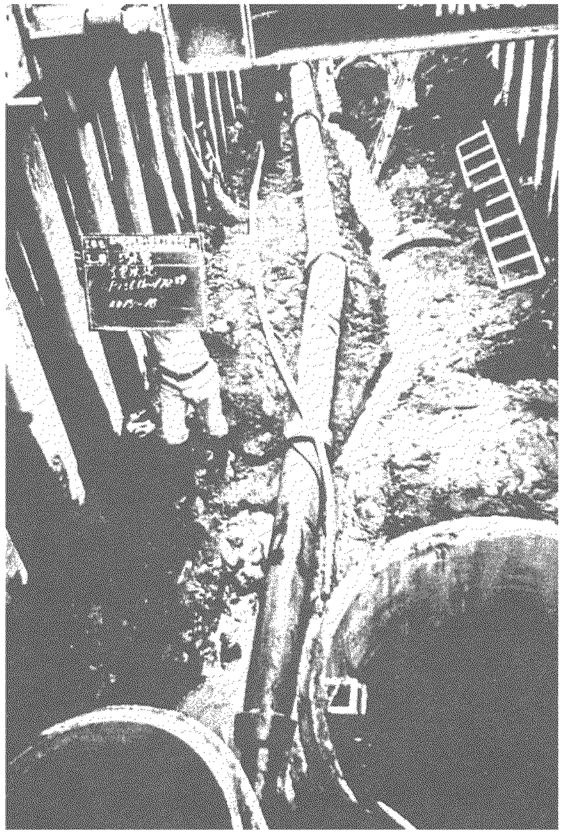

Photo 3 Deformation of a Wastewater Pipeline
(Courtesy of Kushiro City Government)

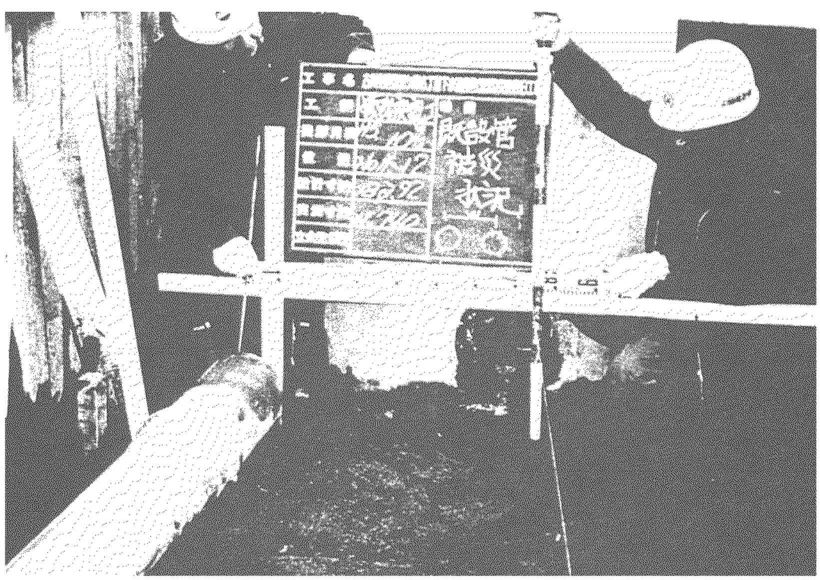

Photo 4 Rupture of Connection between Manhole and Pipe
(Courtesy of Kushiro City Government)

