16TH EUROPEAN CONFERENCE ON
EARTHQUAKE ENGINEERING THESSALONIKI
18 - 21 JUNE 2018

IMPACTS OF DAMAGE TO HOSPITALS ON PERFORMANCE AFTER IN THE 2016 KUMAMOTO EARTHQUAKE IN JAPAN

Ryosuke NOGUCHI[1], Masakatsu MIYAJIMA[2],

ABSTRACT

A questionnaire survey for medical institutions affected by the 2016 Kumamoto Earthquake in Japan was done and the influence of earthquake damage on medical functions was quantitatively evaluated. In order to understand to what extent the medical function declines due to various damages occurred in the hospitals, the mathematical quantification theory class 2 which is one of the multivariate analysis methods was carried out. The result was similar to a single correlation analysis mentioned above. It was found that the influence of damage to water supply/drainage facility and water shortage on medical malfunction was largest.

Keywords: Questionnaire survey; Water stoppage; Hospital; Earthquake damage

1. INTRODUCTION

In Japan, many earthquakes had occurred, for example the 1995 Hyogo Prefecture Nambu, the 2011 Tohoku Region Pacific Offshore and the 2016 Kumamoto Earthquakes, and had suffered great damage. The 2016 Kumamoto Earthquake, which is the target of this study, was occurred at 21:26 on April 14 at the highest seismic intensity of 7 in Mashiki-machi in Kumamoto Prefecture (hereafter designated “foreshock”), about 28 hours later at 1:25 on April 16 at the highest seismic intensity of 7 in Mashiki-machi, Nishihara-mura in Kumamoto Prefecture (hereafter designated “mainshock”). The seismic intensity of 7 is the highest grade of JMA seismic intensity. The number of damaged houses in Kumamoto and Oita Prefectures was nearly 180,000 and the casualties were 120. The medical institution becomes an important base for conducting life-saving and emergency activities in the earthquake disaster like the above. It is, therefore, important to grasp the degree of deterioration of medical functions induced by earthquake damage in order to quickly rescue critical care and emergency activities. If medical institutions can demonstrate adequate medical functions against a big earthquake which is said to occur in Japan in the near future, human damage can be drastically decreased in the affected area. In this study, a questionnaire survey for medical institutions affected by the 2016 Kumamoto Earthquake was done and the influence of earthquake damage to medical functions was quantitatively evaluated.

There are many studies have conducted relating to earthquake damage to medical institutions and medical functions in the past. Kou et al. (2004) studied an earthquake damage and medical function deterioration by using the seismic intensity scale. Inagaki (2007) clarified the relation between strength of earthquake ground motion and medical institution's damage but did not focus on medical function. Although Banba and Higashihara (2005) and Ikeuchi et al. (2008) focused on the influence on medical functions. However, not much research on the degree of deterioration of medical functions by the earthquake damage has be done. This

[1]Master student, Kanazawa University, Kanazawa, Japan , grad.kin15@gmail.com
[2]Professor, Kanazawa University, Kanazawa, Japan , miyajima@se.kanazawa-u.ac.jp

study aims to clarify the degree of deterioration of medical function due to the degree of damage.

2. METHOD

A questionnaire survey was conducted in the areas suffered building damage and lifeline damage by the 2016 Kumamoto earthquakes.

2.1 Target medical institutions

The medical institutions having the bed, registered in the medical association in each prefecture were targeted in this study. Hospitals not considered to be important base facilities in conducting life-saving and rescue activities, such as ophthalmology, dentistry etc., were excluded. The questionnaire survey sheets were mailed to 389 medical institutions then responses were obtained from 125 medical institutions. Therefore the questionnaire collection rate was 32.1%. The location of the institutions that were responded is shown in Figure 1.

