



## CLASSIFICATIONS OF STRUCTURAL TYPES AND DAMAGE PATTERNS OF BUILDINGS FOR EARTHQUAKE FIELD INVESTIGATION

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### SUMMARY

A lot of field investigations for damage to buildings are carried out after large earthquakes. In concordance with the variety of investigations, the building damage descriptions are really incoherent because a well-coordinated damage scale has not been prepared yet. This paper proposed a new chart for describing the building damage patterns by seismic vulnerability so as to help investigators to classify building damaged without a gross error. Furthermore, various damage scales defined by the organizations concerned can be compared with each other by using this chart as a common scale. Moreover, we proposed new damage vulnerability functions of various kinds of structure, the functions which can depict the relation between ground motion severity and damage degree of building.

### INTRODUCTION

Without doubt, field investigation for buildings destroyed due to a large earthquake is the most primitive activity on earthquake protection strategies. A lot of ways of field investigations have been carried out all over the world after large earthquakes. The Earthquake Engineering Research Institute (EERI) proposed the guidelines for post-earthquake investigations for the purpose of improving the science and practice of earthquake engineering and earthquake hazard reduction. According to the field guide published by EERI (1996) it is crucial to conduct an overall building survey on a block-by-block basis, in addition to identifying damage to individual structures.

A block-by-block basis survey is indispensable, when damage distribution of buildings in the whole region must be noticed, especially, a prompt making decision for various countermeasures immediately after an event requires information about damage distribution in the whole region, which is possible to be prepared only by block-by-block basis survey. A painstaking survey, which needs the long time for the investigation for individual structures, is unsuitable in this case. Success in a block-by-block survey depends on standards supporting an exact judgment of damage degree of buildings, because many investigators would participate in the survey. However, it cannot be said that the common understanding about building damages has been formed among researchers and related organizations. Table 1 shows examples of damage scale of buildings. Although building damages are described by using the word phrase of the resemblance for the scale definitions, it is delicately crossed in the sense. The building damage descriptions end up being in an incoherence in proportion to investigations in great variety on the basis of ununified standards on damage. That would be continuing by the reason why a well-coordinated and standardized damage scale has not been prepared yet.

In order to solve the above problem, this paper proposes a new chart for describing the building damage patterns by seismic vulnerability so as to help investigators to classify building damaged without a gross error. A damage pattern of building strongly depends on the type of building structure. In this paper we illustrate a chart of damage patterns on buildings of which structural types are masonry, wood frame, and reinforced concrete with moment-resisting concrete frame. By comparing damage to individual structures with the illustrated chart we propose it would be possible to conduct a short-time and low-misidentify survey.

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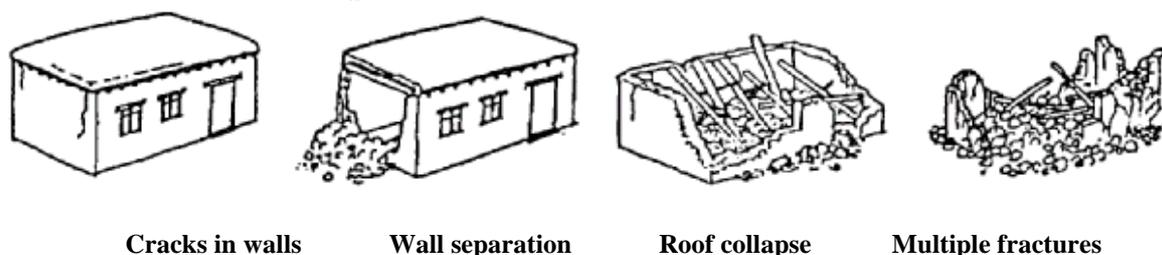
**Table 1: Examples of existing damage scale**

