Results of A Real-time Questionnaire on the Vibration Sense of Human During Earthquakes

Harumi Yoneda*1 Mutsuhiro Yoshizawa*2
Rin Ohmoto*3 Akira Kuriyama*4

Summary

JMA seismic intensity scale is known for index of intensity of earthquake motion. However, it should be noted that vibration sense of human during an earthquake differs depending on the scale and characteristics of the building even at the same intensity. Aiming at improvement of information support after earthquake, the authors compared seismic intensity scale with the vibration sense of human and analyzed free-description comments using data of real-time questionnaire about earthquake. The responses to the questionnaires show that people begin to feel fear from about JMA seismic intensity 3. In addition, it was found that even people far from the hypocenter feel large shaking during a long-period earthquake motion.

Keywords: JMA seismic intensity scale, long period ground motion, real-time questionnaire, vibration sense

1 Introduction

The Japan Meteorological Agency (JMA) seismic intensity score is recognized as an index that comprehensively represents the intensity of shaking caused by an earthquake. The JMA previously determined seismic intensity based on the shaking experienced by observers in meteorological observatories and surveys of surrounding conditions; however, since April 1996, the seismic intensity has been calculated according to the value of the instrumental seismic intensity automatically calculated by a seismic intensity meter installed on the ground[1)]. The explanatory table related to the JMA seismic intensity scale presents human experiences and behaviors, indoor conditions, outdoor conditions, wooden buildings, and reinforced concrete buildings; however, it should be noted that even with the same seismic intensity, the human experiences and indoor conditions differ depending on the scale and characteristics of the building[2)]. Long-period ground motion, which attracted attention with the Great East Japan Earthquake, is more likely to occur when the epicenter is shallow and the magnitude is large[3)], and it may cause major shaking in high-rise buildings with a long natural period. Therefore, in September 2020, the JMA began announcing long-period ground motion classes[4)] to evaluate shaking in different structures due to long-period ground motion, which is difficult to evaluate based on seismic intensity. It was announced in newspapers that from the latter half of 2022, long-period ground motion classes will also be used in the issuance criteria for early earthquake warnings and that there has been a movement toward diversification of the dissemination of earthquake-related information from the JMA. Recipients must interpret this seismic information with reference to the characteristics of the target building.

We previously conducted a survey on the human experience of the shaking of buildings during an earthquake in order to provide effective disaster prevention information that gives building users a sense of security during an earthquake. Numerous post-earthquake surveys of building users have been conducted on the shaking of buildings and interior damage during the Great East Japan Earthquake[5)-7)], providing valuable knowledge. However, the cases in which such surveys are conducted are limited to large-scale earthquake disasters, i.e., they are not conducted for small earthquakes. Furthermore, surveys are not conducted immediately after an earthquake, meaning the shaking experience is forgotten. Therefore, we developed a real-time questionnaire system linked to early earthquake warnings and seismometers and collected data on the human experience of shaking. The first system was developed as part of an emergency early earthquake warning application for mobile devices. The app is open to the public, has been downloaded six million times, and collects a wide range of data from an unspecified number of people during an earthquake. The second is a system for specific building users, which automatically conducts an online questionnaire immediately after an earthquake is observed in a building; it is currently being implemented in seven office buildings. All buildings are equipped with

*1 Senior Researcher, Research & Development Institute, Dr. Eng.
*2 Senior Chief Researcher, Research & Development Institute, Dr. Eng.
*3 RC Solution Co.
*4 Chief Executive Officer, RC Solution Co.

seismometers on the lowest and uppermost floors, and the relationship between observation records and questionnaire responses can be explored.

This paper aims to provide disaster prevention information to building users and facility managers after future earthquakes. We analyzed the relationship between the real-time questionnaire results for major earthquake records collected using both systems and disaster prevention indices, such as the JMA seismic intensity and the long-period ground motion scale.

2 Overview of real-time questionnaire

In this paper, we analyzed the results of two types of real-time questionnaires. The first is the data from the "shaking experience" function (henceforth referred to as "shaking experience") in an emergency early earthquake warning notification application[8]. Shaking experience is divided into five classes: "no shaking," "maybe shaking?," "some shaking," "moderate shaking," and "extreme shaking," this is then shared on a map (Fig. 1). There is also the option for the user to enter their floor and a comment of up to 17 characters. Their shaking experience can be input at any time, regardless of whether an earthquake has occurred or not. Shaking experience began operation in November 2015, and as of June 30, 2022, it has accumulated approximately 1.37 million data points.

