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Tamotsu Matsui
Osaka University, Japan

Muneki Mitamura
Osaka City University, Japan

Toshihiko Sakagami
Kawasaki Geological Engineering Co., Japan

Fumio Shimizu
Shimizu Co., Ltd., Japan

Teruyuki Hamada
Geo-Research Institute, Japan

See next page for additional authors

Author

Tamotsu Matsui, Muneki Mitamura, Toshihiko Sakagami, Fumio Shimizu, Teruyuki Hamada, Yasuo Tanaka, Seiji Suwa, Hiroshi Tsurukawa, and Akira Takeishi

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Tamotsu Matsui
Osaka University
Suita, Osaka 565-0871, JAPAN
Muneki Mitamura
Osaka City University
Sumiyoshi, Osaka 558-8585, JAPAN
Toshihiko Sakagami
Kawasaki Geological Engineering Co.
Naniwa, Osaka, 556-0015, JAPAN
Fumio Shimizu
Shimizu Co.
Chuo, Osaka 541-0053, JAPAN
Teruyuki Hamada
Geo-Research Institute
Nishi, Osaka 550-0012, JAPAN
Yasuo Tanaka
Kobe University
Nada, Kobe 657-0013, JAPAN
Seiji Suwa
Geo-Research Institute
Nishi, Osaka 550-0012, JAPAN
Hiroshi Tsurukawa
Osaka Prefecture Government
Chuo, Osaka 540-0008, JAPAN
Akira Takeishi
Kokusai Kogyo Co.
Kita, Osaka 530-0001, JAPAN

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ABSTRACT

The 1995 Kobe Earthquake (Hyogoken-nanbu Earthquake) caused a severe damage to various kinds of structures. As damage factors of these structures, the characteristics of seismic motion, distance from the earthquake source fault, ground conditions, liquefaction, and strength of structures can be considered. In this paper, paying attention to the distance from the earthquake source fault and ground conditions among them, the relevance to structures damage in wooden houses (on-ground structure) and water supply pipelines (under-ground structure) in Nishinomiya-City area was examined. As the results, the relationship between wooden houses damage and the distance from the fault can be approximately represented as a unique exponential function. In liquefied areas, however, the rate of completely collapsed wooden houses decreases 5 to 20% from the average value. This might be because the damping of earthquake motion brought the decrease of the damage rate. While, the relationship between water supply pipelines damage and the distance from the fault completely differs from the above-mentioned for wooden houses. A characteristic value "Tg" estimated from the distribution of N value at each location can be used for the ground classification in earthquake-proof design. The damage rate of water supply pipelines increases as increasing "Tg", while that of wooden houses decreases as increasing "Tg".

INTRODUCTION

The 1995 Kobe Earthquake (Hyogoken-nanbu Earthquake; M=7.2; epicenter: 34.595°N, 135.038°E; depth of focus: 15km) occurred at 5:46am, 17, January 1995. This earthquake caused severe damages to various kinds of structures, such as buildings, bridges, highways, railways, rivers, shore-protections and pipelines for water supply and sewer. These damages distributed not only in Kobe and Awaji area near the epicenter but also the surrounded wide areas. The Japanese Meteorological Agency (JMA) reported that the area of the fault planes estimated by the inversion method with the strong earthquake intensity VII, which is defined as the area having more than 30% of the collapse rate of wooden house, spread in 2km wide, 40km long along the mountain foot of Mt. Rokko as shown in Fig. 1. The earthquake intensity VII zone is called "earthquake disaster zone". The area having over 70% of the collapse rate called "over intensity VII", partly distributed in this zone (Ishikawa et al. 1995).

Surface ruptures appeared along the Nojima fault in the northwestern part of the Awaji Island. In Kobe area where surface ruptures were not clear, the earthquake source fault is estimated by measured ground motions as shown in Fig. 1(Sekiguchi et al., 1996).

The sub-committee about soil and foundations on the Great Hanshin-Awaji Earthquake Disaster, which was established in the Kansai Chapter of Japan Society of Civil Engineers have investigated the relevance of such factors as the characteristics of seismic motion, distance from the earthquake source fault, ground conditions, liquefaction, and strength of structures to structures damage.