Name of scale	Organizer	No. of class	Building type
<b>Damage grade</b>	<b>EMS-98</b>	6	Masonry buildings
Grade 0:No damage Grade 1:Slight damage (Hair-line cracks in few walls) Grade 2:Moderate damage (Fall of large pieces of plaster) Grade 3:Heavy damage (Large and extensive cracks in walls) Grade 4:Very heavy damage (Serious failure of walls) Grade 5:Destruction (Total collapse)			
<b>Damage statistics</b>	<b>Japan Prime Minister's Office</b>	4	Wood frame buildings
No damage Moderate damage (A part of building is damaged) Heavy damage (Structural damage cost occupies from 20 to 50% of total repair cost) Major damage (Structural damage cost occupies over half of total repair cost)			
<b>Damage rank</b>	<b>Architectural Institute of Japan</b>	6	RC buildings
Rank 0:No damage Rank 1:Negligible damage (Hair line cracks in columns and beams of frame) Rank 2:Slight damage (Shear cracks in non-structural walls) Rank 3:Moderate damage (Shear cracks in columns and beams and in structural walls) Rank 4:Major damage (Spalling of concrete cover, Buckling of reinforced rods) Rank 5:Collapse (Collapse of total or parts of building)			

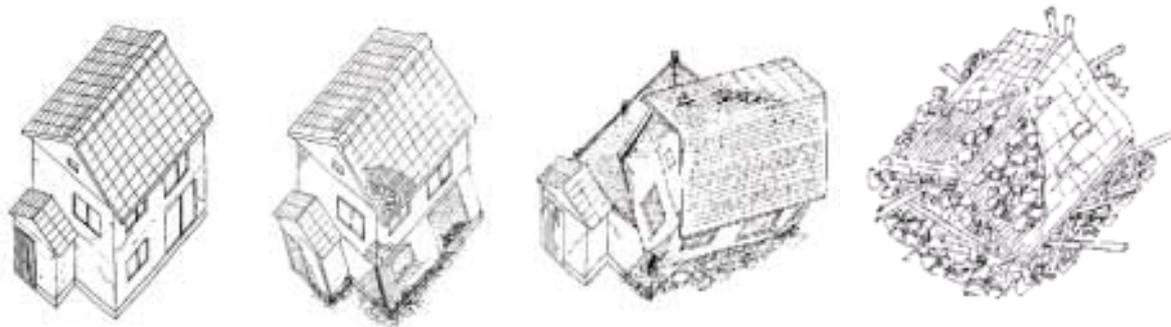
### BUILDING DAMAGE PATTERN CHART

Coburn (1989) classified damage to unreinforced masonry into four types of damage patterns (Fig.1) in viewing collapse of walls and roof that are building elements supporting vertical loads. When it comes to damage to wood frame structure, we categorized damage patterns shown in Fig.2 by paying attention to collapse of building story on the basis of about 500 photographs in the 1995 Hyogo-ken Nanbu earthquake [Kawai (1995)]. Damages to reinforced concrete with moment-resisting concrete frame structure were categorized as patterns in Fig.3 by referring to some photographic albums of the 1985 Mexico earthquake [Moriya (1985)] and classification on damage to buildings of reinforced concrete proposed in European Macroseismic Scale (EMS-98 [Grunthal (1998)]).

We essay to arrange the above damage patterns on the absolute numerical scale of damage degree in order to help possessing the understanding about damage jointly. On the basis of the Damage Grade classifying six grades of building damage degree in EMS-98, a new numeric scale is defined by dividing the Damage Grade at stated intervals; it is named as Damage Index in this paper. It is defined on a scale of 0.0 (No damage) to 1.0 (Total collapse). The damage index values of 0.2 to 0.4 on this scale are equivalent to D2 (Moderate damage) in Damage Grade that describes the damage situation of fall of pieces of plaster. Buildings damaged structurally are classified into the value equal to or greater than D3 (Substantial to heavy damage). The D3 damages for unreinforced masonry buildings and reinforced concrete buildings are characterized by large and deep cracks in walls and illustrated in Fig.4. A warp in a wall board is characteristic of wood frame buildings damaged in D3 as illustrated in Fig.5. The severe destruction in which the repair of damaged building is impossible is racked over D4 (Damage Index 0.6), and the stories of buildings disappear in a damage situation over D5 (damage Index 0.8). Following the above damage standards, we selected examples characterized by a typical damage pattern among many photographs about building damaged, and we illustrated a chart in Figs.4 and 5 for simplified damage patterns and damaging process of three types of building such as unreinforced masonry, wood frame structure and reinforce concrete with moment resisting concrete frame.



