Citizen-oriented Web-based Seismic Hazard and Risk Maps for Promoting Seismic Retrofitting of Housing

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SUMMARY
It is important for citizens to recognize their seismic risks and take measures to mitigate the damage caused by earthquakes. We have developed web-based seismic hazard and risk maps that allow citizens to recognize their seismic hazards and risks in order to promote seismic retrofitting of their houses. The detailed maps show estimates of the seismic intensity and the risk of building damage. A questionnaire survey on the web-based maps has been conducted to evaluate how the maps affect the citizens' disaster awareness and disaster prevention actions. The results show that the citizens are more likely to apply disaster-prevention measures, such as seismic diagnosis and seismic retrofit, when they know the seismic intensity and the degree of damage of their houses.

Keywords: seismic hazard map, seismic risk map, residential building, building damage, questionnaire survey

1. INTRODUCTION

When promoting earthquake resistant urban development, as a first step, it is important for individual citizens to recognize their own seismic risk and to perceive it as their own problem. Hazard maps can play an important role by giving citizens an image of what disasters could occur in their neighborhoods and making them think about what actions they should take. For example, concerning the seismic risk information sought by citizens, Olshansky[1] has pointed out that people have a strong desire to know what would happen to their own homes, and providing this kind of information can have a major effect on disaster prevention actions such as seismic retrofitting.

However, hazard maps are not being utilized adequately. Murosaki[2] has stated that this is because the maps are difficult to read and are distributed without explanations or information on what actions should be taken. To overcome these problems, maps should be easier for citizens to understand, provide adequate scientific explanations, and include information that will lead citizens to take disaster prevention actions after recognizing their risk. For citizens to accurately perceive risk information and take action for disaster prevention, as Fukuwa et al.[3] have noted, in addition to knowledge about earthquake phenomena, people need to have a correct and familiar understanding of the damage that earthquakes cause, to see this as something that affects them personally, and to fully accept the need for accident reduction measures; and therefore, it is important to give citizens a greater sense of personal relevance and acceptance.

Seismic hazard maps that indicate the degree of shaking are prepared by local governments and other agencies as seismic hazard and risk information for citizens. For example, the City of Yokohama[4] has prepared detailed hazard maps with a 50-meter grid. Some regional hazard and risk maps even include estimations of building damage, such as maps prepared by the Cabinet Office[5] for areas such as Setagaya-ku, Tokyo. Such maps show the distribution of building damage due to an earthquake as relative evaluations by town and street. Although these maps are very useful in helping citizens to be aware of seismic hazards and risks, they do not show damage to individual homes, since evaluation is based on a 50-meter grid or by town and street. As an improvement, maps have been proposed that would include damage estimations for individual buildings.[6]

To help citizens feel a sense of personal relevance and acceptance, it is significant to estimate the damage that their own homes would suffer in an earthquake, the matter of greatest concern to citizens. Therefore, the authors have prepared a building earthquake damage risk map[7] that includes estimations of damage to buildings. This map of wooden and reinforced concrete buildings classifies each building by type of structure, number of stories, and age, and maps out the dangers of building damage from the anticipated earthquake for each group of buildings on a 50-meter grid.

However, an interactive format is needed because there are limits to the information that can be expressed on a paper-based map, such as allowing users to select individual building types or locations to see the results, or giving explanations regarding the estimations. Therefore, in this study, based on that map, we have developed a web-based seismic hazard and risk map which citizens can access on the Internet. We also performed a questionnaire survey for the web-based map in order to examine citizens' disaster prevention awareness and the map's effects on their disaster prevention actions. The web-based map developed in this study, entitled "Seismic hazard and risk map of your neighborhood," can be accessed at <http://riskmap.enveng.titech.ac.jp/>.

2. FEATURES AND CONTENT OF THE WEB-BASED SEISMIC HAZARD AND RISK MAP

As stated in section 1, for citizens to adequately utilize seismic hazard and risk information, maps need to be easier for citizens to understand, provide sufficient scientific explanations, and include information that will lead citizens to take disaster prevention actions after recognizing their risk. It is also necessary to improve people's sense of personal relevance and acceptance in order to help them become properly aware of the risk information and take disaster prevention actions. Considering these points, we have developed a web-based seismic hazard and risk map that uses an interactive format to show people what would happen to their own homes in an earthquake.[1] In development of the web-based map, we took the following steps, keeping in mind the need for scientifically accurate evaluation as well as the need for an understandable presentation of information in order to build a sense of personal relevance and acceptance.