Because strength of structure is different at each site, for

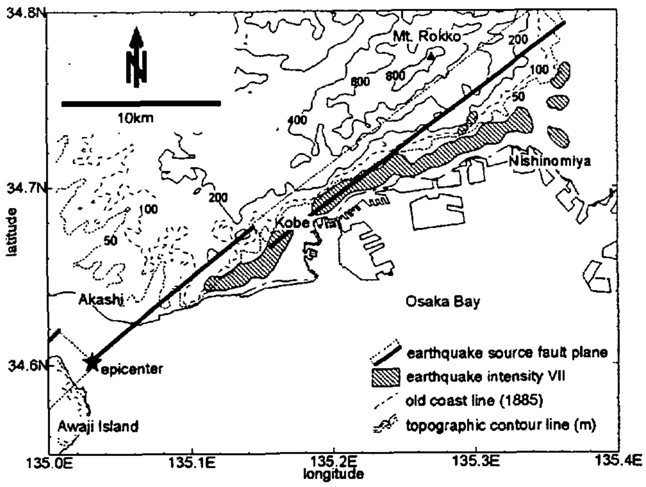

Fig.1 Map of JMA seismic intensity VII

investigating relationship to ground properties, it is necessary to handle similar structures. The object of this study is to get the general relationship between ground properties and structure damages in lowland areas.

Wooden houses and water supply pipelines were selected as the main objective of damaged structures. And the study was carried out in Nishinomiya area, which locates in the eastern part of the disaster zone, because the ground condition in this area can be clearly classified, and there are many drilling data.

GEOLOGICAL SETTING

The study area is located at lowland area in Nishinomiya City between the southeastern part of the mountain foot of Mt. Rokko and the coast of the Osaka Bay. This area is divided into hill, terrace, alluvial fan and alluvial plain. These geomorphologic features distribute from mountain foot to coastal line in descending order. The alluvial plain is classified into natural levee, raised bed stream, flood plain, sandbar, coastal delta, back marsh, abandoned channel and coastal reclaimed land.

The Rokko mountain range mainly consists of Cretaceous granitic rocks. The hilly area and terrace consist of Pleistocene sedimentary layer. The alluvial fan consists of thick gravel bed. The subsurface in the alluvial plain consists of Pleistocene to Holocene deposits.

In the subsurface of the lowland area, two thick marine clay beds called Ma12 and Ma13, widely distribute as shown in Fig. 2. The Ma12 bed is a Pleistocene clay layer with 5 to 9 of N value. Ma13 bed is the Holocene soft clay layer with 0 to 4 of N value. Above the Ma 13 bed, a loose sandy layer with less than 20 of N value widely distributes in the lowland area. Pleistocene sand and gravel layer is intercalated between Ma12 and Ma13. Under Ma12, thick Pleistocene deposits widely distribute and expose in hilly area and terrace.

EARTHQUAKE INTENSITY

The distribution of earthquake intensity was reported by JMA after the earthquake. The study area is located at the eastern part of the zone of intensity VII. This intensity zoning was made based on the rate of collapse of wooden houses and degree of these damages. In coastal areas, the collapse rate is lower than the other areas, because loose sand layers widely liquefied by the main shock.

In order to get the distribution of intensity eliminating influence of the structure property, the zoning map of sensible intensity was made as shown in Fig. 3. This zoning map was modified from the result by questionnaire survey carried out to 20000 people at 2 months later after the earthquake (Kobe University, 1996).