The second is the result of an online questionnaire that used an earthquake observation system targeting office buildings[9] (henceforth, "earthquake questionnaire"). When an

(a) Shaking experience display screen (b) Shaking experience response screen (c) Comment display screen

"no shaking" "maybe shaking?" "some shaking" "moderate shaking" "extreme shaking" "post experience"

Fig.1 Function of shaking experience

Table 1 Questionnaire items

No.	Question	Answer choices
Q1	Where did you experience the earthquake shaking? (If you did not experience it, please choose your location when the earthquake occurred.)	Floor/absent from building/do not remember
Q2	Please tell us your position when you experienced the earthquake shaking. (If you did not experience it, please select your position when the earthquake occurred.)	Sitting/standing/walking/lying down/other/do not know, do not remember
Q3	Did you take emergency action when you experienced the earthquake shaking?	Nothing/sheltered under desk/protected myself from falling objects (e.g., wore helmet)/opened door and evacuated immediately/other action/do not remember/did not experience shaking
Q4	What was the strength of the earthquake shaking that you experienced?	Experienced slight shaking/clearly felt shaking, but no difficulty in performing activities/some difficulty in performing activities, like walking or moving/unable to stand/tossed around due to the shaking and was unable to do anything of my own will/do not know, do not remember/did not experience shaking
Q5	What kind of shaking did you experience? You may select multiple answers.	Slow shaking/rotating shaking in all cardinal directions/shaking that moved from side to side/shaking that thrust up and down/shaking that felt like a sudden increase in movement/do not know, do not remember since shaking was small/do not know, do not remember since shaking was large/did not experience shaking/other
Q6	How long did you feel the shaking (experienced length)?	Less than 10 s/approximately 30 s/approximately 1 min/approximately 2 min/2 min or more/do not know, do not remember/did not experience shaking
Q7	Did you feel scared when the earthquake shaking occurred?	Not scary/slightly scary/scary/very scary/do not know, do not remember/did not experience shaking
Q8	Did you feel unwell during the earthquake shaking?	Nothing at all/felt somewhat unwell, such as being dizzy/felt very unwell, such as being dizzy or having nausea/felt extremely unwell, such as vomiting/lying down due to feeling unwell/do not know, do not remember/did not experience shaking
Q9	How much shaking did you experience in terms of the seismic intensity scale (henceforth, "seismic intensity experienced")?	Seismic intensity 1 or lower to seismic intensity 6 Lower or higher/do not know, do not remember/did not experience shaking
Q10	Please provide any other description	(Free response)

earthquake is observed in a target building and the acceleration exceeds a trigger level (set at approximately 1–2 cm/s^2), an e-mail is immediately sent to the registered users at that building, prompting them to respond to the questionnaire. The effective response period is set to one week after an earthquake to ensure that people who felt the shaking can respond before they forget the experience. Table 1 presents the survey questions, which were set with reference to previous research on questionnaires after major earthquakes. Additionally, participants were asked to provide their age and sex and to register the seismic intensity they experienced during the Great Hanshin Earthquake and the Great East Japan Earthquake, as well as provide information on the maximum seismic intensity experienced in other earthquakes.

Table 2 shows the earthquakes selected for analysis. The shaking experience data show a certain number of irrelevant responses that are unrelated to earthquake shaking. Therefore, if the scale of the earthquake is small and the number of responses is small, then there will be a relatively large amount of irrelevant data. In this analysis, we targeted earthquakes with a maximum seismic intensity of 6 Lower or 7, and which had 2,000 or more responses within one hour of the earthquake (henceforth, "one-hour number of responses"). We also added earthquakes for which class 1 long-period ground motion or higher was observed and where the number of responses exceeded 5,000.

Table 2 Earthquakes for analysis

Earthquake No.	Date and time YYYY/MM/DD, HH:MM (24 h)	Hypocenter	Magnitude	Maximum seismic intensity	Maximum long-period ground motion class	One-hour number of responses
1	2016/4/1, 11:39	Southeastern Mie Prefecture	6.5	4	1	5,747
2	2016/4/16, 01:25	Kumamoto region, Kumamoto Prefecture	7.3	7	4	9,403
3	2016/10/21, 14:07	Central Tottori Prefecture	6.6	6 Lower	3	6,291
4	2018/6/18, 07:58	Northern Osaka Prefecture	6.1	6 Lower	2	2,633

3 "Shaking experience" data analysis results

3.1 Status of data submission

Fig. 2 shows the changes in the number of shaking experience responses one hour after each earthquake. Earthquakes No. 1, 3, and 4 received many responses in the first 10 min, with the number then gradually increasing. Earthquake No. 3 received a number of responses that slightly increased locally approximately 45 min after the earthquake. This may be because an early earthquake warning was issued for the aftershocks that occurred at this time. Earthquake No. 2 involved an earthquake with a maximum seismic intensity of 6 Lower occurring approximately 20 min after the main shock, and an early earthquake warning was issued. As a result, its rate of increase was larger than that of other earthquakes.