[1] In addition to showing the expected seismic intensity and estimated building damage, the maps describe in detail the seismic ground motions and the earthquake-resistance of buildings.
[2] The 50-meter grid detailed damage estimation maps show the seismic risk in the area around each house, enable each citizen to recognize the seismic risk as “a personal problem".
[3] Each of the three degrees of building damage described in the maps (collapse, severe damage and moderate damage) are illustrated so that citizens can more easily understand them.
[4] The risk of building damage is displayed not as a probability expression, which may be unclear to some citizens, but as one of ten rankings.
[5] If building is old, the effect of a seismic retrofit can be seen by indicating the reduction of extent of damage.
[6] Links are provided to sites for seismic diagnosis, retrofit and information about ways to prevent furniture from toppling, allowing citizens who have used these maps to determine their seismic hazards and risks and take appropriate disaster-prevention action.

Figure 1 indicates the sequence of screens. The main region covered by this map consists of the 23 cities of Tokyo and the cities of Kawasaki and Yokohama, and the anticipated earthquake is a magnitude 7.3 earthquake in northern Tokyo Bay, a model used by the Central Disaster Prevention Council. To provide citizens with a scientifically accurate and understandable presentation of building damage due to an earthquake, as indicated in measure [1], screen 4 states that building damage is determined by the earthquake resistance of the ground and building, which influences the extent of shaking. Building damage will be more serious if either the ground or the building has weak earthquake resistance, so explanations are given concerning the ground's earthquake resistance in screen 5, and concerning a building's earthquake resistance in screen 8. In other words, we explain the difference in extent of shaking depending on the type of ground in screen 5, and we explain the differences in building earthquake resistance based on the structural type and age of the building in