In the study area, the sensible intensity ranges from 4 to over 7. The intensity 6.5 widely distributes in this area. The

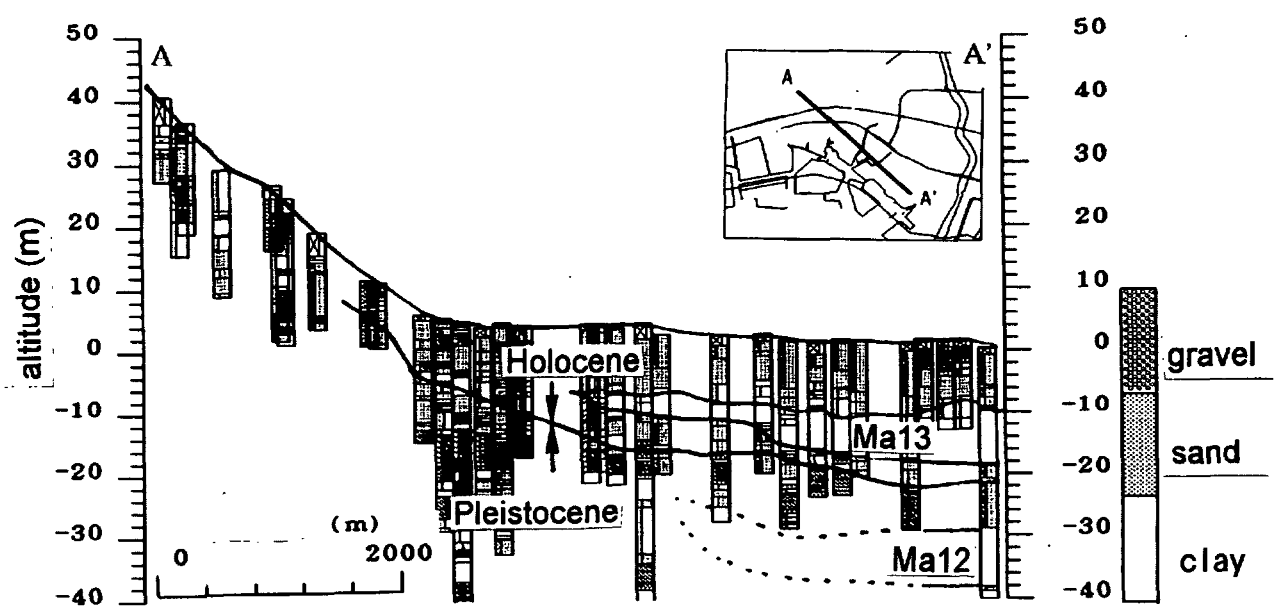

Fig.2 Geological section of Nishinomiya City

intensity 7 partly appears in the western part of this area. Fig.3 shows also the intensities at drilling locations used in the analysis.

DAMAGE DISTRIBUTION

Wooden House Damage

Primarily, our analysis needs each house damage and detailed structure conditions. But, the detailed damage condition of

