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Study on judgment process on continuous use of disaster management buildings after earthquake

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ABSTRACT: Some local governmental buildings had not functioned after the 2011 off the Pacific coast of Tohoku Earthquake in Japan, which were expected to use as the disaster countermeasures office. Some of them seemed like to be usable according to the post-earthquake field investigation executed by the authors, because the damage degree of structural members were not so severe of course but, almost of those buildings suffered minor or moderate damage. Therefore the authors investigated the reason that the administrative staffs of the buildings decided to abandon the continuous use of them. The authors proposed a hypothesis for the judgment procedure on the continuous use of building and analyzed the barriers to post-earthquake functionality for building. In addition, the authors offer a tentative suggestion in order to make the judgment on the possibility of continuous use of disaster management building more reasonable.

1 INTRODUCTION

The 2011 off the Pacific coast of Tohoku Earthquake (hereinafter referred to as the 2011 Tohoku earthquake) caused a lot of damage to buildings in wide area of eastern Japan. The earthquake was extremely devastating one, but the structural damage of buildings by the vibration was not particularly severe in spite of the measured seismic intensities. In the meantime, the report on the earthquake disaster presented a notable example that some local governmental buildings which were expected to use as disaster countermeasures office had not operated after the earthquake, BRI (2011). This matter reminds us the importance of keeping the function of disaster management building immediately after earthquake.

Therefore the authors investigated the situation of buildings and the measures taken by the administrative staffs after the earthquake, and then analyzed them in order to account for the procedure of judgment on the continuous use of the buildings. The results of them will give us the useful information to make or improve the evaluation method for seismic performance of disaster management buildings to maintain the function of them. And the authors propose a tentative suggestion for smooth judgment on the possibility of continuous use of disaster management buildings.

2 FEATURES OF RC BUILDING DAMAGE BY THE 2011 TOHOKU EARTHQUAKE

Though several damage patterns on reinforced concrete (RC) buildings were observed in the affected areas where the seismic intensities were classified as 6 lower (6-) and over by the Japan Meteorological Agency (JMA), those were almost same as what had been observed in past

earthquake disasters, BRI (2011). The observed serious damages were listed as follows; story collapse of low-rise buildings, collapse of soft-first story (pilotis) as shown in Figure 1a, and the loss of vertical load carrying capacity of columns due to shear failure. Most of severely damaged buildings were designed with the old seismic design code which had been enforced before June 1981. Shear failure occurred on a column of a seismic strengthened building was only a characteristic structural damage which hasn't been known before (Figure 1b).

At the same time, various damages occurred on non-structural members of buildings such as destruction of mullion (Figure 1c), falling of cladding, collapse of concrete block or stone masonry wall and damage of ceiling and windows, et al. Some reports show the matter that the damage of non-structural members restricted the continuous use of building after the earthquake, and some local governmental buildings corresponded to those, BRI (2011).

(a) Story collapse of soft-first story.

(b) Shear failure of adjacent column to seismic strengthening steel braces.

(c) Damage of mullions.

Figure 1. Damage examples of buildings by the 2011 Tohoku earthquake.

3 JUDGMENT ON CONTINUOUS USE OF DISASTER MANAGEMENT BUILDINGS

3.1 Attribute of the investigated buildings

The research was executed on 18 disaster management buildings as shown in Table 1. The all investigated buildings were designed with the old seismic design code of buildings in Japan before 1981, of which 11 buildings (61%) were constructed from 1961 to 1970, 2 buildings (11%) were before 1960 and 5 buildings (28%) were from 1971 to 1981 when the period of the seismic design code had been partially revised. Here, the year of 1981 was the important turning point for the seismic design of buildings in Japan, when the seismic design code has been revised drastically and it is still in force now even though some articles have been amended. The criteria of the seismic design code are considered proper on the whole, because no severe damage on newly designed buildings has been detected in the recent damaging earthquakes in Japan.

The authors estimate that new buildings designed by the current seismic design code after 1981 don't suffer any significant damage concerning to the continuous use of building by the Tohoku earthquake 2011, because neither report nor information has pointed out any problems on disaster management buildings.

Table 1. List of investigated disaster management buildings

Building Reference No.	Construction period	Seismic evaluation	Measures after the earthquake	Seismic intensity by JMA scale	Damage evaluation *4
A	1960s	completed *1	keep out	6-	not completed
B	1970s	completed *1	limited entry	6-	moderate
C2	1960s	completed *1	limited entry	6-	not completed
D	1970s	completed *1	keep out	6-	moderate
E	1960s	completed *1	keep out	5+	light *4
F	1970s	completed *1	keep out	6-	light
G	1970s	completed *1	keep out	6-	light
H	1970s	unknown	keep out	6-	not completed
I	1960s	completed *1,*2	keep out	5+	major *5
J1	1960s	not completed	keep out	6-	light *5
J2	1960s	not completed	unknown	6-	moderate *5
K	1970s	completed *1	keep out	6+	major *5
L	1960s	completed *1	keep out	6+	light *5
M	1960s	completed *1	keep out	6-	major *5
N	1950s	not completed	keep out	6+	moderate *5
O	1960s	not completed	keep out	6+	moderate *5
P	1960s	not completed	keep out	6+	major *5
Q	1960s	completed *3	keep out	6+	moderate *5

*1 Seismic index of structure I_S is less than Seismic demand index of structure I_{S0}
*2 Temporary restored after Southern Sanriku Earthquake 2003
*3 Seismic retrofitted
*4 Classified by the reference of JBDPA, 2002
*5 Classified by the reference of BRI, 2011

The 15 buildings were classified as the disaster control facility which is required keeping its function immediately after earthquake, and the remaining 3 buildings were the facilities for preserving security for human lives and contents. All buildings were RC moment frame structures including with bearing walls, some of them were combined with reinforced concrete building with embedded steel frame (SRC) structure. The seismic intensities of building locations were from 5 higher (5+) to 6 higher (6+) by the JMA seismic intensity scale, almost buildings existed in 6 lower (6-).

The every building was the target of the seismic evaluation provided by "*Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings, 2001*", JBDPA (2001), of which 12 buildings (66.7%) had been completed, but 6 buildings (33.3%) hadn't yet at that time. The minimum values of the seismic index of structure, I_S of the 4 buildings (22.2%) ranged $0.3 \leq$

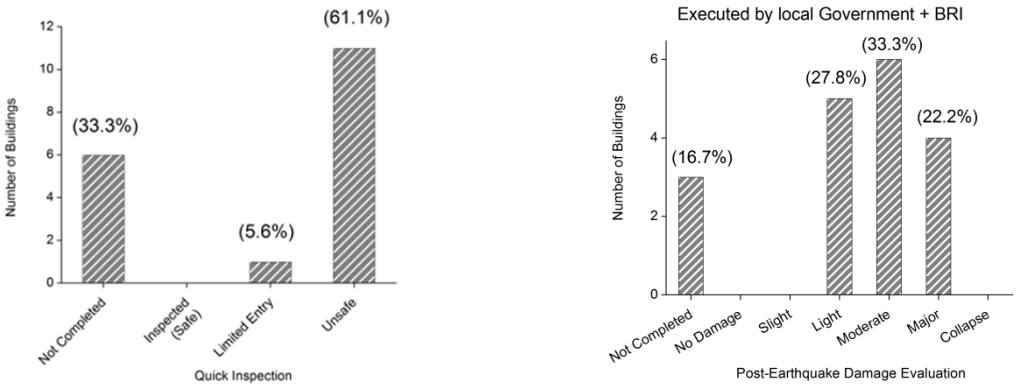
$I_S < 0.6$ and the 7 buildings (38.9%) were $I_S < 0.3$, i.e. almost all of the buildings were evaluated as deficiency in seismic performance. One building was only completed the seismic retrofit work.

3.2 Building damage situation

After the earthquake, the staffs of local governments and/or structural engineers executed the quick inspection on the 12 buildings (66.7%), of which the 11 buildings were determined as "Unsafe" and one building was as "Limited Entry" as shown in Figure 2a. The quick inspection of building is the procedure conducted by local government as soon as possible after large earthquake in accordance with "*Manual of Post-earthquake Quick Inspection*", JBDPA (1998), the main objective is to judge the safety of building in affected area against aftershock. The building was screened into three classifications as "Unsafe", "Limited Entry" and "Inspected (probably safe)" on the basis of the visible damage condition.

On the other hand, the post-earthquake damage evaluation were carried out on the only 4 buildings, that is, more detailed investigation on the 10 buildings which were judged as "Unsafe" by the quick inspection hadn't been implemented by the local governments. The post-earthquake damage evaluation is the another diagnosis method on damaged buildings, it is executed according to "*Guideline for Post-earthquake Damage Evaluation and Rehabilitation*", JBDPA (2002). The main purpose of this method is to evaluate damage rating of building and to judge the necessity for repair and/or retrofit on it, and the judging work is generally executed in the stage when the state of confusion after earthquake rather calm down. The method classifies the situation of building into 6 damage rating as "No Damage", "Slight", "Light", "Moderate", "Major" and "Collapse". Figure 2b shows the results of the post-earthquake damage evaluation on the 15 buildings including the 11 buildings evaluated by the authors. The 5 buildings (27.8%) were classified as "Light", 6 (33.3%) as "Moderate" and 4 (22.2%) as "Major", no building was classified as "No Damage", "Slight" and "Collapse".

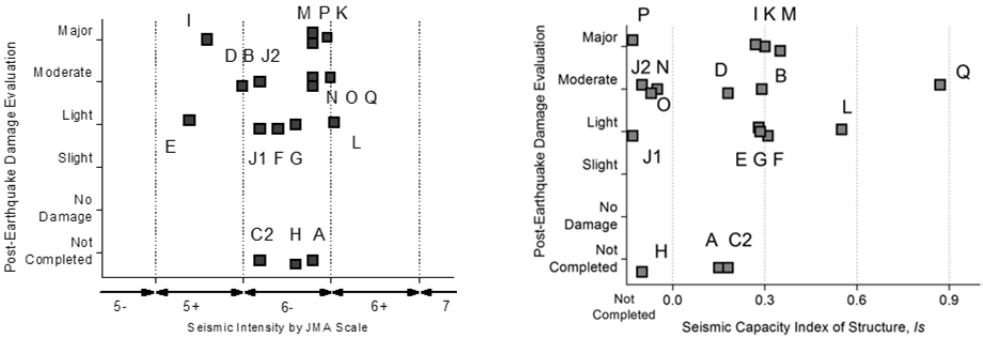
The damage rating of the buildings are distributed from "Light" to "Major", and any particular relationship with seismic intensities isn't observed in Figure 3a. On the relationship with the seismic index of structure, I_S in Figure 3b, the damage rating are also widely distributed including the buildings with $I_S < 0.3$, there is no obvious relationship too. By the way, the building with mark Q was suffered "Moderate" damage, even though it had been retrofitted.



(a) Results of quick inspection.

(b) Results of post-earthquake damage evaluation.

Figure 2. Building damage situation after the 2011 Tohoku earthquake.



(a) with Seismic intensity. (b) with Seismic capacity index of structure, I_S.

Figure 3. Relationship between post-earthquake damage evaluation and other indices.

3.3 Analyses on judgments on continuous use of the buildings

The authors collected the information on what investigation and/or consideration for judging the possibility of continuous use of building had been taken by the administrative staffs of buildings after the 2011 Tohoku earthquake, and analyzed them for clarifying the procedure of judgment. Figure 4 shows a flowchart on judgment proposed as a hypothesis, the flow is consisted of two parts, the first half corresponds to the quick inspection method of building, JBDPA (1998), and the second half is the method according to the post-earthquake damage evaluation, JBDPA (2002). The purpose of judgment is focused on the possibility of continuous use of building shortly after earthquake, it doesn't concern to the possibility of permanent use of building. The marks from NG1 to NG5 in the flow indicate "Impossible for continuous use" and marks from OK1 to OK3 express "Possible for continuous use".

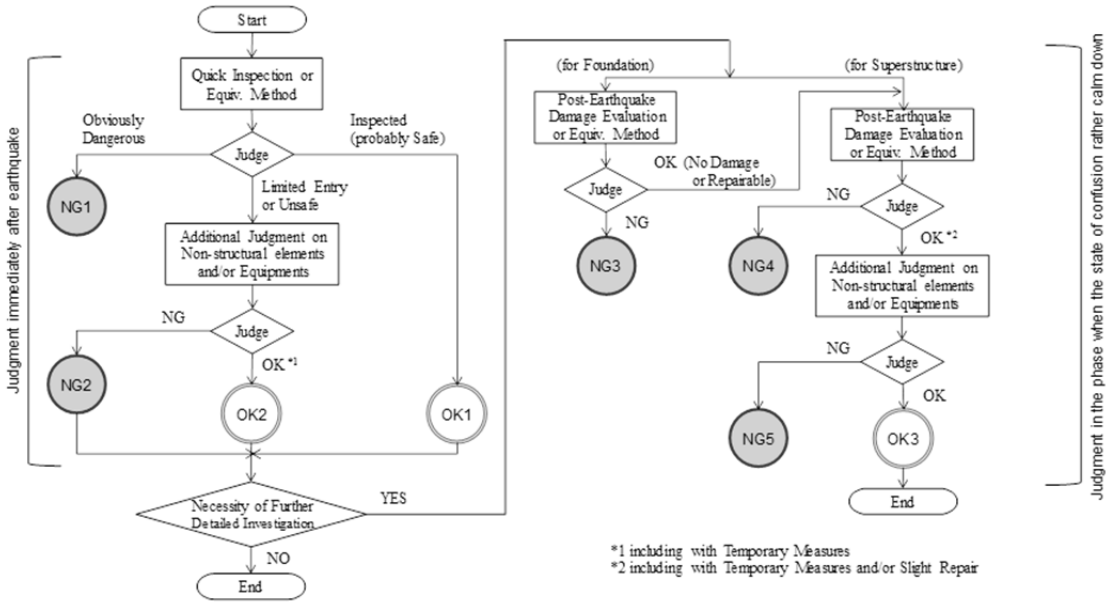


Figure 4. Flowchart of judgment on continuous use of damaged building.

The results of judgment on the buildings are illustrated in Figure 5, the broken lines of the buildings B, C2, D, E, F, G and Q show that the judgment have been corrected in accordance with the second half procedure. The buildings A, H, I, K, M and P which were determined as “Unsafe” by the quick inspection and were closed down, were classified as NG1. The final decisions on the buildings J1, J2, L, N and O were NG2, of which damage level were rated as ”Light” or ”Moderate” by the post-earthquake damage evaluation. It seems that the situation of the buildings N and O were almost same as NG1, because the results of the quick inspection of them were “Unsafe”. Regarding the building L, the administrative staff decided as same as the adjacent building K which was judged NG1. It has prospects of the grounds for judgment on the building J1 and J2 of which quite a few damage of non-structural members such as windows etc. were observed.

The buildings B and D were continuously used after the earthquake under the condition that only undamaged portion of building were utilized and/or dangerous members were taken away, it corresponds to OK2 in the flow, but the final decisions of them were changed to NG4 after the following detailed investigation. The building C2 was temporary stopped to use due to damage in upper stories, it’s classified as NG2, after restoration work the building recovered the usability without upper floors, it corresponds to OK3 as the final decision. The building F also resumed its functionality with some restoration, going through the period of setting limits to usage of it, this case falls into OK3. The final decisions on the buildings E, G and Q were NG4 after the following detailed investigation, though the first decision of them were NG2 just after the earthquake. On the other hand, though the damage of windows etc. might have an effect on the judgment, there are no example corresponding to NG5 within this study, which means the major criteria of judgment bases on damage of non-structural members.

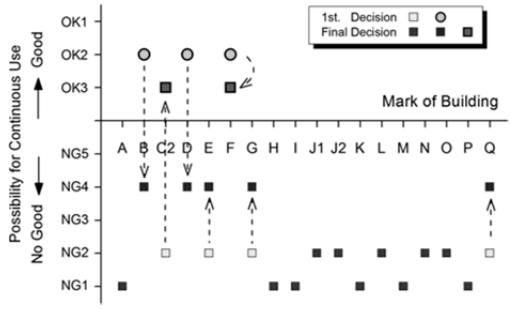


Figure 5. Final decision and transition of each building on possibility for continuous use.

Figure 6 illustrates the relationship between the final decisions for the possibility of continuous use of buildings and the results of the quick inspection, and the post-earthquake damage evaluation. The most buildings judged as “Unsafe” by the quick inspection were decided as “Impossible for continuous use”, it’s reasonable (Figure 6a). There are 5 buildings decided as NG4 in Figure 6b even though the damage rating of them were ”Light” or ”Moderate”. It should be the appropriate decision for the administrative staffs of buildings, because the damage rating of those almost coincide with “continuous use/occupancy not allowed unless the complete structural rehabilitation is performed to meet the criteria of Seismic Evaluation Standard”, according to the guideline for post-earthquake damage evaluation, JBDPA (2002). Furthermore the three of them were the buildings with $I_S < 0.3$, it should have affected on the judgment.

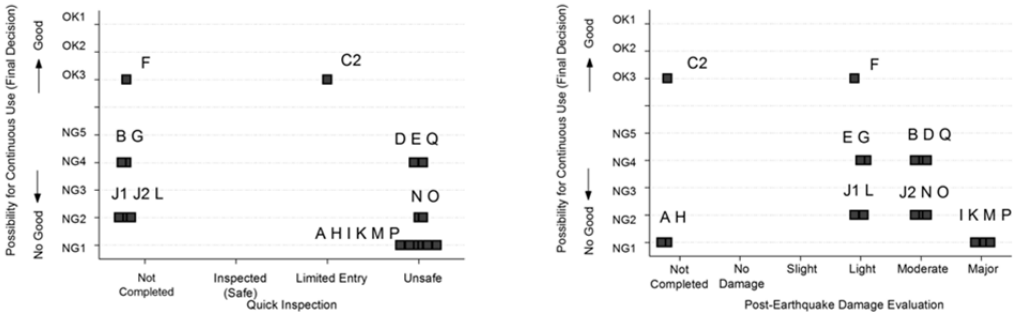
From this study, the grounds of judgment for the possibility of continuous use of building were summarized as follows;

a. judgment based on the damage rating of building

b. judgment combining the damage rating of building and the seismic index of structure, I_S

c. judgment considering the damage of non-structural member in addition to above a. and b.

It can be supposed that the administrative staffs of buildings were forced to make decision on the problem with hesitating, after the 2011 Tohoku earthquake. The derived subject is that there are no clear judgment procedure for the possibility of continuous use of public building, particularly the building as disaster control facility which is expected to keep its function immediately after earthquake.



(a) with Quick inspection.

(b) with Post-earthquake damage evaluation.

Figure 6. Relationship between final decision on possibility for continuous use and indices on damage evaluation of each building.

4 A PROPOSAL FOR JUDGMENT ON CONTINUOUS USE

The authors propose a tentative procedure for the judgment of continuous use of disaster management building from the view point of structural performance of building. The scope of application is the medium or low-rise RC building designed by the old seismic design code, which has been diagnosed by the seismic evaluation method, JBDPA (2001) and/or retrofitted if necessary.

The method consists of the combination of the residual seismic capacity ratio of building against the original one, R calculated by the post-earthquake damage evaluation, JBDPA (2002) and the seismic index of structure considering damage class of structural members, ${}_DI_S$. The possibility for continuous use of building can be visually drawn on a graph, if the R is plotted on axis of abscissa and the ${}_DI_S$ on axis of ordinate as shown in Figure 7. The reason why the combination of R and ${}_DI_S$ is adopted, we intend to evaluate the possibility for continuous use of building accurately and conveniently, i.e. the damage rating of building is indicated by the R and the ${}_DI_S$ gives the residual seismic capacity of building after earthquake.

For example, if the results of investigation is located within the scope of shaded portion in Figure 7, it will be evaluated to have “Possible for continuous use”. Here, the scope of shaded portion is ranged that the value of ${}_DI_S$ is higher than 0.6 which is the recommended minimum value by the standard for seismic evaluation, JBDPA (2001) and the value of R is higher than 80% which roughly corresponds to the damage rating is smaller than “Light”. The scope of shaded portion shall be determined by the administrative staff of building supported by structural engineer in advance. And it will be important and effective for the smooth judgment

of building in emergency situation, to examine the following subjects etc. as preparedness, because the administrative staff of building isn't always the structural expert.

a. to sort out the structural members which should be investigated closely
b. to simulate the structural performance of building with some earthquake damage
c. to set up the criteria of judgment for non-structural members and/or equipment

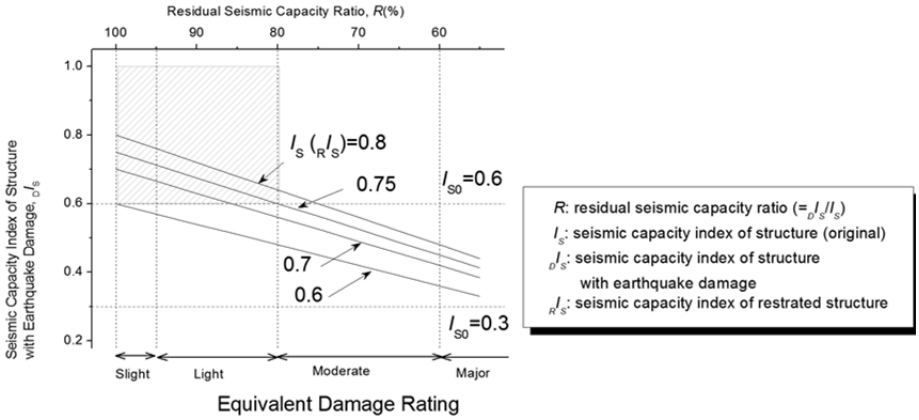


Figure 7. Tentative proposal for decision-making on continuous use of building.

5 CONCLUSION

This paper described the investigation results on the judgment procedure on the possibility of continuous use of disaster management building. The major criteria of judgment depended on the situation of buildings damage but the seismic index of structure, I_S had also an effected on it. And the investigation makes it appear that the administrative staffs of buildings were confused on the judgment of it, because the criteria for the judgment isn't clear. And the authors propose a tentative suggestion for smooth judgment on the possibility of continuous use of disaster management building.

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