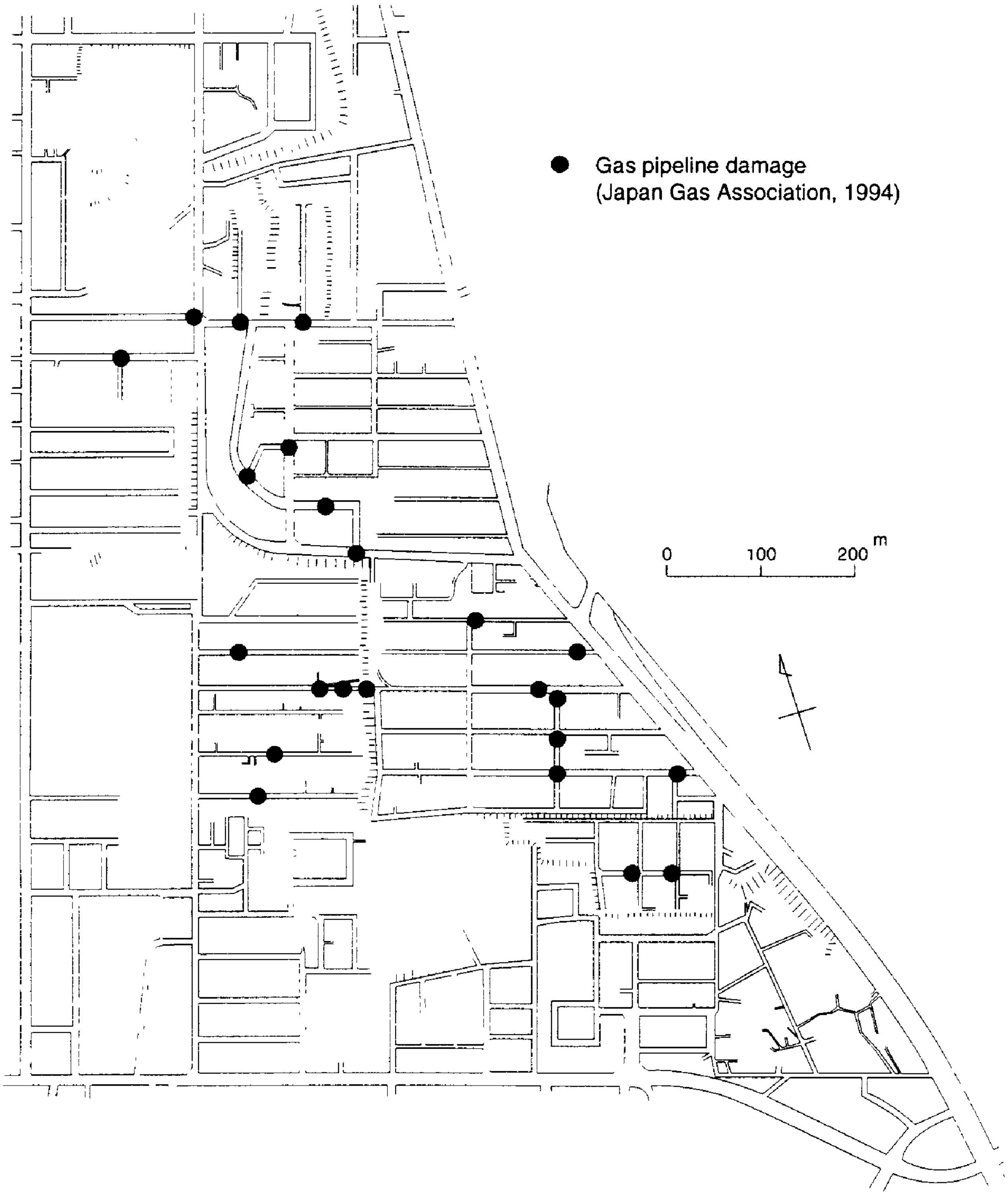

Fig.9 Map of Midorigaoka Showing Locations of Damage to High and Low Pressure Gas Distribution Systems

