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SEISMIC PERFORMANCE OF WOODEN DETACHED HOUSES SUBJECTED TO THE 1995 HYOGO-KEN NANBU EARTHQUAKE

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ABSTRACT

Approximately 150,000 wooden houses were damaged by the 1995 Hyogo-ken nanbu Earthquake. 1,068 houses of comparatively new ones financed by The Government Housing Loan Corporation of Japan (G.H.L.C.J.) among them were surveyed, and the conclusions are as follows: (i)The damage of these houses was small even though they were located in areas of seismic intensity 7 (JMA scale). (ii)Among 530 houses aged less than 10 years, 28 houses suffered intermediate damage(5.3 %), 3 houses major damage(0.6 %) and 2 houses collapse(0.4 %). (iii)Older houses were more severely damaged than newer ones. The ratio of houses which suffered intermediate or more severe damage in those aged 10-15 is about 2.5 times as large as in those aged less than 10, and the ratio in those aged 15-20 is about 3.0 times. (iv) The ratio of houses which suffered intermediate or more severe damage in post and beam construction is 3-4 times as large as in two-by-four houses and as in prefabricated houses.There is little difference in damage grade between old and new houses for two-by-four houses or prefabricated houses.

KEYWORDS

1995 HYOGO-KEN NANBU EARTHQUAKE, WOODEN DETACHED HOUSES, SEISMIC PERFORMANCE, DAMAGE SURVEY

INTRODUCTION

Approximately 600,000 wooden detached houses are built every year in Japan. Most of them are of post and beam construction. Tipical modern and older houses of it are shown in Picture 1 and Picture 2. They include about 20,000 prefabricated houses and 15,000 two-by-four houses. Those are shown in Picture 3 and Picture 4, respectively. Prefabricated houses are of wood panel construction. They are built according to the detailed specifications approved by the Minister of Construction. So-called two-by-four houses are of modified construction of American platform construction. The detailed specifications for them are given by the notification of the Ministry of Construction.

On the other hand, Japanese houses of conventional type are of post and beam construction.They resist lateral force by diagonal braces installed on wood frame. The specifications of each house depend on the designer or the contractor, because the way of design is very diversified. However about half of the houses of post and beam construction are built with finance provided by The Government Housing Loan

Corporation of Japan(G.H.L.C.J.). They are built according to the standardized specifications made by the G.H.L.C.J.

About 150 thousands wooden houses were damaged by the 1995 Hyogo-ken nanbu Earthquake on 17th January 1995, and the damage survey has been carried out on the houses which were located in areas of seismic intensity 7 and financed by the G.H.L.C.J.

OUTLINE OF SURVEY

Method of Survey

Table 1 shows seismic intensity scale of the Japan Meteorological Agency of Japan. The areas of seismic intensity 7 in this earthquake extend for 40 km in EW direction and 2-5 km in NS direction as shown in Fig.1. The survey was carried out on houses in selected cities, towns and wards, which were in the areas of seismic intensity 7.

Most houses in Takarazuka City are comparatively large and built in large lots, the houses in Higashinada Ward are medium sized, the houses in Nagata Ward are comparatively small and the houses in Hokudan Town in Awaji Island are built by local style. In addition to them, houses aged 10-20 years in Nishinomiya City and Nada Ward were also surveyed.

The houses to be surveyed were picked out from the financing list of the G.H.L.C.J., and the sites were plotted on the residential map. Sixty-six percent of total listed houses were identified.

Table 1. JMA Intensity Scale.

