Evaluation of Seismic Diagnosis Methods for Wooden Housing Intended for Web Service

Masayuki KOHIYAMA[1], Nodoka UJITA[2], Osamu MURAO[3], Takaaki KATO[4], and Fumio YAMAZAKI[1]

1) Institute of Industrial Science, The University of Tokyo
2) Department of Civil Engineering, The University of Tokyo
3) Institute of Policy and Planning Science, The University of Tsukuba
4) Department of Urban Engineering, The University of Tokyo

Abstract

Recently, many private and public sectors have provided methods of seismic diagnosis for wooden housing on their Web pages. Since the Internet can easily gather a large number of participants, it is expected that these Web pages will promote house owners to recognize earthquake risks, to carry out the retrofit works, and to join to earthquake insurance. This paper proposes an effective and adequate method for seismic diagnosis of wooden houses through the Internet. First, a questionnaire was carried out to wooden-house owners in Tokyo with the simple diagnosis method that is widely adopted in Japan. Secondly, experts visited and inspected the houses by two methods: the simple method, and an in-depth more accurate method, which calculates eccentricity and story stiffness based on the wall materials and allocations. Finally, three diagnosis results were compared. The results revealed that the owners, who are non-experts, returned the diagnosis results diverging from that of experts while the results of the simple and the accurate methods by the experts matched fairly well. Thus, the simple method itself is effective, but in order to improve non-expert result, the followings are suggested: a) provide a land condition (geologic and geomorphologic) database, b) present sample photographs of foundation cracks to prompt them to check carefully before their diagnosis, c) indicate alternatives of wall length along with a house plan and consider a roof type, d) add the questionnaire entry on types of inner and outer walls, and e) add the questionnaire entries on the second-floor area and the center of gravity.

1. Introduction

According to the 1998 Housing and Land Survey (Statistics Bureau & Statistics Center, 2000) in Japan, there are 44 million dwellings and among them, 25 million are detached houses, which are mostly wooden construction (23 million in total). In 1981, the Building Standard Code is largely revised, but about 60% of these wooden houses were built before the year. Because 80% of the old houses do not have enough strength to satisfy the present standard, it is one of the most important issues to promote retrofitting of these houses. Therefore, some local governments have provided subsidies for seismic diagnosis and retrofitting of private buildings, and many private and public sectors have provided Web sites to raise disaster awareness including a simple seismic diagnosis method, which non-experts can easily use.

Most of the house owners do not envisage when and where a large earthquake will occur, and furthermore, they cannot estimate how much risk their houses are exposed to. This difficulty and deficiency of risk recognitions impede the owners to take a concrete measure such as retrofitting or taking earthquake insurance. If seismic diagnosis of a house is conducted and demonstrates how large earthquake would damage it and endanger the owner and his or her family, this awareness may promote these concrete measures. In other words, the seismic diagnosis plays an important role as a first step of earthquake countermeasures for private houses.

Based on evaluation results in Tokyo using the simple and the accurate diagnosis methods, this paper proposes an effective and adequate method for seismic diagnosis of wooden housing, which is designed for non-experts to employ through the Internet.

2. Methods of assessing the earthquake resistance of wooden buildings

Various methods of assessing the earthquake resistance of wooden housing have been proposed to date. Among them, the method prepared by the Japan Building Disaster Prevention Association in 1979 has come into wide use throughout the country. The method was revised in 1985, and published under two headings: "*Assessing the Earthquake Resistance of Your Home and Home Reinforcement*" (Housing Bureau, 1985) (hereinafter referred to as the "the simple diagnosis method") offering a basic method of assessment for the general public, and "*Accurate Assessment of the Earthquake Resistance of Wooden Housing and Home Reinforcement*" (Housing Bureau, 1985b) (hereinafter referred to as the "the accurate diagnosis method"), which details methods of assessment for building engineers. These guidelines are currently in wide use (Sakamoto, 1995).

