DAMAGE TO WOODEN HOUSES AND HUMAN BEINGS BY THE 1978 MIYAGIKEN-OKI EARTHQUAKE IN SENDAI CITY

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Abstract Damage caused by the 1978 Miyagiken-Oki Earthquake was investigated in Sendai City. Geomorphological conditions well explained the distribution of the maximum horizontal acceleration and the damage to wooden houses. The number of the injured was expressed by a function of the number of damaged wooden houses. These results showed that a geomorphological land classification map is useful for a seismic microzoning.

1. Introduction

Seismic microzoning could be defined as the process of dividing an area into a number of micro zones on the basis of earthquake damage potential. This potential can be regarded as a function of seismicity, subsurface geological conditions, seismic engineering characteristics and functions of man-made structures, various conditions concerning human beings and other socio-economic factors. Seismicity is usually replaced with expected values of the maximum earthquake acceleration in gals or the maximum intensity for various return periods. The values are statistically deduced from the past earthquake records. As for subsurface geological conditions, soil deposits are classified into several types on the basis of those characteristics which are prone to contribute to damage man-made structures and each type is evaluated from a seismic engineering point of view. Other factors concerned with damage potential are the conditions of the subjects of the damage, e.g., man-made structures and human beings.

It is indispensable for seismic microzoning to relate subsurface geological conditions to damage distribution and to analyze the relationships between various kinds of damage. This brief paper discusses the damage to wooden houses and human beings of the 1978 Miyagiken-Oki Earthqukae (hereafter referred to as the 1978 Earthquake) in Sendai City from a geomorphological view point. Damage distribution of wooden houses is often cited as the most standard index to show distribution of the whole earthquake damage, for a wooden house is the most common man-made structure in Japan and is broadly distributed. Geomorphological conditions are well known as an indicator showing subsurface geological conditions (for example, Kadomura, 1967). If damage distribution is able to be related to topographic conditions, it can be proposed to make a seismic microzoning map on the basis

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of a geomorphological land classification map. As for injury to human life, it is related to damage to wooden houses in this paper.

The 1978 Earthqukae shook in and around Miyagi Prefecture, Tohoku Japan, on June 12, 1978. Japan Meteorological Agency allocated its epicenter at 38.1°N and 142.2°E. Its depth and magnitude were estimated to be about 40 km and 7.4 on the Richter's Scale, respectively. The fatalities numbered 27 and the number of injured totalled more than 10 thousand. About 60 thousand wooden houses were damaged and about 600 of them were totally destroyed.

2. Topographic Division of Sendai City

Sendai City, the largest city in Tohoku Japan, is located at about 120 km from the epicenter of the 1978 Earthquake. The topography of Sendai City is roughly classified into hills, terraces and lowlands (Fig. 1 and Table 1).

The hills 100 – 200 m high are composed of Tertiary strata (Hanzawa et al, 1953) and are gently rolling. Three terrace surfaces which were formed in three different ages can be recognized in Sendai City (Nakagawa et al, 1960). Their geological conditions, however, are regarded as being identical in this paper, for all of them originate from an alluvial fan and are composed of thick gravelly deposits. Several parts of hill slopes and terrace slopes were artificially transformed in order to develop a housing estate. These artificially transformed slopes are regarded as one of the topographic units. As a result, the hills and terraces are classified into three topographic units for damage distribution analysis: Natural Slope (A), Artificially Transformed Slope (B1), and Terrace Surface (B2). Distribution of B1, however, is too complex to be shown in Fig. 1.

The lowland found in the southeastern half of Sendai City is called the Sendai Lowland. Thick sandy deposits with a large N-value on the standard penetration test broadly cover the Sendai Lowland. These sandy deposits were formed around the maximum stage of the Flandrian Transgression about 5,000 years ago (Hase, 1967). The deposits distributed under these thick sandy deposits may be more ineffective to amplify seismic waves than the loose or soft deposits distributed near the ground surface. Accordingly, it is estimated that the damage distribution can be related to the deposits distributing near the ground surface, that is, the materials composing micro-reliefs of the Sendai Lowland.

Because two kinds of processes, alluvial and coastal, have been at work on the Sendai Lowland since the maximum stage of the Flandrian Transgression, the Sendai Lowland is divided into alluvial and coastal lowlands.

The coastal lowland is subdivided into two topographic regions: the Coastal Barrier (D1) which is the sand bar broadly developing along the coast of the Pacific Ocean and the Coastal Plain (D2) which is composed of two units of alternately developing sand bars and muddy interbar flats.