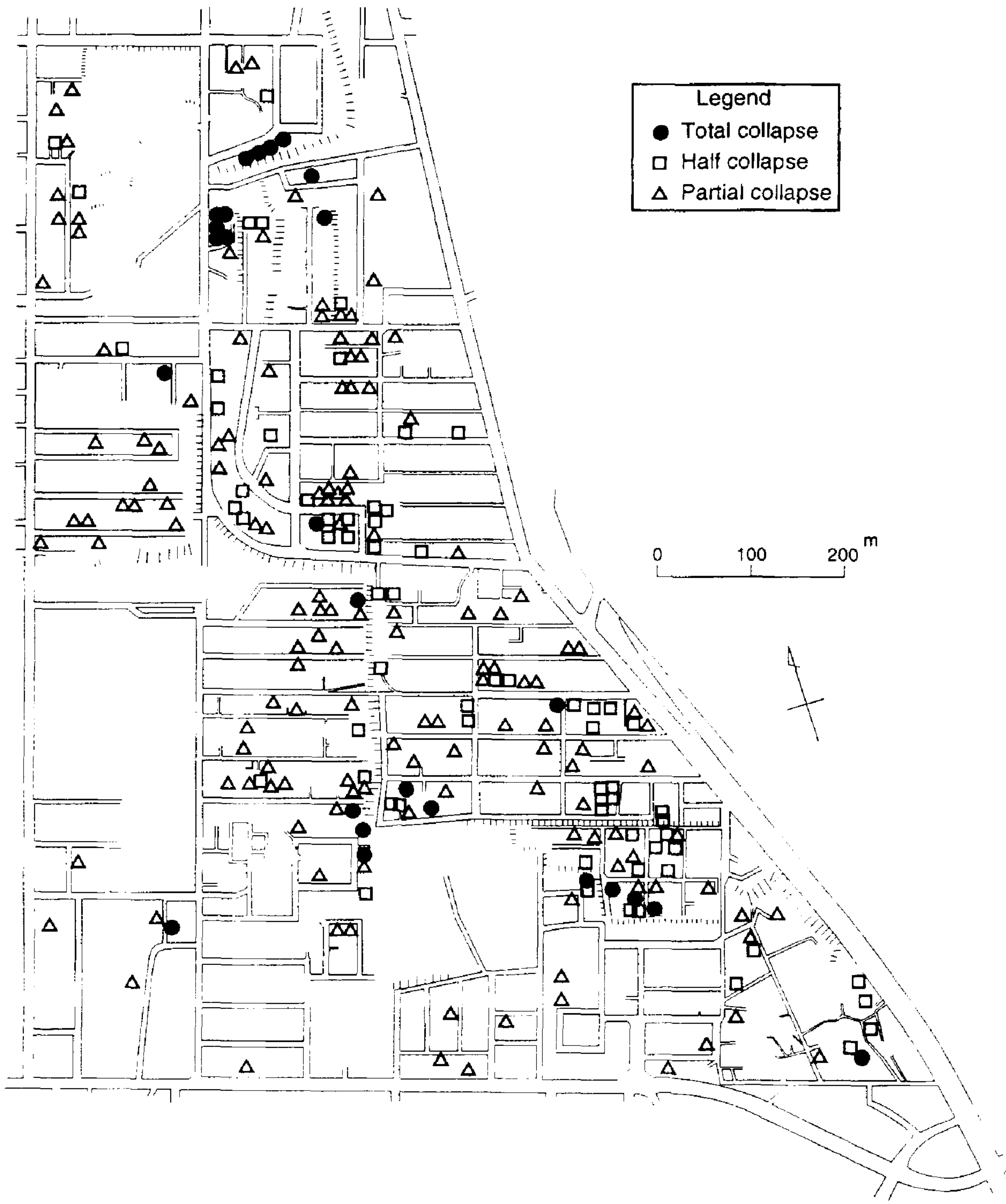

Fig.10 Map of Midorigaoka Showing Locations of Collapsed Houses

which were built in the last twenty years with some engineering design. These houses were significantly affected by the earthquake as shown in Fig. 10. Damage was primarily in the form of cracks of walls and foundation, broken chimneys, differential settlement and horizontal displacement of the foundation. Total collapse indicates damage to main structural members, but does not imply complete collapse of the structure. The most serious instances of damage occurred at site ① in Fig.5 where a slope failure occurred as previously shown in Photo 2.