The Building Standard Law was drastically amended in 1980. In 1981, the law came into effect; however, damage later caused by the 1995 Hyogo-ken Nanbu (Kobe) Earthquake to buildings constructed before the revision was extremely high. Consequently, "the Law for Promotion of Seismic Retrofit" was formulated (promulgated on October 27, 1995, and enforced on December 25, 1995) to promote retrofitting of public buildings where urgently required and of buildings used by the general public. The accurate diagnosis method is authorized by the Minister of Land, Infrastructure and Transport as effective as part of an overall policy for the assessment of earthquake resistance (1995 Notification No. 2089 of the Ministry of Construction) under the Law for Promotion of Seismic Retrofit (1996 Official Notice No. 74 of the Ministry of Construction).

Under the law, the earthquake resistance of buildings that are primarily public have been improved; however, only few private homes have been retrofitted. In particular, wooden houses that require improvement in densely built-up areas have presented a significant problem. In order to promote the reconstruction of poor-seismic-capacity wooden houses in densely built-up areas, "the Act of Densely Inhabited Areas Improvement for Disaster Mitigation" was formulated (promulgated on May 9, 1997, and enforced on November 8, 1997). Under the law, the Standard for Assessing Earthquake Resistance (Urban Housing Improvement Office, 1998; Okada, 1998) was developed to set guidelines for the reconstruction or demolition of wooden buildings in areas defined under the law as "Districts for the Promotion of Redevelopment for Purposes of Disaster Mitigation".

On the other hand, in order to assure quality in housing, protect the benefits of home buyers, and solve disputes related to housing promptly and properly, "the Housing Quality Assurance Act" was formulated (promulgated on June 23, 1999, and enforced on April 1, 2000). To solve problems related to housing construction and home sales, the law prescribes the establishment of a system of ranking housing performance, stipulates improvement of the system for handling disputes related to housing, and provides for the assurance of a 10-year warranty against defects. Under the system for ranking housing performance, there are three grades, from 1 to 3, of earthquake-resistance. Grade 1 is equivalent to the performance required under the Building Standard Law. Grade 2 designates 1.25 times the performance under the standard and Grade 3 is reserved for structures demonstrating 1.5 times the standard performance (Housing Production Division, 2002).

The Earthquake Insurance System, which was amended on October 1, 2001, provides discounts according to the year of construction, in addition to a system of discounts linked to the three grades of earthquake resistance (2001 Notification No. 50 of the Financial Services Agency). These grades conform to the above-referenced Law for Promotion of Seismic Retrofit, and the Housing Quality Assurance Act. Therefore, the policies governing the assessment of earthquake resistance under the Law for Promotion of Seismic Retrofit, the accurate method, and the Housing Quality Assurance Act can be applied to assess the grades of earthquake resistance for the Earthquake Insurance System. With respect to the assessment of the earthquake resistance of buildings constructed before 1981, manuals detailing the accurate method are widely available and will likely prove a valuable resource.

2.1 The simple diagnosis method

The simple diagnosis method was developed in 1985 (Housing Bureau, 1985; Sakamoto, 1995), and aimed that non-expert people could easily check their houses. The method consists of five scores from A to F, and the total score is calculated by multiplying these scores as shown in Table 1. The seismic capacity of a house is assessed based on Table 2. A brief description of each score is given below:

A Score of ground and foundation: the score is determined by a combination of foundation type and ground condition; it is considered that soft soil amplifies seismic waves.

B Score of building shape: a low score is assigned when a house plan or elevation is not regularized; a complex building shape induces damage.

C Score of wall allocation: a low score is assigned when a house has a short or no wall in one or more house faces; unbalanced wall allocation induces torsional oscillation, which may cause damage.

D Score of bracing: a high score is assigned when a house has bracing; a house has a strong horizontal resistant force if bracings are properly placed.

E Score of wall-length ratio: a high score is assigned when a house has a large wall-length ratio; the wall-length ratio is determined based on a unit wall-length, which the total wall length and floor area give, and the required unit wall-length, which the number of stories (1 story or 2 stories) and roof type (heavy or light) give. The smaller value for beam and girder directions is adopted.

F Score of aging: a low score is assigned when a house is degraded, decayed or damaged by termite.