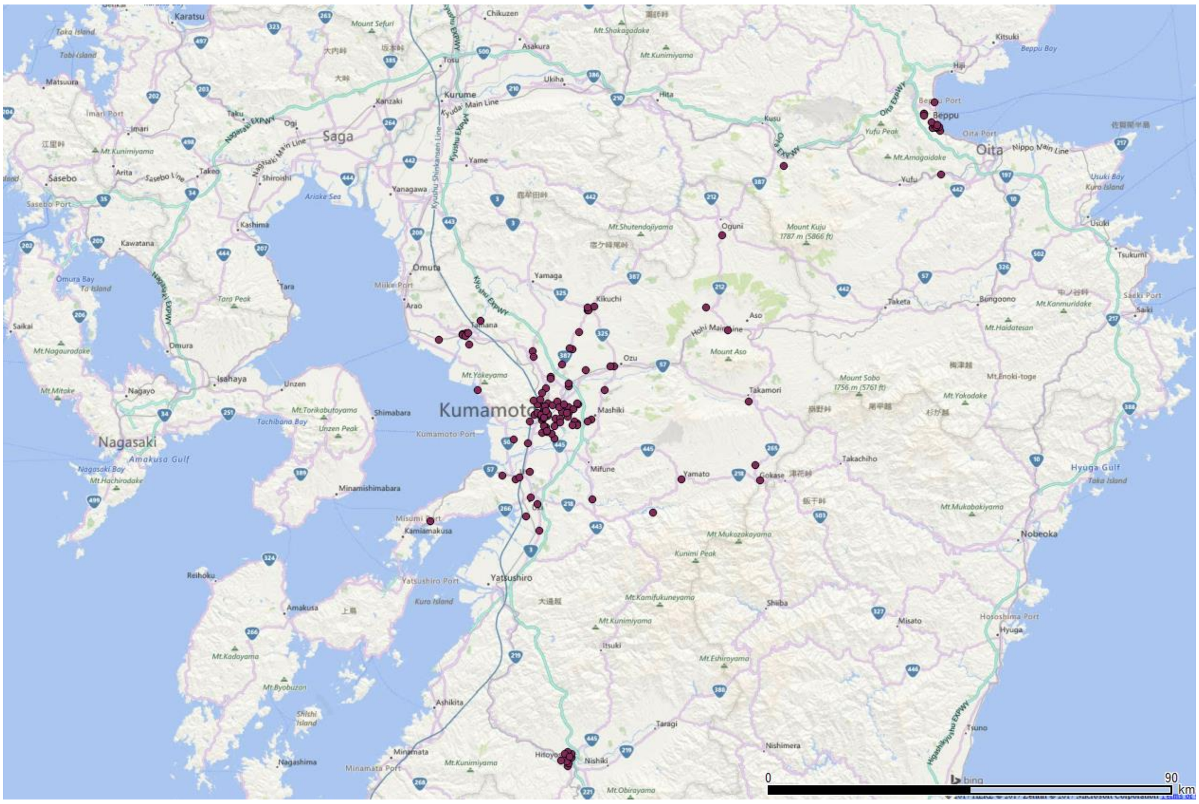

Figure 1. Location of questionnaire collection institutions

2.2 Outline of questions

The purpose of the research is to grasp the earthquake damage that leads to deterioration of the medical function most in the medical institution in the earthquake disaster. For that reason, we investigated six items as follows, hospital specifications, building damage, lifeline damage, facility damage, medical equipment damage, and emergence response in the earthquake. Table 1 shows details of the each item of the questions

2.3 Result

The questionnaire was conducted by mail on July 7, 2016, and answers were obtained from 125 medical institutions. Fig-2 shows the number of answered institutions in each seismic intensity. We firstly paid attention to the seismic intensity of the nearest observation station to the target institution [10]. However we did not analyze the influence of seismic intensity because that there is bias in the number of samples in each seismic intensity shown in Figure 2. The number of floors of the target institution and the existence of an elevator are shown in Figure 3, and the structure type is shown in Figure 4. As for the number of floors and structure type, it can be seen that they have 2, 3 or 4 floors in the many medical institutions and almost all of the structure type was RC.

Table 1. Contents of questions.

Survey item	Details
Building damage	Structual element damage
	Non-Structual element damage
	Furniture and fixtures damage
	Damage to chemicals
Lifeline function damage	Blackout
	Water stoppage
	Gas supply interception
Facilities damage	Plumbing damage
	Air Conditioning / Electricity
	Elevator facilities
Medical equipment damage	Damage to medical equipment such as artificial dialyzer
Medical activity after the earthquake	Outpatient hospitalization and transfer
Hospital specifications	Number of floors, building type