Intensity	Degree	Description
0	Not felt	Too weak to be felt by humans; registered only by seismographs.
1	Slight	Felt only feebly by persons at rest or by those who are especially observant of earthquake.
2	Weak	Felt by most persons; slight shaking of windows and Japanese latticed sliding doors.
3	Moderately strong	Shaking of houses and buildings, heavy rattling of windows and Japanese latticed sliding doors, swinging of hanging objects, stopping of some pendulum clocks, and moving of liquids in vessels; some people are so frightened that they run out of doors.
4	Strong	Strong shaking of houses and buildings, overturning of unstable objects, and spilling of liquids out of vessels.
5	Very strong	Cracking brick and plaster walls,overturning stone lanterns and gravestones, and mud-and-plaster warehouses,and causing landslides in steep mountains.
6	Disastrous	Causing destruction of 1-30 % of Japanese wooden houses;causing large landslides; fissures in flat ground and some in low fields, accompanied by mud and watersponts
7	Ruinous	Causing destruction of more than 30 per cent of the houses; cousing large landslides, fissures and fault.

The exterior survey and the detailed survey were carried out as follows:

- Exterior survey: Observation of attributes and damages of houses from outside according to the survey sheet, taking some photographs and distribution of questionnaire sheet to the residents.
- Detailed survey: Recording floor plans and asking the residents about interior damage.

The survey was carried out for five times from 9th March till 2nd May 1995.

Definition of Grades of Damage

The grades of damage by earthquakes are defined as follows:

- Collapse: Any story has collapsed markedly.
- Major damage: Very hard to repair. he story deformation angle is mostly more than 1/20 radian.
- Intermediate damage: Possible to repair. The story deformation angle is mostly 1/60 - 1/20 radian.
- Minor damage: Slightly damaged. Small cracks on exterior walls or foundations.
- No damage: No damage is observed apparently.

RESULT OF SURVEY

Attributes of Houses

The houses surveyed are classified into three categories according to the age of them. The number of houses aged less than 10 years, aged 10-15 years and aged 15-20 years are 530, 225 and 313, respectively. Among them, 722 houses are of post and beam construction (67.7 %), 146 are prefabricated construction (13.6%), 90 are of two-by-four construction (8.4 %) and others. 60.1 % of the houses of post and beam construction have clay roof tiles and 29.5 % have colored cement roof tiles. As for two-by-four houses and prefabricated houses, those of clay tiles are much less than those of post and beam houses. Mortar finish on metal lathing as ext. wall construction is 75.8 % and wall siding is 7.5 % for post and beam houses. On the other hand mortar finish ext. wall was 52.1 % for prefabricated houses. Two-storied houses are 84.9 % of the total houses.

Exterior Survey

The conclusions of damage ratio from exterior survey is as follows:

Damage Ratio. Figure 2. shows the damage grade of 1068 houses, financed by the G.H.L.C.J. Of the 1068 houses there were 104(9.7%) houses of intermediate damage, 31(2.9%) major damage, and 8(0.7%) collapse. There were also 29(2.7%)houses already demolished at the time of the survey, and 11(1.0%) were burned. The ratio of intermediate damages was approximately 10%, and the damage ratio of major or more severely damaged houses was 3 - 4%.

Difference of Damage Ratio by Aging. Figure 3. shows the difference of the damage ratio by aging. The grade of damage has a tendency to be higher for the older houses. Although the damage ratio differs according to the construction type, and the proportion of the construction type differs according to the age of the house, The figure shows that the ratio of intermediate damages is higher for the houses aged more than 10 years.

Difference of Damage Ratio by Construction Type. Figure 4. shows the difference of the damage ratio by structure. The damage ratio of houses of post and beam construction was as follows: intermediate damage was approximately 12%, major or more severe damage was approximately 8%. This fact indicates that one fifth of post and beam construction houses were intermediately or more severely damaged. On the other hand the damage ratio of houses of two-by-four construction and prefabricated houses was low. The ratio