Table 1: Evaluation chart of the simple diagnosis method (Housing Bureau, 1985)

Diagnosis items			Score*			
A	Ground and foundation		Good or normal	Rather bad	Very bad	☐
		Strip foundation of reinforced concrete	1.0	0.8	0.7	
		Strip foundation of plain concrete	1.0	0.7	0.5	
		Strip foundation of cracked concrete	0.7	not applicable to score evaluation**		
		Others (boulder, masonry, concrete block)	0.6			
B	Building shape	Fair (regularized form)	1.0			☐
		Irregular plan	0.9			
		Irregular elevation	0.8			
C	Wall allocation	Well balanced	1.0			☐
		Outer wall shorter than 1/5 of the frontage	0.9			
		No wall in one or more house fronts	0.7			
D	Bracing	Bracings are used	1.5			☐
		Bracings are not used	1.0			
E	Wall-length ratio	1.8 –	1.5			☐
		1.2 – 1.8	1.2			
		0.8 – 1.2	1.0			
		0.5 – 0.8	0.7			
		0.3 – 0.5	0.5			
		– 0.3	0.3			
F	Aging	Sound	1.0			☐
		Degraded	0.9			
		Decayed or damaged by termite	0.8			
Total score		A ☐ × B ☐ × C ☐ × D ☐ × E ☐ × F ☐ =				

*: For a two-story building, only the first floor wall is considered. If two or more items are identified in the same score category, please select the smallest score.

**: Please take expert's accurate diagnosis if it is not applicable.

Table 2: Seismic capacity assessment (Housing Bureau, 1985)

Total score	Seismic capacity	Comment
1.5 or more	Safe	–
1.0 – 1.5	Roughly safe	Secured if taking expert's accurate diagnosis
0.7 – 1.0	Rather danger	Please take expert's accurate diagnosis
Less than 0.7	Collapse or major damage risk	Please consult an expert about retrofitting

2.2 The accurate diagnosis method

The accurate diagnosis method is developed as a companion volume of the simple diagnosis method (Housing Bureau, 1985b; Sakamoto, 1995). While the simple diagnosis method is aimed for non-experts, the accurate diagnosis method is based on a more advanced engineering approach, e.g. expert's on-site investigation of a structure and ground, consideration of drawings, geologic and geomorphologic reports, etc. As with the simple diagnosis method, this method assesses seismic capacity focusing attention on only first-story wall, which would be damaged more than a second-story wall in many cases. The total score is evaluated by multiplying all scores in a similar manner, but the scores consist of A, B×C, D×E, and F. With respect to B×C and D×E, smaller combination for beam and girder directions is adopted for evaluation.

B×C Score of eccentricity: the score, which corresponds to the amplification factor of seismic load by eccentricity, is evaluated by the eccentric factor based on the location of the centers of gravity and rigidity; the center of gravity is determined by the allocation of a roof and a second floor, and the center of rigidity is determined by the allocation of earthquake resisting walls as well as other walls without openings considering resisting force ratios.

D×E Score of resistance force: the score is evaluated based on the ratio between the total wall length and required wall length; the total wall length is calculated for earthquake resisting walls and other walls without openings considering resisting force ratios, and the required wall length is calculated based on the weight of upper structure.

The accurate diagnosis method assesses seismic capacity based on the ratio of horizontal resistant force retained by the first story of a house to that required by the Building Standard Law. To put it briefly, seismic capacity of a house is judged by the ratio of the resistance force to a seismic load whether it stands up against a moderate earthquake, which is assumed to come within its service life, once in about fifty years, without yielding any crack on its wall. Incidentally, the accurate method recommends checking the following items: the ground condition around a house, e.g. retaining walls, joint connections (joiner metal existence), the stiffness of horizontal diaphragm, etc. These check results are not reflected in the total score, but are very critical for seismic capacity.

Target buildings of this diagnosis method (also the simple diagnosis method) are limited to conventional wooden-frame structures, which mainly use walls and bracings to transfer horizontal seismic forces, and structures with large section beams and columns, which are considered as rigid and semi-rigid frame structures, are not included. With respect to the number of stories, one- and two-story houses are the targets. Based on compulsion of the Building Standard Law, a three-story wooden construction requires a structural analysis and its seismic capacity seems to be assured by the law. But actually there are many cases that the roof space was remodeled to an attic or a house was newly enlarged with an upper story without authorization, and those houses often have problems in their seismic capacity.

3. Comparison between results evaluated by experts and non-experts

3.1 The survey methods

In this section, the results by three diagnoses: by non-experts using the simple diagnosis method, by experts using the simple diagnosis method, and by experts using the accurate diagnosis method, are compared and discussed in order to improve the accuracy of the simple diagnosis method for non-experts.

