RESEARCH AND DEVELOPMENT ON SAFETY OF BUILDINGS AGAINST NATURAL DISASTERS AND URBAN FIRES AT THE BUILDING RESEARCH INSTITUTE

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This paper is a summary introducing the Building Research Institute, National Research and Development Agency and its activities such as its organization and medium to long-term objectives. As the latest situation, it introduces the following R&D and technical guidance conducted in the "Safe and Secure Program" which is one of the main program of the institute.

1. R&D aiming to ensure structural safety of buildings through prevention of damage and collapse due to natural disasters such as a major earthquake, etc.
2. R&D aiming to ensure fire safety for buildings and urban areas through prevention and reduction of fire damage.
3. Summary of the Building Research Institute's activities on disasters such as the 2016 Kumamoto Earthquake in Japan.

I. Introduction. This paper briefly explains about the Building Research Institute, National Research and Development Agency (hereinafter called BRI) and its activities. It will provide the introduction of the BRI's organization, the position of its activities, and the summary of tasks conducted in recent years. In this paper, the explanation especially centers on the R&D conducted in "Safe and Secure Program" which is its main research program and on the disaster response.

II. Summary of the BRI (its position and goals).

1. Summary of the BRI. The BRI is a National Research and Development Agency with 70 years of history. It is concerned with wide range of studies on building, housing, and urban community.
The BRI is an institute which conducts R&D on housing, building, and urban planning technologies and training on earthquake engineering comprehensively, systematically, and continuously by utilizing its high level experimental facilities in a fair and neutral perspective, also based on a medium to long-term objectives.
The results will be reflected to the new governmental policies and/or technical standards related to building technology. By these policies and standards being utilized for technology development as well as design and construction by the private-sectors, they contribute to ensuring and improving the quality of Japanese housing, building and urban community: ensuring safety for Japanese citizens, realizing healthy and comfortable housing, ensuring sustainability e.g. saving energy and environmental-friendliness, and providing security to consumers.
Moreover, training course for earthquake engineering contributes to improvement of worldwide countermeasures against earthquake disaster through training of technical experts from developing countries.

2. Medium to long-term objectives and main focus of R&D. "To realize sustainable housing, buildings, and urban communities" is the goal set in the fourth medium to long-term objectives (FY 2016 to 2021) directed by the Minister of Land, Infrastructure, Transport and Tourism. In order to achieve this goal, the BRI has prepared two programs in the fourth medium to long-term plan: "Safe and Secure Program" and "Sustainability Program", and is conducting various R&D activities that contribute to mitigation of building damage caused by natural disasters or fires, reduction of CO_2 emissions, etc. The R&D is conducted through collaborating with public and private sectors (*Figure 1*).

Figure 1. The BRI's position and its goals.

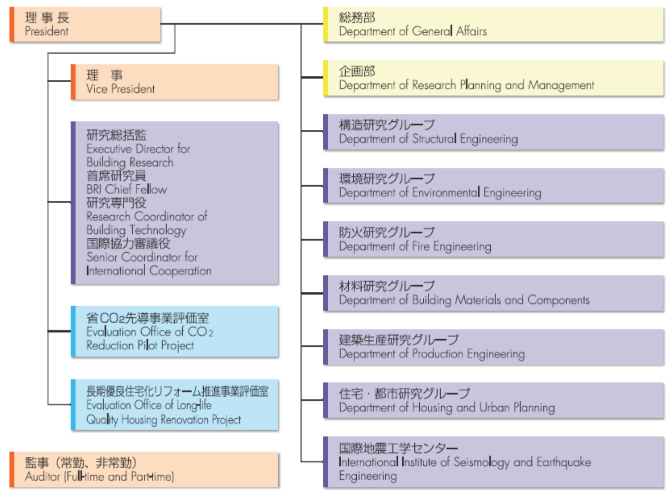

Figure 2. Organization of the BRI.

3. Organization of the BRI. An organization of the BRI consists of the following: 6 research groups which conduct R&D for each field of research, International Institute of Seismology and Earthquake Engineering which conducts training, and Department of General Affairs as well as Department of Research Planning and Management which manage overall administrative matters (*Figure 2*).
The number of full-time staff is 80, and among them, there are 50 researchers.