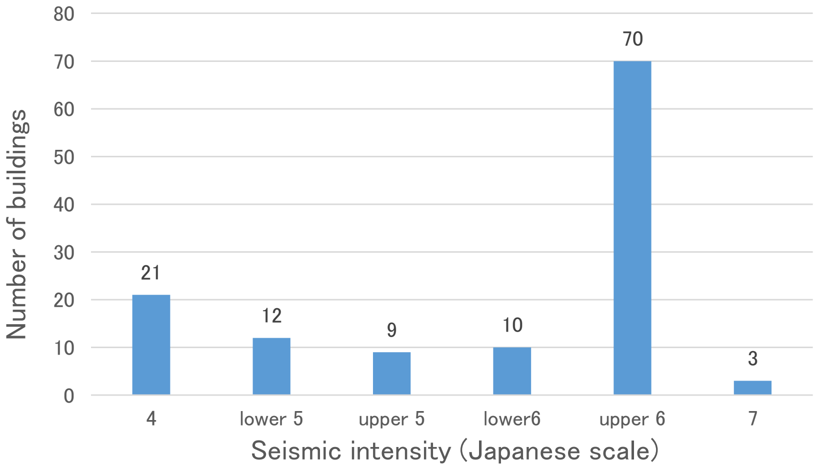

Figure 2. Number of answered institutions in seismic intensity

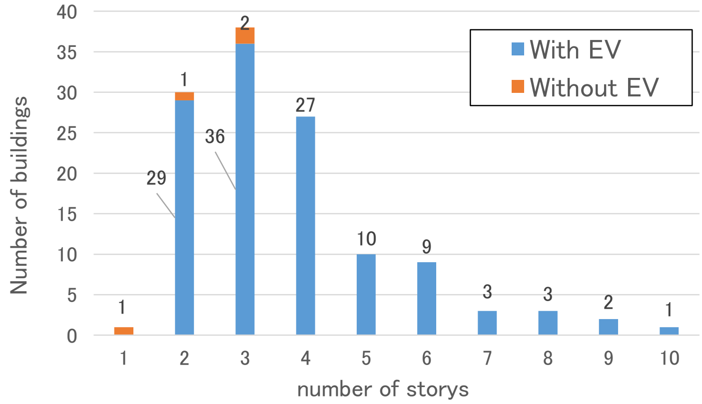

Figure 3. Number of buildings in each floor number and existence of an elevator

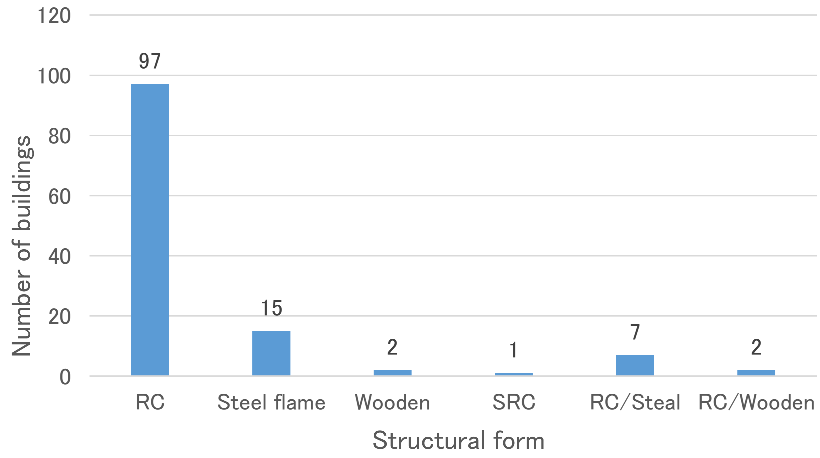

Figure 4. The number of buildings in each structure type

3. SUMMARY OF DAMAGE

We firstly tried to investigate the influence of both earthquakes to the damage and medical function. The damage occurred at 44 institutions, that means 35.2% of the whole answers by the foreshock. However, there were only two institutions were influenced on the medical function due to the foreshock. The damage due to foreshock, therefore, were omitted in this study. The damage to buildings, lifeline function, equipment, and the impact of each damage are explained below. Influence to medical function is defined in this research as the condition that it is impossible to perform surgery, and the situation that it is necessary to restrict the medical treatment, such as shortening of the time of leave and dialysis, due to the earthquake damage, and the case of transfer of patients.

3.1 Structure element damage

We focused on the damage to outer wall, inner wall, pillar, and beam as an element of building. Figure 5 shows the damage rate and Figure 6 shows the impact rate. In this study, the damage rate is defined as the number of the damaged hospitals divided by that of pillar the total hospitals. And the impact rate is defined as the number of hospitals affected on medical function divided by that of the damaged hospitals. These figures indicates that the structure element damage occurred at the outer wall and inner wall around more than 60%. However, the impact rate was only about 10%.

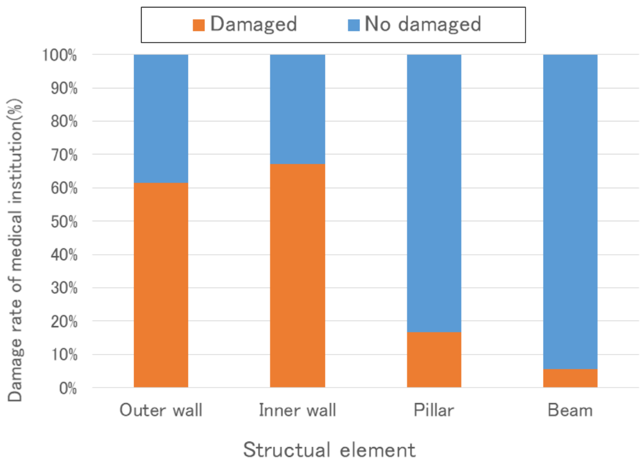

Figure 5. Damage rate of structural element

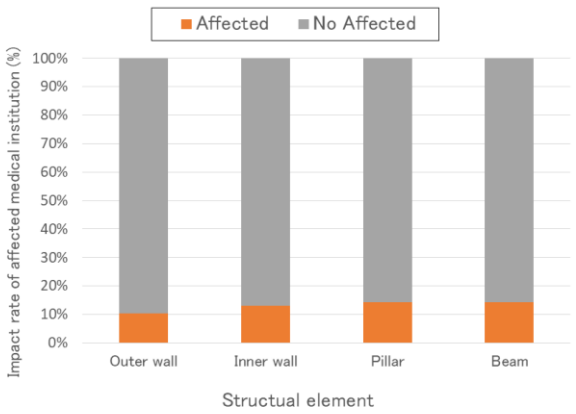

Figure 6. Impact rate of structural element damage

3.2 Non-structure element damage

We investigated the damage to window glass, floor, ceiling, and door as a non-structure element. Figure 7 shows the damage rate and Figure 8 shows the impact rate of non-structure element. Non-structure element damage occurred at floor and ceiling more than 30%. The impact rate of ceiling exceeds 20% but the impact rate of glass damage is very small.