The alluvial lowland is subdivided into four topographic regions: the Hirosegawa-Natorigawa Lowland (C2), the Old Hirosegawa Lowland (C3), the Nanakitadagawa Lowland (C4) and the Marshy Lowland (C5). It is necessary to add two other topographic regions to alluvial lowland. One is the Colluvial Slope (C1) which is developing between the terraces and the Sendai Lowland. The other is the Valley Flat (C6) which consists of the small valley flats dissecting the terraces and hills.

The Colluvial Slope (C1) has the best soil conditions in the lowlands, for it is composed of thick gravelly deposits.

The deposits distributed near the ground surface in the alluvial lowland were supplied by the Rivers of Natorigawa, Hirosegawa and Nanakitadagawa. They form sandy natural levees and muddy back swamps on the thick sandy deposits accumulated at around the maximum stage of the Flandrian Transgression. Some parts of the back swamps have been filled up for residential or industrial land use. These three micro reliefs compose topographic units of the Hirosegawa-Natorigawa Lowland (C2), the Old Hirosegawa Lowland (C3) and the Nanakitadagawa Lowland (C4).

The uppermost deposits of the Marshy Lowland (C5) are composed of muddy and organic materials, except for some artificial fillings. The Lowland has survived without being covered by the alluvial deposits. All houses in this region have been built on the artificial fillings.

The deposits in the Valley Flat (C6) are muddy, too. Filling up is a common device for developing housing estates.

3. Distribution of the Maximum Horizontal Acceleration

Distribution of the maximum horizontal acceleration generated by an earthquake has often been discussed on the basis of the results of gravestone size measurement in cemeteries. There are some reasons why Japanese seismologists often examine the size of gravestones distributed in a shaken area and use them as a substitute for a seismograph. Because Japanese gravestones usually have the form of a rectangular parallelepiped, it is regarded as a body and an approximate value of the maximum horizontal acceleration (K) necessary to throw it down can be obtained by the equation (1).

$$K = \frac{B}{H} \times g \qquad (1)$$

H and B mean the height of a gravestone and the width of the shorter side of its base, respectively; g is acceleration of gravity. The maximum horizontal acceleration deduced from the width - height ratio of an overturned gravestone shows a rather lower value than the real one which shook the cemetery. On the other hand, a higher value is deduced from the width - height ratio of a non-damaged gravestone. That is, the real maximum horizontal acceleration is expected to exist between those derived from overturned and non-damaged gravestones.

Cemeteries are broadly and fairly densely distributed, for every old community usually has a common cemetery. Gravestones in a cemetery are a good tool to grasp the distribution of the maximum horizontal acceleration. Also, the maximum horizontal acceleration deduced from gravestone size analysis has very high reliability. Mochizuki, one of the authors, and Kobayashi (1976) analyzed the motions of a body caused by earthquake excitation. They classified the motions into four types: slip, rocking, rocking-slip and jump.

And they examined the relationship between overturning of a body and these four types of motion. As a result, they ascertained that gravestones are useful for estimating the maximum horizontal acceleration caused by an earthquake.

The authors estimated the maximum horizontal acceleration at many cemeteries in Sendai City (Fig. 1). The sizes of more than thirty gravestones were measured in each cemetery, about half of which had been overturned. Fig. 1 shows that while the maximum horizontal acceleration is large in the Hirosegawa-Natorigawa Lowland (C2), the Nanakitadagawa Lowland (C4) and the Coastal Plain (D2), it is small on the Terrace Surface (B2), the Coastal Barrier (D1) and the Colluvial Slope (C1). It means that the maximum horizontal acceleration is much affected by the uppermost deposits in the Sendai Lowland.

Two of the authors read a paper at the International Geographical Congress, 1980, in Tokyo and introduced the method for predicting the intensity distribution on the basis of the maximum horizontal acceleration deduced from the analysis of gravestone size (Matsuda and Mochizuki, 1980). They mentioned that the intensity distribution of the Great Kanto Earthquake of 1923 is explained as a function of topography and the minimum distance from the fault plane which generated the earthquake. As mentioned above, it was confirmed that the maximum horizontal acceleration was closely related to topographic conditions on the occasion of the 1978 Earthquake, too.