The questionnaires were distributed to house owners in Setagaya and Sumida Wards of Tokyo. The questionnaires included items required for the simple diagnosis method as well as a request of volunteers for expert's visit and investigation. The answers of the questionnaire are assumed to be the results by non-experts using the simple diagnosis method. Figure 1, which is the simplified version of an option in the simple diagnosis method for people who cannot draw a plan, is used to evaluate the wall-length ratio (score E).

A total of 48 wooden houses were investigated by experts from March, 2001 to October 2002. The experts inquired house residents (owners) about construction conditions and also assessed by their eyes. The ground information of the site is also inquired, and land condition maps (Geographical Survey Institute, 1980 and 1981) and, if available, reports on ground survey and/or soil improving are considered.

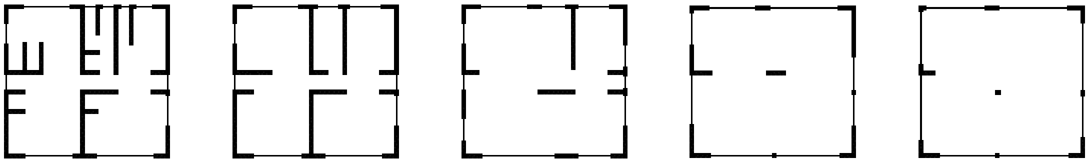

Figure 1: Alternatives to evaluate the wall-length ratio (score E) in the questionnaire

3.2 Building property distributions

In 20% houses, structural details, e.g. wall material, bracing existence, could not be identified because there were not sufficient drawings. In these houses, necessary drawings were made based on on-site measurement and investigation. In other houses, remodeling, enlargement or other changes were also recorded by the experts. Regarding the number of floors, one-story house numbers only one. The other 47 are two-story, and 7 of them have attics. Regarding the building use, detached houses only for living use count 39, semi-detached houses (two household houses): 2, tenement and apartment houses: 3, buildings for living and commerce: 2, and buildings for living and factory: 2.

Figure 2 shows the distribution of construction years; 20 houses (42%) were built after 1981, the year of major amendment of the Building Standard Law. Figure 3, which compares the result of this study with the aggregation result of detached wooden houses in Tokyo of the 1998 Housing and Land Survey, indicates that two distributions are almost coincidental. The distribution of the total floor space is shown in Figure 4; the average floor space is 120.2 m^2. In Figure 5, which compares with the 1998 Survey, the houses with the total floor space smaller than 50 m^2 number 10% less, and those not smaller than 150 m^2 count 20% more than the statistics. With respect to remodeling and enlargement, 21 houses (44%) were reformed. Seven of them were enlarged at the second story, and two out of the seven increased their floors from one-story. Three were enlarged by connecting with existing buildings.

When calculating the score A, Table 3 is used to give a value for all the combinations. With respect to the ground type, 24 houses were on a good or normal ground, rather bad: 14, and very bad: 10. Regarding the foundation type, a strip foundation of reinforced concrete is used in 9 houses, a strip foundation of plain concrete: 28, a strip foundation of cracked concrete: 8, and other types: 3. For houses with an attic, heavy roofs are assumed so as to consider its load. Thirteen houses (27%), whose total scores are 1.0 or more, were assessed as 'roughly safe' or 'safe', while about 70% houses were identified as problematic. The week axes of the eccentricity and the horizontal resistant force scores exist in the North-South direction for 15 houses, the Northeast-Southwest: 1, the East-West: 28, the Southeast-Northwest: 4, respectively. The East-West axis doubles the North-South axis in number because large windows are often placed on the south side.

Table 3: Conversion of the ground and foundation score A

Foundation type	Ground type		
	Good or normal	Rather bad	Very bad
Strip foundation of reinforced concrete	1.0	0.8	0.7
Strip foundation of plain concrete	1.0	0.7	0.5
Strip foundation of cracked concrete	0.7	0.5*	0.3*
Others (boulder, masonry, concrete block)	0.6	0.4*	0.3*

*: not applicable to score evaluation in the original accurate diagnosis (Table 1).