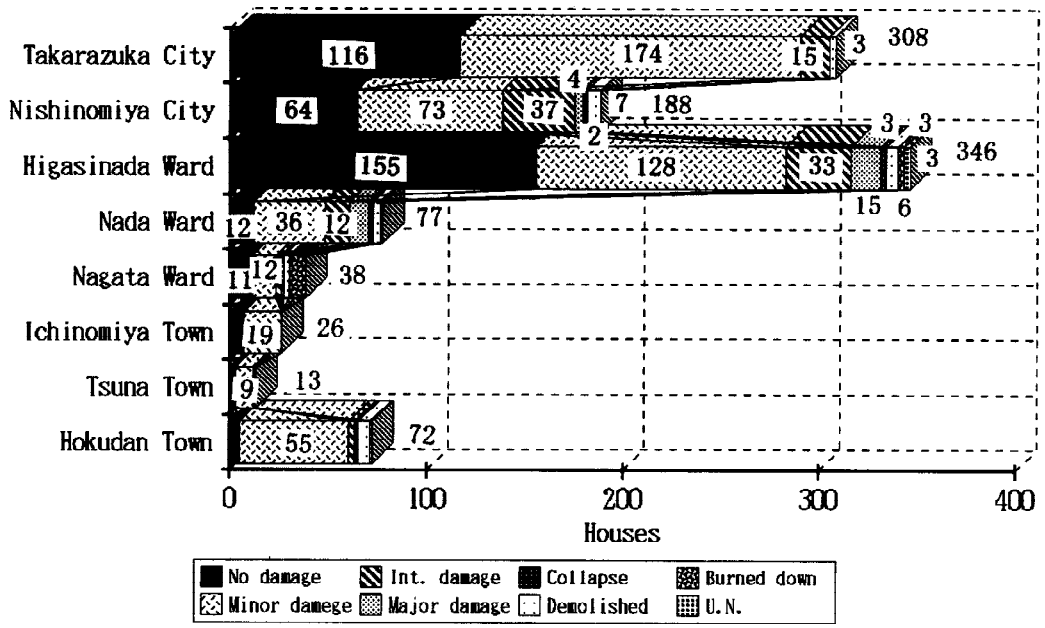

FIG. 2 NUMBER OF DAMAGED HOUSES SUBJECTED TO AREA

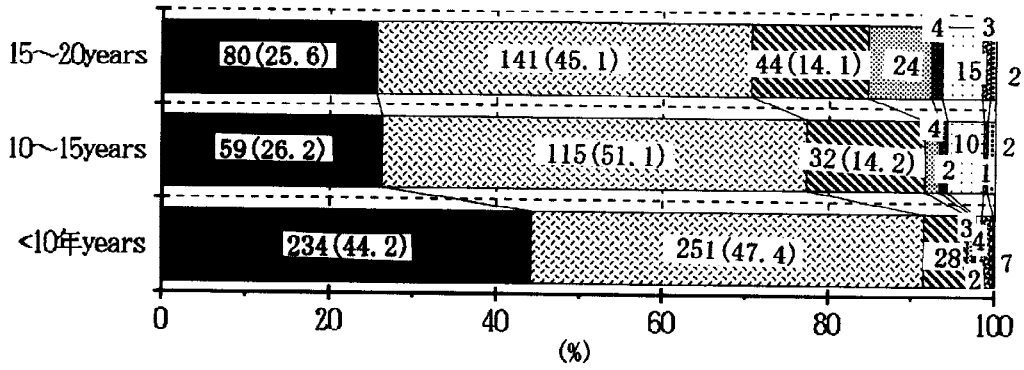

FIG. 3 RATIO OF DAMAGED HOUSES SUBJECTED TO AGE

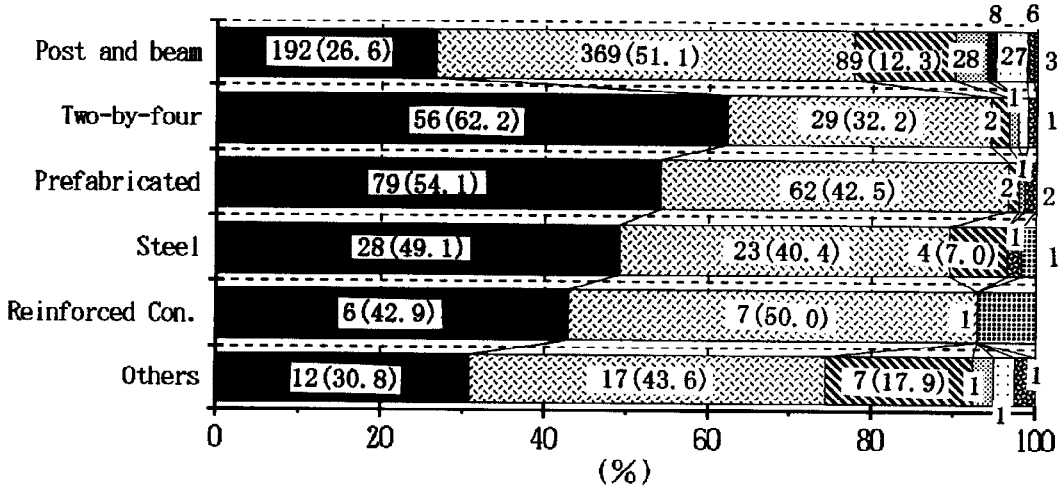

FIG. 4 RATIO OF DAMAGED HOUSES SUBJECTED TO CONSTRUCTION

of intermediate damages was approximately 2%, major or more severe damages was approximately 1%.

Examination by Questionnaire

General Facts. By the survey of the questionnaire, 514 answers received, 189 suffered no damage, 254 minor damages, 55 intermediate damages, 9 major damages, 2 collapsed, and 2 were already demolished. The furniture tumbled down (tripped over)in almost all the houses. Another distinctive feature is the high damage ratio of exterior walls. Cracked exterior walls were identified in 324(63.0%) houses and in 119(23.2%) houses the exterior walls crumbled down. Also in most of the houses the interior walls suffered some kind of damage. The tiles in the bathroom were damaged in many of the houses. Houses with damages such as ripped paper sliding doors, broken sash locks, dislocated doors and windows must have had very large relative story deformation. These damages were seen in one fourth of the total house. Approximately one half of the residents received the impression that their house would crumble down, 40% did not, 10% felt no uneasiness.

Difference of Damage Ratio by Construction. Figure 5. shows the difference of the damage ratio by construction. The number of answers to the questionnaire was as follows: 374 post and beam construction, 64 two-by-four construction, 76 prefabricated construction. The ratio of slanted or twisted houses was higher for the post and beam construction compared with the other two. There were very few prefabricated houses which were twisted. The damage ratio of clay roof tile was high for the houses of post and beam construction, but as was mentioned earlier clay roof tile is seldom used in houses of two-by-four houses or prefabricated houses. The same can be said for exterior walls. Assumingly gypsum board is used to undercoat the interior wall for all construction type. The damage ratio of interior walls is high for the houses of post and beam construction. Damages such as cracked or fallen out interior walls, indicating large deformation of the skeleton, were identified. On the other hand, many torn or wrinkled paper wall were seen in the two-by-four houses and prefabricated houses. However it must be noted that for the houses of post and beam construction, especially ones with shin-kabe(wall type), any kind of damage can be easily located. However cracked tiles in the bathroom were seen in one half of the houses of two-by-four houses and prefabricated houses.

Questionnaire and Exterior Survey. Figure 6. shows the answer to the following question, "Which do you think is the grade of damage of your house?". The result of the two corresponding surveys indicates that, the residents, answering the questionnaire, incline to judge the damage more severely than the result of the exterior survey, done by researchers. To compare the result of the two surveys by construction type ,here too the results of the questionnaire tend to be harsher than the exterior survey. The damage ratio of partially collapsed or more severely damaged houses was more than 50% of the post and beam houses, 20% of the prefabricated house, and more than 10% of the houses of two-by-four house. The fact that houses of two-by-four construction was judged better by the resident, than the prefabricated houses is an interesting point.

Analysis of Plan

Floor plans of 42 houses were collected, that show only arrangement of walls without openings but detailed wall index. The apparent length of walls without openings per square meter of floor is regarded as wall length for the purpose of dicussion.

Apparent Wall Length. Figure 7. shows the wall length of 42 houses, and the averages of them are 25.9 cm (EW direction) and 28.7 cm (NS direction). Figure 7. shows that the wall length has a tendency to be small at least in one of the directions. Most houses with such wall length were more severely damaged, but the rest were not so much damaged. These houses need to be examined separately.

Apparent Modulus of Eccentricity. Figure 8. shows the modulus of eccentricity calculated on the

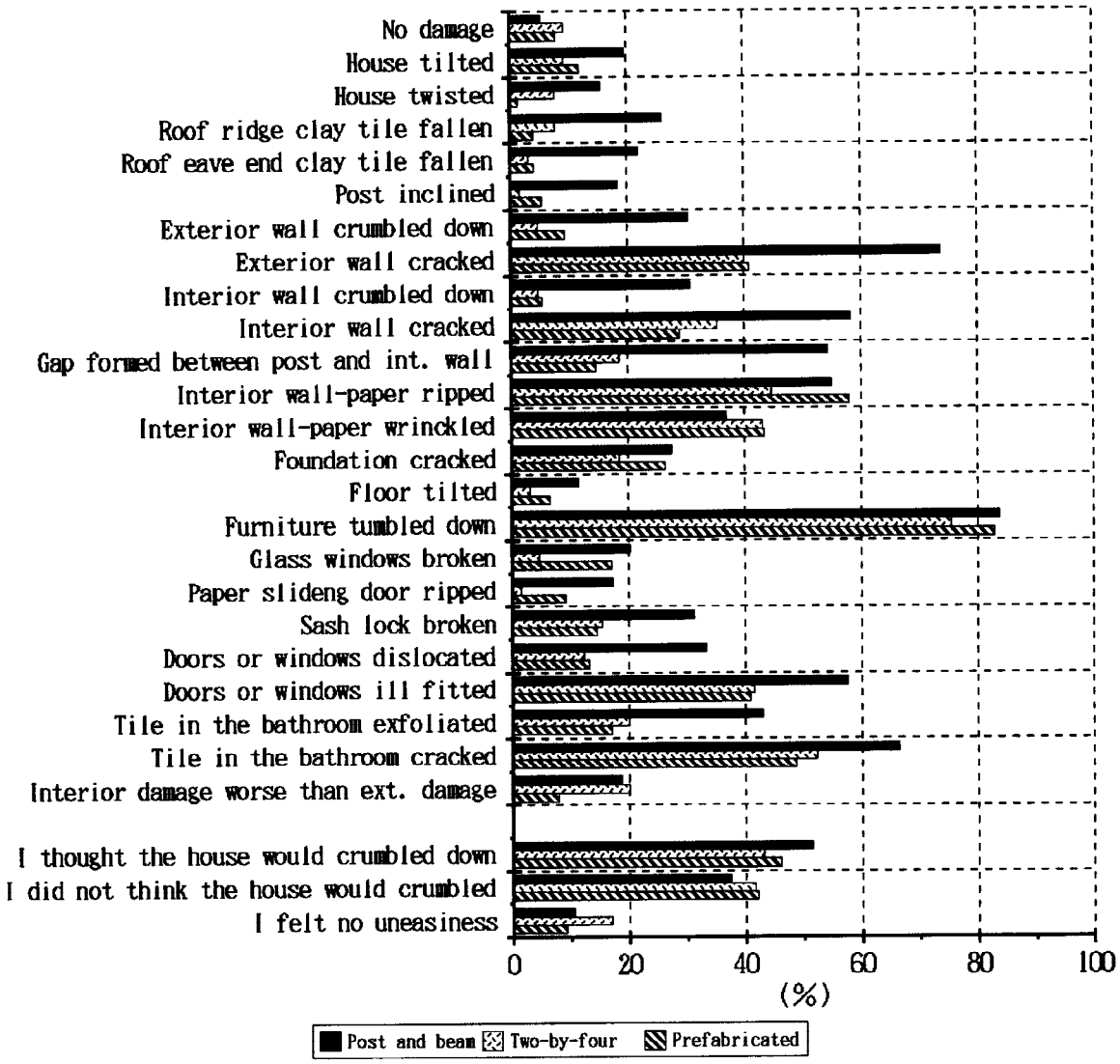

FIG. 5 RESULT OF QUESTIONNAIRE SUBJECTED TO CONSTRUCTION

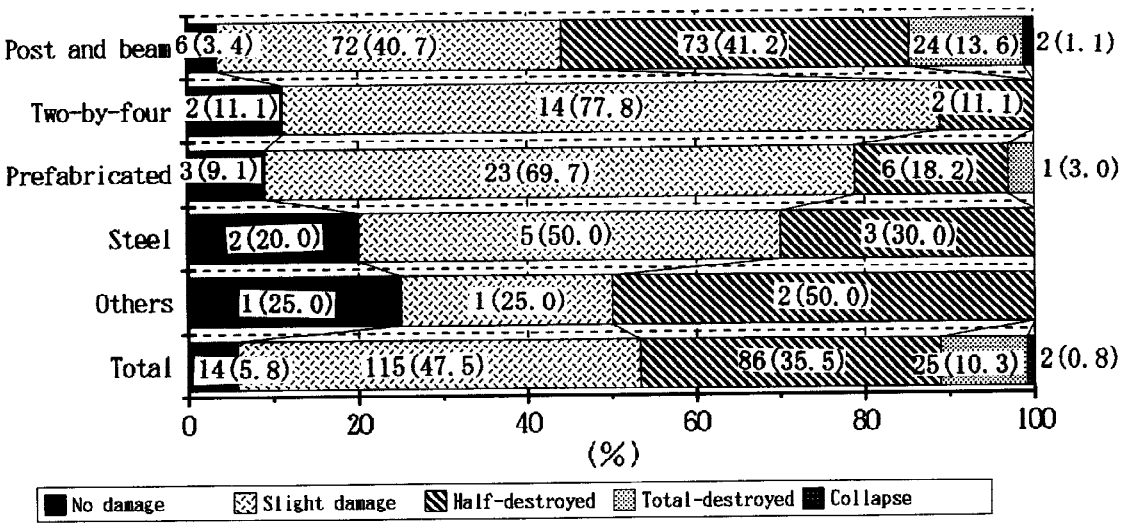

FIG. 6 RATIO OF DAMAGED HOUSES SUBJECTED TO CONSTRUCTION BY QUESTIONNAIRE

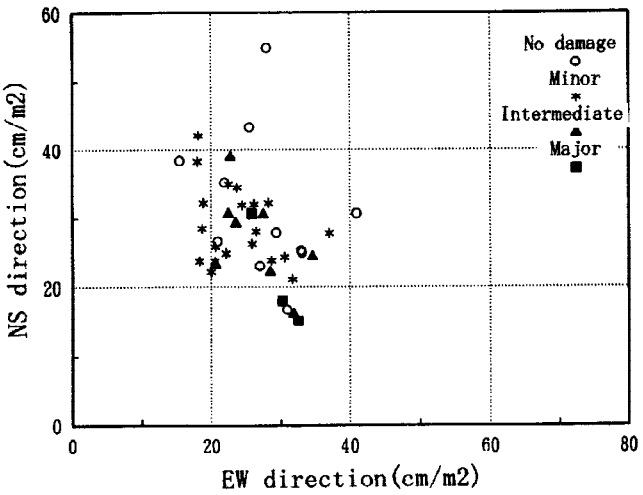

FIG. 7 LENGTH OF WALLS WITHOUT OPENING

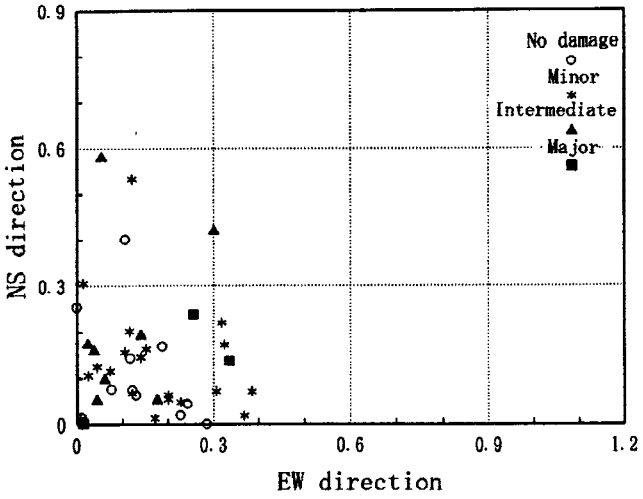

FIG. 8 MODULUS OF ECCENTRICITY OF WALL

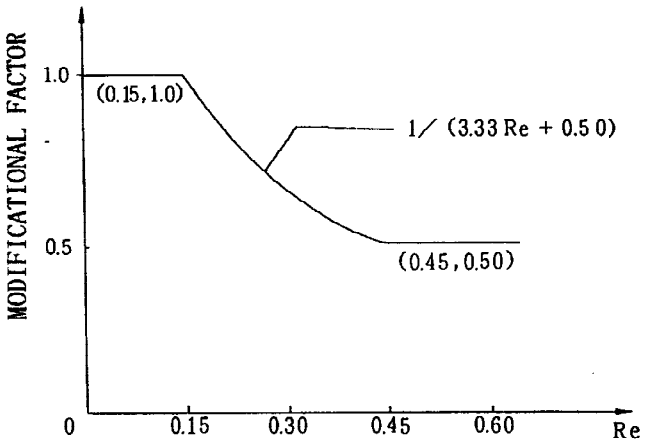

FIG. 9 MODIFICATIONAL FACTOR

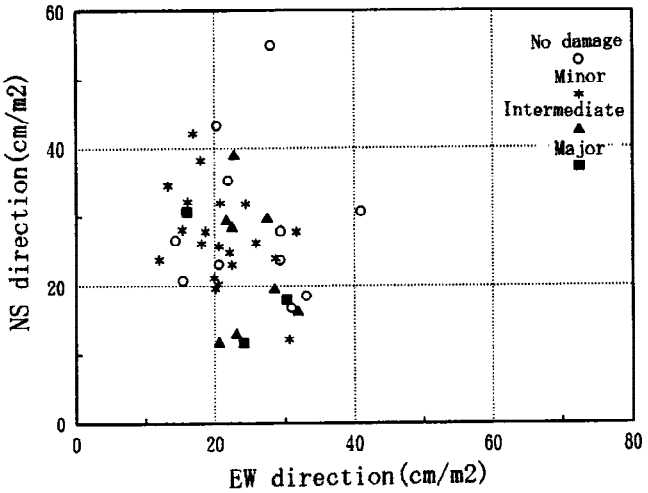

FIG. 10 MODIFIED LENGTH OF WALLS

assumption that the wall index of walls without openings is equally 1.0. In 30 houses(41.7%) the modulus is more than 0.15 in both direction, some of them are more than 0.5. Fig.10. shows the modified wall lengths, that are recalculated considering the effect of modulus of eccentricity as shown in Fig.9. The formula is used to modify the wall length caused by eccentricity in "diagnosis method of seismic performance of wooden house" (The Japan Building Disaster Prevention Association). There seems to be a tendency that most of the severely damaged houses have small modified wall length. However it is difficult to estimate the grade of damage simply by the wall length of walls without openings, for this tendency is not very distinct.

CONCLUSIONS

The conclusions are as follows:

(i) The total number of surveyed houses financed by The Government Housing Loan Corporation of Japan is 1,068, which include 104 houses of intermediate damage(9.7%), 31 major damage(2.9%), 8 collapsed(0.7%), 29 already demolished(2.7%) and 11 burned down(1.0%).

(ii) Considering that the surveyed houses are located in the area of seismic intensity 7, they are thought to be smaller in damage than houses not financed by theG.H.L.C.J.

(iii) Old houses were more severely damaged than new ones.

(iv) The major or more severe damage ratio of post and beam houses was 8 %. It was 1 % for two-by-four houses and prefabricated houses.