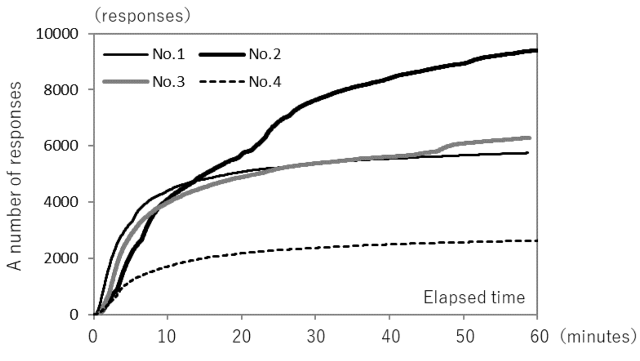


Fig.2 Plot of responses versus time

3.2 Comparison with instrumental seismic intensity distribution

The shaking experience data includes the latitude and longitude of each respondent, which were compared with the estimated

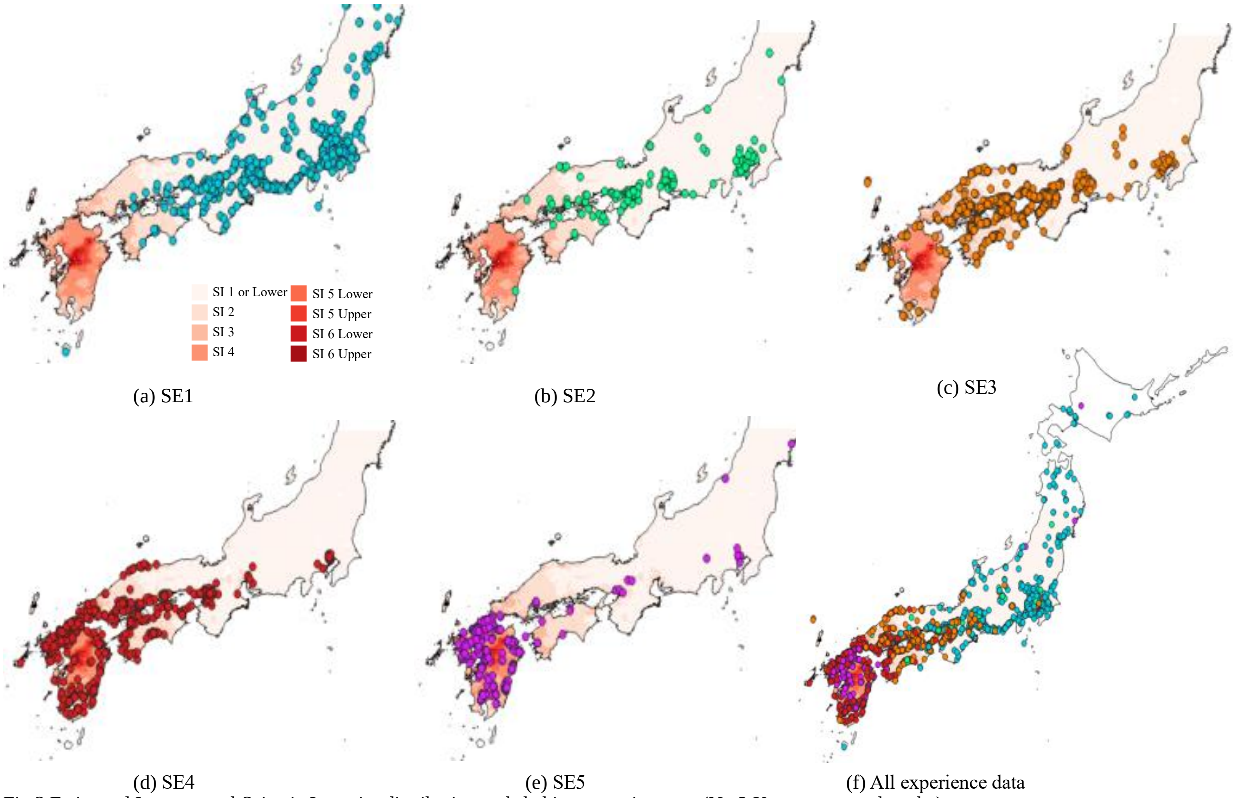


Fig.3 Estimated Instrumental Seismic Intensity distribution and shaking sensation map (No.2 Kumamoto earthquake)