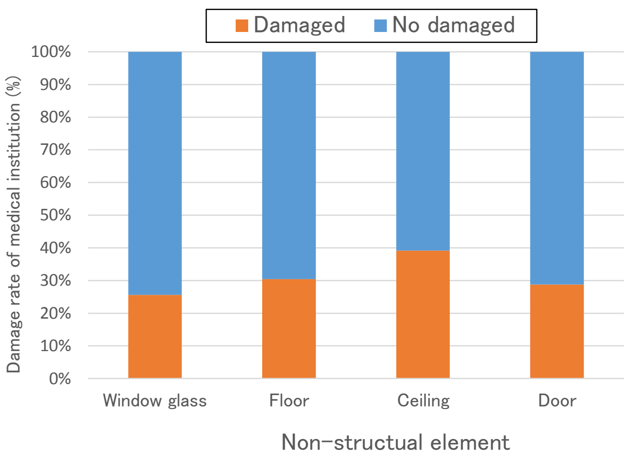

Figure 7. Damage rate of non-structural element

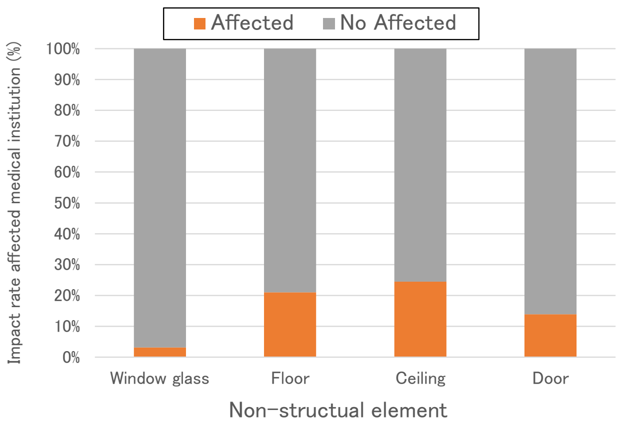

Figure 8. Impact rate of non-structural element damage

3.3 Facilities damage

We focused on water supply/drainage, air conditioning, elevator as facilities in this study. Figures 9 and 10 show the damage rate and the impact rate, respectively. Facilities damage occurred at water supply/drainage in 40%. The damage to elevator exceeds 50% and is highest in these facilities. The impact rate of water supply/drainage exceeds 60% and is great.

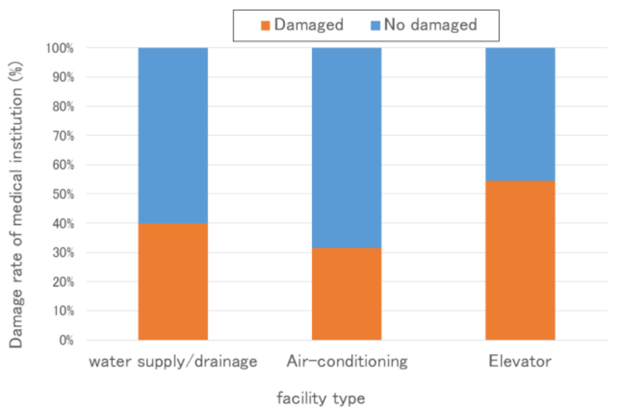

Figure 9. Damage rate of facilities

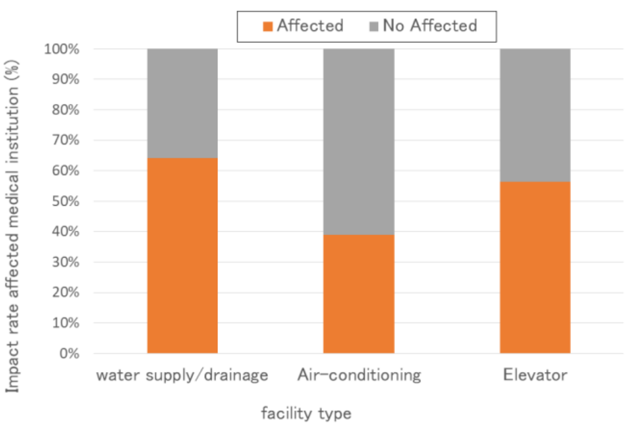

Figure 10. Impact rate of facilities damage

3.4 Lifeline function damage

We investigated blackout, water stoppage, gas supply interception, interception of an internal telecommunication line and an outside telecommunication line as lifeline function damage. Figures 11 and 12 show the damage rate and the impact rate, respectively. The medical functions were influenced by blackout at 52% of the hospitals, the water stoppage at 71% and the gas supply interception at 57%. The water stoppage mostly influenced on medical function because of malfunction of water supply/drainage facilities. It is clarified that the damage to lifeline function has large influence on the medical function.

