Investigation on index of building resilience and BCP level

May 2021

Architectural Institute of Japan
Special Investigation Committee on
Index of Building Resilience and BCP Level

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本書は、『建物のレジリエンスとBCPレベル指標検討特別調査委員会報告書：事業継続計画策定のための地震災害等に対する建物維持・回復性能評価指標の提案に向けて』（2020年３月）の英語抄訳版です。

Summary of the committee activity

BCP (Business Continuity Plan) in companies and society together with resilience of buildings and society after natural hazards is getting much interest recently. Resilience consists of resistance (damage mitigation performance) and recovery. The AIJ special investigation committee 'Investigation on index of building resilience and BCP level' was organized and conducted investigation activity during 2017-2020 to define an index and quantify the building resilience and BCP level. This is a report from that committee. In this committee, the following three working groups were organized.

(1) **Investigation on index of BCP and resilience level**

1) In addition to the relation with the structural safety of buildings, the relation of many factors related to building function maintenance with the BCP level is investigated.

2) The uniform treatment of design earthquake ground motions is investigated for buildings, facilities, machineries, warehouses.

3) Clear scenarios of application of the proposed indices are investigated.

(2) **Investigation on role of structural health monitoring system in improving building resilience performance**

1) Current working status of monitoring systems in buildings is investigated.

2) The evaluation of communication in the monitoring system is investigated.

3) Successful examples of evacuation using the monitoring systems and shortening of downtime are shown.

(3) **Investigation on spread of BCP concept and activity**

1) Loan and insurance systems as incentives for BCP activity are investigated.

2) Leaflets and pamphlets for the spread of BCP activity are made.

In Japan, severe damages to buildings and houses occurred due to several major earthquakes and typhoons in 2018 and 2019. Especially the stop of building functions resulting from structural and nonstructural damages together with the malfunction of facilities and machineries induced large social issues. It is hoped that the investigation by this special committee helps to upgrade the overall resilience of buildings and society and promote the activity on BCP.

Members of the committee

Izuru Takewaki (Chairman)
Masayuki Kohiyama (Secretary)
Takeshi Asakawa, Tomohisa Okuno, Shigehiro Sakamoto, Kazuaki Torisawa,
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1. Aims and scope of committee towards the proposal of resilience performance index and BCP level rating for evaluating the performance of building functionality preservation and recovery after natural disasters

1.1 Preface

Recently, BCP (Business Continuity Plan) and BCM (Business Continuity Management) of companies and society together with Resilience, consisting of resistance (damage mitigation performance) and recovery, of buildings and society are getting much interest[1-9]. Resilience possesses a broad meaning and is related to robustness and redundancy[10-12]. The concept of Performance-Based Design (PBD) is extended to the concept of Resilience-Based Design (RBD) by taking into time account. Furthermore, the terminology of Resilience-Based Performance is used and RBD can be regarded as an extension of PBD.

While BCP is related to business and society, Resilience is related to general or overall aspects of company activities and social activities. Furthermore, Resilience is also used for buildings. In this special committee organized in Architectural Institute of Japan (AIJ), buildings are the main target. The main purpose of BCP is to make plan for continuing the company and society activities even during natural disasters. It is absolutely necessary to enhance the level of resilience of buildings and society groups for continuing the company and society activities.

This report summarizes the research conducted in the AIJ special committee of 'Investigation on index of building resilience and BCP level' (2017-2020). The following themes are treated.

❶ Concept of resilience and its conventional assessment indices

❷ Concept of BCP and its conventional assessment indices

❸ Creation and proposal of resilience performance index and BCP level rating

❹ Utilization of structural health monitoring for resilience enhancement

❺ Examples of application of BCP level rating

❻ Action plan and advertisement of BCP activity

❼ Record of panel discussion at 2019 AIJ annual meeting

❽ Introduction of examples of previous activities on resilience and BCP

1.2 Bruneau's resilience triangle[2)]

Recently, the word 'resilience' is often used not only in the field of building design and construction, but also in various phases in modern society. It is defined commonly that resilience is related to the recovery ability of an object from a damaged state after the experience of external disturbances, e.g. natural hazards. It is well known that the first resilience measure was proposed by Dr. Bruneau using a 'resilience triangle' (see Fig.1) [6, 7]. Actually, Dr. Bruneau has a strong relationship with Japan. He was staying at Dr. Nakashima's laboratory of DPRI in Kyoto University at the occurrence of Hyogoken-Nanbu earthquake in 1995. At that time, a damage survey was conducted by the Kinki branch of AIJ and a preliminary reconnaissance report was written in Japanese by the Kinki branch of AIJ. It was recognized at that time that this earthquake was a quite rare devastating earthquake which occurred in an urban mega city. For this reason, the headquarter of AIJ and the Kinki branch decided to translate this Japanese report into English and distribute this to the world. After some time, I was heard that Dr. Housner of California Institute of Technology highly evaluated this report. A working group was set by Dr. Nakashima and I joined this working group. In this working group, Dr. Bruneau helped our working group. I imagine that Dr. Bruneau got some insights from the survey of Hyogoken-Nanbu earthquake at this time when he proposed his unique resilience concept.

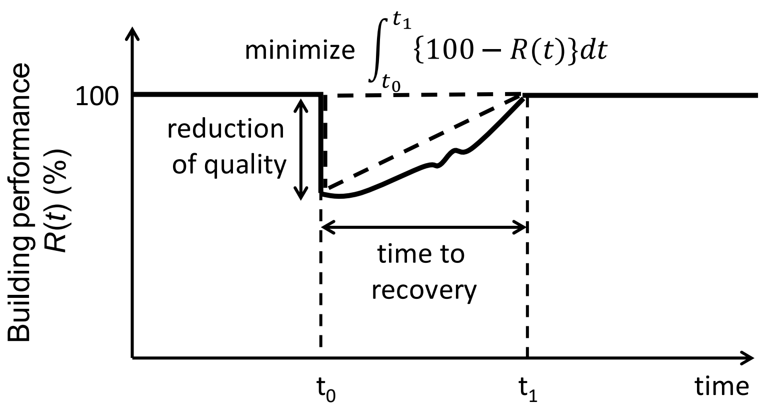


Fig.1 Bruneau's resilience triangle

Dr. Bruneau and Reinhorn[6-8] investigated 'resilience' of building structures and infrastructures. They defined that 'resilient structures and systems' possess (1) small failure probability, (2) well-reduction of lives loss, system damage, negative economic and social influence, (3) fast recovery to a normal state from a damaged state after the experience of disasters. Fig.1 shows a temporal example of the performance curve of a building or a system after the experience of action of earthquake. The requirements (2) and (3) mentioned above mean that the enhancement of resilience can be achieved by minimizing the area of the triangle (called Bruneau's resilience triangle), expressed by the time integration of the performance reduction quantity '100-performance R(t)' in Fig.1.

Bruneau and Reinhorn[6] picked up the following four items as the important key words for expressing resilience: <u>Robustness</u>, <u>Redundancy</u>, <u>Resourcefulness</u>, <u>Rapidity.</u>

To achieve these factors, the following factors can be considered from architectural aspects.

<Structural engineering>

1. Development of structural control technologies for building responses to earthquake ground motions (structural control, base-isolation)
2. Reconsideration of safety factor: Performance-based design, Reconsideration from the viewpoint of the worst scenario (variability in earthquake ground motion properties and

building structural properties), Quantification of safety considering fail-safe, Quantification of robustness and redundancy

3. Development of novel building design methods which enable the fast recovery from damaged states after experiencing earthquake ground motions, e.g. damage-controlled design

4. Application of structural health monitoring technologies to building structures

<Environmental and equipment engineering>

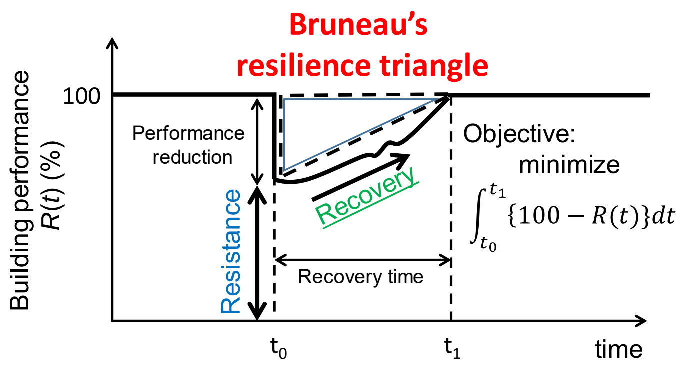
1. Plan of electric and energy power during and after disasters
2. Preparation of equipment restoration during and after disasters
3. Health care during and after disasters
4. Smart city planning

<Architectural planning>

1. Evacuation training during and after natural disasters
2. Architectural planning of rooms
3. Building location plan in community
4. Dwelling plan of people who works primarily after disasters
5. Introduction of insurance

1.3 Resilience performance index and BCP level rating for evaluating the performance of building functionality preservation and recovery after natural disasters

Fig.2 shows an example of definition of several terminologies related to building resilience performance and BCP level rating using the Bruneau's resilience triangle in Fig.1. Resistance (mitigation performance) and recovery are the two major constituent factors for resilience and the combination of these two factors is the overall resilience performance. In addition, the resilience performance index is an index for resilience performance and the BCP level rating is an index for expressing the overall resilience performance level.