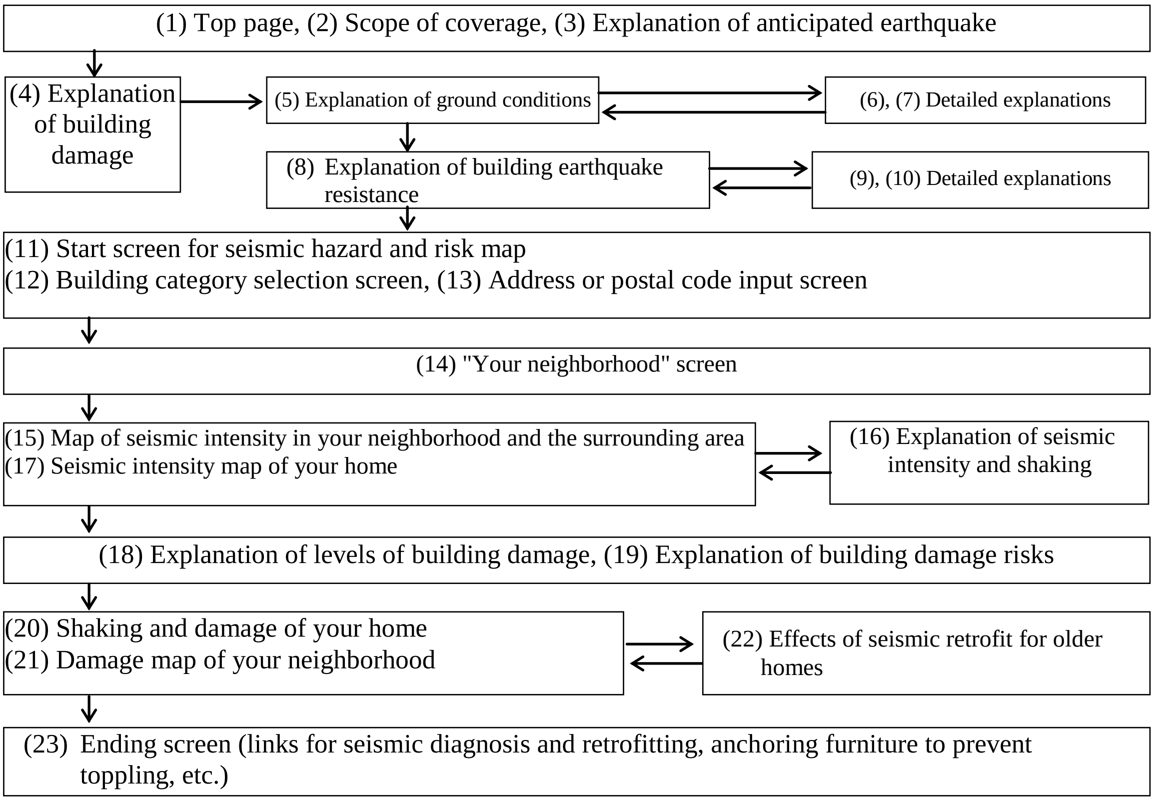


Figure 1. Sequence of Seismic Hazard and Risk Map Screens

screen 8. Users who want to learn more can access detailed information concerning ground conditions on screens 6 and 7, or concerning building earthquake resistance on screens 9 and 10.

Next, on screen 12, citizens select the building category of their own home, and on screen 13, they enter the address or postal code. This brings up a regional map of the area of their own home on screen 14, in order to provide a sense of personal involvement as indicated in measure [2]. The hazard map portion comes next. First, a seismic intensity map of the anticipated earthquake is shown on screen 15, so that users can determine seismic intensity in the area of their house. Next, an explanation of seismic intensity and shaking is shown on screen 16. Screen 17 shows an enlarged seismic intensity map in case of the anticipated earthquake, so that users can check the seismic intensity at their own home.

The next part is the building damage risk map. First, as indicated in measure [3], screen 18 describes the three categories of building damage: "collapse" in which the home collapses with the risk of loss of human lives, "severe damage" in which a house must be rebuilt, and "moderate damage" in which repairs are needed. Next, as stated in measure [4], screen 19 explains that the home's level of risk is expressed according to a total of ten ranks based on the potential for collapse, severe damage, or moderate damage. Ordinarily, the potential for collapse, etc. would be indicated as a percentage, but we decided instead to express it in terms of ranks, such as "high risk of collapse," because most citizens are not familiar with probability expressions.[8] The home's anticipated seismic intensity and building damage are shown on screen 20, and screen 21 shows the damage that would occur if the surrounding area was of the same building category as the home. Next, as indicated in measure [5], if the home is an older building, screen 22 lets the user determine the effects of a seismic retrofit by showing how much the damage would be reduced by seismic retrofitting to improve earthquake resistance. Last, as indicated in measure [6], screen 23 shows how to obtain information on seismic diagnosis, seismic reinforcement, and anchoring furniture.

3. CONTENT OF QUESTIONNAIRE SURVEY

In January 2011, we conducted an online questionnaire of residents concerning the web-based seismic hazard and risk map (abbreviated below as "seismic hazard and risk map") in order to determine its effects. The questionnaire subjects were heads of households or their spouses, living in their own detached homes of wooden construction for the most part. In selecting areas to be surveyed, we focused on districts with many wooden dwellings in the 23 cities of Tokyo and the cities of Kawasaki and Yokohama, areas that would be threatened by a near-field earthquake in the Tokyo region. The average age of respondents was 49.0, and we received a total of 2,154 responses. Table 1 shows the main questions of the survey.

Among these, questions (b) and (j) were provided to allow determination of changes in disaster prevention measures and costs of planned seismic retrofitting by citizens before and after accessing the seismic hazard and risk map software. Rowan[9] has introduced the CAUSE model to explain the five stages of risk communication: [1] establishing **Credibility**, [2] **Awareness** of risk, [3] enhanced **Understanding** of risk, [4] determining possible **Solutions**, and [5] **Enactment** of such solutions. Figure 2 shows the five stages of the process leading to implementation of disaster prevention measures by citizens, based on the CAUSE model. The disaster prevention measures corresponding to stages [2] to [5] are then listed in Fig. 3. The effects of using the seismic hazard and risk map can be determined by comparing the implementation status of each item before and after accessing the seismic hazard and risk map. A strict application of the CAUSE model can only evaluate actions that have actually been implemented; however, it takes time for such actions to be taken. Therefore, we asked instead about intended actions. The survey questions were determined with reference to the CAUSE model although this model is not followed strictly.