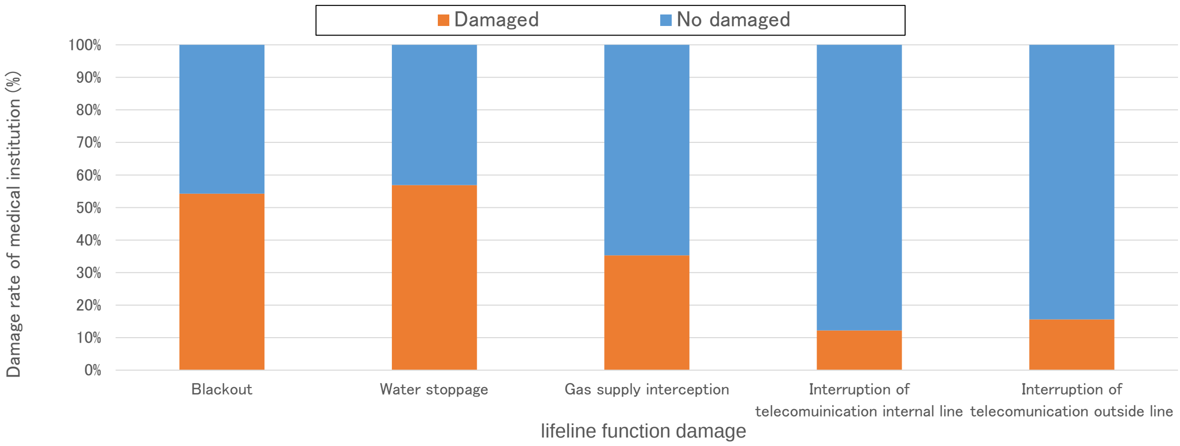

Figure 11. Damage rate of lifeline function

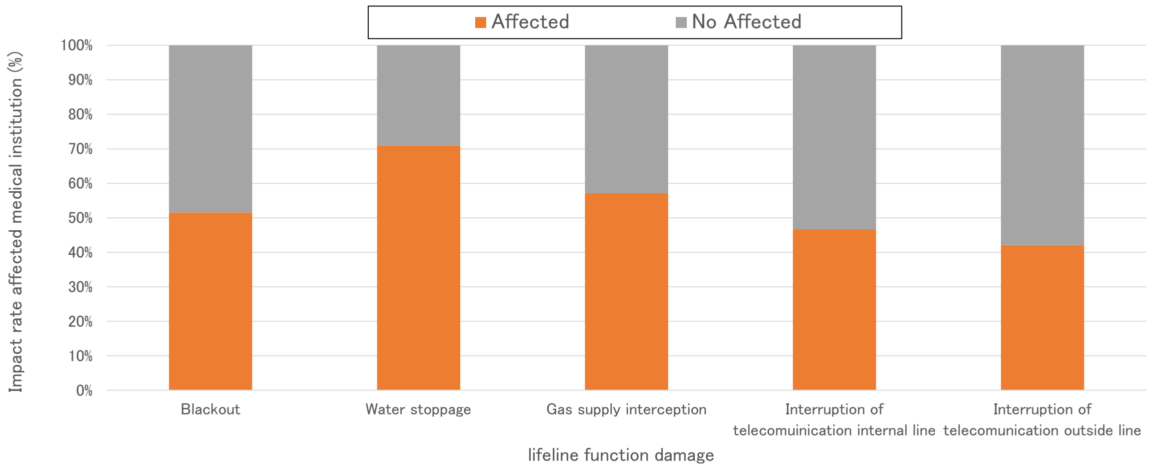

Figure 12. Impact rate of lifeline function damage

4. IMPACT OF EARTHQUAKE DAMAGE ON MEDICAL FUNCTION

4.1 Evaluation of the affected damage

We classified the impact levels of medical function into four levels to analyze the impact of each damage on the medical function as follows; Level 0: No damage, Level 1: No influence of damage on medical function, Level 2: Restriction of medical treatment, Level 3: Transfer of patients due to damage. Details of each damage with a particularly great impact will be shown below.

4.2 Impact of structural element damage

In the case of structural element damage, outer walls and inner walls are larger impact than pillars and beams, therefore the relationship between the level of medical function by the damage to outer and inner walls in the damage category is shown in Figure 13. According to this figure, almost all the impact by cracks in the outer and the inner walls is level 1, and about half of the chipped is level 2 and 3. It is considered that there is almost no influence on the medical function due to crack. According to the description in the questionnaire, the largest impact on the medical treatment due to the breakage of the outer and inner walls is unusable of examination room of a medical institution. Therefore, if breakage of the inner wall occurs in the examination room or the waiting room, the medical treatment is restricted and the medical function is deteriorated.

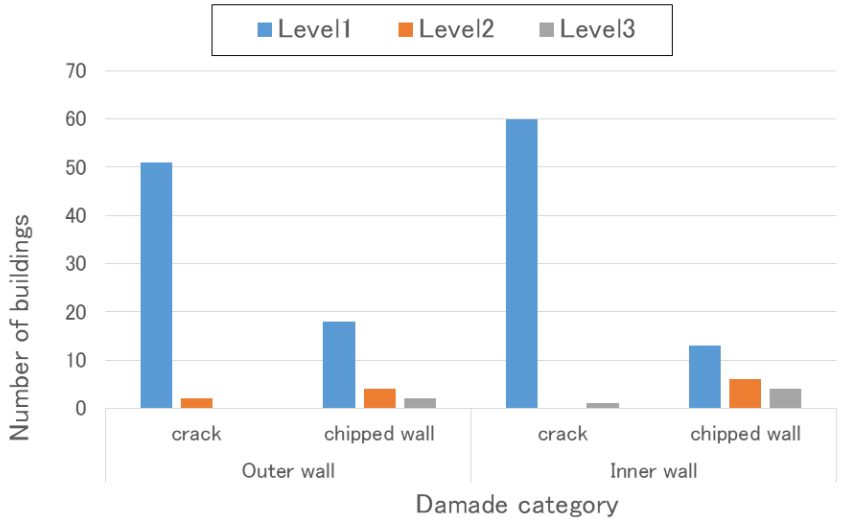

Figure 13. Impact level of structural element damage

4.3 Impact of non-structural element damage

The level of medical function by the damage to the ceiling with the highest impact rate and the floor with the most damage rate is shown in Figure14. Most of cracks of were level 1, and about half of breakage and other damage was level 2, 3. According to the description in the questionnaire, there were many water leaks due to breakage of water pipe by damage to ceiling.