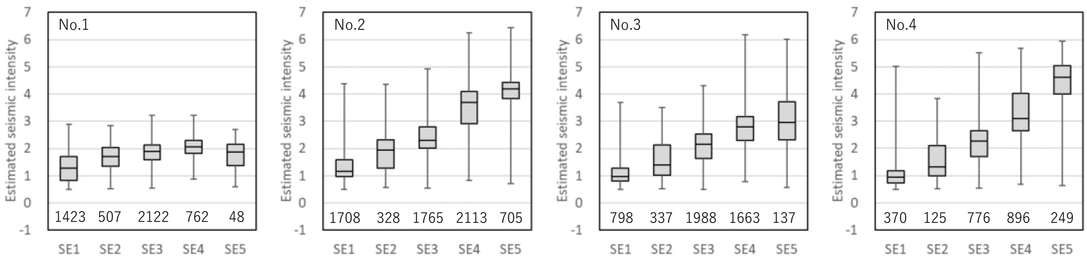


Fig.4 Relationship between shaking experience answer and estimated seismic intensity

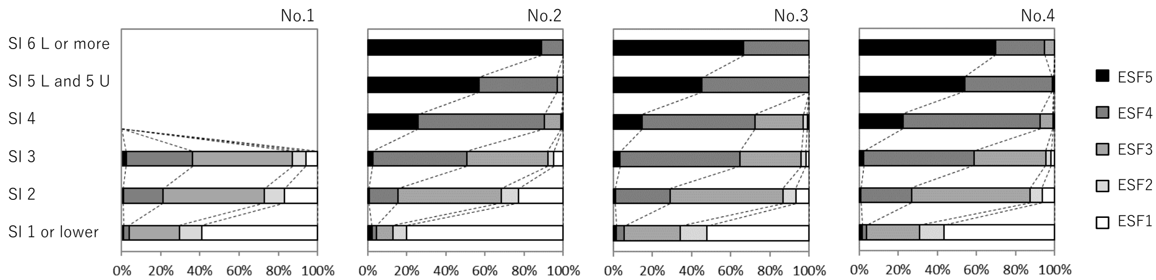


Fig.5 Ratio of shaking experience answer and estimated seismic intensity

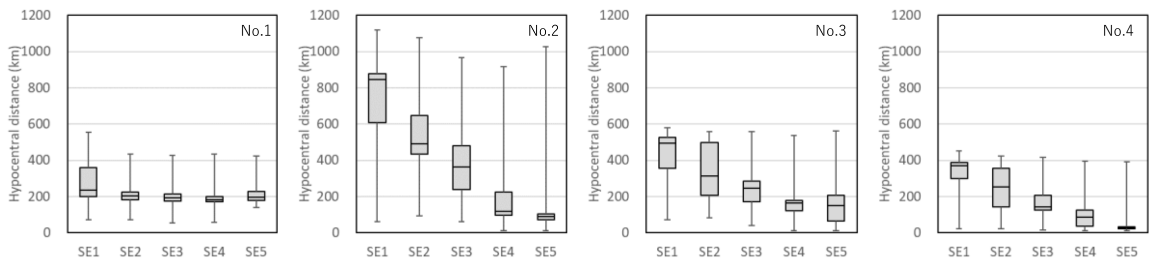


Fig.6 Relationship between shaking experience answer and hypocentral distance

measured seismic intensity distribution of the seismic motion map published on the seismic motion map real-time estimation system (henceforth, “QuakeMap”)[10]. For Earthquake No. 2 (2016 Kumamoto earthquake), Fig. 3 shows the shaking experience data in the 10-min period after the earthquake and the estimated measured seismic intensity distribution. Henceforth, the shaking experience will be expressed as follows: “no shaking" will be referred to as “SE1” (where “SE” is an abbreviation for " Shaking Experience”), “maybe shaking?” as “SE2,” “some shaking” as “SE3,” “moderate shaking” as “SE4,” and “extreme shaking” as “SE5.” “SE1” is distributed all over Japan, “SE2” has a slightly narrower range than that of “SE1,” and responses from urban areas with large populations are prominent. “SE3” corresponds to more submissions from rural areas adjacent to the hypocenter than those from other areas, whereas “SE4” and “SE5” are concentrated near the hypocenter and urban areas. For the rest of the study, among the responses submitted within the range where estimated instrumental seismic intensities are available from QuakeMap, those within one hour of the earthquake were analyzed. Additionally, for data submitted multiple times by the same user, the first response was used. Notably, the estimated instrumental seismic intensity of smartphone GPS and QuakeMap may contain an error of several hundred meters, and the estimated instrumental seismic intensity of QuakeMap is the instrumental seismic intensity estimated for the entire area and is different from the actual instrumental seismic intensity. Fig. 4 shows a box plot of the estimated measured seismic intensity for each experience as well as the number of submissions for each experience category. The median value of each experience is roughly proportional to the estimated instrumental seismic intensity. Fig. 5 shows the ratio of experience data for each estimated seismic intensity scale, which is arranged by seismic intensity scale. Seismic intensity 1 or lower tended to correspond to “SE1;” seismic intensity 2 to “SE3;” seismic intensities 3 and 4 to “SE 4;” and seismic intensity 5 Lower and higher to “SE5.” For all earthquakes No. 1–4, a phenomenon was observed in which the ratio of “SE5” with a seismic intensity of 1 or lower was greater than the ratio of “SE5” with a seismic intensity of 2. This can be attributed to a certain number of irrelevant responses. Fig. 6 shows a box plot of the hypocentral distance for each experience. For earthquakes No. 1 and 3, many people felt “SE5” in a range as far as 200 km from the hypocenter; whereas for earthquakes No. 2 and 4, this was concentrated within approximately 100 km. Earthquakes No. 1 and 3 exhibited long-period ground motion classes even in Osaka and Aichi Prefectures, which have large populations. In particular, almost all the responses for “SE5” in No. 1 had distances of 150 km or more from the hypocenter, which is likely due to long-period ground motion.