Table 1. Main Questions of Online Questionnaire

(a)	Attributes of respondent (Age, gender, number of household members, type of residence, age of building, type of building structure, number of stories, location of home, and household income)
(b)	Disaster prevention measures, etc., taken before accessing the software
(c)	Seismic retrofit costs envisioned before accessing the software
(d)	Comparison of anticipated seismic intensity with respondent's previous conception
(e)	Seismic retrofit costs envisioned after learning the anticipated seismic intensity
(f)	Comparison of anticipated building damage with respondent's previous conception
(g)	Seismic retrofit costs envisioned after learning the anticipated building damage
(h)	Seismic retrofit assistance programs of local governments
(i)	Usability and understandability of the software
(j)	Disaster prevention measures, etc., desired after accessing the software

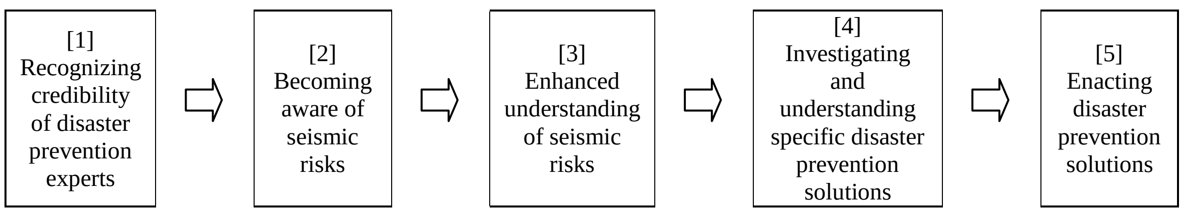


Figure 2. Process Leading to Disaster Prevention Measures by Citizens

Questions (c), (e), and (g) in Table 1 are designed to allow the effects of the seismic hazard and risk map to be determined more quantitatively. We asked respondents to assign monetary amounts to the costs of planned seismic retrofitting at three stages: before accessing the seismic hazard and risk map, after accessing the seismic hazard and risk map and learning the anticipated seismic intensity at one's home, and after learning the anticipated building damage to one's home.

4. EFFECTS SEEN IN INTENTIONS FOR DISASTER PREVENTION ACTIONS

Figure 3 shows respondents' intentions for the items of disaster prevention measures corresponding to the four stages numbered [2] through [5] in Fig. 2 before and after accessing the seismic hazard and risk map. This data covers all respondents (2,154 persons), and multiple responses were permitted. In Fig. 3, persons who had already performed a particular disaster prevention item before accessing the seismic hazard and risk map are shown in blue, while persons who intended to take such actions in the future after accessing the seismic hazard and risk map are shown in red. To prevent double counting of respondents, the number of persons who had already implemented an action before accessing the map was subtracted from the number of persons who intended the same action after accessing the map.

Figure 3. Disaster Prevention Actions Performed Before Accessing the Seismic Hazard and Risk Map and Planned After Accessing the Map

While 15% of the respondents had already used earthquake maps, etc. issued by local governments to check seismic intensity (stage 2) before accessing the seismic hazard and risk map, another 25% stated that they intended to do so after accessing the seismic hazard and risk map. Also in stage 2, while 4% of respondents had participated in seminars by disaster prevention experts to learn about earthquake disasters before accessing the map, another 6% planned to do so afterward. In stage 3, before accessing the map, 19% had checked how to use the disaster phone message system, but another 21% planned to do so after accessing the map. In stage 4, while 6% had checked the earthquake resistance of their homes by obtaining a seismic diagnosis from the local government, etc., before accessing the map, another 19% intended to do so afterward. Before accessing the map, 6% had checked on seismic retrofit methods and costs, but another 26% planned to do so afterward. While 6% had checked on their local government's seismic retrofit assistance programs before accessing the map, another 23% intended to do so after accessing the map. And in stage 5, 4% of respondents had already implemented a seismic retrofit before accessing the map, but another 8% planned to do so afterward. Also in stage 5, 33% had anchored their furniture before accessing the map but another 25% planned to do so afterward; and 32% had prepared disaster prevention items before accessing the map but another 23% planned to do so afterward.

As we have seen, the percentages intending to take action increased greatly, especially for items related to seismic diagnosis and seismic retrofit, which belong to stages 4 and 5 in which citizens actually engage in disaster prevention measures. It was confirmed that many citizens intended to take measures after they had accessed the seismic hazard and risk map.