Resistance (Mitigation performance) : One aspect of resilience

Recovery : One aspect of resilience

Resistance (Mitigation performance) + recovery : Overall resilience performance

Resilience performance index : Index indicating resilience performance

BCP level rating : Index indicating overall resilience performance

Fig.2 Definition of building resilience performance and BCP level rating

1.4 Formulation of national resilience basic plan and target of building resilience and BCP

It seems that the 2011 off the Pacific coast of Tohoku earthquake and the East Japan Earthquake disaster are the turning point which directed our concerns to BCP and BCM. After this earthquake, the Japanese Government released a plan of national resilience basic plan and pointed out that it is very important for the government and people to respond to such devastating natural disasters with full power. Table 1 is an example of such plan and indicates the worst scenarios to be avoided during and after such disasters[13]. The basic targets I-III are related to resistance (mitigation performance) and the basic target IV is related to recovery. It may be intended to think about the countermeasures for such worst scenarios[1-3] by showing these examples. The first matter 1-1 in Table 1 is concerned with the avoidance of collapse of houses, buildings and transit systems. The present special research committee deals with buildings primarily and focuses on the setting of measures on resilience and BCP level of buildings.

Table 1 Worst event to avoid occurrence [13)]

Basic target	Target set in advance			Worst scenario to avoid
I Minimum lives loss attained II Important function of nation and society guaranteed without fatal damage III Minimum damage of national property and public facilities IV Fast recovery and restoration	1	Avoidance of direct death	1-1	Many lives loss due to collapse of house, building and transit system and public facility
			1-3	Many lives loss due to wide spread of tsunami
			1-4	Many lives loss due to sudden,wide and long-term flood
			1-5	Many lives loss due to volcanic eruption and large landslide
	2	Fast action of rescue and medical activity and guarantee of sufferer's healthy environment	2-1	Long-term stop of supply of food, water, electroric power, energy relating to life
			2-3	Shortage of rescue activity due to damage to self-defense force, police, fire dept
			2-7	Many lives loss and diseases due to bad sufferer's environment and insufficient health care
	4	Guarantee of information and communication function and service	4-3	Function stop of information service during disaster and delay of evacuation and rescue
	5	Avoidance of functional disorder of economic activity	5-1	Decrease of international competitive power due to cut of supply chain
			5-5	Critical damage to physical and human mobility due to principal transit network cut at Pacific-belt lane
			5-8	Delay of stable supply of food
	6	Minimum damage and fact recovery of lifeline, energy supply facility and transit network	6-1	Long-term functional stop of electric supply network and town gas, oil, LP gas supply
			6-2	Long-term stop of water supply
...		...		...

1.5 Previous research and design in structural engineering and new research and design considering resilience [1)]

In this section, we will focus on structural engineering field. In the field of structural engineering, the main theme in the past is the safety of buildings at the instance of design and construction (see Fig.3) and the recovery during and after disasters has never been treated as a main target except the theme of seismic repair or restoration of respective buildings after earthquake disasters. For this reason, BCP has never been discussed sufficiently for buildings.

The structural design paradigm of building frames under severe earthquake ground motions in the 20th century relied on the capacity of plastic energy dissipation in structural members for the design earthquake ground motions which are regarded empirically as the maximum ones. The earthquake resistant design code revised in 1981 was based on such paradigm. However, the target to the low-carbon city and building and the environmental-oriented concept based on low-energy consumption, sustainable design, the recognition of the importance of BCP concept etc. requested the need for a drastic change of paradigm in building construction fields. In other words, the main target of the design of buildings is changing from the safety during disasters to the reduction of fear during disasters and the business continuity issue from BCP problems is becoming an important factor.

From these points of view, the damage-controlled design, the structural control by dampers, the base-isolation systems etc. have been investigated recently. The developments in these fields are remarkable.

Furthermore, the structural health monitoring is being investigated extensively to make the above-mentioned design concepts and techniques realizable. The structural health monitoring techniques are expected to enable the fast recovery from a damaged state to the normal one in a short time range.

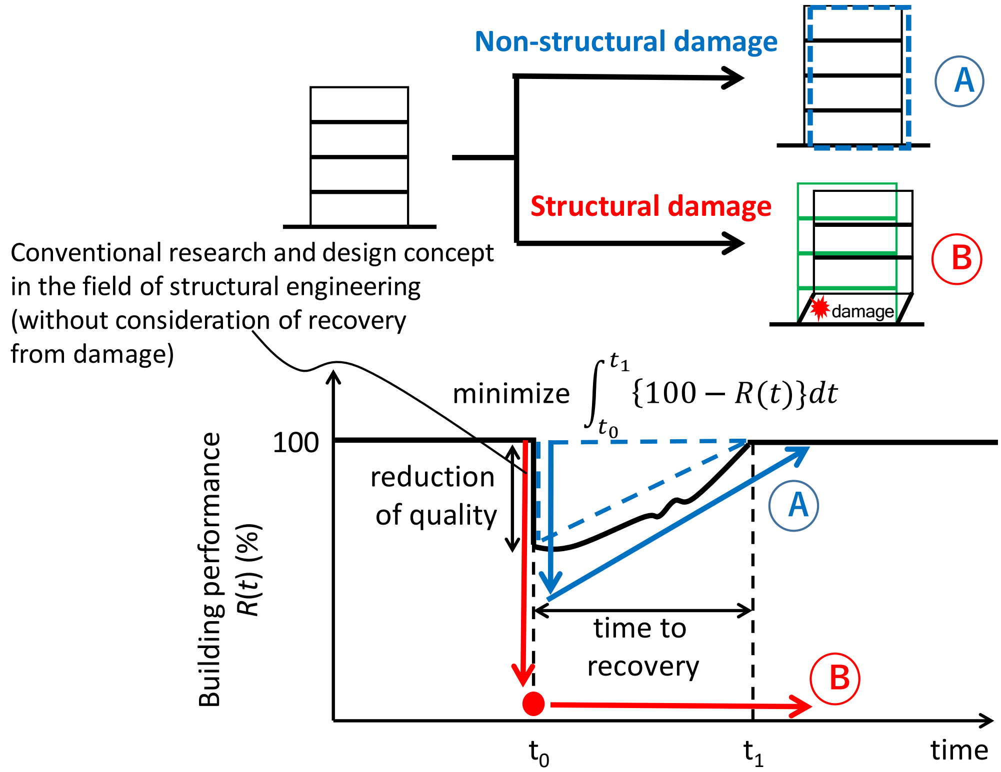


Fig.3 Conventional research and design concept in the field of structural engineering and novel research and design concept considering resilience

1.6 Response to disturbance beyond predetermined design level and various factors related to resilience [1)]

Since the properties and occurrence time of earthquake ground motions are uncertain even with the present cutting-edge knowledge, it is hoped that building structures resist such uncertain earthquake ground motions beyond code-specified level with a small reduction of structural performance and are designed so as to possess sufficient robustness and redundancy. Fig.4 shows examples of a robust design and an unrobust design from the viewpoint of performance reduction under design earthquake ground motions beyond code-specified level. Structural control and base-isolation technologies are examples for satisfying such requirements on robust design.

Finally, Fig.5 presents some factors related to building resilience [12)]. The keywords included in this figure are the worst scenario, the development of fast damage detection system using structural health monitoring systems, the preparedness for earthquakes, the development of novel structural systems with high robustness and redundancy even beyond code-specified earthquake ground motions.

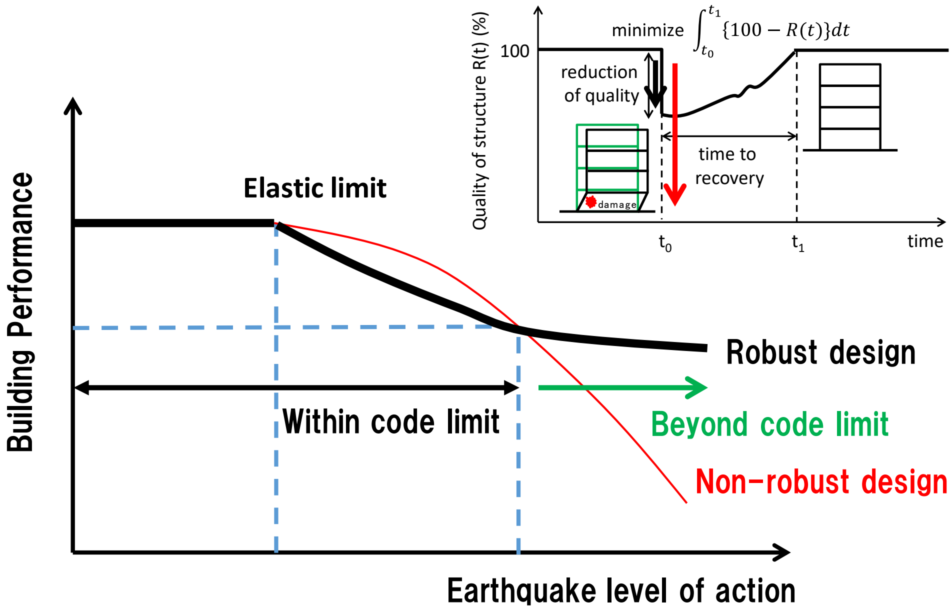


Fig.4 Robust design and unrobust design for disturbances beyond predicted level in view of performance reduction