**Fig.1: Typical damage pattern of unreinforced masonry buildings after Coburn (1986)**



**Cracks in walls**

**First floor**

**Second floor failure**

**Total collapse**

**Fig.2: Typical damage pattern of wood frame buildings**



**Fall of pieces Ground floor failure Mid-floor failure Upper floor failure Pancake collapse Multiple fractures**

**Fig.3: Typical damage pattern of reinforced concrete with moment-resting concrete frame buildings**

### APPLICATIONS

The following applications by using the proposed new chart as shown in Figs. 4 and 5 are expected:

- 1□ Various damage scales defined by the organizations concerned can be compared with each other by using this chart as a common scale.
- 2□ As even nonprofessionals can distinguish from damage degree of building without a gross error in terms of this chart, this tool is expected to develop into a simple damage investigation keeping high specialty level.
- 3□ By classifying rural dwelling damage, which occurred in Awaji Island in the 1995 Hyogo-ken Nanbu earthquake, into the proposed damage patterns, we could make clear the relation between building damage pattern and death. Following this result, we are trying to make a model, by which casualties in destroyed dwellings can be estimated, on the basis of the proposed damage patterns.
- 4□ We propose new damage vulnerability functions of various kinds of structure in this paper, the functions which depicts the relation between ground motion severity and damage degree of building.

#### 3.1 Comparing various damage scales

One of the results of this study is to have given the standard for the interpretation of building damages by charting the degree of damage. It is possible to reconstitute various existing damage scales on the Damage Index and compare with them by diagrammatizing building damage condition described in each damage scale. Fig.6 shows some examples of diagrammatized damage pattern in existing scales. Comparing this figure with the proposed chart in Figs. 4 and 5, we gave the relation among various damage scales in this figure. From this figure we can understand the correspondence of the existing damage scale.