SUBSURFACE CONDITIONS IN MIDORIGAOKA

Subsurface Soil Conditions

Many boring investigations and standard penetration tests have been performed to clarify the foundation conditions of wastewater utilities in Midorigaoka. On the basis of the boring information, a cross-section oriented in the north-south direction was developed as shown in Fig.11. Loose fill with SPT N-values less than 5 extends along the section with a thickness ranging from 1 to 9 m. The depth of the water table is shallow ranging from 0.3 to 2 m in the valley, whereas in the terrace it is several meters deep. Underlying the fills is very soft peat, which was originally at the bottom of the valley.

The slope failure described before (① in Fig.5) occurred where thickness of fill material is large and the slope is steep, as shown at the left side end of the figure. Sand boils were observed in the gentle slope of valley wall where 1- to 2-m thick fill overlies the water table. Major ground cracks and settlements occurred in the upper part of the slope with sand boils. This pattern of ground deformation implies that lateral movement toward the center of the valley occurred due to the liquefaction of loose fill. This agrees with the fact that grain size characteristics of sand boils was similar to the grain size of the volcanic ash used as fill in Midorigaoka.

Landform Changes due to Development

To examine further the relationships between ground deformation and subsurface conditions, landform changes due to development are investigated by analyzing a pair of aerial photographs taken before and after the development. A total of 13 sections were selected for analysis; 12 sections through Midorigaoka and 1 outside Midorigaoka where few effects of the earthquake were observed. The accuracy of the measurements is about ±1 m in the vertical direction.

The typical examples of the photogrammetric analysis were shown in Fig. 13, in which the locations of streams before development and ground failures and damage to structures are plotted. In the figure, the damaged houses previously shown in Fig.10 are re-classified according to damage mode based on the record by the city government into three types: 1) damage in foundations; 2) damage other than that in foundation such as

