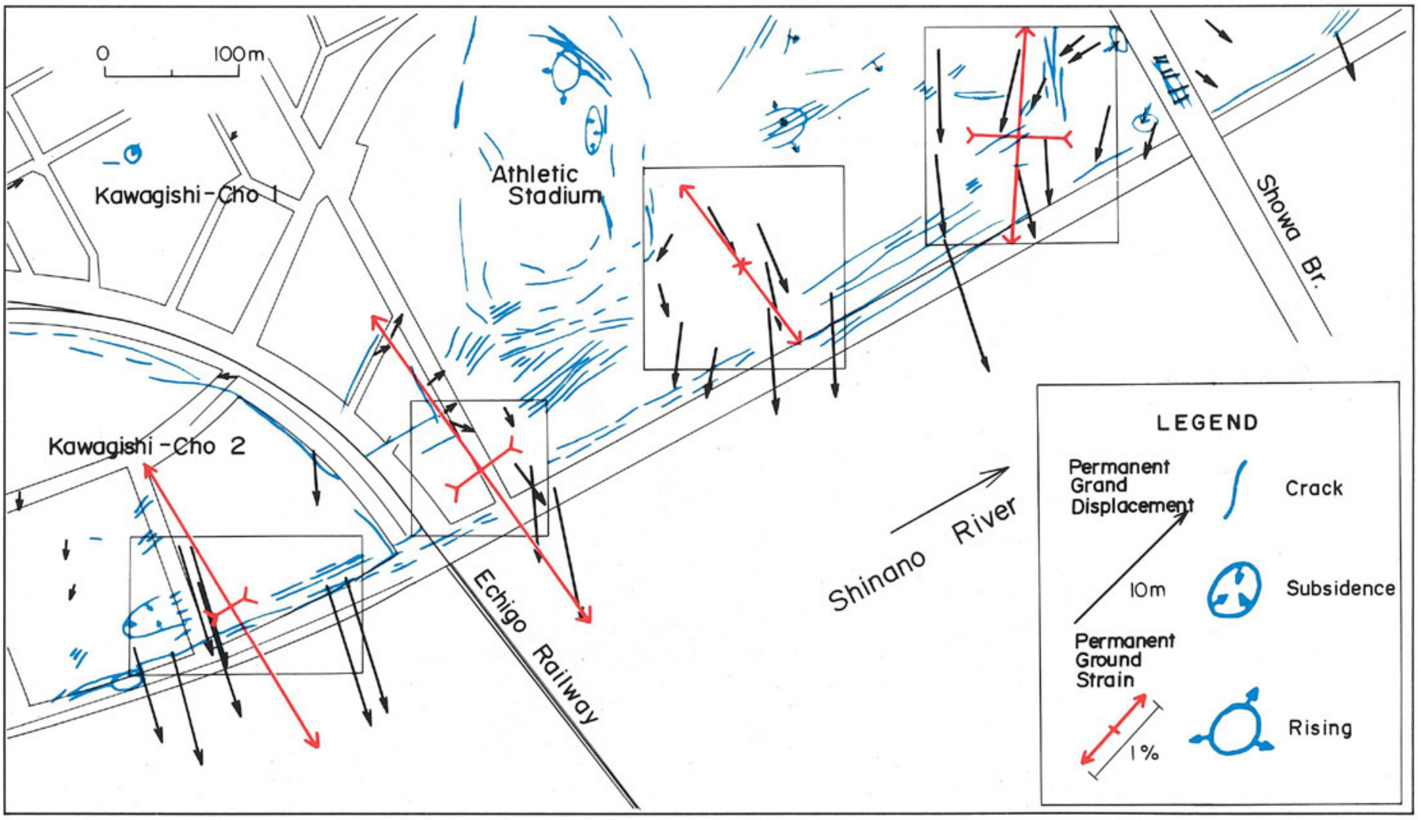


Fig. 5-8 Permanent ground strains, displacements, and ground failures in the area along the Shinano River

slope of Sunadome Hill.

Figure 5-8 also shows the permanent ground strains on the left bank of the Shinano River in Niigata City, obtained by the same procedure. In this case, however, the area of the cell where the strains were calculated was not necessarily a perfect 200 m square. In the Kawagishi-cho area, where the maximum permanent ground displacement was 8.5 m, the tensile strain of the ground exceeded 4 %. The directions of the large tensile strains were mostly perpendicular to the river and intersected the cracks on the river bank at right angles.