The relationship between construction year and total score of the accurate diagnosis is illustrated in Figure 6. Although older houses tend to have low total scores and low seismic capacity, ten houses built after 1981 had the total scores lower than 1.0. The main reason is that their scores A were relatively low. Six houses were built on rather bad or bad ground, and foundations of 3 houses had cracks; two of them were on good or normal ground. Other than them, one house was enlarged at the second floor, which increases the weight. Concerning another house, its eccentricity and horizontal resistant force scores were low because it was connected to an old one-story building with few walls in the connecting part and was evaluated as an isolated structure in the diagnosis.

The relationship between the total floor space and total score of the accurate diagnosis is shown in Figure 7. Though the correlation is not high, positive correlation can be observed in the graph. It is because buildings with a small floor space are prone to have a narrow frontage, and the facades tend to have a shorter wall due to openings such as entrances or windows as well as to have bad balanced allocation of walls.

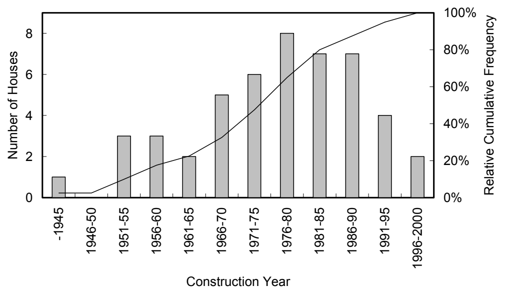

Figure 2: Distribution of studied houses with respect to construction year

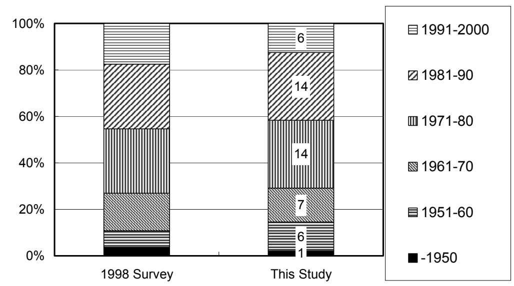

Figure 3: Comparison of ratios of construction years between statistics and studied houses

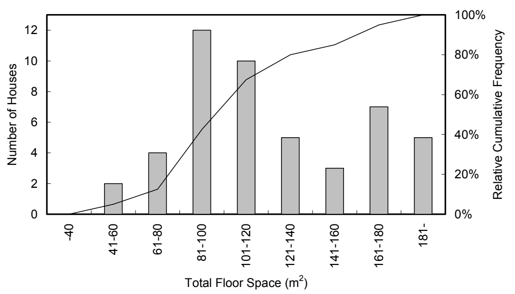

Figure 4: Distribution of studied houses with respect to floor space

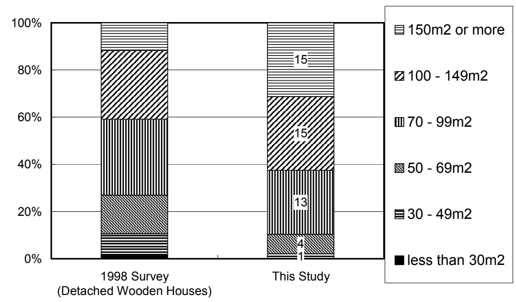

Figure 5: Comparison of ratios of total floor spaces between statistics and studied houses

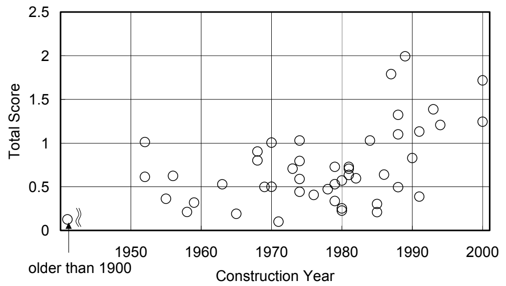

Figure 6: Relationship between construction year and total score of the accurate diagnosis

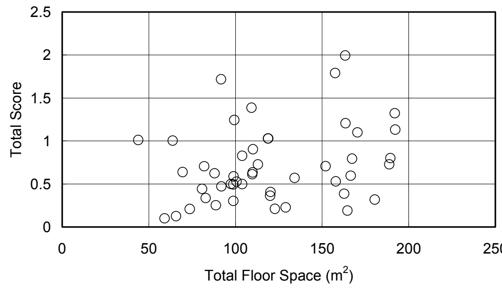

Figure 7: Relationship between total floor space and total score of the accurate diagnosis