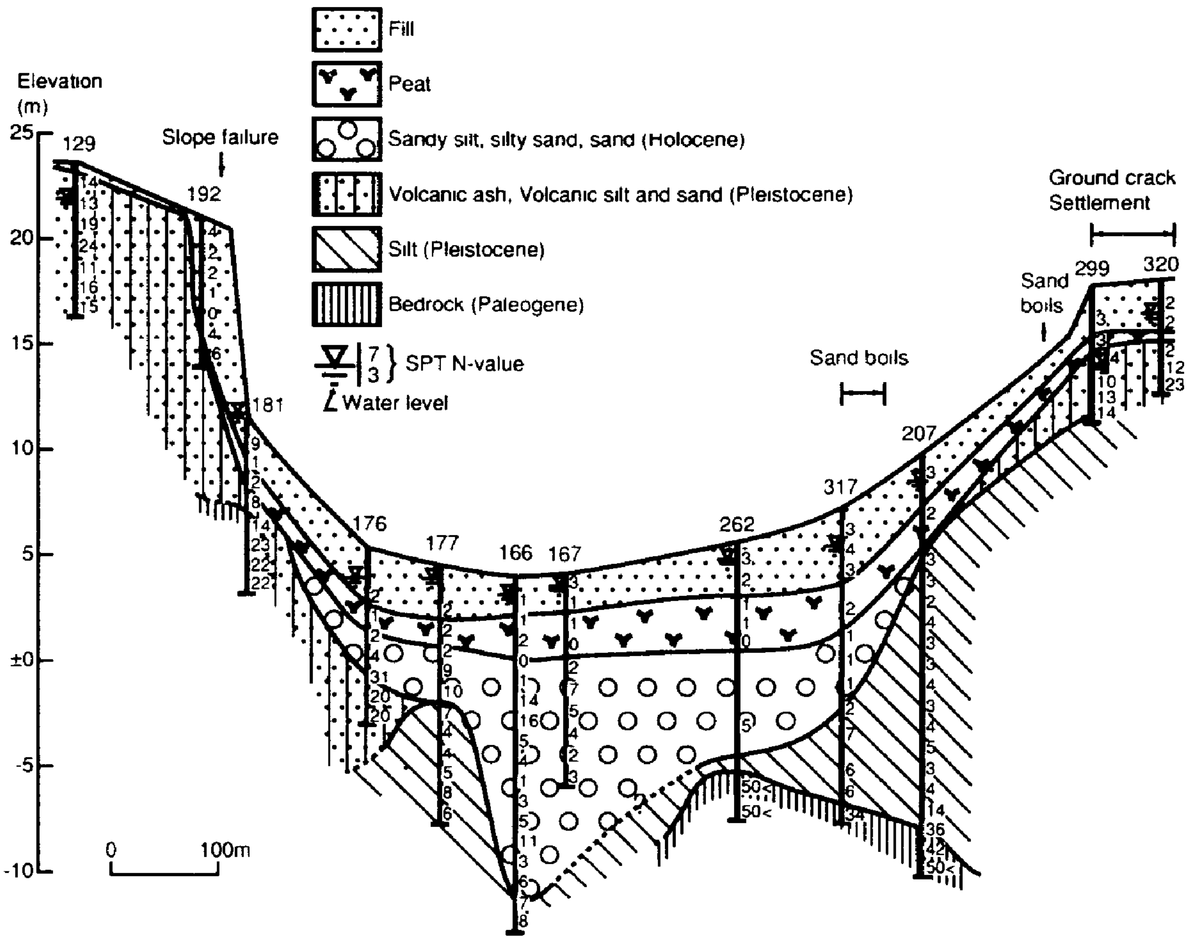

Fig.11 Soil Profile along Cross-Section A-A' in Midorigaoka (see Fig.12 for location)