5 . 2 . 2 Correlation of damage rate to buried pipes and ground cracks with the permanent strains

Figure 5-9 shows the relationship between the length of cracks on the ground surface and the

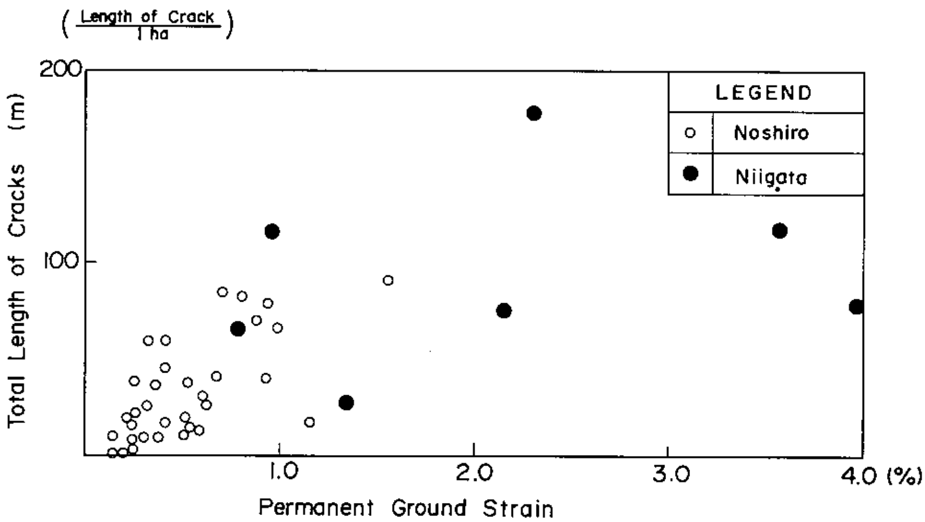
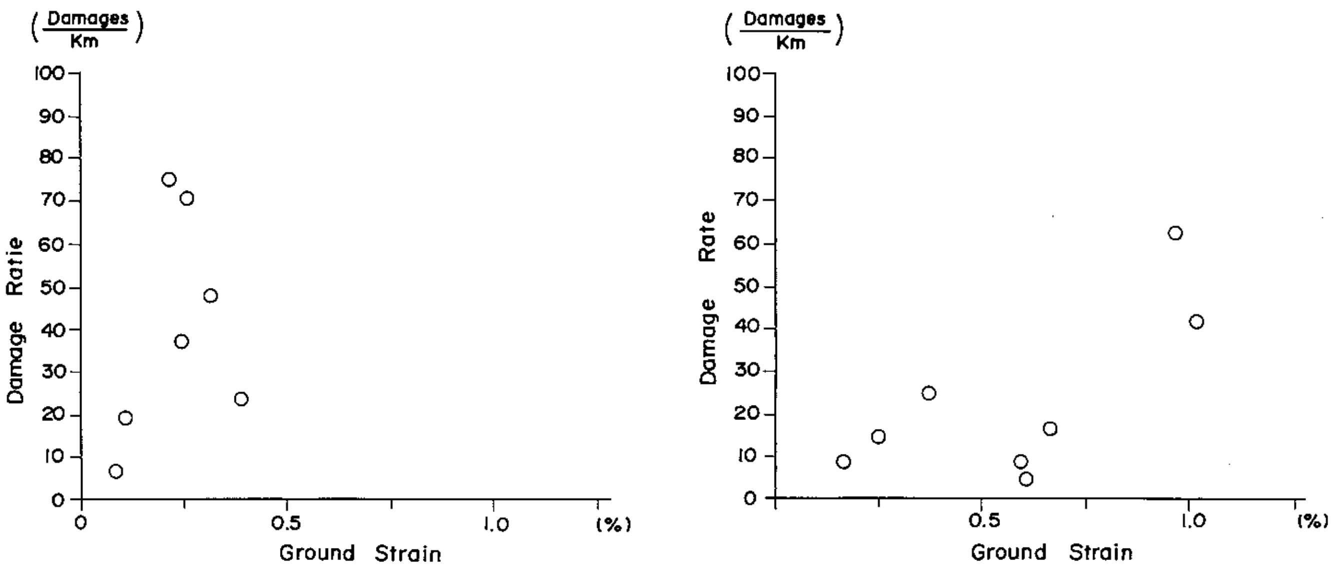


Fig. 5-9 Relationship between the lengths of cracks and the permanent tensile ground strains



(a) Cast iron gas pipes (b) Steel pipes

Fig. 5-10 Relationship between the damage rate to buried gas pipes (ϕ =75～150 mm) and the permanent ground strains permanent tensile strains. The ordinate shows the total length of the cracks within an area of 1.0 ha. in Noshiro City and along the Shinano River. The precise locations and lengths of the cracks were taken from references (3) and (8). However, since the width of each crack was not recorded, the total length of cracks was obtained simply by summing the length of each crack, assuming that they were all equivalent.

It is recognized that there is an evident correlation between the total length of ground cracks and the permanent tensile strain. From the results shown in Figure 5-9 it may be concluded that some cracks will occur on the ground surface if the tensile strain exceeds 0.1-0.2 %.

Figure 5-10 shows the damage rates to cast iron and steel gas pipes with diameters of 75 to 150 mm, where the abscissa is the maximum absolute value of the two principal ground strains.

It is also recognized that a certain correlation can be found between the damage rate to buried gas pipes and the permanent ground strains, however, the correlation with the ground strain is not much higher than that with the displacements, as shown in Figure 5-4. The following are considered to be the reasons for this result: The accuracy in calculating the ground strain was insufficient, and there may be other causes of damage to buried pipes besides the permanent ground deformation, as previously mentioned.