3.3 Comparison between the results by experts and non-experts

Figure 8 compares the total scores by the simple diagnosis method and those by the accurate diagnosis method. The results of the simple diagnosis method by non-experts are marked using '×', and those by experts '○', in which the experts evaluated the wall-length ratios based on the wall lengths and floor areas in drawings, not by Figure 1. While the total scores evaluated by experts using the simple diagnosis method matched very well with those using the accurate diagnosis method, the results of the simple diagnosis method by non-experts were relatively dispersed. Incidentally, the weak axes of the both method accorded in 32 houses (67%) when experts evaluated. With respect to the simple diagnosis method, difference in each score between the evaluation results by experts and non-experts are shown in Table 4. The table contains the average, standard deviation, and root mean square (RMS) of differences in each score.

With regard to the ground and foundation score A, the average value of non-experts, 0.12, is higher than that of experts because the residents misunderstood the ground as better and they overlooked cracks on foundations. The RMSs of the bracing score D and the wall-length ratio score E, about 0.2, were as large as that of score A. One of the causes is that owners did not know the existence of bracings. Another is that, in evaluating the wall-length ratio, no consideration of wall types increases error, and a figure selecting method like Figure 1 has a limitation in accuracy, especially when an actual plan of a house is different from the figure. Although the simple diagnosis method has a questionnaire entry to identify a roof type from a heavy or light roof, only the number of floors is considered and the roof type is not considered when evaluating the wall-length ratio based on the figure.

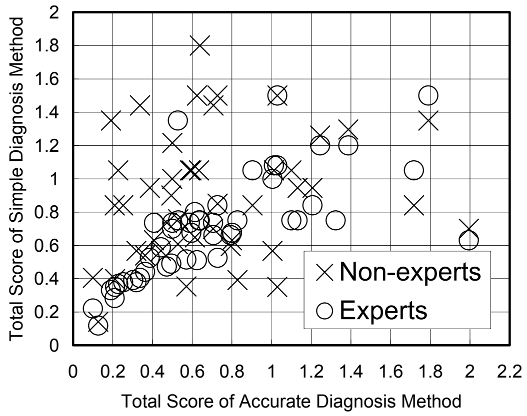

Figure 8: Comparison between the evaluation results by experts and non-experts

Table 5 shows difference in each score between the evaluation results using the simple diagnosis method and the accurate diagnosis method. Tables 4 and 5 are the same with respect to scores A and F because the same scores are used in the both methods. With respect to the non-experts results, the RMS in the eccentricity score B×C, 0.21, is rather large while the average of differences is 0.08. The average of differences in the horizontal resistant force D×E, 0.04, is close to zero, but the RMS, 0.52, is so large as to influence accuracy of the total scores.

Concerning the experts results, the averages and standard deviations and RMSs are all zero because the scores A and F are the same in the both diagnosis methods. Regarding scores B×C and D×E, the averages of differences, 0.07 and –0.06, respectively are rather small, and RMSs, 0.18 and 0.37, are 16% and 28% smaller than those by non-experts. But RMS of D×E, 0.37, is not so small as to be negligible. When both walls with and without bracing exist, or when the stiffness of inner walls is much different from that of outer walls, the simple diagnosis method cannot evaluate its horizontal resistant force precisely because the method does not consider the wall type. In addition, areas of the first and second floors are assumed to be the same in the simple diagnosis method, and the error increases when the second floor space is extremely smaller than that of the first floor.

Table 4: Difference in each score between the evaluation results by experts and non-experts

	A	B	C	D	E	F	Total score
Average of differences	0.12	0.00	0.01	–0.06	0.09	–0.01	0.17
Standard deviation of differences	0.19	0.07	0.09	0.20	0.22	0.06	0.41
Root Mean Square	0.22	0.07	0.09	0.21	0.24	0.06	0.45

A positive difference value means that non-experts' score is higher than that of experts.