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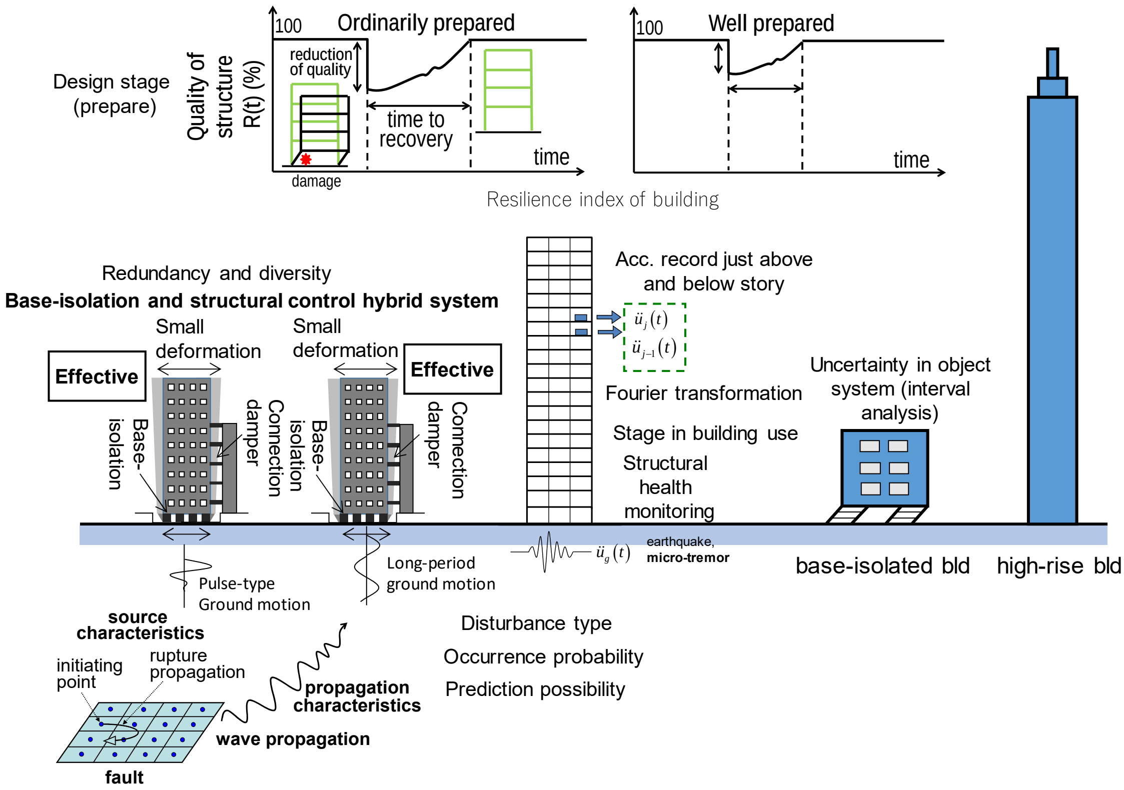

Fig. 5 Various factors related to resilience [12)]

2. Necessity of performance index to evaluate resilience of buildings for business continuity planning

2.1 Organizational resilience and business continuity management from the perspective of businesses and building users

The International Organization for Standardization (ISO) introduced definition of Business Continuity Management (BCM). The standard defines BCM as follows[1):]

Business Continuity Management (ISO 22301:2012(en))

Holistic management process that identifies potential threats to an organization and the impacts to business operations those threats, if realized, might cause, and which provides a framework for building organizational resilience with the capability of an effective response that safeguards the interests of its key stakeholders, reputation, brand and value-creating activities.

As such, BCM is an approach to improve the organizational resilience, and Business Continuity Plan (BCP) is a deliverable that is documented as a part of BCM. In this system, a series of plans, procedures, and lists are prepared to ensure that important tasks are not disrupted in the case of crises such as disasters and accidents. If such a disruption occurs, these tasks can be restarted within an allowable range. It is important that details pertaining to the handling of a building to be used as the base are clearly stated within the BCP. Therefore, the resilience-related performance of buildings must be evaluated, and results must be shared.

BCP is different from conventional disaster prevention plans because it is an approach to achieve supply responsibility for products and services of organizations. Based on the assumption that comprehensive protection is difficult, the discussion is about what to protect, select, and focus on. For this purpose, clear goals must be set and stakeholders must reach a consensus. Because this plan has been implemented into organizational overall disaster prevention and mitigation policies, it is important to maintain the premise of advance preparation to minimize problems and damages. Additionally, for business continuity, it is important to consider how to handle problems and damages in advance and undertake efforts to improve the ability to respond to crises. If important resources are limited, various restrictions will be imposed on actions. To improve the chances of achieving these goals under such severe circumstances, it is crucial to examine the methods for continuing important tasks and restarting businesses with the Recovery Time Objective (RTO) and prepare the environment for post-disaster response. Thus, the degree to which building performance can contribute and respond to these requirements and management decisions must be clarified.

2.2 Building function continuity and recovery plans

As discussed above, BCP is formulated as a method for improving organizational resilience. In other words, the purpose of BCP is to improve organizational resilience. To execute BCP or a BCP-based system, a building function continuity and recovery plan is formulated. It is crucial to evaluate building resilience performance.

When constraints such as disrupted lifelines or damaged facilities are encountered following a disaster, important functions are maintained in operation using parts of buildings and by lowering the level of functions. The situation in which functions are completely disrupted must also be considered. In any cases, ideas and measures for restarting building functions must be determined in case building functions are disrupted.

In situations where buildings are used by tenants, such information must be confirmed because it is associated with the product appeal and real estate value of the tenant building. However, information transmission and mutual understanding of building performance from the viewpoints of users and markets are not always effective. For instance, in the present BCP response, designs are often created without clarifying the required performance and basis for decision making. Designs are often over-engineered or under-engineered, incompatible with the required performance. Moreover, the responsibility, authority, and division of roles are not always clarified in operation and management systems. Diverse stakeholders are present in the design, construction, management, and usage, resulting in extreme challenges in cross-sectional examination within the organizations and fields as well as in the adaptation/organization of multiple requirements such as energy conservation, seismic resistance, and economy. As Resilience Performance Index and BCP Level Rating of Buildings for Business Continuity proposed by the Architectural Institute of Japan (AIJ) committee will become more widespread in the future, communication among various stakeholders, societies, and users must be promoted in each step of the building's life cycle.

2.3 Building function continuity and recovery plans

According to the conceptual framework of resilience triangle developed by Bruneau[2) 3)] for evaluating resilience, organizations and local societies cannot avoid a certain level of damage in the event of a major disaster even when thorough preventative measures are undertaken. Thus, it is important to develop methods for avoiding life-threatening situations and withstanding and overcoming harsh and difficult situations. Fig. 1 is a conceptual diagram showing the level of daily-life activities and tasks discontinuing when a disaster occurs. In addition to the measures that minimize damages caused by a disaster, it is crucial to maintain the critical functions of an organization and possess the capability to quickly recover and achieve a Recovery Level objective (RLO) close to normal. Situations continue to develop even after a disaster. Thus, for resilience, it is necessary to set the concept of time and goals. Time is an important resource after a disaster; thus, measures against disasters must always consider the passage of time. The area showing the dashed part in Fig. 1 (integral) expresses the extent of damage, which will be small for resilient buildings and cities. Generally, resilient buildings and cities can withstand challenging conditions by comprehensively considering the ability to recover after a disaster and make improvements with respect to prevention, resistance, and protection. Indices for evaluating these aspects have become necessary in engineering applications.

Maruyama et al.[4)] reported the opinion of Dr. Leena Ilmola of the International Institute for Applied Systems Analysis, who said that resilience indices are "performance metrics" that evaluate past behaviors of systems after the fact to demonstrate the resulting resilience. Moreover, they discussed a "competency metric" for evaluating the present resilience against future incidents. The formulation of building resilience performance and BCP level indices proposed by the AIJ committee is expected to be equivalent to the competency metric.

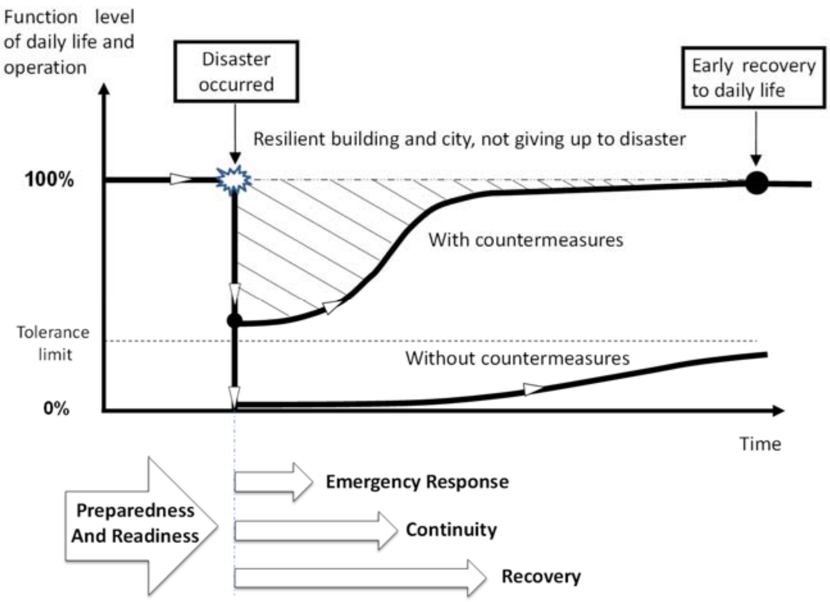

Fig. 1 Concept of resilience of buildings and cities

2.4 Early recovery strategy of BCP and necessity for resilience performance index and BCP level rating of buildings for business continuity

The approach for formulating BCP involves early recovery strategy and alternative strategy. The former aims at local business continuity, whereas the latter is associated with securing alternative bases in distant locations and continuing production through cooperation with business partners. The alternative strategy is a powerful approach that is particularly effective in major disasters; thus, it has become more valuable in current business continuity efforts. However, measures and investments for establishing resilient buildings are usually related to the early recovery strategy. If Resilience Performance Index and BCP Level Rating of Buildings for Business Continuity is unclear, it is difficult to evaluate the importance of a building as a resource within the early recovery strategy. To promote investment in constructions and build high-quality buildings, information that contributes to the early recovery strategy is extremely important. Although the alternative strategy has gained popularity, aiming for "fort"-like buildings is not necessarily the best measure. In management, investment superiority in buildings is most carefully evaluated compared with other measures.