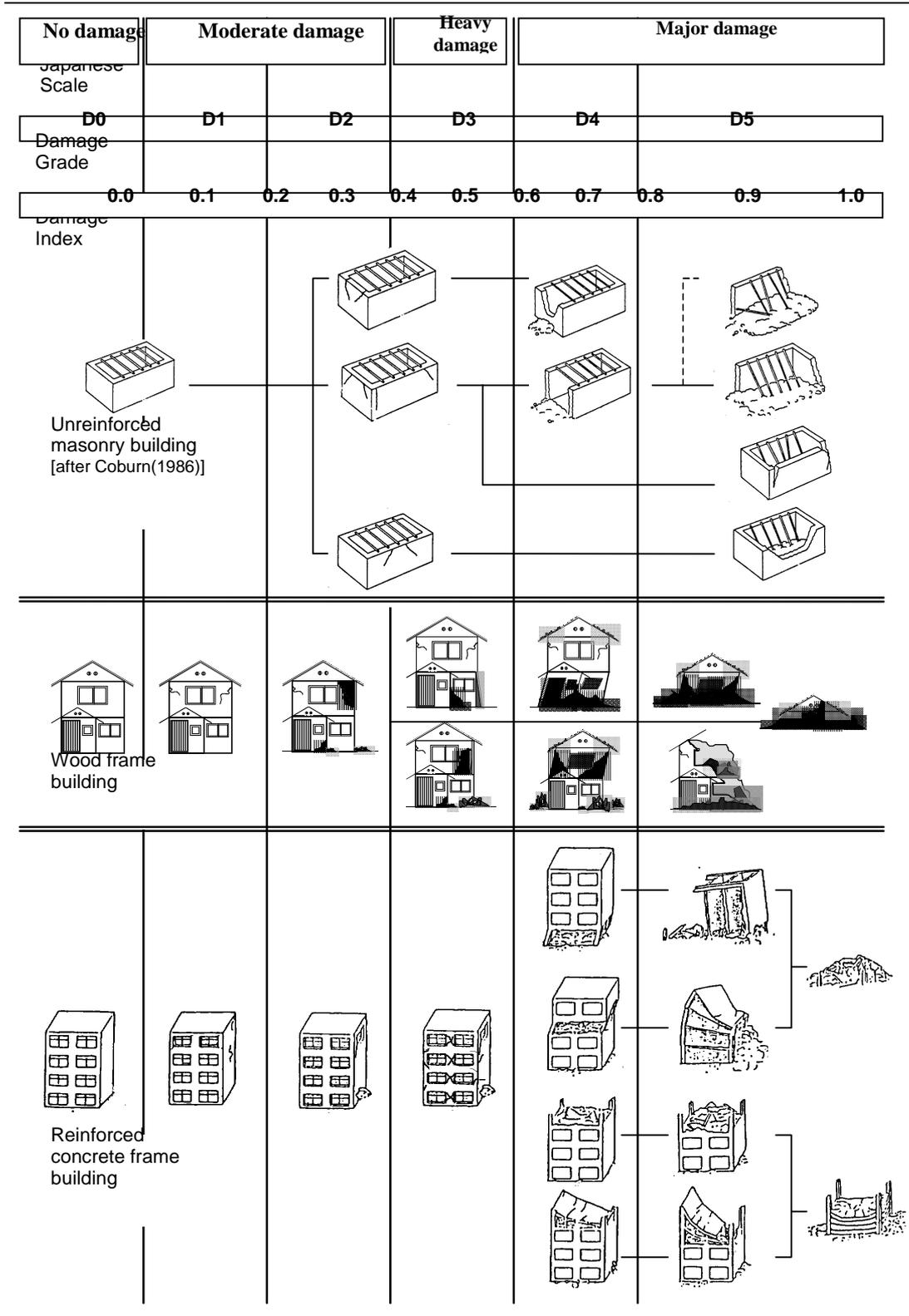


Fig.4: Damage pattern chart



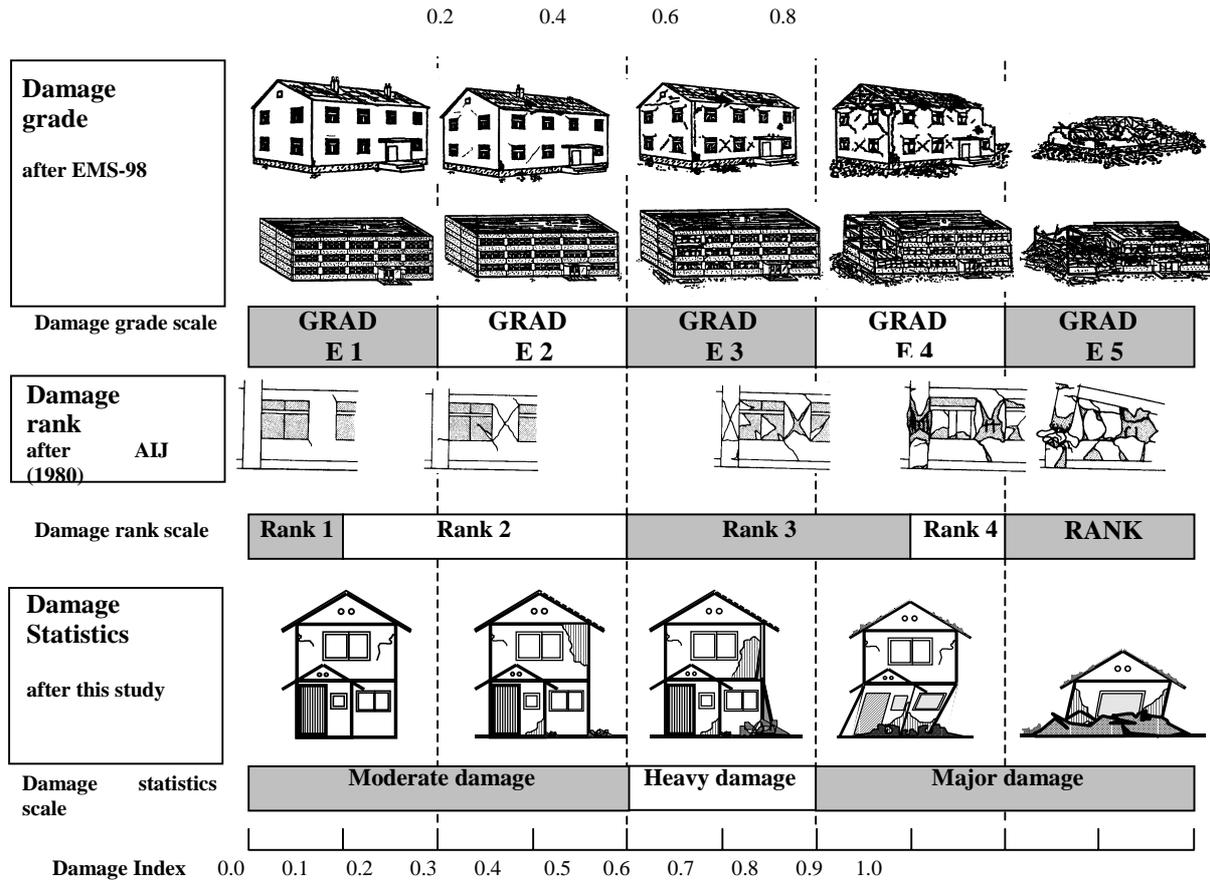


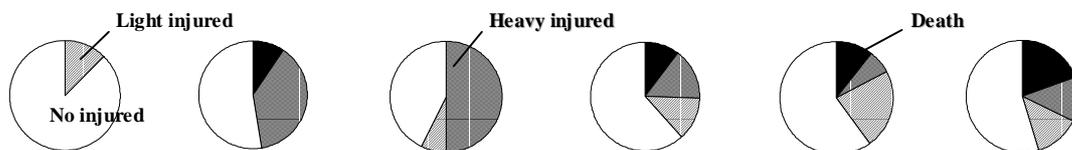
Fig.6: Comparison among various damage scales

### 3.2 Advancing a simple damage investigation for nonprofessionals

Only the specialists must be entrusted to the post-earthquake investigation of which purpose is to judge the safety of damaged buildings, however, a mass of investigation by the regional inhabitants is considered to be very effective in attempt to almost grasp the outlines of the damage situation in the whole area. If they used our visualized damage pattern in this case, they could intuitively grasp the degree of the damage; and it can be expected that the judgment of damage situation becomes possible without such expertise. That is to say, it is possible to apply our chart to a handy building damage investigation method without a decrease in investigation accuracy [Koyama and Ohta (1999)].

### 3.3 Modeling causal chain of casualty occurrence due to building damaged

Most of the equations modeling death with building destruction are constructed on the assumption that casualties are proportionate to the total number of complete collapse buildings. In this paper, we placed emphasis on the variety of damage patterns even in complete collapse buildings. Knowing which pattern is greatly concerned in the death is sure to contribute to the improvement of the model and the minimization of casualties in dwellings. Fig.7 shows the relation between the building damage patterns and the casualties in each pattern. The data is based upon the field investigation at Hokudan-cho Town in Awaji Island where was severe damaged in the 1995 Hyogo-ken Nanbu earthquake. This figure points out that the pattern of which ground floor disappears like pancakes is the riskiest one of all the patterns. Following this result, we are considering a causal chain model of occurrence of death in dwelling damaged.