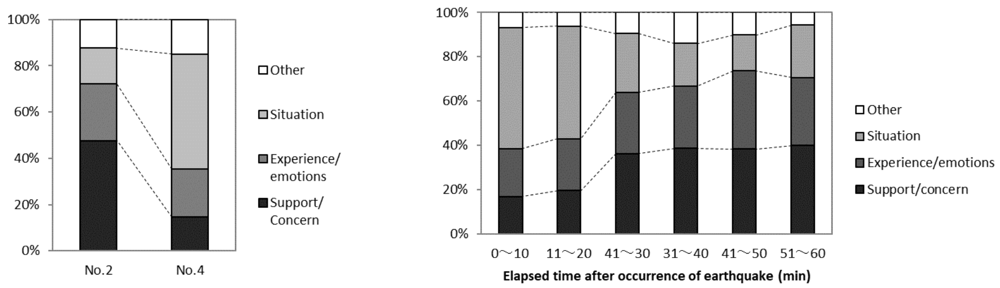
3.3 Additional comments

Approximately 40% of all shaking experience data were added as additional comments for each earthquake. Since there was a limit of 17 characters, 90% were short, with approximately 10 characters or fewer. The comment contents were examined for earthquake No. 2, which had a seismic intensity of 7, and inland earthquake No. 4, whose hypocenter was near a major city. The comments were classified as those about the “situation” of the shaking or damage, “experience/emotions” about the shaking, classification. For No. 2, the shifts in the ratios of each category in the elapsed time are also shown. Upon comparing No. 2 and 4,

Table 3 Classification of additional comments and examples

Classification	No. 2 (Kumamoto earthquake main shock)	No. 4 (earthquake in northern Osaka Prefecture)
Situation	Incredible/glass broke/house collapsed/ many aftershocks/ground rumbling/long	Shook a lot/upward-thrusting shaking/horizontal shaking/objects scattered indoors/ground rumbling
Experience/emotions	Scary/crazy/cannot sleep/sick of it/thought I would die	Surprised/scared/crazy/thought I would die
Support/concern	Are you ok?/concerned/do your best/take care/ let us do our best/thanks for the support	
Other	Shaking slowly/looking for girlfriend/sign of Nankai Trough earthquake?	

*No specific characteristic differences due to earthquake in “support/concern” and others. Other



(a) Comparison between No. 2 and No. 4 (b) Shifts in elapsed time of No. 2

Fig.7 Ratio of classifications of additional comments

No. 2 had the most "support/concern"-related comments, whereas No. 4 had the most "situation"-related comments. No. 2 also had the most "situation"-related comments immediately after the earthquake, but "support/concern" increased over time. This is an example of an app functioning as a bulletin board for information transmission and support for disaster areas by users who learned about the earthquake from the news. No. 4 also had a large number of "support/concern" comments, but there were few subsequent aftershocks compared to that for No. 2, and the ratio was smaller. For the relationships with experience, seismic intensities of 2 or lower had many "support/concern"-related comments, and seismic intensities of 3 or higher had more "experience/emotions"-related comments that communicated feelings of urgency and fatigue. Comments such as "it was scary" began to increase from an estimated measured seismic intensity of the respondents of approximately 3 onward.