BCP is different from conventional disaster prevention plans because damages and disruptions to functions are considered in its plan. Thus, information on the number of days needed for recovery, details on recovery performance that considers the durations of function disruption, and information that clearly states the dates until recovery with a specific time concept—such as "90% recovery within one week," "90% recovery within one month," and "90% recovery within six months"—have become useful indices. As these indications become organized, accountability to stakeholders will be met and new frameworks are anticipated that will be highly valued in insurance and financial markets, including real estate evaluation and collaboration with new insurance products.

The early recovery strategy also contributes to the maintenance of urban functions, which is considerably valuable. As buildings are protected, urban functions are maintained. When BCP is implemented in an organization, if only the alternative strategy is valued, urban functions can deteriorate even if the organization survives. Organizations receive benefits from various assemblages in cities; thus, a decrease in the values and capabilities of cities negatively affects the organizations. By protecting individual bases and spaces, urban functions are maintained. Even if individual companies survive, if the capabilities of cities are weakened, companies are ultimately negatively affected. Therefore, it is important to protect integrated functions of the base city. Discussions must be toward achieving both continuation of organizations and maintenance of urban functions.

2.5 Business continuity and building continuity

As discussed above, BCP is a management strategy for the survival of organizations. BCP clearly states Recovery Time Objective (RTO) and formulates strategies and measures. By assuming a disaster, BCP examines the Recovery Time Objective (RTO) and Recovery Level objective (RLO) achieved under various restrictions. These goals are clearly stated and shared among stakeholders. This approach is different from past approaches that focus on disaster prevention. BCP uses various techniques based on the type of industry, business style, geographical development between the headquarters and branches, division of roles, and building ownership; however, the prominent strategies, i.e., alternative and early recovery strategies, in business continuity are common in all approaches. The protection of building functions is related to the early recovery strategy, as mentioned above. When examining this strategy in BCP, measures undertaken for buildings at the disaster site become important. As resources for continuing important tasks of organizations, the base building is identified and building function continuity and recovery plan to execute BCP as well as building function continuity and recovery plan that consider BCP are examined. In the construction field, the building function continuity and recovery plan can be handled as BCP; however, the BCP of an organization and building function continuity and recovery plan (Building Continuity) do not necessarily correspond to each other. Thus, if information on real estate, finance, related industries, and building performance is to be exchanged, the topic of discussion and the value of the building used for the business must be confirmed to ensure that there is no inconsistency in the context and situation. As mutual understanding progresses using Resilience Performance Index and BCP Level Rating of Buildings for Business Continuity, it becomes possible to evaluate the level of contribution made by protecting building functions to ensure business continuity of an organization. Under such a perspective, Resilience Performance Index and BCP Level Rating of Buildings for Business Continuity proposed by the AIJ committee play an important role. Through efforts made toward business continuity, various stakeholders can hold in-depth discussions, ideally achieving buildings with a true BCP-accommodating style.

2.6 Viewpoint of resilience evaluation

Regarding the resilience evaluation framework, the resilience triangle developed by Michel Bruneau and others[2) 3)] presents a quantitative evaluation framework for resilience, as discussed above. In the MCEER's Resilience Framework by MCEER (Multidisciplinary Center for Earthquake Engineering Research), reduced failure probabilities, reduced consequences from failures, and reduced time to recovery are listed as resilience characteristics. As a characteristic of resilience, the concept of four "Rs" (Robustness, Redundancy, Resourcefulness, and Rapidity) is presented.

Fig. 2 presents the framework of disaster resilience evaluation. It shows the necessity for adequate preparedness and readiness and measures the responses during a disaster in minimizing damages caused by a disaster, maintaining the most important functions, and promoting rapid recovery and reconstruction in a tabular format. Such a systematic approach aims to improve abilities to prevent, protect, resist, continue, recover, respond, and execute and minimize the ultimate damage. Qualities such as robustness, redundancy, resourcefulness, flexibility, independence, accuracy, and speed are the focus of the evaluation.

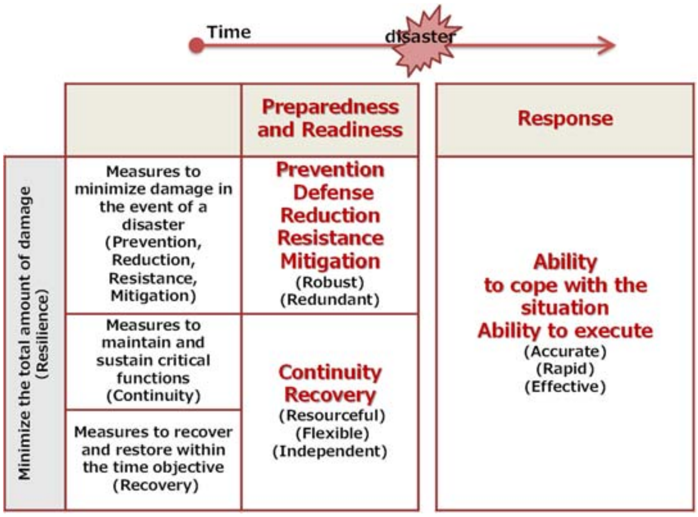

Fig. 2 Disaster resilience assessment framework

2.7 Importance of post-disaster response and monitoring of building conditions

The response after a disaster is important in the early recovery strategy. However, an ad hoc response cannot overcome impending crises. To improve the ability to respond and execute after a disaster, monitoring building conditions is important.

As discussed above, in business continuity, crisis response during and after an emergency is important in addition to preparation and measures undertaken before the emergency. The crisis response refers to the response to major crises regardless of the assumption, which is equivalent to Crisis Management. When disasters and problems occur, situations must be accurately understood, evaluated, and promptly addressed to minimize the damage and appropriately manage the situation. With such an active approach, response to major and unexpected situations can become possible. Risk involves the handling of uncertainty, and crisis refers to the handling of an actual event. Terms such as "risk" and "crisis" must be correctly differentiated, and preparations must be made with future responses in mind. In addition to developing measures for minimizing problems and damage, it is important to consider problems and damages in advance. Moreover, it is desirable to prepare an environment for post-disaster response.

To this end, unified situational awareness is a necessary foundation for people and organizations that must respond to a disaster: i.e., the Common Operational Picture (COP) is desired. This allows for understanding of the damage and usable resources, cooperation between organizations, and examination of regional cooperation. Each type of monitoring technique is a useful tool for such a purpose and should be actively utilized. It is important to consider disaster response in terms of time because time is the most important resource after a disaster. Situations must be accurately understood shortly after a disaster, such as the event cause and conditions. For instance, in cases of office buildings and hospitals, the building usability must be promptly determined in addition to understanding whether spaces are usable for important tasks, the cause of the dysfunction, the duration and the level of functions that can be maintained, the meaning of alarms, and the immediately necessary tasks that must be performed; further, the usability of a building must be determined.

While maintaining the building functions, the following challenges are encountered: the extent of damage is unclear after a disaster; responses become ad hoc during confusion; responsibility and authority of responders are unclear; preparation is inadequate for long-term response after a major disaster; and stocked resources (energy and water) are rapidly consumed. To address these challenges, an environment must be prepared in advance to allow crisis management during an actual crisis.

2.8 Conclusions

In this chapter, we introduced the importance of Resilience Performance Index and BCP Level Rating of Buildings for Business Continuity from the viewpoint of the BCP early recovery strategy. Prompt return to normal life is a crucial requirement of residents and companies; thus, we need to develop resilient organizations, communities, and cities with flexible strength to withstand crises. Herein, we explained the necessity of an index for building function continuity and recovery performance evaluation in association with business continuity of organizations. BCP can be considered as a decision plan for options, and it focuses on what to protect and what to surrender under limited conditions when facing a crisis. Therefore, the bases for decisions must be clearly stated. Additionally, accountability for clients and stakeholders must be met. BCP must clearly state Recovery Time Objective (RTO). Thus, information on whether a building can meet such a need is crucial.

Even if we cannot stop disasters from occurring, it is possible to achieve a society that cannot be defeated by a disaster. Resilient buildings can comprehensively improve the capacity to withstand disasters, thus providing an important opportunity to advance and improve building systems using a combination of designs, structures, environments of buildings and cities as well as through discussions on planning, design, operation, and maintenance/management. Such a plan can also lead to discussions that benefit building users, such as ways in which buildings can provide good services for users. Resilience is a human-centered concept.

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3. Concept of BCP and existing evaluation indicators (indices)

3.1 Introduction

The concept of business continuity plans (BCP) likely began spreading after the September 11 attacks in 2001. The speed of business recovery purportedly varied among companies that had an office in the World Trade Center (WTC) in New York depending on their preparedness to continue business. At the time, the Federal Emergency Management Agency (FEMA) promoted Continuity of Operations (COOP), guidelines for business continuity, among government agencies. The 2000 edition of NFPA1600 the Standard on Disaster/Emergency Management and Business Continuity Programs, issued by the National Fire Protection Association (NFPA) also presented the business continuity concept to companies and organizations.