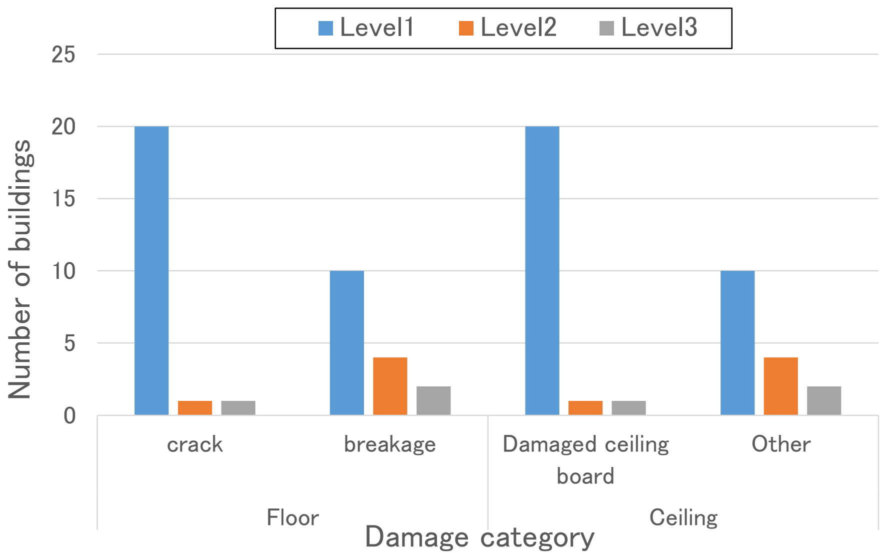

Figure 14. Impact level of non-structural element damage

4.4 Impact of equipment damage

Damage to water supply/drainage facility was greatly affected in equipment damage. The water stoppage by breakage of the water pipe and water storage tank was related to the damage to water supply/drainage facility. Therefore, the impact of water stoppage is large. Moreover, the impact of the elevator facility damage was large because that the movement of many patients and the transport of meals became difficult.

4.5 Impact of lifeline function damage

The relation between impact level of blackout and water stoppage, and the location of the lifeline function damage is shown in Figure 15. Expression of “inside institution” in this figure means that function damage occurred by the physical damage in the hospital, and “outside institution” means that function damage occurred by the physical damage at outside of the hospital. Also, “inside and outside” means that the physical damage occurred at both of inside and outside. In the case of blackout, level 2 is small when the damage occurred at only inside or outside the hospital, and it can be seen that level 2 rapidly increases when the damage occurred at both. If the damage occurs at only inside hospital, it can be considered that the impact can be reduced by private power generation. In case of water stoppage, the number of building in level 2 exceeds those in level1 in all categories. This means that the impact on the medical function due to water stoppage is great.

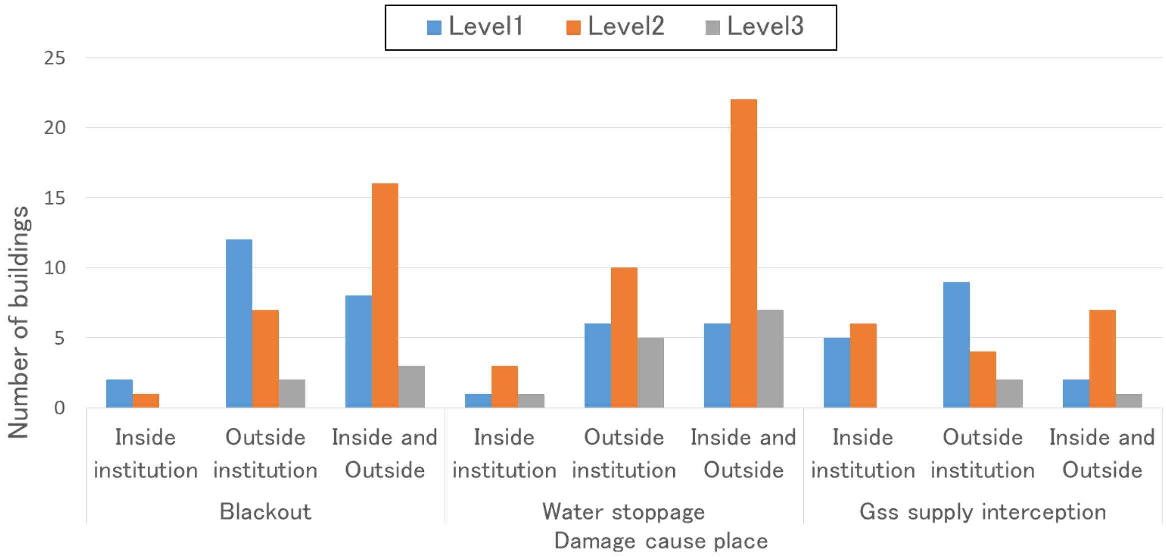

Figure 15. Impact level of lifeline function damage

5. DAMAGE ANALYSIS BY MATHEMATICAL QUANTIFICATION THEORY CLASS 2

We clarified the impact on medical function in the single correlation analysis in the previous chapter. However, it is not clear which damages are particularly great for deteriorating of the medical function. A mathematical quantification theory class 2 which is one of the multivariate analysis methods was, therefore, carried out here. Objective variables are defined as follows; Level 1: medical function is not affected, Level 2: medical function is affected, Level 3: hospitals that is closed or transferring of patients. The number of samples was 90 because some of the answers were omitted because of inadequate sample in the analysis. If there are significant frequency deviations among the categories of the same variable, distortion occurs in the result of quantification class 2 and it should be remove. In the following variables as "beam", "outside line", "extension" were excluded in the analysis because that more than 90% of samples are concentrated in the category of no damage. The correlation between each variable is shown in Table 2. Those with independent coefficients of more than 0.5 are defined as strongly correlated functions and those with low correlation with objective variables were excluded. Therefore, we analyzed eleven variables shown in Table 2 except "floor" and "gas interruption".