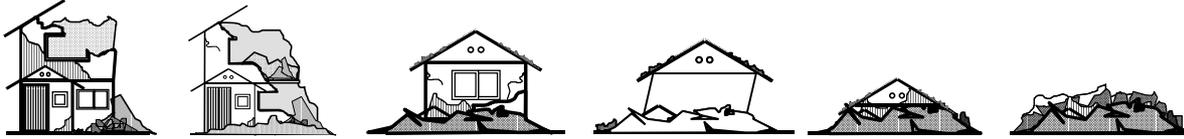


Fig.7: Casualty ratio for damage patterns at D5 level (Circle means casualty ratio in percentile)

### 3.4 Estimating vulnerability function of buildings

The resistance of various building types to earthquake loads can be defined by the use of vulnerability analysis. The vulnerability of a building is one of the principal factors affecting the occurrence of casualties in earthquakes. Up to now, vulnerability functions on wood frame structures has been studied as to three types of damage degree, i.e., moderate, heavy and major damages in Japanese Scale. Paying attention to the influence of the damage pattern on the rate of the death in dwellings, we tried to estimate the vulnerability functions on damage degree from D1 (slight damage) to D5 (total damage) in the MSK Scale. Based on the data obtained by the building damage investigations in Kobe City in the 1995 Hyogo-ken Nanbu earthquake, we classified the damaged buildings into D1 to D5 utilizing our damage pattern chart, and we obtained the relation between damage rate and ground severity such as the Japan Meteorological Agency (JMA) seismic intensity. Applying the Gaussian distribution  $\phi(x)$  to this relation, we obtained the following vulnerability function.

$$V(I) = 1/2(\phi(x)) \quad (1)$$

$$\phi(x) = 2/\sqrt{\pi} \int_0^x \exp[-x'^2] dx' \quad (2)$$

Where,  $V(I)$  is the damage rate of buildings at the ground severity of JMA seismic intensity  $I$ .

Parameter  $x$  is given as follows:

$$x = (I - I_0)/(\sqrt{2}\sigma) \quad (3)$$

Where,  $I_0$  is the average structural strength of this building structure type, and  $\sigma$  means structural inhomogeneity of this building group. Furthermore, We transformed JMA seismic intensity  $I$  into peak ground velocity  $V_{max}$  by the following equation [Muramtu (1966)].

$$\log V_{max} = (I + 0.5)/2 - 1.4 \quad (4)$$

In this case, parameter  $x$  is given as follows:

$$x = (2 \log V_{max} - \lambda)/(\sqrt{2}\sigma) \quad (5)$$

Table 2 shows the parameters of the obtained functions and Fig.8 and 9 shows the functions that give damage rates with JMA seismic intensity and peak ground velocity.

## CONCLUSIONS

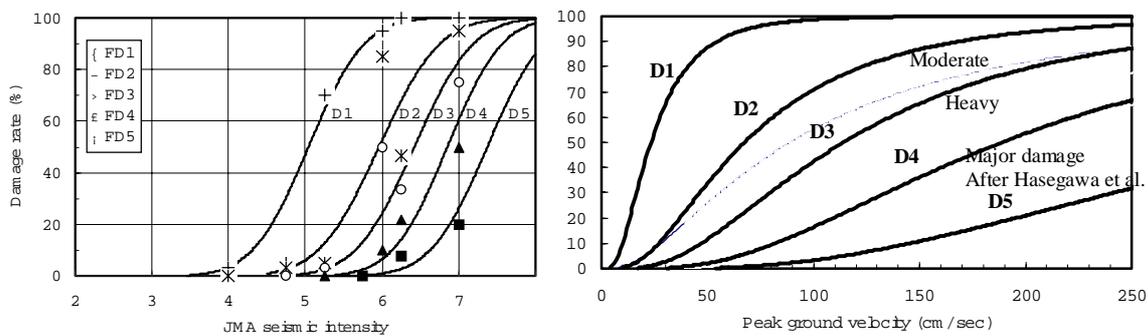
In this paper, we could systematically arrange the patterns of the building destruction from damage photographs and references, etc. The significance of visualization of the building damage pattern is as follows: (1)The correlation among various damage scales in the world can be visually understood, and it will come to give the standard for the damage description of various investigations; (2)By visualizing the destruction pattern like this study, the degree of the damage can be intuitively grasped, and it can be expected that the judgment of damage degree of buildings becomes possible without expertise; (3)Research group including us has been constructing the database on affected buildings in Hokudan-cho Town, which experienced JMA seismic intensity of 7 in the Hyogo-ken Nanbu Earthquake, using the destruction pattern proposed in this paper. Though many researchers tried to judge the damage level in the building from a lot of photographs, the judgement with high work of promptness and reproducibility was extremely possible independent of those who judged owing to our pattern chart. In addition, the relation between destruction pattern and fatality occurred in the building was seen very clearly. By having visualized the feature of damaged building, we are sure that qualitative description about damage degree has changed to a quantitative amount easy to observe. That is the reason why we propose the

destruction pattern shown by this main discourse as one of the amounts of the observation. Such an application can be expected.

Finally, we are grateful to Profs. T. Suzuki (Akita Prefectural Univ.) and M. Miyano (Osaka City Univ.) for their cooperation to construct the damage database of this study.

**Table 2: Obtained parameters of vulnerability function for wood frame building**

	Using Eq.(3) for JMA intensity		Using Eq.(5) for peak ground velocity	
	$I_0$	$\sigma$	$\lambda$	$\sigma$
Damage grade D5	7.37	0.582	5.07	0.582
Over Damage grade D4	6.85	0.565	4.55	0.565
Over Damage grade D3	6.42	0.600	4.12	0.600
Over Damage grade D2	5.96	0.621	3.66	0.621
Over Damage grade D1	5.04	0.574	2.74	0.574



**Fig.8: Obtained function (damage rate vs. JMA intensity)**      **Fig.9: Obtained function (damage rate vs.  $V_{max}$ )**

## REFERENCES

- Coburn, A.W. (1989), "Seismic vulnerability and risk reduction strategies for housing in Eastern Turkey", Dissertation for Ph.D., Univ. of Cambridge, pp1-212.
- Earthquake engineering Research Institute (1996), "Post-earthquake investigation field guide, Learning from earthquakes", Earthquake Engineering Research Institute, Publication No.96-1, pp1-144.
- Grunthal G. (1998), "European Macroseismic Scale 1998", Cahiers du Centre Europeen de Geodynamique et de Seismologie, 15, pp1-99.
- Hasegawa K., S. Midorikawa S., and M. Matsuoka (1998), "Seismic risk mapping of wooden house in large area using the grid-square statistics", J. Struct. Constr. Eng., 505, pp53-59 (in Japanese with English abstract).
- Kawai A. (1995), "Photo album: Buildings destructed in the great earthquake", Dai-san-shokan, pp1-207.
- Koyama M. and Y. Ohta (1999), "A rapid earthquake damage data collection questionnaire system based on local people cooperation", The 10<sup>th</sup> Earthquake Engineering Symposium, 3, pp3497-3502 (in Japanese with English abstract).
- Moriya K. (1985), "Summary of the 1985 Mexico earthquakes", Shigakusha, pp1-64.
- Muramatu I. (1966), "Expectation of Maximum of Earthquake Motion within 50 years throughout Japan", Science Report of Gifu University, 3, pp470-481.