5. EFFECTS SEEN IN PLANNED SEISMIC RETROFIT COSTS

5.1. Overall Trends

Figure 4 shows changes in planned seismic retrofit costs among all 2,154 respondents. Before accessing the seismic hazard and risk map, the average amount of planned seismic retrofit costs was ¥665,000, but upon accessing the map, the average amount rose to ¥827,000 after finding out the anticipated seismic intensity and to ¥856,000 after learning the extent of damage that would affect their own homes.

Respondents who had no funds budgeted for a seismic retrofit or believed that their homes were already adequately earthquake resistant gave "zero" as the planned seismic retrofit cost. The proportion of respondents giving this response was 56% before accessing the seismic hazard and risk map, but upon accessing the map, this response declined to 48% after finding out the seismic intensity and to 47% after learning the extent of estimated building damage. Also, before accessing the seismic hazard and risk map, 27% planned to spend at least ¥1 million on a seismic retrofit, but this proportion increased to 33% after finding out the seismic intensity and to 34% after learning the extent of estimated building damage.

As the data shows, more respondents intended to perform a seismic retrofit after they had accessed the seismic hazard and risk map and learned about the seismic intensity and building damage estimated for their own homes.

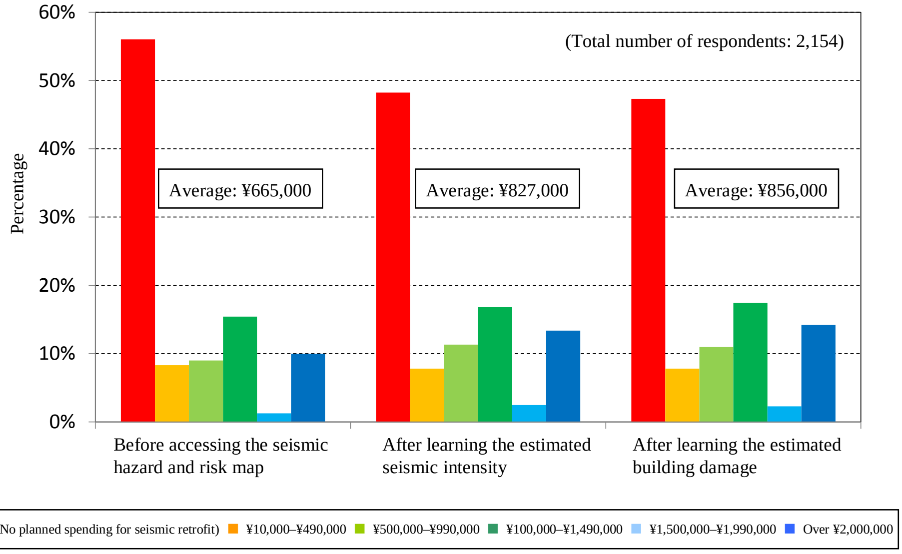


Figure 4. Trends in Planned Seismic Retrofit Costs (Overall)

5.2. Results in Terms of Respondent Attributes

First, Fig. 5 shows the average planned seismic retrofit costs for respondents falling into three categories according to household income: under ¥6 million, ¥6-¥10 million, and over ¥10 million. The higher the household income, the higher the average planned seismic retrofit costs. For households having incomes of over ¥10 million, planned retrofit costs were approximately double those of the other two groups.