4 Analysis of earthquake questionnaire

4.1 Earthquake observation results and survey questions

This report focuses on the results of earthquake No. 4, in which a seismic intensity of 5 Lower was observed at M-building (RC structure, B4F9) in Chuo-ku, Osaka. The M-building had a hypocentral distance of approximately 20 km, and the shaking shown in Table 4 was observed inside the building. The largest earthquake since the start of the earthquake questionnaire was observed in this building, so we conducted not only the real-time questionnaire for online questionnaire users but also an emergency offline survey with the questions shown in Table 1, where we expanded the scope to include building users other than the app users; we obtained a total of 156 responses between June 18th and 27th. The earthquake occurred approximately 30 min before the start of work, meaning 66 respondents were inside the building and 90 outside the building at the time of the earthquake, with many people on the train. Some people outside the building did not feel the shaking, but everyone inside the building felt the shaking.

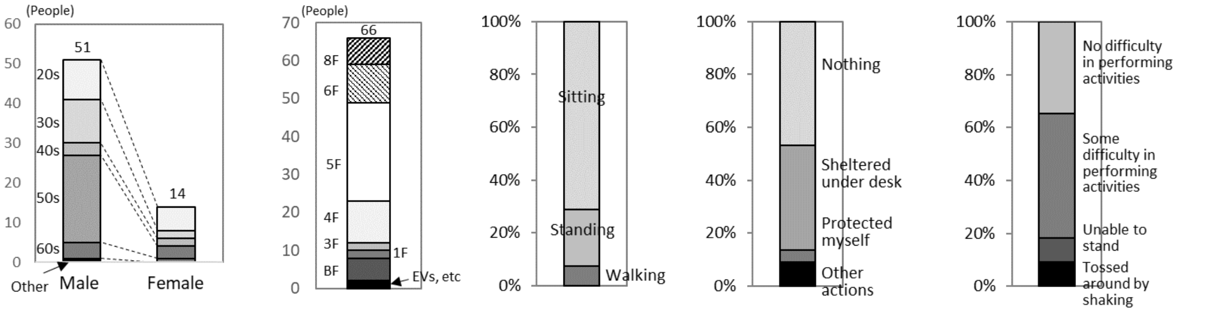
Fig. 8 shows the results of the survey of the people inside the building. The male:female ratio of the questionnaire respondents was approximately 8:2, and approximately half the respondents were 50–59 years old or older. Fig. 8(b) shows the distribution of respondent location by floor. For their position when they felt the shaking (Q2), "sitting" was the most common response; for emergency action (Q3), "nothing" was the most common response, followed by "sheltered under the desk." For difficulty of activities (Q4), "some difficulty in performing activities" accounted for >60% of the total. For shaking experienced (Q5), "shaking that thrust up and down" was the most common response at 55% of the total, followed by "shaking that felt like a sudden increase in movement" and "shaking that moved from side to side." For duration of shaking experienced (Q6), "approximately 30 s" and "less than 10 s" accounted for approximately 90% of the total, and many of the respondents felt short periods of shaking due to the nature of the inland earthquake. There were also responses such as "slow shaking" and "shaking for over 1 min." For fear experienced (Q7), "not scary" accounted for an extremely small fraction at 6%. For physical condition (Q8), "nothing at all" was the majority response, but approximately 20% selected "felt somewhat unwell" and "felt unwell."

Fig. 9 shows the relationship between the questions. The relationship between position and difficulty of activities showed that the percentage of people who felt difficulties in performing activities due to shaking was higher in those standing and walking than those sitting. The relationship between the experienced length and fear showed a tendency a longer duration of shaking resulted in greater fear. There was generally a correlation between the seismic intensity experienced and fear, with many "not scary" and "slightly scary" responses for a seismic intensity of 4 or lower, and "scary/very scary" for seismic intensities of 6 Lower or higher.