III. Two R&D programs the BRI focuses on.

1. Summary of the Safe and Secure Program. In order to realize resilient housing, buildings and urban communities, the BRI works on three types of research (*1-1, 1-2, and 1-3*) in the Safe and Secure Program to improve the necessary performance of buildings and communities, by ensuring safety of the citizens against fires or natural disasters such as massive earthquakes triggered by the Nankai Trough or underneath the metropolitan area which is considered to possibly occur in the near future.
The details will be introduced in IV.

1-1. Ensuring structural safety of buildings through prevention of damage and collapse due to natural disasters such as a major earthquake, etc. The BRI develops the seismic performance evaluation method for the ultimate limit state of steel buildings until beam fracture and collapse following earthquakes beyond the current seismic design level.

1-2. Ensuring fire safety for buildings and urban areas through prevention and reduction of fire damage. The BRI pushes forward performance-based fire safety design methods for new materials and spaces to promote safer large wooden buildings and to keep elderly or disabled people secure.

1-3. Advancement of assessment methods for damaged buildings and establishment of design methods for buildings that can remain functional post-disaster, aiding prompt recovery from earthquake or fire disasters. Seismic design methods for structural systems with post-earthquake functional use and quick seismic inspection methods for damaged buildings will be developed.

2. Summary of the Sustainability Program. In order to realize sustainable housing, buildings and urban communities, the BRI works on research (*2-1* and *2-2*) to avoid economically and socially significant impacts caused by the climate change, etc. The BRI also works on research (*2-3*) to deal with challenges regarding housing/urban management and labor shortage in the construction industry, etc.

2-1. Effective use of resources and energy in the field of housing, building and urban communities in harmony with the environment for reduction of greenhouse gas emissions. The purpose of this research is to construct/deepen energy-saving performance evaluation methods for buildings which is more rational and in harmony with the environmental performance of buildings.

2-2. Expanded use of wood-based materials in the building field to contribute to carbon storage, etc. In order to spread and generalize safe and rational mid-and high-rise, large scale timber buildings, the BRI conducts R&D for clarification of technical standards for timber structures and materials.

Photo 1. BRI activities related to 2-2
(left: CLT experimental house, right: 2by4 experimental building).

2-3. Promoting utilization and advancing management technologies for housings, buildings, and urban stocks corresponding to depopulation, birthrate decline and aging population.

(a) Evaluation method and improvement of performance of materials and components. The BRI works to develop new technologies for prompt deterioration evaluation for RC building envelopes and analyzes the corrosion of reinforcing bars in structures.

(b) Housing and urban management in aging/shrinking society. The BRI develops guidelines for making “third places” and local activity hubs for elderly people through utilizing vacant houses and spaces.

(c) Dealing with decrease and aging of construction workers. The BRI considers a scenario to improve productivity to cope with mid-terms changes in working environment on construction site, and develops the digitization and work-saving technology to realize such scenario.

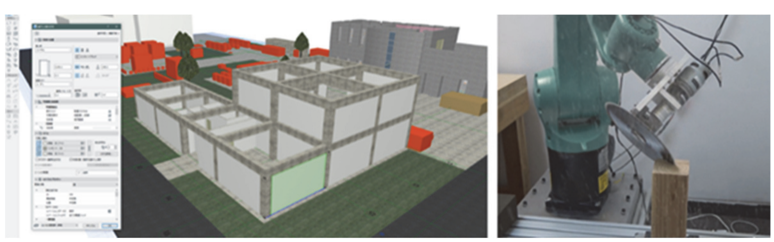

Photo 2. Example of BRI activity related to 2-3 (c).

IV. Introduction of the specific R&D subjects in Safe and Secure Program.

1. Study on performance evaluation method for the ultimate limit state of steel buildings and damage detection under excessive seismic motions. In a massive earthquake underneath the metropolitan area or in a trench-type big earthquake, which are considered to possibly occur in the near future, the ground motion with unexpectedly larger velocity response spectrum, or with longer duration than the one in the current design (the ground motion with large energy spectrum) might affect buildings. For this kind of excessive seismic motions, in order to prevent collapse of buildings, it is necessary to reveal the ultimate limit state, post-peak behavior of buildings and to establish seismic performance evaluation method.
In this study, it conducts experiments and analysis targeting steel buildings in order to propose a method to evaluate the fracture and local buckling of beam under the excessive seismic motions, and also the subsequent ultimate limit state behavior until the collapse (seismic performance evaluation method for ultimate limit state of steel buildings). Moreover, it examines the method to estimate the fractures occurred in a beam etc. of actual buildings after the earthquake by using earthquake records etc. (damage detection method of steel buildings)
In this study, the following three topics are investigated in line with the above research purpose:

1. ultimate repetition performance until the beam fracture.
2. seismic performance evaluation method at the ultimate limit state of steel buildings.
3. damage detection method for beam fracture etc. of buildings.