Initiatives for the standards of business continuity plans include Private Sector Preparedness (PS-Prep), a standard certification program to improve the disaster-response capability of private-sector companies, started in the US. In the UK, the British Standards Institution (BSI) issued standards for business continuity management (BS25999) in 2006. In 2012, the International Organization for Standardization (ISO) established ISO 22301 (business continuity management systems). In Japan, JIS Q 22301 was established in response to ISO 22301.[1)]

Guidelines have been developed also in Japan by the Cabinet Office, Japan Business Federation, the Ministry of Economy, Trade and Industry (METI), and other organizations since 2002, including a certification system for conformity to ISO 22301 requirements.

The following summarizes major standards and guidelines, based on which it organizes the concept of BCP, presents an overview of technical information related to building design related to the achievement of BCP, and describes evaluation indicators used in such materials. The article will also describe cases in business that are useful as a reference.

3.2 JIS Q 22301

Business continuity management systems – Requirements (JIS Q 22301)[2)] was established in 2012 (revised in 2020) in response to ISO 22301 (revised in 2019). JIS Q 22301 defines a business continuity plan (BCP) as a documented procedure that leads an organization to respond to business suspension or interruption, restore and resume the business, and recover it to a level prescribed in advance. JIS Q 22301 defines business continuity management (BCM) as a comprehensive management process of identifying possible effects of potential and actual threats on business activities and of providing a framework for building organizational resilience, which is equipped with an ability to protect the interests of major stakeholders effectively, along with the reputation of the organization, its brand, and value-creation activities.

This standard defines the business continuity management system (BCMS) of an organization as the part of the entire management system responsible for establishing, introducing, operating, monitoring, reviewing, maintaining, and improving business continuity. It presents requirements for developing and operating a BCMS. Important elements of a BCMS are specified as explained below.

1. understanding of an organization's needs and the necessity of establishing a policy and purpose of business continuity management
2. introducing and operating management measures and methods to make use of the organization's comprehensive ability to respond to an incident causing business suspension or interruption
3. monitoring and reviewing the performance and effectiveness of the BCMS
4. continually improving the BCMS based on objective measures

To implement these elements, the standard additionally requires that an organization apply a plan, do, check, and act (PDCA) model to the planning, establishment, introduction, operation, monitoring, review, and maintenance of its BCMS and that the organization improve its effectiveness continually. The PDCA model that applies to the BCMS process is cited in Fig. 1 and Table 1.

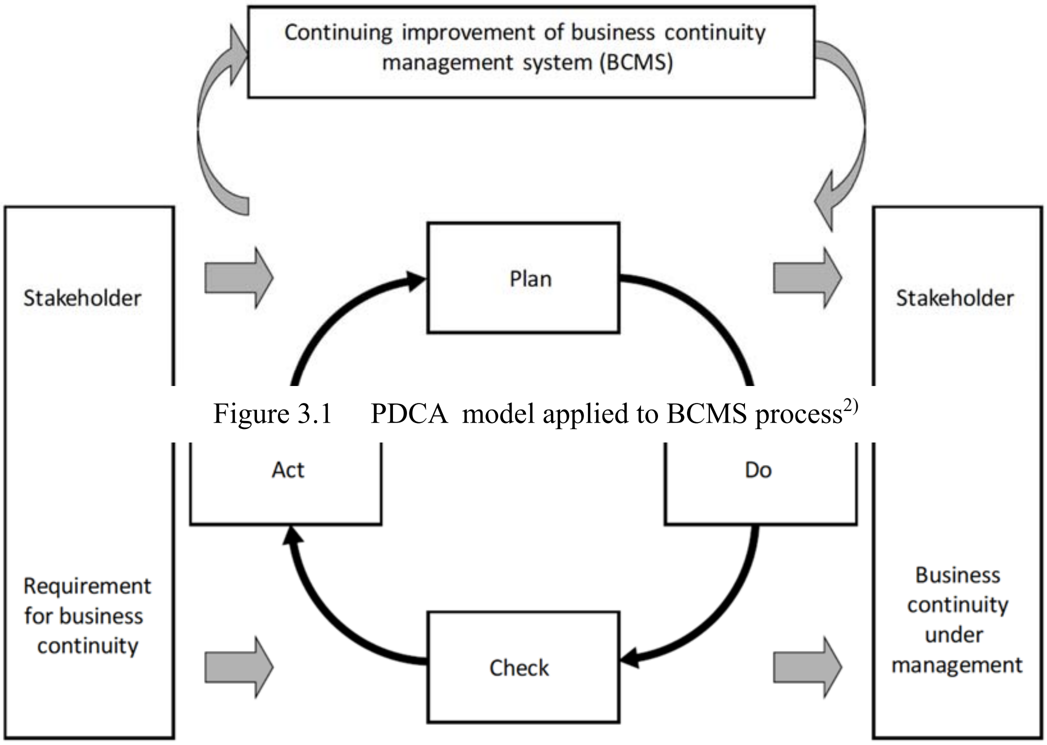

Figure 3.1 PDCA model applied to BCMS process[2)]

Fig. 1 PDCA model applied to BCMS process[2)]

Table 1 PDCA model[2)]

Plan	Establish directions, objectives, goals, management measures and processes required to deliver the desired results for improvement of business continuity.
Do	Follow the directions, objectives, management measures and processes from the previous step and carry out.
Check	Check and review the performance of business continuity plan in compliance with directions and objectives of business continuity. Report the outcomes to business managers. Then, determine the correction and improvement, and give permission.
Act	Improve the system based on the outcome of management review. Re-evaluate the applicable range of BCMS, directions of business continuity and objectives. Then, continue and improve BCMS.

3.3 Guidelines for BCP

The following organizes the concept of BCP in the guidelines above.

(1) Basic Proposal for Disaster Control Strategy that Uses Private-sector and Market Capabilities[3)]

In this case, BCP is defined as a management strategy for resuming important functions in the shortest time possible after interruption of business activities because of a disaster by developing a backup system, securing a backup office, securing personnel, accelerating employees' safety confirmation, etc. and for protecting the company from losing customers to competitors because of business interruption, a fall in its market share, a decline in its reputation, etc. Support for a company's continuous operation is presented as a specific measure, which is explained as shown below.

- Prepared in advance as a company-wide management strategy rather than a response to individual business establishment
- Used in everyday management practice rather than as a contingency plan
- BCP is an effective measure to reduce economic damage.
- Infrastructure developed through public–private cooperation to promote companies' BCP development
- Infrastructure and support for early recovery of lifelines, financial and stock markets, etc. to help companies meet their targets

The standard stipulates, in addition, that companies must take thorough disaster control measures for themselves first to continue their business in case of disaster, and subsequently provide community support and contribute to economic recovery.

(2) Business Continuity Guidelines – Strategies and Responses for Surviving Critical Incidents – Third Edition (August 2013)[4)]

In light of Japan's experience of the Great East Japan Earthquake, the guidelines emphasize a need for a business continuity strategy that is effective against severe damage from disasters, taking measures, and continually improving such efforts. The guidelines describe business continuity activities, i.e., the concept, necessity, effectiveness, implementation methods, development methods, matters requiring attention related to business continuity management (BCM), including BCP, to emphasize the need to urge companies and other organizations in Japan to work voluntarily on business continuity and to improve the business continuity capacity of Japan as a whole. The concept is shown in Fig. 2.

Moreover, the guidelines are allegedly made to conform to basic ideas of international standards and efforts made in other countries in light of establishment of ISO 22301. Taking measures in line with the guidelines presumably helps ensure the international consistency of BCM.

Regarding the relation between BCP and BCM, a plan presenting policies, systems, procedures, etc. for preventing the interruption of important business and rapid recovery from interruption if it occurs in case of contingencies, including natural disasters such as a large earthquake, an epidemic of diseases, incidents such as terrorist attacks, interruption of supply chains, and sudden changes in management environment is called a BCP. Management activities at normal times such as securing budgets and resources to develop, maintain, and renew a BCP and to achieve business continuity, taking advance measures, providing education and training to facilitate the penetration of activities, and inspecting and continually improving BCP are called BCM, which are purportedly positioned as management-level strategic activities.

(3) Guidelines for Formulation of Business Continuity Plan[5)]

A company is asked whether it can fulfill its social obligation to continue operating its business when faced with a crisis. This represents the company's attitude in its corporate management when coping with a crisis. The guidelines require that a company take measures not only to limit the damage it incurs, but to ensure its legal compliance and fulfill social responsibilities. BCP and BCM are defined as the following using PAS 56 Guide to Business Continuity Management developed by the British Standards Institution (BSI) as a reference.