Table 5: Difference in each score between the evaluation results by using the simple diagnosis method and by using the accurate diagnosis method

	Non-experts					Experts				
	A	B×C	D×E	F	Total score	A	B×C	D×E	F	Total score
Average of differences	0.12	0.08	0.04	–0.01	0.17	0	0.07	–0.06	0	–0.01
Standard deviation of difference	0.19	0.19	0.52	0.06	0.51	0	0.16	0.37	0	0.31
Root Mean Square	0.22	0.21	0.52	0.06	0.54	0	0.18	0.37	0	0.31

A positive difference value means that the simple diagnosis method score is higher than that of the accurate.

5. Conclusions

In order to propose an accurate but simple seismic diagnosis method for wooden houses in Japan, two seismic diagnosis methods were applied to wooden housings in Tokyo. By this survey, the following results are obtained: evaluation results by non-experts using the simple diagnosis method have large error in the horizontal resistant force score D×E with RMS of 0.52, as well as the ground and foundation score A, and the eccentricity score B×C with RMSs of 0.22 and 0.21, respectively. However, evaluation results by experts using the simple diagnosis method do not have small error (RMSs of 0.37 and 0.18, respectively), either. Therefore, the following measures can be proposed to improve the accuracy of the simple diagnosis method:

a) Provide land condition (geologic and geomorphologic) database
b) Present sample photographs of foundation cracks to prompt them to check carefully before their diagnosis
c) Indicate alternatives of wall length along with a house plan and consider a roof type
d) Add the questionnaire entry on wall types of inner and outer walls
e) Add the questionnaire entries on the second floor area and the center of gravity

In the above measures, b) and c) can be easily taken into account with illustration. Regarding a), there have already been some services to provide geological information through the Internet.

The simple diagnosis method has the great advantage that non-experts can identify week points of their houses with short time. Actually, many private and public sectors are offering interactive Web pages in which one can evaluate his or her home using this method. The present authors are expecting that the Internet diagnosis service with the above proposed improvements will promote retrofitting of low-seismic-capacity houses, and taking earthquake insurance of high-seismic-capacity houses in order to decrease total seismic risk of buildings.

Acknowledgements

The authors wish to thank the Non-Life Insurance Rating Organization of Japan and the Association for the Development of Earthquake Prediction for their supports to this research project.

References

Geographical Survey Institute, Ministry of Construction, 1980, 1:25,000 Land Condition Map, North-East of Tokyo.

Geographical Survey Institute, Ministry of Construction, 1981, 1:25,000 Land Condition Map, South-West of Tokyo.

Housing Bureau, Ministry of Construction (supervisor), the Japan Building Disaster Prevention Association and the Japan Federation of Architects and Building Engineers Associations (editors), 1985. *Assessing the Earthquake Resistance of Your Home and Home Reinforcement* (in Japanese).

Housing Bureau, Ministry of Construction (supervisor), the Japan Building Disaster Prevention Association and the Japan Federation of Architects and Building Engineers Associations (editors), 1985b, *Accurate Assessment of the Earthquake Resistance of Wooden Housing and Home Reinforcement* (in Japanese).

Housing Production Division, Housing Bureau, Ministry of Construction (supervisor), Society for the Study of Housing Quality Assurance (editor), 2002, *Handbook on the Housing Quality Assurance Act (revised edition 2002),* Center for Better Living (in Japanese).

Okada, H., 1998, Standard for Estimation of Earthquake Resistance of Existing Wooden Buildings as Related to the Act of Densely Inhabited Areas Improvement for Disaster Mitigation, *Kenchiku Bousai,* No. 243, pp. 25-30 (in Japanese).

Sakamoto, I, 1995, Standard for Assessment of the Earthquake Resistance of Wooden Houses, *Kenchiku Bousai*, No. 208, pp. 8-18 (in Japanese).

Statistics Bureau & Statistics Center, Ministry of Public Management, Home Affairs, Posts and Telecommunication, 2000, Housing and Land Survey: Results of the 1998 Survey (Statistical Tables).

Urban Housing Improvement Office, Housing Bureau, Ministry of Construction (supervisor), 1998, *Commentary on the Standard for Assessment of the Earthquake Resistance of Existing Wooden Buildings under the Act of Densely Inhabited Areas Improvement for Disaster Mitigation,* the Japan Building Disaster Prevention Association (in Japanese).