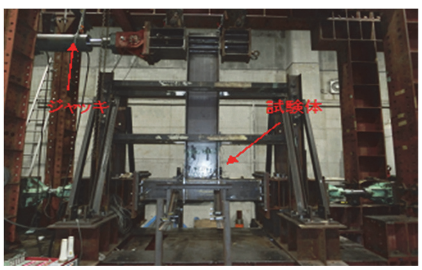

Photo 3. Cyclic loading test on beam.


Photo 4. Shaking table test on two-bay frame.

2. Development of fire-evacuation safety-design technology of buildings with wooden interior.
Although there is a higher demand for wooden interior etc. in various buildings, caused by the popularization of green buildings and promotion of utilizing wooden materials, the usage of interior materials such as timber, which is not classified as fire-proof material in a current fire safety standard, is strictly limited regardless of ways to attach them. On the other hand, recent findings in engineering research show that wooden material possibly has the same fire performance as fire proof materials used in an interior. For instance, in a large size room, burnt area on wooden surface was localized due to self-extinction. Therefore, the study aims to formulate performance evaluation framework and fire-evacuation safety-design method which enable more flexible use of interior materials such as timber.

<u>1) The development of predictive method for fire performance in an interior lining.</u>
The study challenges to accomplish the following tasks in order to develop the fire performance predictive method for each room depending on ways to attach the interior materials such as timber, the room's floor area and ceiling height, and opening conditions, based on experiments such as a full-scale fire experiment (*figure 3*) .
1-1) Quantification of flame spreading on an interior lining.
1-2) Quantification of smoke generation of an interior lining.
1-3) Investigation of required performance in the evacuation safety of an interior lining.
1-4) formulation of the performance evaluation framework of an interior lining.

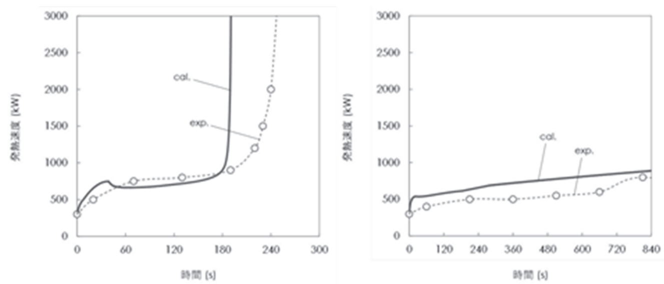

Figure 3. fire development by the difference of a room interior lining
(solid line: calculation value, dotted line: experimental value)

<u>2) The development of fire-evacuation safety-design method</u>
Considering fire behavior predicted by ways to attach interior lining and space condition of the room as a design fire, and also considering room exits and the effect of smoke control system or sprinkler system in an evacuation route such as corridor, the study challenges to accomplish the following tasks in order to develop evacuation safety-design method covering evacuation from rooms, from floors, and from the entire building.

2-1) Investigation of the design evacuees considering occupant characteristics.
2-2) Investigation of the necessary conditions of evacuation route.
2-3) Quantification of the effect of smoke control system or sprinkler system (*figure 4*).
2-4) Construction of fire-evacuation safety-design method.

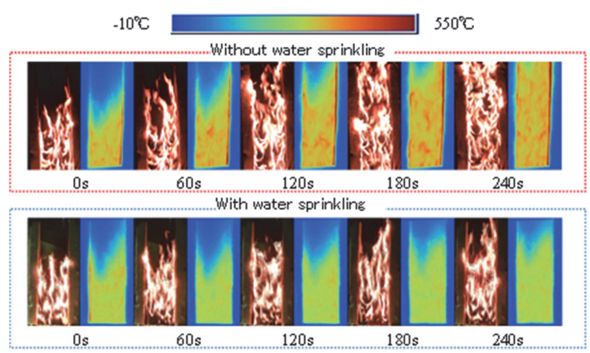

Figure 4. The difference of flame spreading in a wall surface by watering.