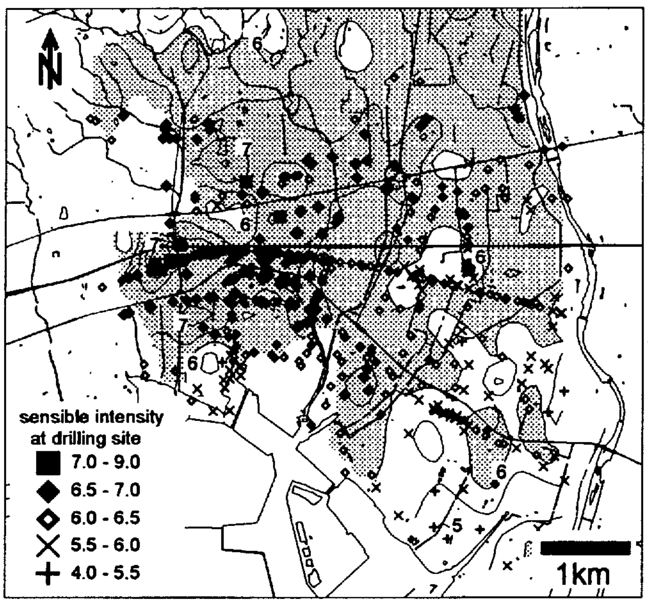

Fig.3 Distribution of sensible intensity by questionnarie survey

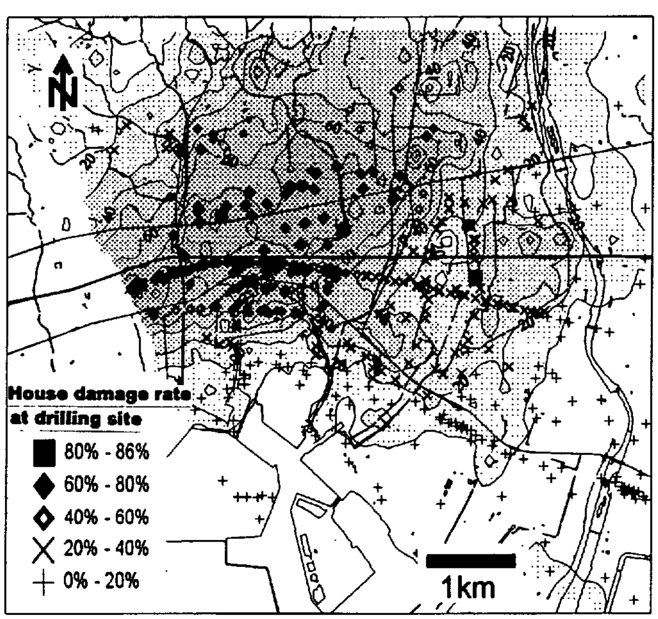

Fig.4 Distribution of houses damage rate

individuals is not published. Iwasaki et al. (1996) reported the detailed collapse rate of wooden houses in each street block of Nishinomiya City. The rate is used for our analysis, as shown in Fig. 4.

Japanese wooden houses are generally put on the ground surface by direct foundation. Compared with the other construction structures, these houses are very light and flexible.

The distribution of the collapse rate appears as the accumulation of detached damages. The collapse rate was ranged from 10 % to 80%. The large collapse rate zone (over 60%) distributes in the center and western part of the study area. On the other hand, the coastal area has low collapse rates. Because boiling sands widely appeared, the loose sandy layers in shallow part were liquefied by the main shock in the coastal area. The damping of main shock on the liquefaction causes the distribution of the low rate zone in the coastal area.

Water supply pipelines Damage

Japanese Water Works Association reported the damage location of the water supply pipelines in Nishinomiya City as shown in Fig. 5 (Hamada and Iwasaki, 1997). The degree of pipelines damage at each drilling site was estimated from the total count of damages in a circle area with radius of 200m.

Because water supply pipelines are buried in shallow part of subsurface, it is easy to receive deformation damage by ground displacement. The distribution of pipelines damage in

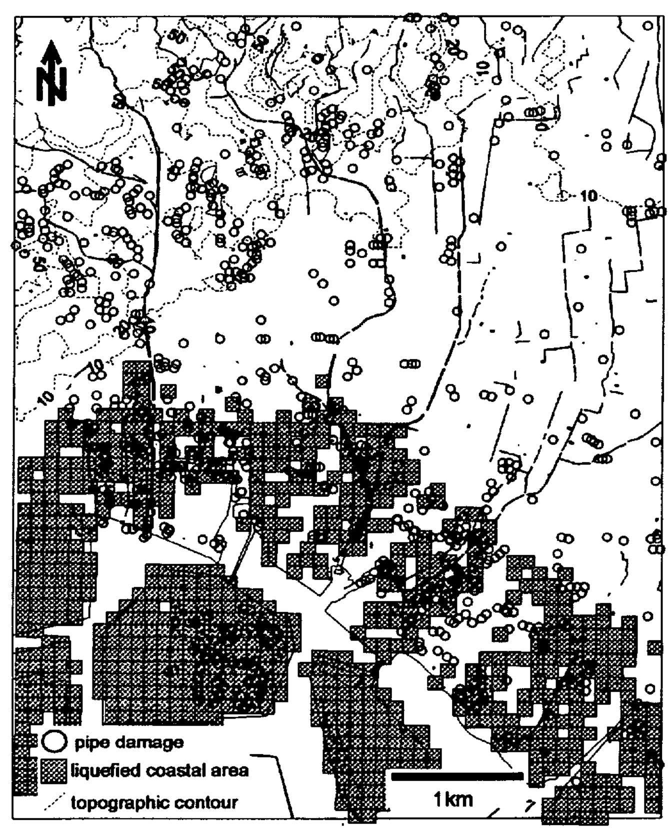

Fig.5 Damage location of the water supply pipelines

Nishinomiya City clustered in the coastal and hilly areas. This distribution differs from the houses damage rate. It is suggested that such complex factors, as structure form, ground property and ground motion, cause these differences.