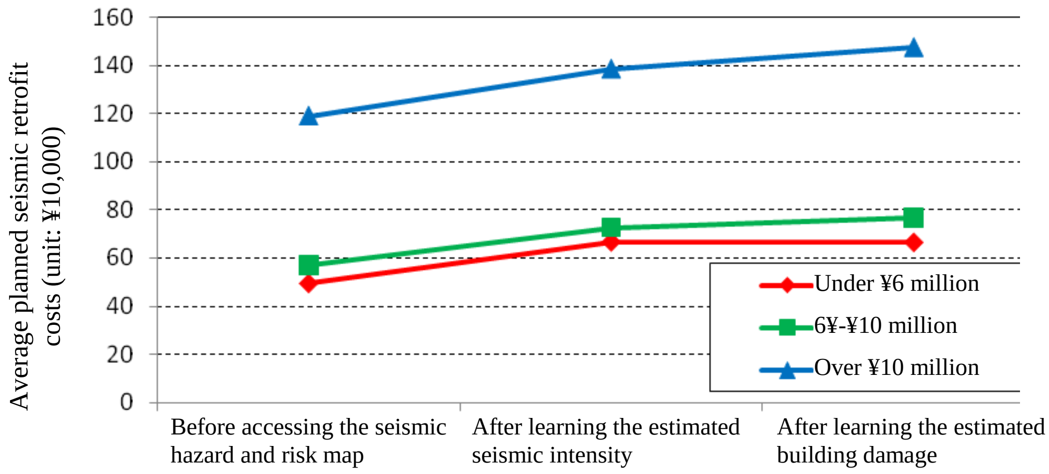


Figure 5. Trends in Planned Seismic Retrofit Costs (By Household Income)

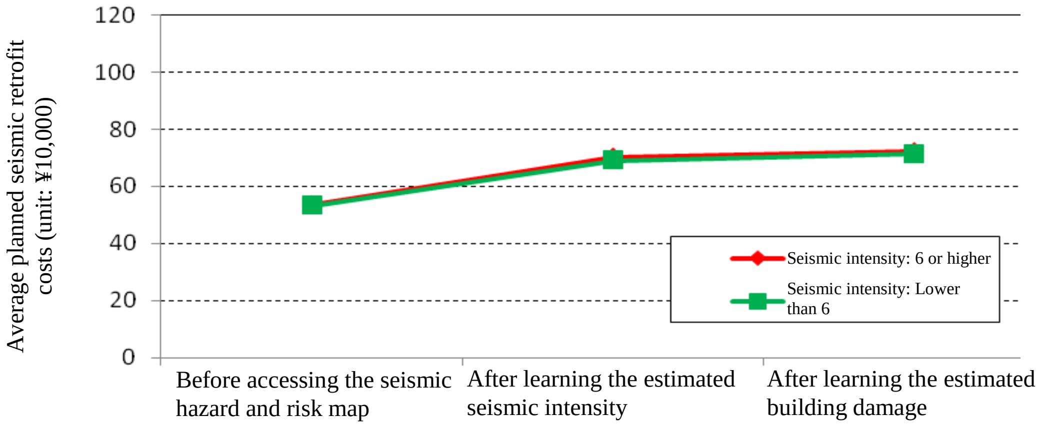
To express the above in other words, it is important to improve plans for seismic retrofitting among persons having household incomes under ¥10 million who are not planning to spend much money on seismic retrofitting. Below, we will examine the 1,369 respondents having household incomes under ¥10 million according to estimated seismic intensity, estimated building damage, and building age.

First, we divided respondents into two groups according to whether the anticipated seismic intensity at their homes according to the seismic hazard and risk map was magnitude 6 and up, or less than magnitude 6, and compared their average planned seismic retrofit costs. As shown in Fig. 6, part (a), there was practically no difference in planned costs between these two groups. In other words, their intentions concerning seismic retrofitting did not change much just by learning the seismic intensity.

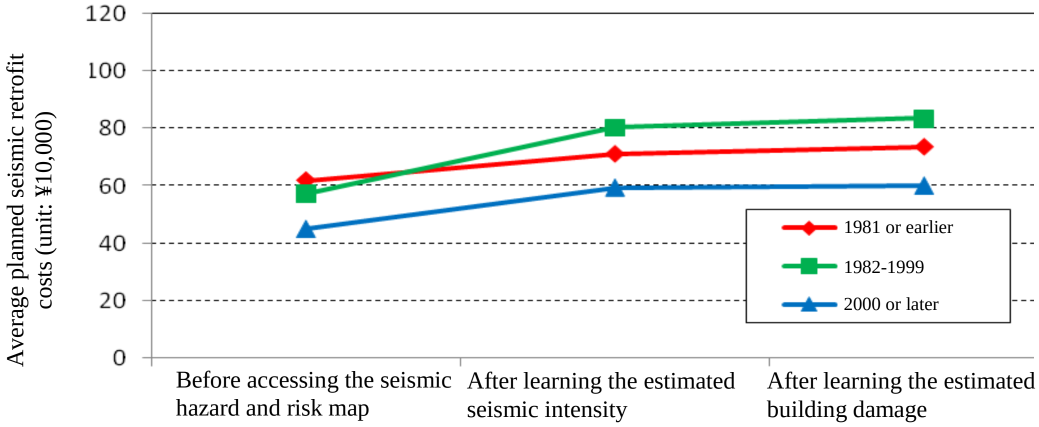
Next, we divided respondents into three groups according to whether their homes were built in 1981 or earlier, 1982-1999, or 2000 or later, and compared their average planned seismic retrofit costs. The results are shown in Fig. 6, part (b). The averages were similar for homes built in 1981 or earlier and homes built from 1982 to 1999, but lower for homes built since 2000. This is apparently because less need for seismic retrofitting is perceived for newer buildings since earthquake resistance was already taken into consideration during their construction, as stated in section 4.