3. Development of seismic assessment method for existing buildings that can remain functional post-disaster. General existing buildings (apartment houses, office buildings and so on) will be targeted, and the technology development necessary for evaluating post-earthquake functional use will be conducted. Additionally, the technology useful for seismic retrofit design for existing medium- and high-rise buildings will be developed and the result will be utilized in the evaluation guidelines accumulated in the future. Furthermore, the study challenges to establish a detection method for rationalization of post-earthquake damage investigation by developing useful tools to detect post-earthquake functional use of damaged buildings. These results contribute to the seismic assessment method for buildings that should remain functional after the earthquake.

The specific subjects are the following:
3-1) Proposal of the seismic assessment method for buildings which contributes to post-earthquake functional use.
3-2) Development of the seismic assessment method for parts and members critical for post-earthquake functional use and the seismic technology to improve post-earthquake functional use of buildings.
3-3) Development of the technology to detect functional use of damaged buildings.

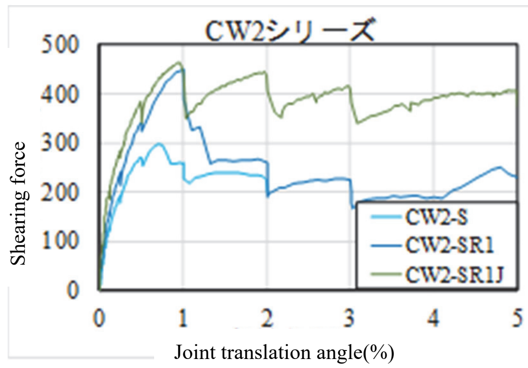

Figure 5. Effectiveness of seismic retrofitting using UFC Panel

V. Examples of disaster response. At the time of extensive earthquake disasters and fires, the BRI dispatches staff members to affected areas and conducts extensive investigation and various types of studies based on this investigation for the damaged buildings, residential and urban areas.

1. Kumamoto Earthquake.

[Building damage investigations and factor analysis for 2016 Kumamoto Earthquake]
In response to the 2016 Kumamoto Earthquake (foreshock: magnitude-6.5 quake on 14th April, main shock: magnitude-7.3 quake on 16th April), the BRI dispatched researchers to the affected area. They surveyed to determine the damage aspects and the cause of damage in cooperation with National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism (hereinafter referred to as NILIM). In the field investigation, verification of effectiveness and validity of the current building code were conducted at the request of MLIT, as well as the data accumulation related to the BRI's research subjects. As these investigations were in progress, the results of investigations conducted by various organizations such as Architectural Institute of Japan were widely collected upon organizing and summarizing the data.

Photo 5. Examples of damage to wooden houses affected by the Kumamoto Earthquake.

2. Itoigawa city fire.

[Damage investigations for huge fire occurred in Itoigawa city on 22nd December 2016]
The urban fire which occurred in Itoigawa City, Niigata Prefecture on 22nd December 2016 caused the huge damage with 147 burned buildings (burned total floor area approximately 30,000m^2) and 17 injured people. Excluding the time of earthquakes, this amount of damage in an urban fire has not been caused since the great Sakata Fire occurred in 1976 in Sakata City, Yamagata Prefecture. The main characteristic of this fire is that the fire spreading damage had enlarged by many leaping flames caused by the strong south- wind.

The BRI has been collaborating with NILIM in investigation and analysis on this fire damage. Specifically, to reveal damage-increasing factors, the following were conducted: 1) prediction of the time for catching fire in each building and the situation of leaping flames by analyzing aerial images taken during the fire, 2) the verification test on tiled roof's tolerance for leaping flames, and 3) the analyzation of the difference of fire-spreading situation in case of different building structures in the city by using a computer-simulation.

Photo 6. Damaged area in the Itoigawa city fire.

VI. Concluding remarks. A summary of the BRI and the recent R&D activities, focusing on the research field of "safe and secure" were introduced.

Not only limited to the field of "safe and secure", but also R&D and its results expected of the BRI are becoming more diversified and sophisticated because of the changes in disaster characteristics linked to the climate change in recent years, as well as the extensive earthquakes predicted in and around Japan. Under these circumstances, the opportunities to conduct the information exchanges on state-of-the-art R&D with the research institutes and researchers among countries in the world are extremely valuable.

Acknowledgements:
The author would like to express his deep gratitude to everyone who extended him such an opportunity. The author is also grateful to Mr. Masashi Mori, Coordinator for International Research Cooperation, BRI, Ms. Noriko Yamaguchi and Ms. Mieko Mizusawa, International Division, BRI, for their excellent help in the preparation of this manuscript.