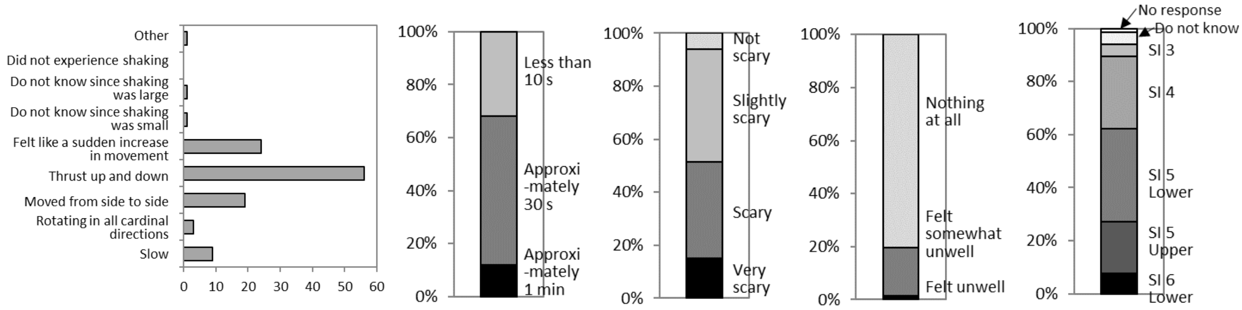
Fig. 10 shows the relationship between floor number and each question. For difficulty of activities, there were more responses of "some difficulty in performing activities" or higher for the fourth floor or higher. In addition, for the seismic intensity experienced, there were more responses of "seismic intensity 5 Lower" or higher on the fifth floor or higher; the shaking experienced tended to increase on higher floors. Meanwhile, fear responses of "scary" or "very scary" did not necessarily increase with higher floors.

Table 4 Observation records at the M-building

Earthquake No.	Date and time of occurrence YYYY/MM/DD, HH:MM (24 h)	Floor	Instrumental seismic intensity	Maximum acceleration (cm/s^2)			Long period ground motion class
				NS	EW	UD	
4	2018/6/18, 07:58	Ninth	5.2	88.0	1	5.2	1
		B4	4.5	61.5	B4	4.5	

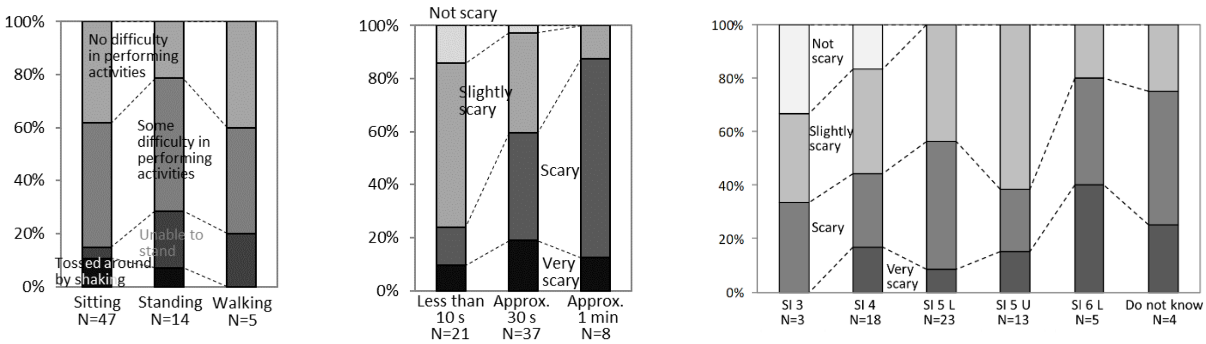


(a) Respondent attributes (b) Q1 Location when shaking was experienced (c) Q2 Position (d) Q3 Emergency action (e) Q4 Difficulty of activities



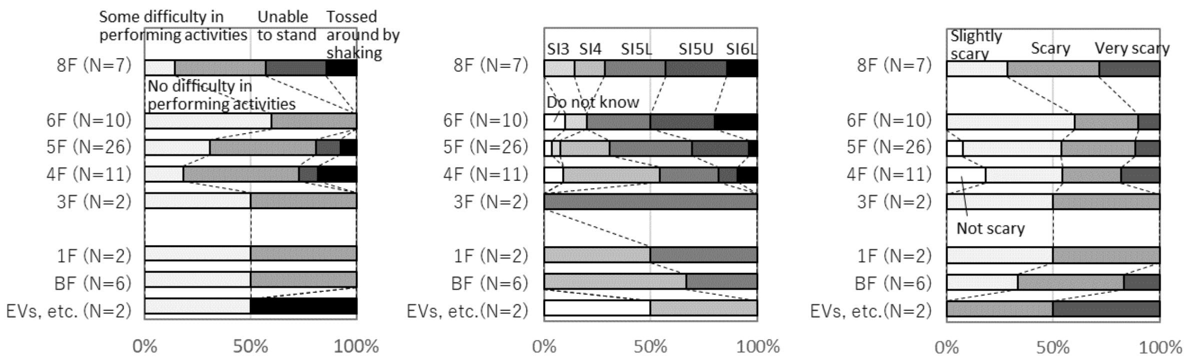
(f) Q5 Manner of shaking (multiple answers) (g) Q6 Duration experienced (h) Q7 Fear (i) Q8 Physical condition (j) Q9 Seismic intensity experienced