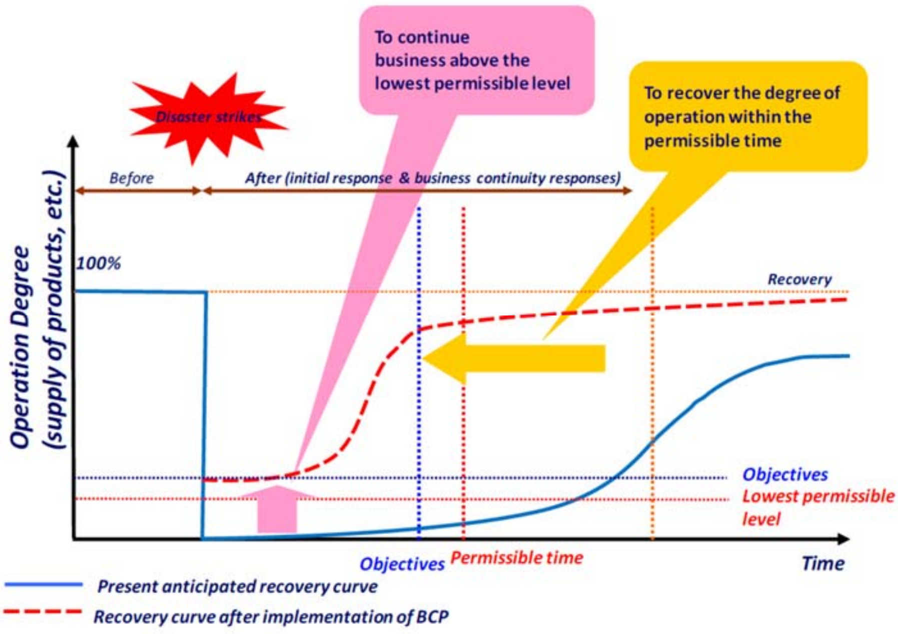

Fig. 2 Concept of Business Continuity Plan

BCP: a continuity plan for recognizing effects of potential loss, developing and implementing a feasible continuity strategy, and ensuring business continuity when a disaster strikes. Documentation of procedures and information developed, organized, and maintained in preparation for a disaster.

BCM: a framework and comprehensive management process of recognizing and effectively responding to a potential effect that threatens an organization to build capabilities for recovery and responses to protect the interests of stakeholders, the organization's reputation, brand, and value-creation activities

Guidelines also define supply chain management (SCM) in view of the importance of supply chains. SCM is introduced based on the idea that

- any single company in a supply chain having a bottleneck might affect the entire company in the chain,
- which means that business interruption of one company in the supply chain will lead to that of other companies;
- therefore, BCP must be produced and followed by all companies in the supply chain rather than individually by each company.

In some cases, Western global companies, through which such ideas have penetrated, demand that companies in their supply chain develop and apply BCP.

Relations with relevant laws and regulations and government offices arise in the application of BCP. Some cases require, for instance, information sharing and cooperation with the central and local governments based on the Basic Act on Disaster Management and prefectural disaster management plans.

3.4 Indicators (indices) for BCP evaluation in technical documents on building design

3.4.1 Guidelines related to public facilities in Japan

Among the following guidelines for government buildings in Japan, this section presents standards aiming for business continuity and maintenance of functions primarily at the time of earthquakes and standards required of construction structures for such aims.

(1) Standards for the Positions, Sizes, and Structures of Buildings and Attached Facilities of National Institutions (December 15, 1994, revised on March 29, 2013)[6)]

This set of standards specifies the positions, sizes, and structures of government buildings and structures, non-structural elements of buildings, and construction facilities, particularly against earthquakes to ensure safety.

(2) Basic Performance Standards for Government Buildings (March 29. 2013, partially revised on March 31, 2020)[7)]

These standards specify the performance of government buildings and technical matters and verification methods with an aim to ensure the performance required of government buildings.

(3) Standards for Comprehensive Aseismic and Anti-Tsunami Planning of Government Buildings (March 29, 2013)[8)]

These standards specify matters related to safety and protection of government buildings from damage of earthquakes, tsunamis, and secondary disasters from them with an aim at ensuring the functionality required of government buildings in the event of disasters caused by earthquakes and tsunamis.

(4) Guidelines for Maintaining Government Buildings' Functioning to Ensure Continued Operation (March 31, 2021, revised on October 14, 2016)[9)]

This set of guidelines specifies the functions required of government buildings in the event of disaster with an aim to help ensure continued operation by presenting specific methods for providing such functions.

(5) Design Guideline for Building at Disaster Bases (Draft) (January 2018)[10)]

This is a compilation of matters to be considered when designing buildings such as a local government's disaster management headquarters, which become a center for disaster response, based on the outcomes of a General Technology Development Project called the Development of Function Sustaining Technologies for Buildings Used as Disaster Prevention Bases to help such a building maintain its function in the event of disaster.

(6) Guidelines for Continued Functions of Buildings Used as a Disaster Control Center (May 2018, supplemented in June 2019) [11)]

This a compilation of information used as a reference at each stage of planning, designing, and managing buildings used as a disaster control center in the event of a large earthquake to ensure the continued functions, in addition to safety, of the building. The supplement includes descriptions of existing buildings.

3.4.2 From the perspective of the design level of government buildings

As described in (1) in Section 3.4.1, Standards for the Positions, Sizes, and Structures of Buildings and Attached Facilities of National Institutions divide government buildings into 12 types, categorize them into a few groups based on importance, and set targets for anti-seismic performance of structures, non-structural elements of buildings, and construction facilities in seismic vibrations that occur only extremely rarely. Based on (1), (2), Basic Performance Standards for Government Buildings, specify the basic performance of government buildings, technical matters, and verification methods not only in terms of safety but in wide-ranging aspects. Particularly, functions required when an earthquake or tsunami strikes are indicated in (3), Standards for Comprehensive Aseismic and Anti-Tsunami Planning of Government Buildings. Relations among these standards are organized in Table 2. Based on this, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) summarizes its seismic safety targets as exhibited in Table 3.

Table 2 Relations among the Three Sets of Standards

<table>
<tr><td rowspan="3">Government building positions, sizes, and structures</td><td colspan="3">Standards for the Positions, Sizes, and Structures of Buildings and Attached Facilities of National Institutions</td></tr>
<tr><td rowspan="2">Standards for government building performance</td><td colspan="2">Basic Performance Standards for Government Buildings</td></tr>
<tr><td>Functions required in case of earthquake/ tsunami</td><td>Standards for Comprehensive Aseismic and Anti-Tsunami Planning of Government Buildings</td></tr>
</table>

Table 3 Seismic Safety Targets

Component	Category	Seismic safety target
Structure	Type I	Maintaining adequate functions, in addition to protecting human lives, aiming for the usability of a building after strong ground motions without repairing the structure
	Type II	Maintaining functions, in addition to protecting human lives, aiming for the usability of a building after strong ground motions without major repair of the structure
	Type III	Protecting human lives, aiming to prevent a major decline in the strength of the entire structure despite partial damage to the structure imparted by strong ground motions
Non-structural element of a building	Type A	Maintaining adequate functions, in addition to protecting human lives, after strong ground motions, aiming to prevent damage, movement, etc. of non-structural elements of buildings, which hinder efficient emergency disaster response or handling of hazardous materials.
	Type B	Aiming to protecting human lives and prevent secondary disasters when a non-structural element of a building is damaged, moved, etc. because of strong ground motions
Construction facility	Type A	Protecting human lives and preventing secondary disasters after strong ground motions and aiming to maintain necessary facility functions for a considerable period of time without a major repair
	Type B	Aiming to protecting human lives and prevent secondary disasters after strong ground motions

3.4.3 From the perspective of maintaining functions at the time of disaster

As shown in Table 3, building functions have been maintained in the event of strong ground motions (ground motions that occur exceptionally) for many years. Guidelines (4), (5), and (6) in Section 3.4.1 emphasize measures for continuing operations. The Cabinet Office (disaster management section) has established Guidelines for Continuing the Operations of Central Government Ministries and Agencies (first edition: June 2007; second edition[12)]: April 2016) and The Government Services Continuity Plan (measures against earthquakes centered directly under the capital) (draft) [13)] (March 2018) on the assumption of earthquakes centered directly under the capital.

As described in (4), Guidelines for Maintaining Government Buildings' Functioning to Ensure Continued Operation is applicable primarily to earthquakes and tsunamis. It specifies functions required of government buildings in the event of disaster with an aim at ensuring continued operation by presenting specific methods for providing such functions. For this purpose, the guidelines describe the performance and functions that should be achieved by government buildings and preparation of operational plans to ensure facility functions in case of disaster.

As BCP evaluation indicators, the guidelines present the types of seismic safety of structures according to seismic safety targets, as shown in Table 4, and seismic safety targets of non-structural elements of buildings and construction facilities, as presented, respectively, in Table 5 and Table 6. The guidelines also instruct that locations of placed furniture, the method of fixing it in place, and the method of fixing office automation (OA) equipment in place to be checked and that furniture and OA equipment to be placed higher than or upstairs of the highest water level on the assumption of flooding.

The above (5), Design Guideline for Buildings at Disaster Bases (Draft), Technical Note of the National Institute for Land and Infrastructure Management No. 1004[10)], are presented as design guidelines from the perspective of maintaining the functions of buildings at disaster centers, including government office buildings, based on outcomes of an MLIT General Technology Development Project called the Development of Function Sustaining Technologies for Buildings Used as Disaster Prevention Bases (FY2013–2016) (designated below as the

“Disaster Control Center Project”). The guidelines set prevention of damage that might interrupt continued functions as the target performance and present safety goals of each part in the case of external disturbances.

Finally, (6), Guidelines for Continued Functions of Buildings Used as a Disaster Control Center, present basic ideas for each stage of planning, designing, and managing buildings, providing owners, designers, and managers with a reference when maintaining functions of a building used as a disaster control center. The guidelines compile basic matters related to locations, construction plans, facility plans, and management and demands of the matters to be considered for continued functions to be confirmed using a checklist based on function continuity guidelines. Details of element technologies in the Design Guideline for Buildings at Disaster Bases (Draft)[11] are incorporated.