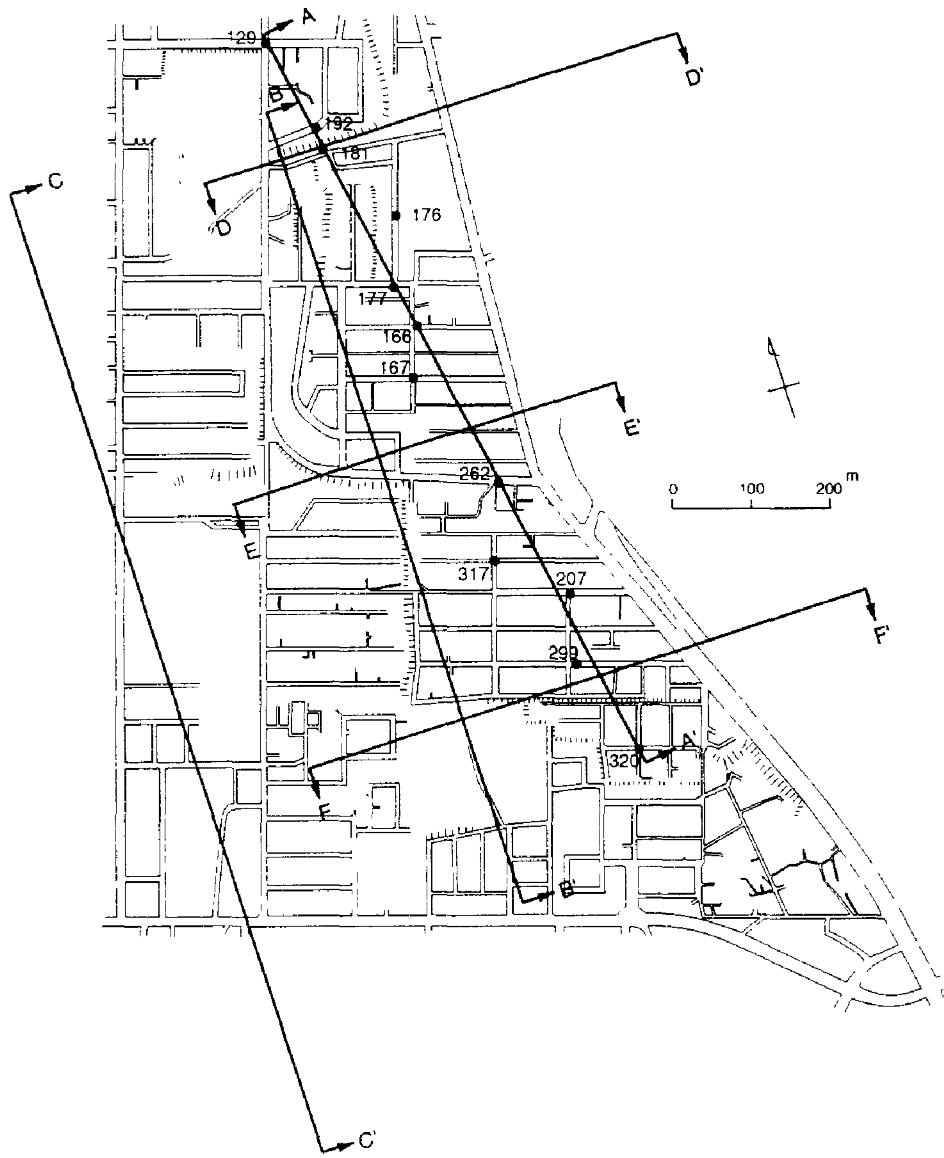

Fig.12 Map of Midorigaoka Showing Locations of Cross-Sections

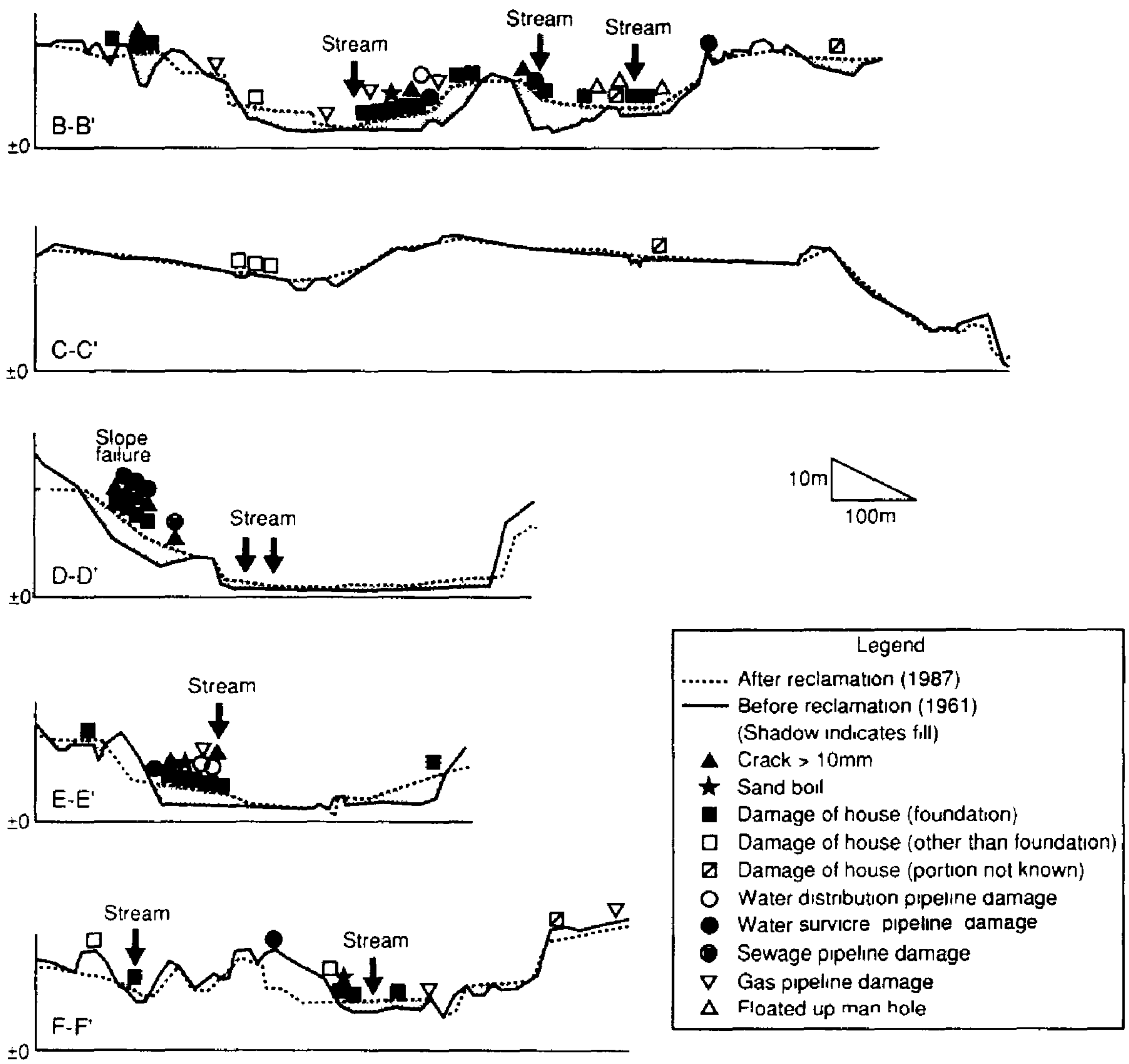

Fig.13 Cross–Sections Showing Landform Changes due to Development (see Fig.12 for locations)

collapsed chimney and cracked exterior wall; and 3) portion of damage not reported. The majority of the damage in Midorigaoka was categorized as the type-1.

It can be seen from the figure that the heaviest concentration of structural damage was observed in the filled area where ground failures such as slope failure, ground cracks and sand boils were concentrated. The slope failure occurred at the boundary between the terrace and the valley where fill is thick and the slope of ground surface is steep as shown in section D-D', whereas liquefaction effects such as sand boils and floated up manholes occurred in the valley where fill is thick, slope is gentle and stream flowed down before the development. Ground cracks also occurred on both steep and gentle slopes in the filled area. Damage to pipelines and foundation of houses occurred in the locations of all ground failures, whereas structural damage was absent in the valley bottom where fills are flat and not so thick, as shown in section D-D'. The data imply that permanent ground deformation and/or movement associated with ground failures was the principal cause of the damage to structures. In contrast, damage other than that in foundation of house such as collapse of chimney and cracks of exterior walls, a few in number, did occur in all part of sections, in both filled and cut areas, which implies that primary cause of the damage was strong ground shaking.

Subsurface Characteristics from Short Period Microtremor Measurement

Microtremor measurements were made in Midorigaoka to determine response characteristics of different sites. Figure 14 shows spectrum ratio H/V, where H and V denote horizontal and vertical Fourier amplitude of microtremors. The solid line denotes the average spectrum and dotted lines at the top and at the bottom are envelops of the measured spectrum It is noted that large spectral values imply large contrast of stiffness between basin and surface deposit. Therefore, ground shaking is supposed to be larger as H/V value increases.

The predominant period at site A in Fig.14 is about 1 sec., which is the largest period in this area. Probably, there exist of thick silt layer beneath the volcanic ash. At site B, soil profile changes rapidly as seen in Fig.11, which may explain that peat is not absent at site B. Spectrum has clear peak at about 2 Hz at site C, which is 2 times as large as that as site A. It agrees with the observation that bed rock is shallow and impedance ratio between surface layer and bedrock is large here. The same discussion can be made at site E. On the other hand, the location of bedrock is not known and there exists thick and soft silt layer at site D. This explains no clear peak in the spectrum at this site. In summary, the difference in stiffness and thickness of the deposits may control predominant periods. Direct correlation were not seen, however, between the predominant periods and occurrence of ground failures.

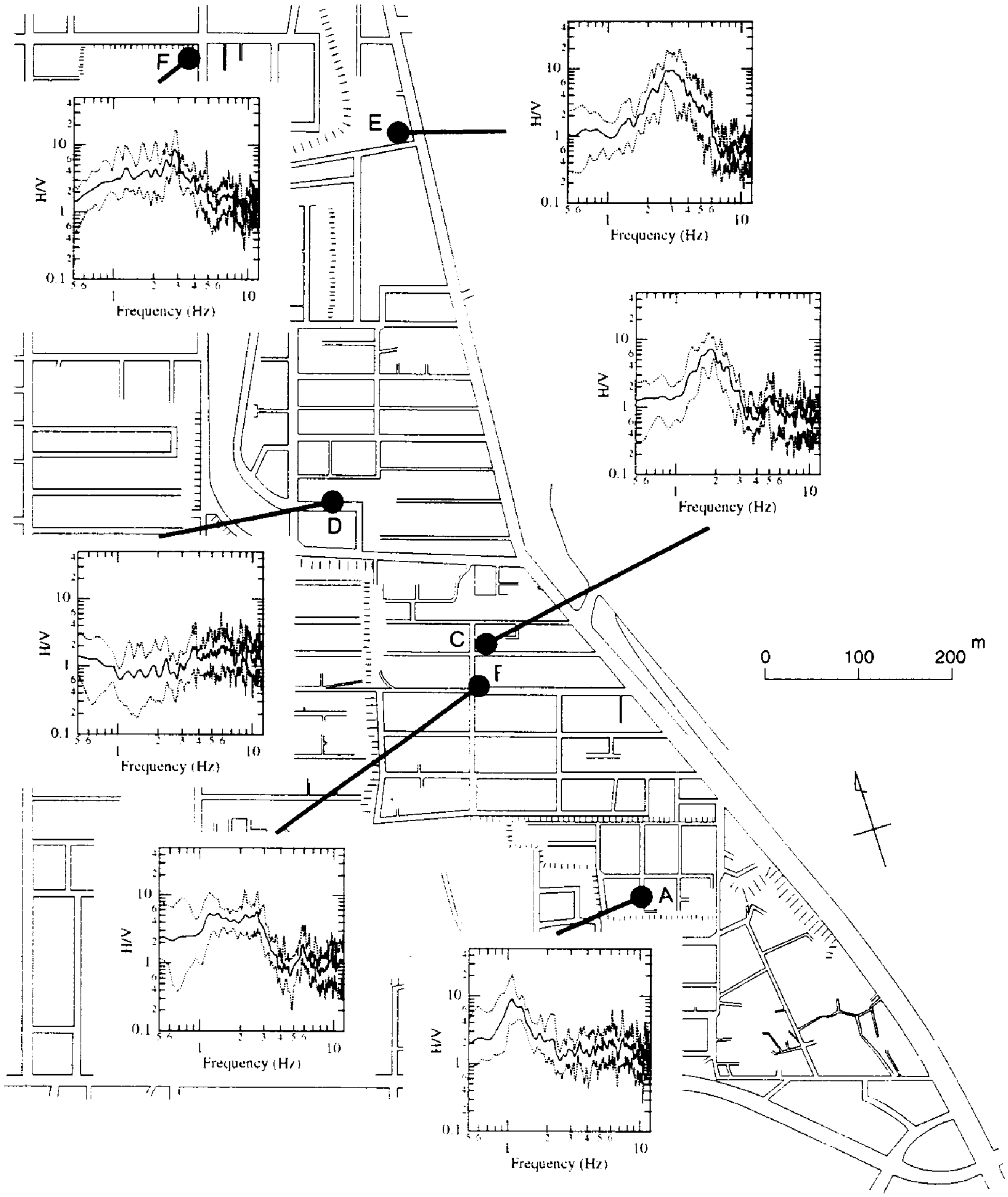

Fig.14 Result of Microtremor Measurements

CONCLUDING REMARKS

There was substantial damage to underground pipelines and buildings in Midorigaoka, Kushiro City during the 1994 Kushiro-oki earthquake. The damage was caused primarily by ground deformations and/or ground movements associated with slope failures, lateral spreading, and liquefaction, and partially by ground shaking.

In summary, Midorigaoka had several adverse conditions such as thickness and density of fills, slope of the ground surface, and subsurface water conditions. The conditions lead to occur various types of ground failures. They were strongly affected to not only locations and pattern of the ground failures but also resulting damage modes of structures. Although the level of damage was much more severe in 1993, it is notable that locations and patterns of sand boils and cracks in 1993 were the same as in the time of the 1973 Nemuro-hanto-oki earthquake.

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