Table 3 shows the results of discrimination by the mathematical quantification theory class 2. The range and partial correlation coefficient are shown in Table 4, and the judgment graph is shown in Figure 16. This figure indicates that level 1 increases as the value of horizontal axis increases, and levels 2 and 3 are distributed more as the value of horizontal axis decreases. This means that the impact of damage is stronger as it decreases. Also, on the vertical axis, the levels 1 and 2 are more distributed in the positive direction and the level 3 is distributed more on the negative side in the positive direction.

Table 2. The correlation between each variable.

Variable name	Ovjective variables	Outer wall	Inner wall	Pillar	Window glass	Floor	Ceiling	Door	Black -out	Water stoppage	Gas supply inter-ception	Water supply/ drainage	Air-conditioning	Elavator
Outer wall	0.240													
Inner wall	0.351	0.494												
Pillar	0.160	0.327	0.224											
Window glass	0.276	0.167	0.271	0.049										
Floor	0.158	0.319	0.321	0.543	0.235									
Ceiling	0.216	0.374	0.339	0.230	0.199	0.305								
Door	0.234	0.320	0.480	0.122	0.262	0.243	0.188							
Black-out	0.342	0.266	0.314	0.135	0.163	0.198	0.260	0.211						
Water stoppage	0.463	0.238	0.429	0.184	0.231	0.182	0.268	0.460	0.479					
Gas supply inter-ception	0.328	0.162	0.316	0.206	0.401	0.268	0.232	0.385	0.395	0.528				
Water supply/drainage	0.435	0.270	0.257	0.150	0.375	0.206	0.246	0.282	0.315	0.418	0.353			
Air-conditioning	0.301	0.250	0.439	0.233	0.361	0.354	0.263	0.350	0.267	0.324	0.332	0.362		
Elavator	0.186	0.330	0.312	0.214	0.307	0.183	0.263	0.217	0.229	0.266	0.286	0.456	0.249	

Table 3. The correlation between each variable.

Actual value	Analysis value			Hit rate
	Level1	Level2	Level3	
Level1	41	4	5	82.00%
Level2	2	23	5	76.67%
Level3	1	1	8	80.00%
All				80.00%

Table 4. Range and partial correlation coefficient.

Horizontal axis				Vatical axis			
Variable name	Range	Partial correlation coefficient	Rank	Variable name	Range	Partial correlation coefficient	Rank
Water supply/drainage	1.5267	0.5910	[1]	Windoe glass	1.6474	0.2063	[2]
Blackout	1.4009	0.4854	[2]	Air-conditioning	1.5664	0.2092	[3]
Air-conditioning	0.9737	0.2367	[5]	Ceiling	1.4884	0.2149	[1]
Ceiling	0.7652	0.2235	[7]	Outer wall	0.9664	0.1854	[4]
Elevator	0.7545	0.2143	[8]	Blackout	0.7764	0.1557	[5]
Inner wall	0.6744	0.2438	[4]	Water supply/drainage	0.6283	0.1143	[6]
Windoe glass	0.6115	0.1587	[9]	Inner wall	0.6062	0.1112	[7]
Outer wall	0.6060	0.2347	[6]	Pillar	0.3991	0.0857	[8]
Blackout	0.5503	0.2865	[3]	Water stoppage	0.3613	0.0665	[10]
Pillar	0.1720	0.0767	[10]	Elevator	0.2628	0.0714	[9]
Door	0.1609	0.0748	[11]	Door	0.0063	0.0015	[11]

The range and the partial correlation coefficient which are used for the evaluation in the mathematical

quantification theory class 2 are shown in Table 4. Table 4 indicates that the influence is large in order of water supply/drainage, water stoppage, air conditioning, ceiling, elevator damage. In order to examine the deterioration of medical function due to the degree of damage, the categories of these variables in the horizontal axis are divided into level 1 and levels 2 and 3. Table 5 shows the category scores of "water supply/drainage" and "water stoppage" which are considered to be particularly important because the partial correlation coefficient is large on the horizontal axis. The larger the negative value of the category score, the stronger the impact on medical practice.
In the case of water stoppage, the damage caused inside hospitals is larger impact than that occurring inside and outside. The reason is considered that a lot of emergency water supply was conducted and hospitals were given preferential water supply when water stoppage occurred outside hospitals. The impact of the inability to use the toilet is particularly large in case of water supply/drainage. The inability to use the toilet was induced by water stoppage. As a results, water stoppage has the most impact overall.

Table 5. The category scores of "water supply / drainage" and "water shortage" at the horizontal score.

Survey item	Category	Sample	Category score
Water supply/ drainage	No damage	62	0.4279
	A restroom is not usable	16	−1.0988
	Other (Wash basin, piping breakage)	12	−0.7458
Water shortage	No damage	44	0.4451
	Occurred inside and outside the hospital	21	−0.9558
	Occurred only within the hospital	25	0.2052