In setting the target levels of non-structural elements and construction facilities, the guidelines are aimed at preventing major damage to non-structural elements and construction facilities and to maintain necessary functions at the target levels for the amount of deformation, floor response acceleration, etc. set for the structure. The guidelines also advise that a target be set for floor response acceleration as a criterion for indoor use continuity.

Table 4 Types of Seismic Safety of Structures According to Seismic Safety Targets

Category	Activity	Applicable Facilities	Type of Seismic Safety Target
Facilities required for emergency disaster response (facilities for directing disaster control measures, communication, etc.)	Gathering information and giving instructions in case of disaster Issuing an alert for secondary disasters Planning and implementing disaster recovery measures Conducting public safety activities such as crime prevention Providing disaster victims with information Conducting health care and disease control activities Stockpiling relief supplies, carrying out emergency transportation, etc.	Central facilities among those on the left	Type I
		Facilities other than the above	Type II
General government buildings			Type III

Table 5 Seismic Safety Targets for Non-structural Elements of Buildings

Type of Seismic Safety Target	Seismic Safety Target
Type A	Adequate functions are maintained, in addition to the safety of human life, after strong ground motions , aiming at prevention of damage, movement, etc. to non-structural elements of buildings, which hinder efficient emergency disaster response and acceptance of disaster victims or handling of hazardous materials.
Type B	Safety of human life is ensured and secondary disasters are prevented when a non-structural element of a building is damaged, moved, etc. because of strong ground motions.

Table 6 Seismic Safety Targets for Construction Facilities

Type of Seismic Safety Target	Seismic Safety Target
Type A	Safety of human life is ensured and secondary disasters are prevented after strong ground motions. Necessary facility functions can be maintained for a considerable period of time without major repair.
Type B	Safety of human life is ensured and secondary disasters are prevented after strong ground motions.

3.4.4 Examples of private-sector guidelines

(1) Guidelines for Buildings Conforming to BCP [14] (September 30, 2016)

Guidelines require that buildings not only protect human lives, but maintain the following functions in the event of strong ground motions that occur extremely rarely and flooding within the confines of a levee and river overflowing its levee that rarely occurs.

1) Providing a working space

2) Meeting conditions for carrying out business operations

The guidelines furthermore require the following measures to ensure the above.

3) Responding appropriately to the aftermath of an earthquake or flood (designated as "Earthquakes, etc." below)

4) Appropriately maintaining buildings in preparation for disasters to ensure the effectiveness of the above conditions 1) – 3) in the event of disaster.

The following describes the grades for ensuring functions at the time of strong ground motions as an example.

The basic idea of grades for ensuring building functions of buildings conforming to BCP includes the following three levels.

Grade I: a building maintaining building functions to enable continued operations in nearly all working spaces in the building without interruption and independently for more than a considerable period of time during lifeline interruption without a need for repair (excluding small repairs of parts other than the structure) after strong ground motions

Grade II: a building maintaining building functions to enable continued operations in most working spaces in the building without any remarkable interruption and independently for more than a certain period of time during lifeline interruption without a need for a major repair after strong seismic tremors

Grade III: a building maintaining or capable of recovering building functions to enable operations in most working spaces in the building without a critical interruption by effecting major repairs (including cases requiring interruption in certain operations) after strong ground motions

The guidelines additionally indicate the structure of buildings at each grade and performance required of non-structural elements, construction facilities, and elevators.

(2) The Guide to Safe Buildings: JSCA Performance-Based Seismic Design[15] (March 2018)

Protection of human life and assets and maintenance of functions have been demanded as part of the seismic performance of buildings since the Southern Hyogo Prefecture Earthquake in 1995. Given the conceivable of effects of various types of seismic vibrations related to earthquakes centered directly under the capital, Uemachi fault earthquakes, and the Nankai Trough and the Sagami Trough, the guide provides references for performance design to achieve seismic performance demanded by building owners and society.

It attempts to establish agreement with building owners using the "Performance menu" (Table 7) of seismic performance. It presents seismic performance grades as an indicator of building condition, including the level of damage to structural frames, the level of building functions maintained, and the level of repair needed for the structural frames, finishing materials, etc.

The guide also notes the efficiency of business continuity and early recovery as well as the reduction of damage (life cycle cost) as benefits of raising seismic performance. The guide mentions the significance of performance design to comply with BCP.

Table 7 Performance menu by Japan Structural Consultants Association (JSCA)

Type of structure	Grade	Under the ground motion occurs rarely Seismic intensity 5-	Under the ground motion occurs quite rarely Seismic intensity 5+	Under the ground motion occurs exceptionally Seismic intensity 6+	Under the ground motion for seismic capacity evaluation
Seismic resistant structure or Response controlled structure (Fixed base)	Most superior	No damage Maintain function	No damage Maintain function	Slight damage Maintain adequate function	Minor damage Maintain necessary function
	Superior	No damage Maintain function	Slight damage Maintain adequate function	Minor damage Maintain necessary function	Moderate damage or more Maintain Specified function
	Standard	No damage Maintain function	-	Moderate damage or more Maintain Specified function	-
Base-isolation system	Most superior	No damage Maintain function	No damage Maintain function	Slight damage Maintain adequate function	Slight damage Maintain adequate function
	Superior	No damage Maintain function	No damage Maintain function	Slight damage Maintain adequate function	Minor damage Maintain necessary function
	Standard	No damage Maintain function	-	Slight damage Maintain adequate function	-

3.6 Summary

BCP has been discussed in both public and private sectors since the beginning of the 2000s. Understanding of the necessity of BCP and measures for implementing BCP has increased among widely various organizations for about 15 years. Business continuity management (BCM) necessary for achieving BCP has been introduced. Subsequently, ISO and JIS standards have been established as BCP standards.

The concepts and details of BCP and BCM are organized in guidelines described in Chapter 3. Indicators in guidelines aiming for BCP are summarized as existing indicators for evaluating BCP.

First, as an example of disaster-proof facilities, the MLIT Standards for Comprehensive Aseismic and Anti-Tsunami Planning of Government Buildings (March 29, 2013) have become the basis of such indicators from the perspective of the design level of government buildings. The Design Guideline for Buildings at Disaster Bases (Draft) published by the National Institute for Land and Infrastructure Management and the Guidelines for Continued Functions of Buildings Used as a Disaster Control Center and Supplement incorporate the technical achievements of the MLIT Disaster Control Center Project.

The Japan Structural Consultants Association has published a Guide to Safe Buildings: JSCA Performance-Based Seismic Design, which has been cited as a useful reference in government guidelines.

The Guidelines for Buildings Conforming to BCP published by Building and Equipment Long-life Cycle Association also provide indicators for structures, non-structural elements and facilities but present an independent indicator for elevators. The indicators include time frames, and the Guidelines for Buildings Conforming to BCP and the Guidelines for Continued Functions of Buildings Used as a Disaster Control Center require that high-grade buildings and disaster control center buildings become self-reliant within 72 hours.

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4. Resilience performance index and BCP level rating of buildings: AIJ proposal

4.1 Introduction

Resilience is now the essential keyword in the field of disaster management, and business continuity during and after disaster has become the new target for disaster reduction activities. It is necessary to evaluate quantitatively "the resilience of A" to implement the resilience concept in the real world of disaster management. "A" represents resilience of or for something, such as an organization, society, infrastructure system, building, etc. Setting "A" is important to discuss regarding resilience.

The resilience triangle by Bruneau (2003) forms the basis of the quantitative evaluation of resilience; and several trials of such evaluation, including REDiTM (Almufti, 2013) and FEMA-P58 (FEMA, 2018), were proposed. However, we are still in the discussion phase.

Special Investigation Committee in the Architectural Institute of Japan (AIJ) (AIJ resilience committee) dealing with the Business Continuity Plan (BCP) and building resilience proposed a way to evaluate the performance of buildings from the perspective of resilience.

When discussing business continuity, an organization is the main player. Meaning "A" corresponds to an organization – the resilience of an organization should be measured. However, the buildings remain important to secure a place for business operations. Thus, we define "the resilience performance of a building" as "the comprehensive performance of a building at the time of disaster, including structural safety, mechanical and electrical service continuity, and building safety management system."

Based on the proposed resilience performance concept, we also developed a rating system for the BCP level of a building, which can be used for Business Continuity Planning by business entities. We set four categories for the BCP level of buildings, as follows:

Three stars ★★★: 90% functional recovery within one week

Two stars ★★: 90% within one month

One star ★: 90% within six months

No star: more than six months

In the case of office buildings, 90% functional recovery means the usable floor ratio. The targeting hazard level is Level 2 (L2) earthquake shaking (maximum possible), not including flood, fire, storm surge, and land slide. The BCP rating levels were set through discussions among committee members consisting of business continuity related consultants and structural and mechanical engineers who are in charge of setting building safety levels.

4.2 Building resilience performance index

"Recovery Time Objective" (RTO) is the key indicator for business continuity, where the resilience performance of a building used for BCP should take into account recovery time. We define the AIJ-proposed building resilience performance index as "the functional recovery Level of A DAY from the event." For example, the resilience performance of three days, or a week means that we can define the resilience indices as the period of recovery in terms of three days or a week from the event.

Fig. 1 shows the concept of the AIJ resilience performance index. The area is the product of “days, such as three or seven days,” and “Recovery Level Objective” (RLO) corresponds to the requested service performance of the building at the time of disaster. The area is the possible service amounts which a building can supply by the set level, RLO. A gradient of the recovery curve of a building (dF(t)/dt) shows the recovery performance. We define the AIJ RESILIENCE PERFORMANCE OF BUILDINGS as the retio (Possible service amounts)/ (Requested service amounts).