Fig.8 Results of the questionnaire



(a) Relationship between position and difficulty of activities (b) Relationship between duration experienced and fear (c) Relationship between seismic intensity experienced and fear

Fig.9 Relationship between questions



(a) Relationship with difficulty of activities (b) Relationship with seismic intensity experienced (c) Relationship with fear

Fig.10 Relationship between floor and questions

4.2 Additional comments

Approximately 60% of the respondents wrote additional comments, which were fairly detailed at slightly less than 100 characters on an average. Table 5 shows the comment classifications and examples. For the manner of shaking, there were many comments consistent with the multiple-choice questions. Some comments mentioned differences from the Great Hanshin Earthquake and the Great East Japan Earthquake. Various behaviors were mentioned, such as acting impulsively, observing their surroundings and taking action accordingly, and being unable to do anything. People who had previous experience and knowledge of earthquakes seemed to be surprisingly calm. It appeared that there was no major damage to the interior of the buildings, however, some respondents commented that they still panicked and felt terrified not at the shaking itself but at the sight of the scattered objects. There was no interruption in telephone service, but some respondents said that they felt uneasy about the extraordinary situation, such as the subsequent interruption of train services. Several other comments indicated that the respondents felt uneasy about the loud noises from just before the earthquake to during the shaking.

Table 5 Classification of additional comment and examples

Classification	Examples of comments
Situation	Shaking that thrust up and down→ from side to side→ slow/shaking that was different from Hanshin Earthquake or Great East Japan Earthquake
Experience/emotions	Thought I was dizzy/disoriented/surroundings were calm/scary/no sense of fear
Behavior	Sheltered under desk/moved away from dangerous location/crouched down in place/observed surroundings and took action accordingly
Other	Warning sounded at the same time as (or during) shaking/loud rumbling sound right before/documents fell down

5 Discussion and summary

We conducted a survey on the human experience of shaking in buildings during an earthquake with the aim of providing effective disaster prevention information that gives building users a sense of security during an earthquake. In this paper, we used two types of real-time questionnaire systems in order to examine the earthquake shaking experienced by respondents. One system was developed as part of an application for mobile devices, and the second was an online questionnaire using an earthquake observation system for office buildings. We compared the seismic intensity information estimated from respondent location information, observed seismic intensity information, and responses regarding the shaking experienced.

For the questionnaire app, when looking at each estimated seismic intensity scale, most responses tended toward “no shaking” for seismic intensities of 1 or lower, “some shaking” for a seismic intensity of 2, “moderate shaking” for seismic intensities of 3 and 4, and “extreme shaking” for seismic intensities of 5 Lower or higher.

Respondents who selected “extreme shaking” had a median hypocentral distance of approximately 25 km for the inland earthquake No. 4 directly under a major city, whereas that of other earthquakes was approximately 100–200 km, with relatively large shaking experienced at a greater distance. Furthermore, the possibility of long-period ground motion affecting shaking was confirmed. The only mandatory question in this questionnaire was the strength of the shaking, but the comment section included descriptions of the surrounding situation, fear, and support for the affected area.

For the questionnaire system targeting a nine-story office building where seismic observation is being conducted, the real-time online questionnaire and an emergency questionnaire conducted in the 10-day period following earthquake No. 4 showed a hypocentral distance of approximately 20 km. For the manner of shaking, 55% of respondents selected “shaking that thrust up and down,” and 88% selected a shaking duration of 30 s or less. The results show that the earthquake duration, which is characteristic of an inland earthquake near the hypocenter, was short, and the shaking duration was mainly short period. For the strength of shaking, over 60% of responses indicated “some difficulty in performing activities” or higher; and for fear, 6% of respondents selected “not scary.” Many of the free-description comments stated that their fear of earthquakes had been reduced based on their previous earthquake experiences and knowledge. Meanwhile, there were also cases where people felt fear when they saw objects scattered about, and people who felt uneasy because of extraordinary situations, such as the suspension of train services.

Effective disaster prevention information should be inferred for future building users based on the experiences of current users and building observation records. Furthermore, information, such as the soundness of the building, should be presented to the facility manager as needed. These measures are useful as a post-earthquake response for reducing the anxiety of building users. In the future, we would also like to learn how humans experience earthquake shaking from real-time questionnaires, and will consider using human experience of earthquake shaking in evaluations of the seismic performance of buildings during the design phase.

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