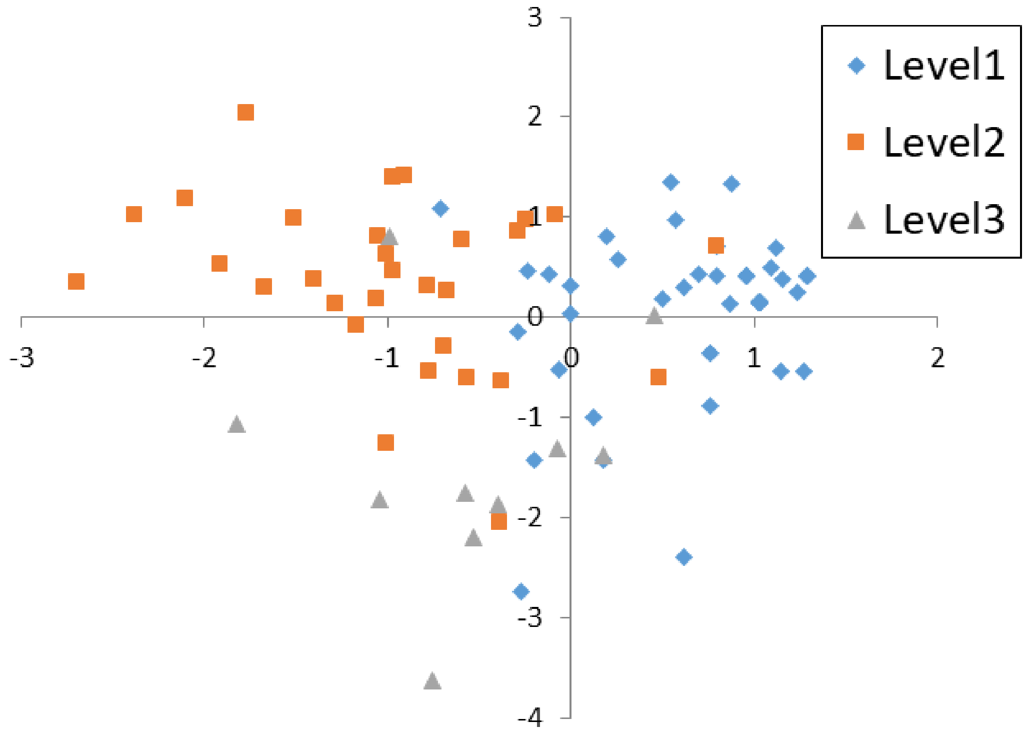

Figure 16. Judgment graph by mathematical quantification theory class 2

6. CONCLUSIONS

A questionnaire survey for medical institutions affected by the 2016 Kumamoto Earthquake in Japan was done and the influence of earthquake damage on medical functions was quantitatively evaluated. The results of this study are summarized as follows.

1) Non-structure damage is likely to occur on the ceiling and the great impact occurred by the damage to breakage of the ceiling board because of limitation of medical space.
2) The water stoppage mostly affected to the medical function in the lifeline function damage.
3) Analysis by using mathematical quantification theory class 2 clarified that the impact of water stoppage caused by damage only inside the hospital was larger. It is clear that the impact of the inability to use the toilet was great in the water supply / drainage facility.
4) The impact of elevator damage was also great because that if the elevator was damaged, medical practice may be restricted.
5) Not only the impact of water stoppage, but also equipment damage was greatly influenced to the medical function.
6) It is important to judge the impact on the medical function by confirming the damage situation after earthquake.

7. ACKNOWLEDGMENTS

We sincerely thank the medical institutions who cooperated in the questionnaire survey. In addition, we used the observation records published at the National Research Institute for Earth Science and Disaster Prevention (K - NET, KiK - net).

8. REFERENCES

Banba M, Higashihara H (2005). Analysis of Damage to Medical Facilities and Disaster Medical System in the Niigata-ken Chuetsu Earthquake, *Journal of Earthquake Engineering*, Japan Society of Civil Engineers, 28:89-98 (in Japanese).

Disaster Prevention Office of the Oita Prefecture, Disaster Information Accompanying the Earthquake Occurred after April 16, No.87, http://www.pref.oita.jp/site/bosaiportal/20161108.html (accessed August 14th,2017 JST) (in Japanese).

Division of Health Crisis Management, Department of Health Science, Ministry of Health, Labor and Welfare, , Earthquake in Kumamoto Prefecture, No.42, http://www.mhlw.go.jp/stf/seisakunitsuite/bunya/0000167667.html (accessed August 14th, 2017 JST) (in Japanese).

Ikeuchi J, Takei E, Ukai T, Higashihara H (2008). A Study on the Improvement of the Disaster Prevention Capabilities in Designated Disaster Hospitals, *Journal of Social Safety Science Institute*, 10:495-502 (in Japanese).

Inagaki J (2007). A Study on Influence of Damage to medical institutions on medical Function, Master thesis of Graduate School of Natural Sciences and Engineering, Kanazawa University (in Japanese).

Kuo KC,.Hayashi Y, Kanbara H (2004). Relationship between Damages to Hospital Facilities and Seismic Intensity Based on Questionnaire Survey, *Journal of Architectural Institute of Japan*, Structural Systems, 586:63-69 (in Japanese).

KumamotoPrefecture, Earthquake Damage by the Kumamoto Earthquake, No.238, https://www.pref.kumamoto.jp/common/UploadFileOutput.ashx?c_id=3&id=15459&sub_id=210&flid=96280 (accessed August 14th, 2017 JST) (in Japanese).

Kumamoto Prefecture Medical Association, Kumamoto Medical Navi, http://mis.kumamoto.med.or.jp/ (accessed August 14th, 2017 JST) (in Japanese).

National Research Institute for Earth Science and Disaster Prevention (K - NET, KiK - net), http://www.kyoshin.bosai.go.jp/kyoshin/ (accessed August 14th, 2017 JST) (in Japanese).

Oita Prefectural Medical Association, Oita Medical Information Hot Net, http://iryo-joho.pref.oita.jp (accessed August 14th, 2017 JST) (in Japanese).