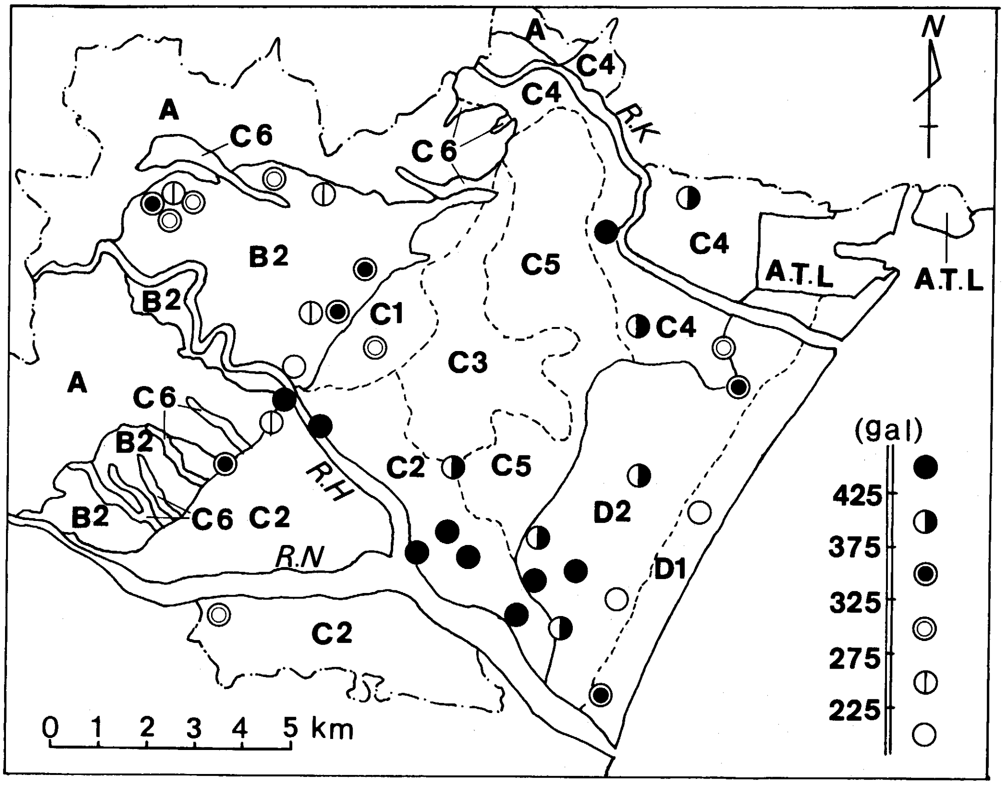

Fig. 1 Topographic division of Sendai City and the maximum horizontal acceleration (Explanation of each region is shown in Table 1)
R.N : Natori River, R.H : Hirosegawa River, R.K : Nanakitadagawa River, A.T.L. : Artificially transformed lowland (Oil plant is located)

4. Distribution of Damaged Wooden Houses

Damage to wooden houses for each topographic unit is summarized in Table 1. Because the total number of wooden houses is unknown, the total number of households is used to calculate the collapse ratio as well as the damage ratio for convenience's sake. The equations for calculating these ratios are explained at the foot of Table 1.

Although wooden houses on the Natural Slope (A) were only partially damaged, 0.29 % of wooden houses were totally destroyed and the damage ratio reached 0.73 % on the Artificially Transformed Slope (B1). In particular, damage to wooden houses was concentrated on artificial fillings in this region (Murayama, 1980). The collapse ratio and the damage ratio were 0.04 % and 0.25 % on the Terrace Surface (B2), respectively.

The heaviest damage was recorded in the lowland, where the mean collapse ratio and the mean damage ratio were 0.61 % and 2.25 %, respectively. The following characteristics of the extent of damage for each topographic unit in the lowland can be pointed out:

(1) Damage was slight on the Colluvial Slope (C1) and the Coastal Barrier (D1). The extent of damage in these regions is similar to that on the Terrace Surface (B2). This fact agrees with the distribution of the maximum horizontal acceleration.

(2) Damage was heaviest in the Coastal Plain (D2), where the collapse ratio was 1.14 % and the damage ratio reached 4.90 %. The Hirosegawa-Natorigawa Lowland (C2) and the Old Hirosegawa Lowland (C3) rank next. On the other hand, the extent of damage on wooden houses in other lowlands was not serious. Based on these facts, it may be said that the extent of damage to wooden houses closely relates to thickness and quality of the uppermost deposits. The uppermost deposits are thick in the Hirosegawa-Natorigawa Lowland (C2) and the Old Hirosegawa Lowland (C3). However, they are thin in the Nanakitadagawa Lowland (C4) and the Marshy Lowland (C5). The quality of the uppermost deposits in the Marshy Lowland is supposed to be worst, for they are composed of muddy and organic materials, but houses have been built on the artificial fillings in this region.

(3) The extent of damage to wooden houses for each topographic unit seems to be rather curious compared to usual results. From the soil engineering point of view, soil conditions of a natural levee and a sand bar are usually better than those of a back swamp and a filled-up ground. Based on the figures in Table 1, it can not be said that both the collapse ratio and damage ratio for the natural levees and the sand bars are always smaller than those for the back swamps and the filled-up grounds. One factor determining that the extent of the damage to wooden houses was high on the natural levees and sand bars is whether the houses are new or old. Murayama (1980) mentioned that damage to old big wooden farmhouses is conspicuous both on the natural levees and the sand bars. While relatively higher parts of the lowland such as the natural levees and the sand bars have been used for residential sites from old times, it is within these two decades that housing estate has begun to move into the marshy parts of the lowland.

Table 1 Relationship between topographic conditions and damage to wooden houses in Sendai City

Topographic units					Number of Households	Number of Totally Collapsed Houses	Numbr of Half Collapsed Houses	Number of Partially Damaged Houses	Collapse Ratio (%)	Damage Ratio (%)
A Hills		A	Natural Slope		444	0	0	69	0	0
B Terraces		B1	Artificially Transformed Slope		46,219	132	409	8,286	0.29	0.73
B Terraces		B2	Terrace Surface		83,795	30	365	15,494	0.04	0.25
Lowland		C1	Colluvial Slope		11,842	3	110	3,977	0.03	0.49
Lowland	Alluvial Lowland	C2	Hirosegawa-Natorigawa Lowland	Natural Levee	23,825	180	1,173	11,055	0.76	3.22
Lowland	Alluvial Lowland	C2	Hirosegawa-Natorigawa Lowland	Back Swamp	4,127	33	160	1,259	0.80	2.74
Lowland	Alluvial Lowland	C2	Hirosegawa-Natorigawa Lowland	Filled-up Ground	6,526	106	394	2,629	1.62	4.64
Lowland	Alluvial Lowland	C3	Old Hirosegawa Lowland	Natural Levee	2,985	78	252	819	2.61	6.83
Lowland	Alluvial Lowland	C3	Old Hirosegawa Lowland	Back Swamp	1,547	8	31	515	0.52	1.52
Lowland	Alluvial Lowland	C3	Old Hirosegawa Lowland	Filled-up Ground	10,776	39	208	3,265	0.36	1.33
Lowland	Alluvial Lowland	C4	Nanakitadagawa Lowland	Natural Levee	6,736	11	111	2,660	0.16	0.99
Lowland	Alluvial Lowland	C4	Nanakitadagawa Lowland	Back Swamp	581	0	4	234	0	0.34
Lowland	Alluvial Lowland	C4	Nanakitadagawa Lowland	Filled-up Ground	1,465	1	12	522	0.07	0.48
Lowland	Alluvial Lowland	C5	Marshy Lowland	Filled-up Ground	584	0	11	116	0	0.74
Lowland	Alluvial Lowland	C6	Valley Flat	Flood Plain	690	1	3	680	0.14	0.36
Lowland	Alluvial Lowland	C6	Valley Flat	Filled-up Ground	6,210	9	52	729	0.14	0.56
Lowland	Coastal Lowland	D1	Coastal Barrier	Sand Bar	514	0	3	171	0	0.29
Lowland	Coastal Lowland	D2	Coastal Plain	Sand Bar	604	13	89	343	2.20	9.51
Lowland	Coastal Lowland	D2	Coastal Plain	Interbar Flat	628	1	4	126	0.16	0.72

$$\text{Collapse Ratio (\%)} = \frac{\text{Number of Totally Collapsed Houses}}{\text{Number of Households}} \times 100$$

$$\text{Damage Ratio (\%)} = \frac{\text{Number of Totally Collapsed Houses} + \text{Number of Half Collapsed Houses} \times 0.5}{\text{Number of Households}} \times 100$$

5. Distribution of the Injured

Fatalities caused by the 1978 Earthquake numbered 13 in Sendai City. More than half of them were pressed to death by fallen walls composed of concrete blocks. Eight lives were lost on the Sendai Lowland and the others on the Terrace Surface. It can be mentioned that the fatality ratio is higher on the Sendai Lowland than on the terraces, for population is larger on the latter than the former. The number of fatalities, however, is so small that their distribution can not be precisely discussed.

The authors examined the distribution of the injured. The number of slightly injured and seriously injured persons in Sendai City was about 9,000 and about 300 respectively. The distribution of the injured is usually explained as a function of the damage ratio or the collapse ratio of wooden houses, for in many cases of past earthquake damage to wooden houses was related to intensity of ground motion and most of the injured were caused by damaged wooden houses. In the 1978 Earthquake, however, many persons were injured in areas where no wooden houses were totally- or half-collapsed, that is, where the damage ratio of wooden houses is zero. Accordingly, the authors regarded the number of partially damaged wooden houses as a factor explaining the occurrence of the injured, too.

The modified number of damaged wooden houses (Z) is defined by the following equation:

$$Z = T + H \times 0.5 + P \times \alpha \qquad (2)$$

T and H mean the number of totally collapsed wooden houses and the number of half collapsed wooden houses, respectively. P is the number of partially damaged wooden houses and α is a constant which maximizes a correlation coefficient between the number of the slightly or seriously injured persons and the modified number of damaged wooden houses (Z).

Fig. 2 shows the relationship between the number of the seriously injured (Y) and Z. Supposing that α is 0.30, the correlation coefficient (R) takes the maximum value of 0.976. Likewise, when α is 0.050, the correlation coefficient (R) between the number of the slightly injured (Y') and Z reaches 0.985, the maximum value (Fig. 3). The numbers of Z, Y and Y' are calculated for each topographic unit but some of large units were divided into two parts in Figs. 2 and 3.

Injuries resulted from many causes. It was possible to examine the causes of injuries for 1,119 persons. The result is shown in Table 2.

It is remarkable that being crushed by collapsed houses does not assume a high proportion of the injured among the various causes. Although both correlation coefficients between Y and Z and between Y' and Z take very high values, damaged houses can not be regarded as an important cause of injury. That means many persons were injured by such less intensive ground motion as do not seriously damage wooden houses.

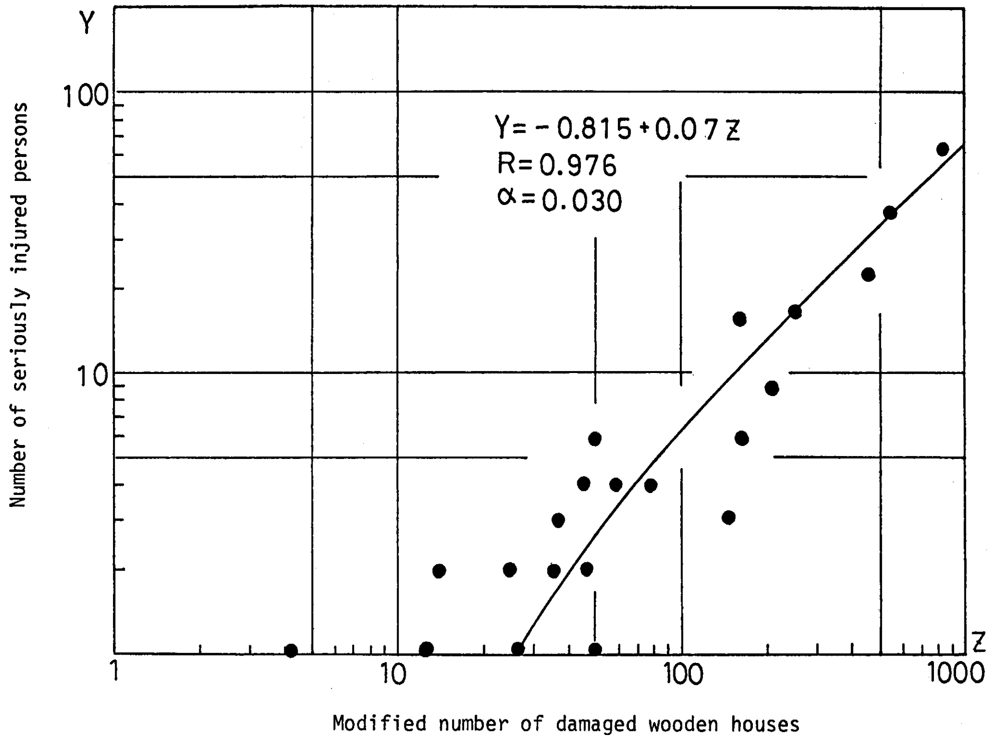

Fig. 2 Relationship between modified number of damaged wooden houses and number of seriously injured persons

Table 2 Causes of injuried in Sendai City

Causes of injuries	Percentage
Tumbling down or falling down from stairs	24.7 %
Stricken by falling materials	23.8 %
Cut by broken window glass	19.8 %
Hit by tumbled furniture	17.1 %
Getting burnt	4.4 %
Stricken by tumbled walls or garden posts	3.8 %
Crushed by collapsed houses	2.1 %
Others	4.3 %

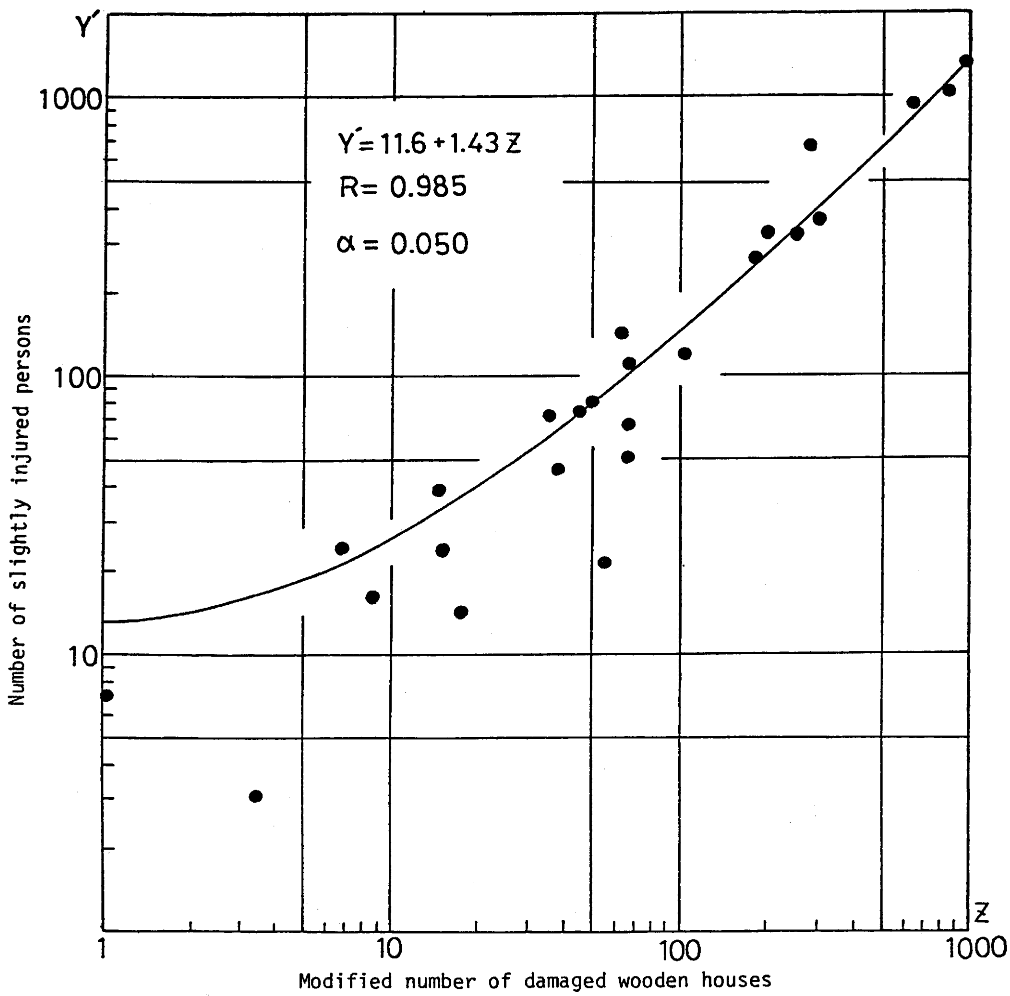

Fig. 3 Relationship between modified number of damaged wooden houses and number of slightly injured persons

6. Concluding Remarks

Damage caused by the 1978 Miyagiken-Oki Earthquake was briefly reviewed. The distribution of the maximum horizontal acceleration and the damage to wooden houses were related to topographic conditions which represent the soil conditions near the ground surface. The number of the injured was expressed by a function of the number of damaged wooden houses. These facts emphasize that a geomorphological land classification map is worthy of seismic microzoning.

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