ANALYSIS OF DAMAGE FACTORS

The factors on the houses and pipelines damage are mainly analyzed from correlation with the distance from the earthquake source fault and the ground characteristics calculated.

Distance from Earthquake Source Fault

The shortest distance from the drilling data point to the earthquake source fault estimated with the inversion method can be obtain. Fig. 6 shows the correlation between the collapse rate of wooden house and the distance from the earthquake source fault.
The collapse rate is about 80% at the distance of 3km from the earthquake source fault. Then, there is a rapid drop with increasing the distance. The collapse rate decreases to 10 – 20% at the distance of 7-8km. The two factors have a negative interrelation. It is clear that the amplitude of earthquake motion is damped with a logarithmic function of the distance from the earthquake source fault. The relationship between the collapse rate and the distance can also be explained by a logarithmic function as shown in the upper figure of Fig. 6. On the other hand, Iwasaki et al. (1996) reported that the collapse rate is in proportion to the arithmetic distance. There is room for further discussions on this point.
The middle figure of Fig. 6 shows the relationship between the degree of pipelines damage and the distance from the earthquake source fault, in which no clear correlation is confirmed.
As shown in the bottom figure of Fig. 6, the sensible intensity of the earthquake gradually decreases with increasing the distance of the earthquake source fault. Then, beyond the distance of 5 km, it becomes steady about 6.

Geomorphologic Feature

The collapse rates make little difference among geomorphologic features. The collapse rates of coastal reclaimed land at the distance of about 6km and coastal delta at the distance of about 5km are lower than the regression curve. These areas correspond to the coastal liquefied zone.
The degree of pipelines damage at coastal delta is higher, and that at flood plain is lower than that at the other areas.
The sensible intensity has a similar tendency of the degree of pipelines damage.
The influence of the geomorphologic features strikingly appears to the degree of pipelines damage and sensible intensity. The mean N value from 10 m to 15 m deep at the coastal delta is 15, while that at flood plain is 30. Because the coastal delta consists of loose sand and soft clay layers, the pipelines damage and sensible intensity appears in higher degree.

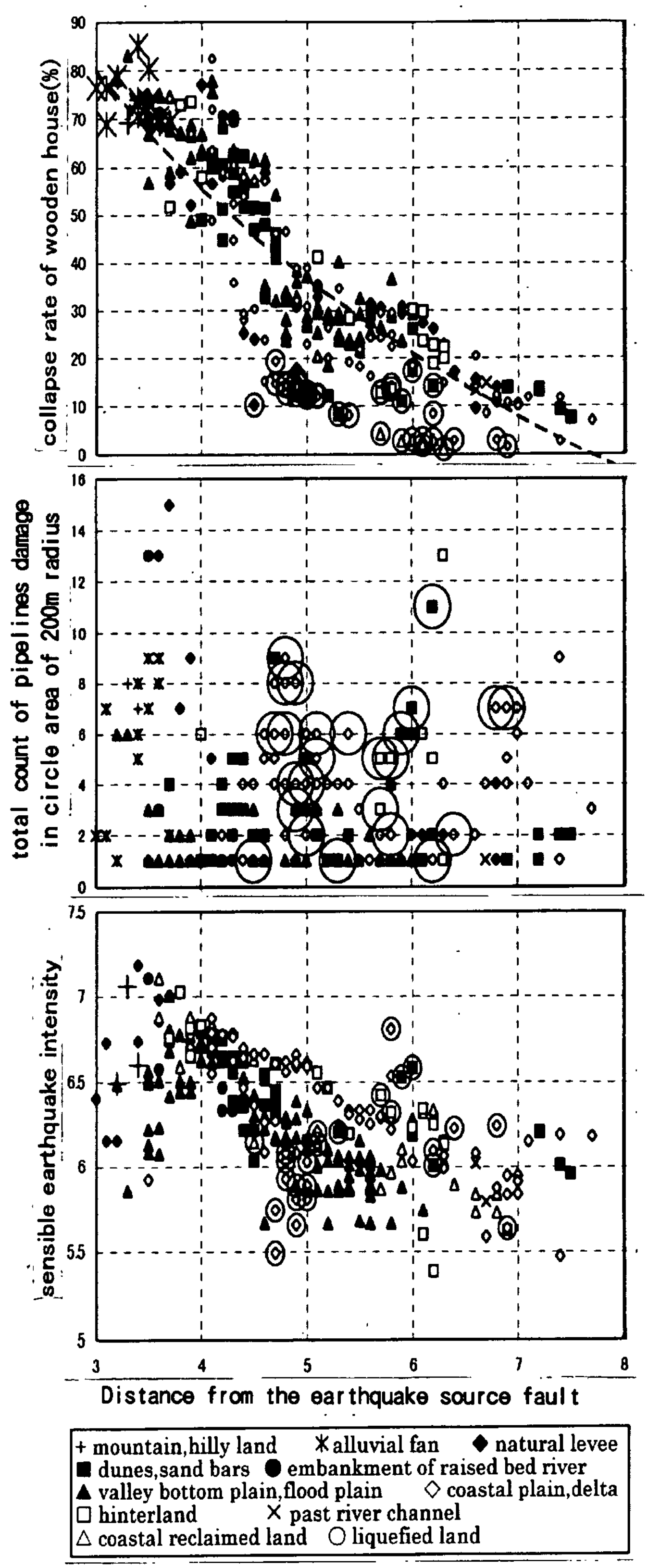

Fig.6 Damage factors correlated with the distance from earthquake source fault

Liquefaction

In liquefied areas where many sand boils appeared, the collapse rate of wooden houses is 5-20% lower than the regression curve. It is suggested that the damping of the main shock by liquefaction caused the drop of collapse rate. On the other hand, the degree of pipelines damage has higher values in the liquefied areas.

The Kinki Branch of Japan Society of Architecture (1996) reported the difference of damages between super-structure and foundation of buildings except wooden houses as shown in Table 1. In liquefied areas located in the south side of the past coast line, the degree of damage to the super-structure is low as well as the collapse rate of wooden houses, while the degree of damage to foundation is high as well as the pipelines damage.

Table 1 Number of building damage and geomorphologic feature

Structure	Plain and fan	Reclaimed land
Super-structure	36	8
Basement structure	35	51

Ground Classification

Ground properties are classified with a characteristic value "Tg" which is used for the ground classification in earthquake-proof design. The characteristic value "Tg" is defined by a following formula:

$$Tg = 4\sum_{i=1}^{n} \frac{Hi}{Vsi} \qquad (1)$$

where Hi is thickness (m) of the i^{th} layer; Vsi is mean shear wave velocity (m/s) of the i^{th} layer, that is $Vsi=100Ni^{1/3}$ ($0<Ni<26$; clayey layer), $Vsi=80Ni^{1/3}$ ($0<Ni<51$; sandy layer) in which Ni is N value of standard penetration test at the i^{th} layer (Japan Highway Association, 1996). The value of Tg indicates the frequency property of dynamic behavior of ground.

Fig. 7 shows the correlations of collapse rate, pipelines damage, sensible intensity with Tg. In each figure is shown a trend line at the distance of 5-6 km from the fault.

At a distance of less than 5km from the fault, wooden houses damage distributes in higher collapse rate (40-90%) through the difference of Tg. At a distance of over 5km from the fault, it gradually decreases with increasing Tg.

The pipelines damage does not have a significant correlation near the fault, while, at a distance of over 5km from the fault, it increases with increasing Tg. The sensible intensity has a similar trend as the pipelines damage.

As mentioned above, the distance of 5km from the earthquake source fault forms the boundary of trends on the relationship with Tg of the houses damage, pipelines damage and sensible intensity. At a distance of less than 5 km, it is suggested that the impact of amplitude of the main shock to the structure damage exceeds the effect of frequency property of ground.

The effect of Tg is clear at a distance of over 5km from the

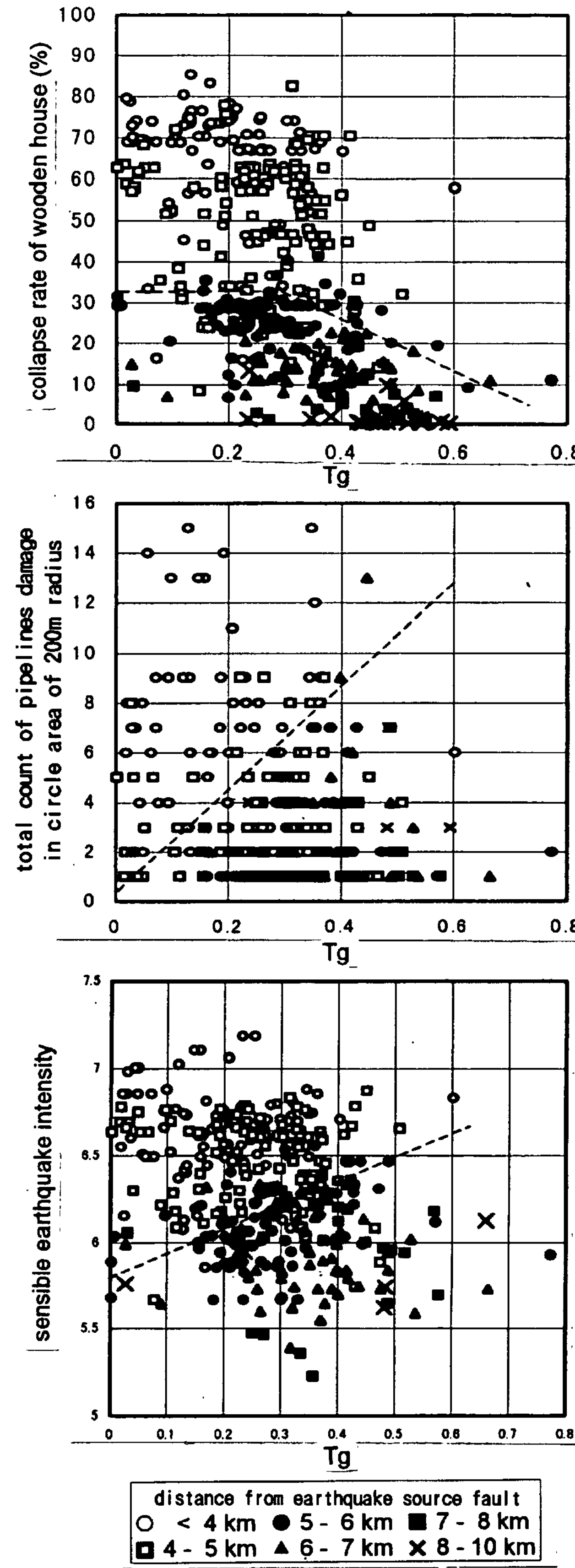

Fig.7 Damage factors correlated with the ground characteristic value

fault. In this area, the difference of the frequency property of ground is one of main factors of earthquake damage.

CONCLUSIONS

In this study, the damages and sensible intensity were correlated with the distance from the earthquake source fault and the ground characteristic value Tg.

The wooden houses damage is clearly dependent on the distance from the fault, which usually occurred by strong ground motion. Especially, at the distance of 3-4 km from the earthquake source fault, a strong ground motion of the main shock broke down many wooden houses. Far from the fault, wooden houses damage depended on the ground characteristic value Tg. It is suggested from these facts that the proper oscillation of the structures and ground and the damping of the main shock through soft layers concerned with the relationships between wooden houses damage and Tg.

The pipelines damage depended on liquefaction and the ground characteristic value Tg. It is because the main factor of pipelines damage is ground displacement. Lateral movement and subsidence accompanied by liquefaction in coastal areas and slope failure in hilly areas caused large ground displacements. The ground characteristic value Tg is larger in soft ground rather than in hard ground. Because ground motion is remarkably amplified in soft ground, coastal areas are susceptible to liquefaction.

Finally, further investigations are left about high frequency ground motion, proper oscillation of the structures and ground, and damping of the main shock through soft layers.

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