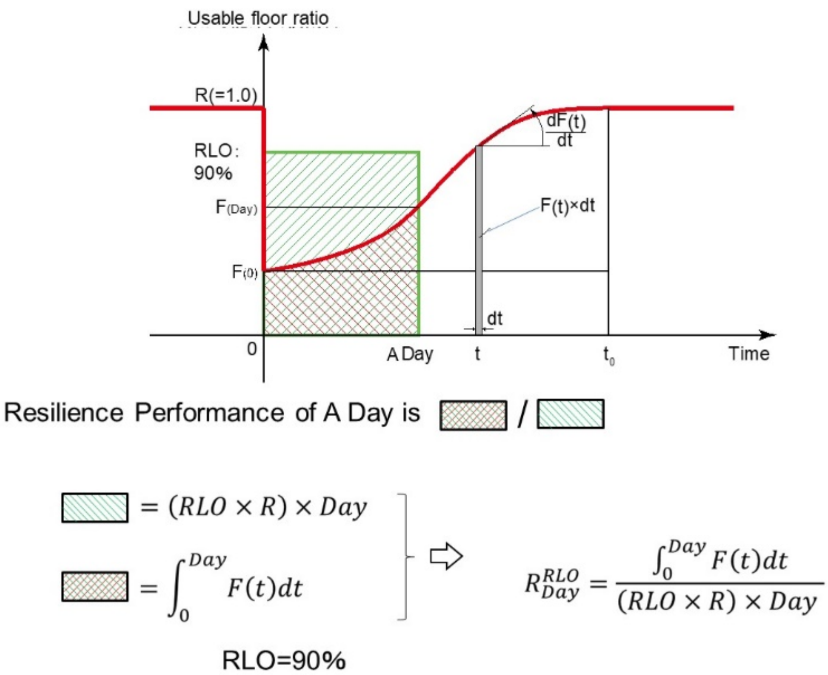


Fig. 1 AIJ resilience performance index

We can show the resilience performance of a building corresponding to the requested client RTO. For example, a client needs a building which can be used from the very first day of a disaster, and the client needs a building with a high ONE DAY resilience performance. The client who set the RTO as one week can select the building which has a high SEVEN DAY resilience performance.

There are two ways to upgrade the resilience performance of a building: reducing or mitigating damage and recovery. When designing a building, we can take three strategies: mitigation-oriented, recovery-oriented, or a combination of the two.

We can consistently evaluate the resilience performance of the mitigation-oriented, recovery-oriented, and combination building types based on the proposed concept. Fig. 2 shows the resilience performance of several types, based on the AIJ resilience performance index. Mitigation-oriented type (b) has a high ONE DAY resilience performance, though the recovery-oriented type (a) (c) has a high SEVEN DAY resilience performance. The combination type has a moderate resilience performance for both ONE DAY and SEVEN DAY. We can quantitatively show these resilience performances.

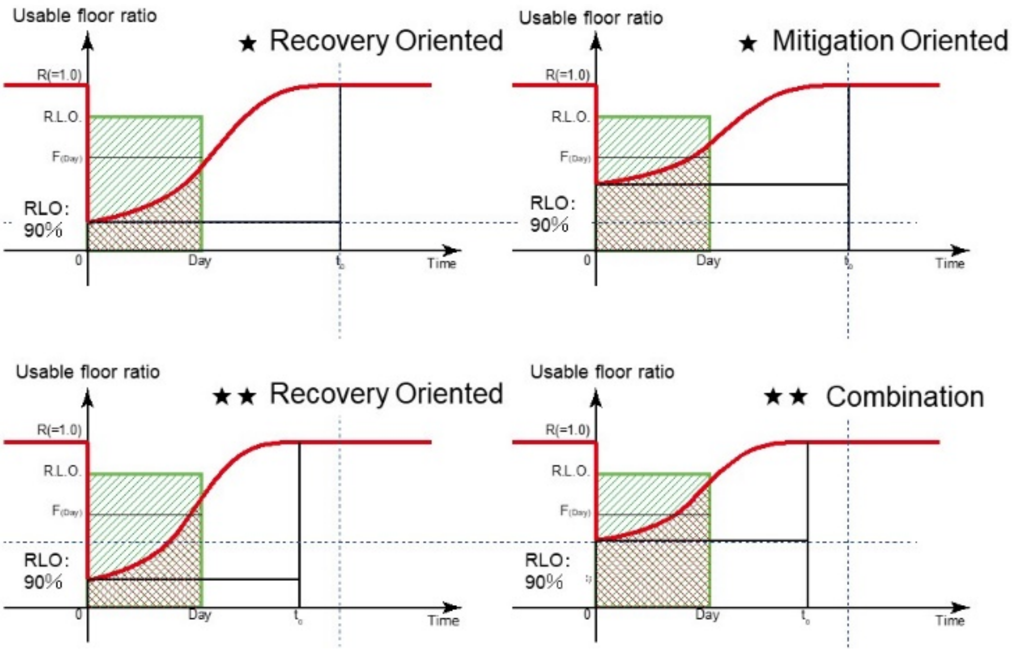


Fig. 2 Mitigation-oriented, recovery-oriented, and combined

4.3 How can we evaluate the resilience of a building?

We set four categories of BCP levels for buildings, from three stars to no stars. How can we rate the BCP level of buildings by using the proposed AIJ resilience performance index? Fig. 3 shows the concept of how to rate the resilience of buildings. Recovery time is the objective variable, and mitigation and recovery performance are the explanatory variables.

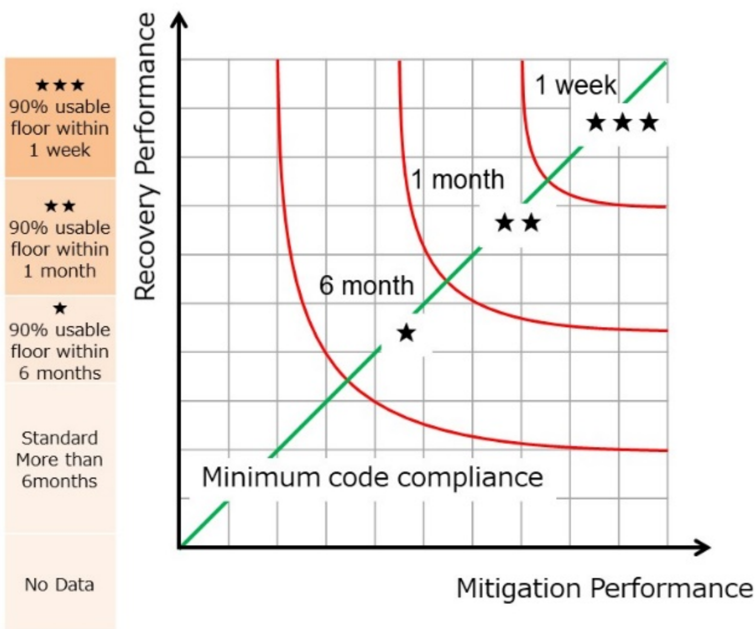


Fig. 3 Concept of BCP levels

Mitigation performance is defined as the structural or physical performance of the structure and its Mechanical and Electrical (ME) components. Recovery performance is defined as the liability of the management system. Table 1 presents the detailed specifications of the mitigation and recovery performances used to evaluate the resilience performance of buildings.

Mitigation performance consists of three components: the seismic performance of 1) a structural element, 2) a non-structural element, and 3) the seismic performance and redundancy of ME systems.

For structural elements, we set five categories of possible damage at the time of an L2 earthquake: Severe, Major, Moderate, Minor, and None. Possible damage is rated based on three levels of seismic performance, Types 1, 2, and 3 (using the definition provided for the seismic safety guidelines of national government buildings (MLIT, 2013)), and two levels of seismic performance for minimum building code compliant buildings.

For non-structural elements, we similarly set five categories of possible damage.

For ME elements, the categories are also five, and the rating is based on the combination of seismic performance and redundancy of ME elements, based on the "Building Research and Development Consortium" (Kimura, et.al, 2016) levels I, II, III.

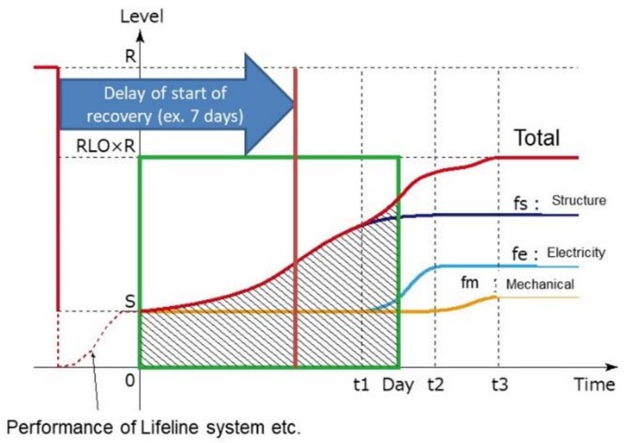
Recovery performance consists of three components: 1) safety check mechanism after the event, 2) training, and 3) data availability for recovery. The "safety check mechanism" includes the structural health monitoring system and prepares the safety check list, "training" includes regular BCP activation training, and "data availability" is the availability of structural analysis data and drawings.

4.4 Quantitative evaluation of the resilience performance of buildings

As mentioned above, the resilience performance of buildings consists of both mitigation and recovery performances. