MANAGEMENT OF CONTINUITY AND/OR RESILIENCY OF BUILDING FUNCTION AFTER EARTHQUAKE DISASTERS

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***ABSTRACT*:** Building Research Institute (BRI) has started a research project on “Development of Concept and Framework of Performance-Based Structural Design System for Evaluating Continuity and/or Resiliency of Building Function after Disasters” in 2007 as a 3-year research project. The expected final outputs of the project are (i) Framework of structural design system for evaluating continuity and/or resiliency of building function after disasters, (ii) Data base format for supporting the framework of structural design system, and (iii) Guidebook on scenarios on losing and recovering building function from the viewpoints of difficulty and inconvenience in life and business after disasters. The guidebook will be used for dissemination of the concept and information on “continuity and/or resiliency of building function after disasters”. This paper presents outline of the on-going project including the background, and the idea how to manage the building structural performance from the view of continuity and/or resiliency of building function after disasters. Since this is a new challenge in the field of structural design, necessary future tasks are also summarized.

KEYWORDS: disaster resiliency, functional continuity, structural design of building

1. INTRODUCTION

Securing human life in disasters is one of the most important objectives of the design of buildings. The building codes of each country, specify the necessary provisions as minimum requirements to avoid collapse of buildings for securing the human life in disasters. In earthquake disasters in recent years, however, serious damages of losing the functions of buildings as the dwelling and as the field of human activities were observed in the buildings which were not collapsed. Thus, adding to the safety viewpoint, recognition of importance of the resiliency viewpoint related on “how to maintain the building functions” or “how rapidly recover the deteriorated functions” is increased. The resiliency viewpoint is also indispensable for the request of the Central Disaster Prevention Council of the Cabinet Office for every business enterprise to establish their Business Continuity Plan (BCP), in order to decrease the amount of loss by about half at the expected huge earthquakes, such as Tokai Earthquake, Tonankai Earthquake, Nankai Earthquake, and strong local earthquake in the Tokyo metropolitan area.

Building Research Institute (BRI) began the 3-year research project on “Development of Concept and Frame Work of Performance-based Structural

Design System for Evaluating Continuity and/or Resiliency of Building Function after Disasters" in 2007. The main objective is to develop a structural design system for designing disaster resilient buildings and evaluation methods for difficulty in social, economic, and human activities after disasters. A structural design framework, a database system for structural design, and guidebooks for dissemination information for general users, etc. will be developed as useful outputs of building design allowing functional continuity and disaster resilience. This paper describes the overview of the research project on the management of continuity and/or resiliency of building functional after disasters which will be conducted by structural designers.

2. BACKGROUND OF PROJECT RESEARCH

The South Hyogo-prefecture Earthquake (Kobe Earthquake) occurred in 1995 resulted 104,906 collapsed buildings, 534,780 damaged buildings, 6,434 casualties and 43,792 injuries (Fire and Disaster Management Agency, 2006). Also since variety of city functions was also paralyzed, many citizens are forced to live at emergency evacuation areas outside their home for a long period. This is because many residential buildings lost their functions as the "dwelling". In addition, there appeared not a small number of cases that, although the buildings designed according to the current seismic code did not collapse as required by the codes and protected the human life, the damages of structural frame were serious, which needed very large restoration cost, thus the damaged buildings were finally demolished and reconstructed, (refer to **Figure 1** as an example.) The cases show the importance

(a) Full view of the building (RC frame structure)

(b) Shear failure and damage of columns

(c) Damage of beam and column joints

Figure 1 Building designed in accordance with the current seismic codes seriously damaged by the Kobe Earthquake in 1995, though not collapsed

Figure 2 Ceiling of the airport terminal fell down by the Off Tokachi Earthquake in 2003

(a) Full view of the Building (b) Damage of the non- structural wall and door

Figure 3 Severe damage of nonstructural wall of a condominium by the West-Off Fukuoka Earthquake in 2005. However, No-damage observed in the structural elements, columns and beams.

of design with a viewpoint of damage reduction and of functional resilience.

The Geiyo Earthquake in 2001, the Off Tokachi Earthquake in 2003, and the Southern Miyagi Earthquake in 2005 generated damages caused by dropping large scale space ceiling as shown in **Figure 2**. The West-Off Fukuoka Earthquake in 2005 generated damages of window glass of office buildings and of non-structural RC walls and fittings of condominiums (**Figure 3**). Thus, there appeared the cases that also the damages of those nonstructural members induce danger of human life similar to the cases of damages of structural frames, and that the loss of building function and of dwelling ability results in the difficulty of continuous use of the buildings after disasters. However, seismic codes as minimum requirement do not regulate any damages of non-structural members caused by the large earthquake except dropping of them.

Severe damage of a semiconductor chip factory happened due to the Chuetsu Earthquake of Niigata-prefecture in 2004, and forced to stop their supply-chain system for a long time. A similar thing was observed in the Off-Chuetsu Earthquake of Niigata-prefecture in 2007, that a factory of a company which is a unique supplier of special engine parts in Japan suffered severe damage. This fact caused the huge loss of profit of the entire Japanese automobile companies due to stop of their production lines for one week. The nuclear power plants in Kashiwazaki city and Kariwa village also stopped their operations due to damage suffered in their equipments. These cases show the importance of strategic countermeasure against stop of operation of key facilities.

A review of the cases of building damages in the earthquakes occurred in recent years clearly showed the actual state that owners and residents of buildings do not expect the conditions of disasters, and they do not prepare action plan after the disasters. On that matter, the suppliers of buildings might also lack the efforts to convey information and

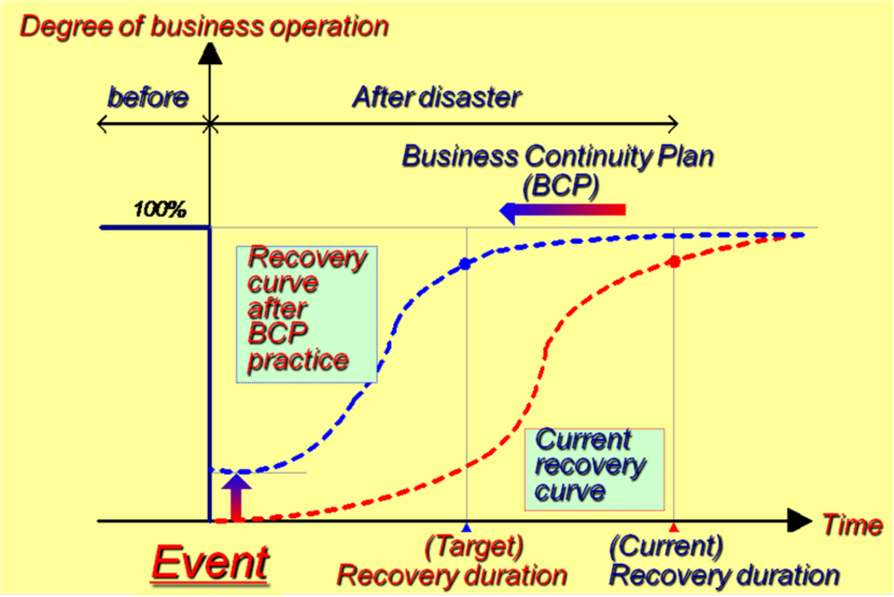

Figure 4 Concept of Business Continuity Plan

special field knowledge to the owners and the residents. The Kobe Earthquake drew attention about the damages of nonstructural members and equipment and fixtures, whose damages were relatively not recognized in the past hidden by the serious damage or collapse of structures. Furthermore, the Kobe Earthquake showed a feature that the residents of damaged buildings emphasized not only the direct loss of the building structure but also the indirect economic loss resulted from the disaster.

Therefore, common clear senses between the people and specialist are indispensable about followings;

i) Scenario on losing building functions: How large damage will happen and which building functions will not be operated.

ii) Scenario on recovering building functions: How much money and time will be required for recovery of losing building functions.

iii) Difficulties of business, inconveniences of life: How severe situation will be forced after disasters in business and daily life.

Through the experiences of above earthquake damages, business enterprises strongly recognized the importance of preventive measures to enable the business to continue after disaster or to enable the core business operation to rapidly recover to the level before the disaster. In this regard, the “Business Continuity Plan (BCP)” has drawn attention inside and outside Japan. The BCP is a strategy of protection of business enterprise from critical profit loss and from deterioration of enterprise rating by avoiding stop operation of important business in disaster and by, even when the business operation is stopped, resuming the important function within a target restoration period as shown in **Figure 4**. In Japan, “Special Field Survey Committee relating to the Disaster Preventive Power Improvement utilizing Private Sector Power and Market Power”, organized under the Central Disaster Prevention Council of the Cabinet Office, published the 1st edition of the Business Continuity Guidelines and the Check List in August 2005 (Central Disaster Prevention Council of the Japanese Cabinet Office, 2005), and the Committee requested all the business enterprises to prepare their own BCP. Not limited to the activities of the government, the general constructors have recently begun practical application of earthquake risk evaluation system which supports BCP of, for example, semiconductor production facilities.

In this manner, the development of structural design technology proceeds targeting not only the damage evaluation but also the evaluation of restoration period and of cost-effectiveness. Many of the above activities, however, use the statistical data of past earthquake damages, and do not reach the level of evaluation in depth to the relation between the response, the damages, and the deterioration of functions of individual buildings. Also, since the BCP is for managers of business enterprises to reduce their economic loss, not for owners and users of residential buildings, both the view points of business and daily life are necessary for discussing "Functional Resiliency" of buildings after disasters.

3. STRUCTURAL DESIGN SYSTEM BASED ON THE "FUNCTIONAL RESILIENCY"

3.1 Definition of "Functional Resiliency"

On the background of Chapter 2, this section newly defines the "Functional Resiliency" as the performance indicating the easiness of disaster resilience of building function after disasters, especially earthquakes. The "Functional Resiliency" can be secured by keeping the restoration cost and the restoration period of the building after the earthquake within the target restoration cost and the target restoration period, respectively, determined by the owner (with an agreement with the designer) in view of functions of the building. This concept is similar to that of ATC-58 (ATC-58, 2007). The ATC-58 aims to evaluate i) life loss, ii) direct economic loss like repair and replacement costs, and iii) indirect economic and social loss like loss of use of damaged or destroyed facilities. Those are represented by 3-D, Death, Dollar and Downtime. In addition to the economic loss and downtime, BRI project aims to evaluate difficulty of business continuity and inconvenience of life. These are meaningful communication languages for building owners and users.

3.2 Scenario-based design flow for "Functional Resiliency" evaluation

The scenario-based structural design flow scheme based on the "Functional Resiliency" is illustrated in **Figure 5** (Fukuyama et.al. 2008). Main articles of the flow are outlined below. Here, although the Business Continuity Plan (BCP) expects the damages of surrounding area of the building and the damages of lifeline, the concept of "Functional Resiliency" of the research deals with the controllable range in the design of individual buildings, and the influence caused by the variables other than those of the building is considered afterward as an additional condition.

i) Calculation of Response Value

Structural calculation method like capacity spectrum method or time-history response analysis should be performed to calculate response values of the building in drift, velocity, and acceleration for each story and in force for each structural element. These structural calculation methods are sometimes used in the structural design of actual projects, not very special one in Japan. After calculation of response values, it should be verified that all of the response values do not exceed the corresponding limit values which represent target performance. Here, the level of target performance should be defined by the building owner and translated in engineering value by structural designer. For example, a relationship between the level of ground motion and drift, acceleration and shear of stories of building can be used as a target performance in case of earthquake.

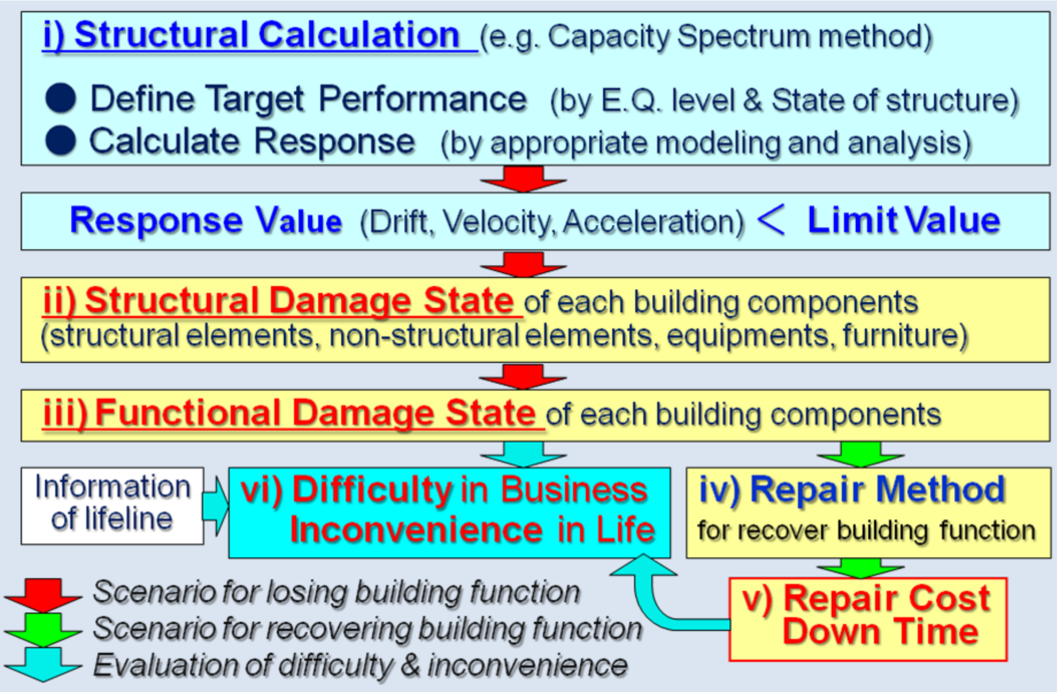

Figure 5 Scenario-based structural design flow scheme based on the “Functional Resiliency”

ii) Structural Damage State

Structural damage state of each building component, structural elements, non-structural elements, equipments and furniture should be evaluated and classified by using every response value,. The relationships between damage level and response value should be defined as a data base based on the test data or reports of damage observation due to previous disasters.

iii) Functional Damage State

Functional damage states of each building components should be evaluated by using results of the structural damage state evaluation, described in the above section ii). Here, functional damage states express the operational level of building from the view of building function. Thus the relationship between structural damage classification and loss of building function should be defined as a data base. However, present available data for structural damage classification and functional damage state evaluation are limited. Continuous efforts to accumulate these data are strongly expected.

The step i), ii) and iii) are a design scheme on the scenario for losing building function.

iv) Repair Method

Appropriate repair method for recover the losing building function due to damage should be selected. For this purpose, information between damage level and repair methods should be prepared as a data base.

v) Repair Cost and Down Time

Repair cost, which is the same as the direct economic loss of ATC-58 described in the section 3.1, and downtime should be evaluated by using information of repair methods. For this, necessary information of cost and time for each repair methods should be prepared as a data base.

The step iv) and v) is a design scheme on the scenario for recovering building function.

vi) Difficulty in Business, inconvenience in life

TC1: - **Framework** for evaluation of scenario on losing and recovering building function due to disasters
- **Evaluation examples**

TC2: - **Database format** for evaluation of scenario on losing and recovering building function

TC3: - **Communication language and tool** for explanation of difficulty of business continuity and inconvenience of usual life from the predicted scenario

Figure 6 Expected final outputs of the three task committees (TCs)

Difficulty in business and inconvenience in life should be evaluated due to the results of iii) Functional Damage State, v) Repair Cost and Down Time, and Information of the state of Lifeline. The evaluation result of the "Functional Resiliency" of the building should be explained to the owner and the resident in an understandable format. The meaningful communication language is not only about the cost and the downtime but the difficulties of business continuity and the inconveniences of daily life.

The step vi) is a design scheme on the indication of performance.

4. OUTLINE OF THE BRI PROJECT

The three Task Committees, TC 1 on framework, TC 2 on database system and TC 3 on communication language and tool are organized as shown in **Figure 6**. Activities of Each TC are as follows;

i) TC 1 on framework:
A framework for evaluation of scenario on losing and recovering building functions due to disasters is proposed. Three trial designs of office, residential and hospital buildings are conducted with the framework to point out problems in the design flow and unavailable data which should be accumulated through the future research. Final outputs are structural design framework for "Functional Resiliency" and its application examples.

ii) TC 2 on database system:
Database format for the data necessary for evaluation of scenario on losing and recovering building functions are discussed. A certain number of data is accumulating to use in the trial design. Final outputs are database format and accumulated data.

iii) TC 3 on communication language and tool:
Information tool and contents for communication of continuity and resiliency of building function from the predicted scenario are discussed. Difficulty of business continuity and inconvenience of usual life of people are also discussed as a meaningful communication language. Final output is communication example using results of the trial designs.

5. NECESSARY FUTURE TASKS

The on-going BRI project proposes the framework for evaluation of "Functional Resiliency" and confirmed its usefulness by trial designs. Then based on the results of the project, the common design guidelines for structural designer based on the established framework should be developed soon in the next project to accelerate the "Functional Resiliency" evaluation. However, very limited database are available, which are used for predicting the scenarios on losing and recovering building

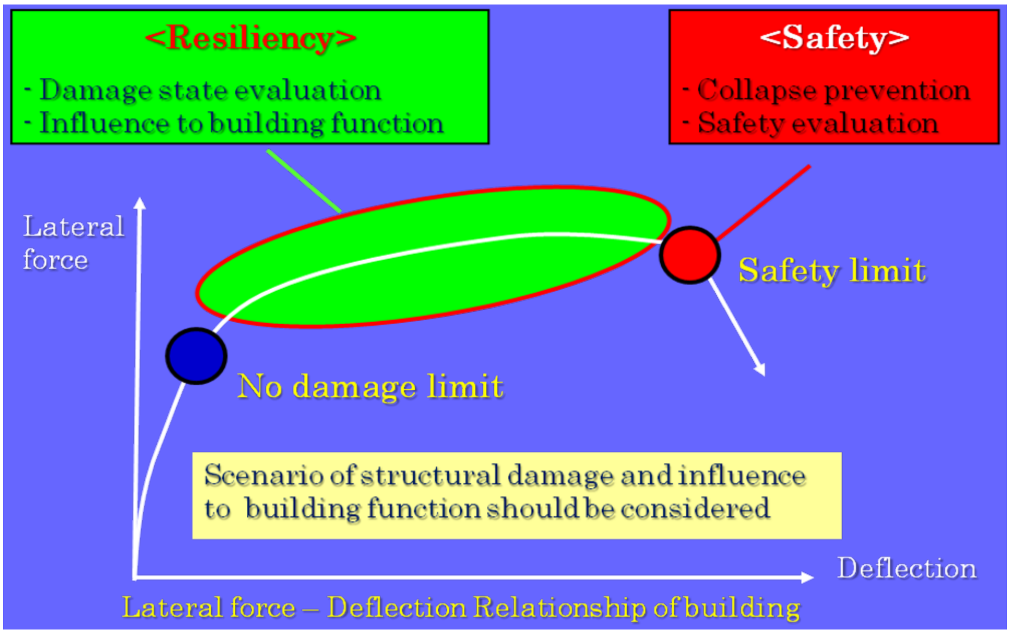

Figure 7 Cover areas of “Functional Resiliency” in the lateral force - deflection relationship

functions, and communication with people. Then solid database should be developed as early as possible. The relationships between the response value, structural damage level, and influence to the building function, and also the relationships between the response value, repair methods, cost and time for repair should be investigated and reflected to the database. Communication language should also be upgraded in order to explain in the more rational manner about the scenarios on losing and recovering building functions, difficulties of business and inconveniences of life.

The expected characteristics of the developed guidelines are as follows;

i) Some economic loss evaluation methods utilize mean value of damage level obtained by the previous earthquake disasters. However, damage can be different by its components and countermeasures. This is because; the guidelines should enable to evaluate the differences of “Functional Resiliency” between each building due to the different components that exhibit different processes of damaging.

ii) The variation between the results obtained by different evaluation methods and databases is a major barrier for direct comparison between the evaluation results. Thus, common evaluation methods and database will be developed to minimize the variation of the evaluation results due to the different evaluation processes and databases.

iii) The structural design procedure for evaluating “Functional Resiliency” should be as simple as possible. This is because, simple and rational design procedure should be developed by the trial designs with detailed procedure and database.

iv) Since the building owner and user have very limited knowledge and information about the structural performance of the building like seismic safety and “Functional Resiliency”, it is hard to select the most suitable structural performance in their most expensive purchase. Then, the guidelines provide a necessary communication language for building owners and users which enable the people to make a good decision.

It is expected to resolve these tasks by the following next research project with the cooperation among private sectors, universities and governmental organizations. Since the area covered by the project is from the no-damage limit to the safety limit as shown in **Figure 7**. However, the conventional research projects for development of rational structural design methods, which mainly cover structural safety limit in **Figure 7**, have taken very long time. Therefore, the research on "Functional Resiliency" management may also take much time as the case of safety management. This is real challenge for the security of future society.

6. CONCLUSION

As a new requirement of society aiming at safety and security, the high resiliency of building function after earthquake disasters is discussed. As described in Chapter 2, considering the problems recognized in the recent earthquake damages, and the disaster-preventive strategy at national level, it is expected that the necessity of technology development relating to the functional continuity and disaster resilience should be emphasized more than ever. Continuing the technology development is expected under sustainable cooperation of organizations relating to the subject.

The research project promotes the activity organizationally and effectively under the same sense of purpose among Japan Structural Consultants Association (JSCA), NPO Japan Aseismic Safety Organization (JASO), university members and many relating organizations. Toward the structuring a performance-based design system which has a true significance requested by the society, we strongly hope to have cooperation of relating sectors in wide fields.

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REFERENCES

ATC-58, 2007. *Guidelines for Seismic Performance Assessment of Buildings, 35% Complete Draft,* URL: http://www.atcouncil.org/pdfs/ATC58-35DraftWeb.pdf (Website References)

Central Disaster Prevention Council of the Japanese Cabinet Office, 2005. *Business Continuity Guidelines 1st ed. ,* URL:http://www.udri.net/portal/kigyoubousai/guideline01_e.pdf.pdf (Website References)

Fire and Disaster Management Agency, 2006. Outline of the Hanshin-Awaji Earthquake Disasters URL:http://www.bousai.go.jp/1info/kyoukun/hanshin_awaji/earthquake/index.html (Website References, in Japanese)

Fukuyama H., Shiohara H., Morita K., Mukai T., Saito T., Kikitsu H., Iwata Y., Wakiyama Y. and Tajiri S., 2008. Research Project on Development of Performance Evaluation System for Structural Resiliency and/or Functional Continuity of Buildings after Disasters, Part. 1 to 5, *Proceedings of the annual meeting of the Architectural Institute of Japan,* Structure I, pp.123-132 (Proceedings, in Japanese)