Last, we divided respondents into three groups according to whether the anticipated damage to their homes was classified as collapse, severe damage, or moderate damage, and compared their average planned seismic retrofit costs. The results are shown in Fig. 6, part (c). The planned seismic retrofit costs were lowest for the "moderate damage" group, higher for the "severe damage" group, and highest for the "collapse" group. The "collapse" group indicated high cost levels even before accessing the map. After accessing the map, the questionnaire asked respondents about how they would have responded if they had never accessed the map. It seems possible that respondents already knew about anticipated building damage before taking the survey, and therefore would have indicated high cost levels before accessing the map. In any case, this indicates that the more severe the anticipated damage to their homes, the higher the planned seismic retrofit costs that were envisioned by respondents.

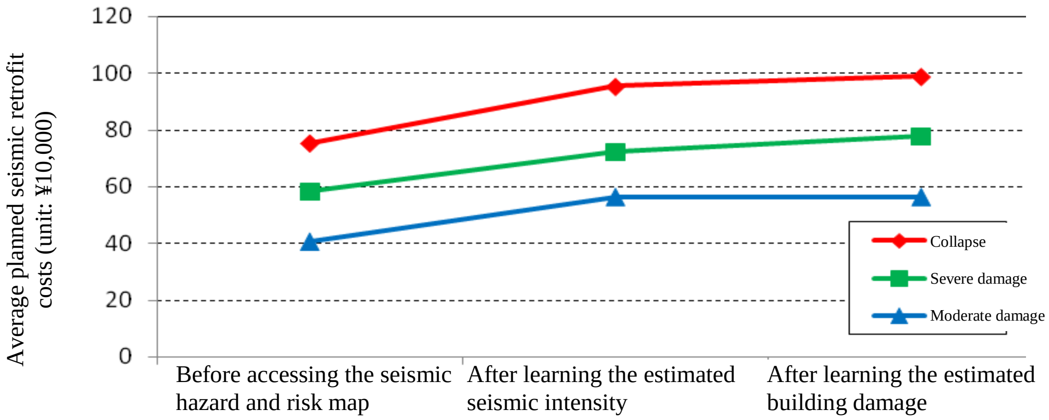
The above data shows that respondents tended to indicate higher planned seismic retrofit costs after accessing the seismic hazard and risk map than before doing so. The extent of damage to their homes had more of an effect than the level of seismic intensity. Therefore, it appears that in order to give citizens a sense of personal relevance and acceptance, it is effective to inform them not only about anticipated seismic intensity at their homes, but also about the extent of building damage.



(a) By anticipated seismic intensity



(b) By age of building



(c) By anticipated building damage

Figure 6. Trends in Planned Seismic Retrofit Costs for Households with Incomes Under ¥10 million

6. CONCLUSION

To make citizens more aware of seismic risks, we developed an interactive web-based seismic hazard and risk map that lets citizens know what would happen to their own homes in an earthquake, promoting a sense of personal relevance and acceptance by making it easy to understand and adding explanations, and taking care to include information that can lead to disaster prevention actions. To determine the effects of this map, we conducted an online questionnaire survey. The results indicate a high likelihood that citizens will take disaster prevention measures such as seismic diagnosis and seismic retrofitting if they understand the seismic intensity and building damage that are estimated for their own homes. To obtain a quantitative measure of the effects, we conducted a comparison of planned seismic retrofit costs before and after accessing the seismic hazard and risk map, and determined that citizens planned to spend more on seismic retrofitting after they had accessed the map, and particularly after they had learned the extent of estimated building damage.

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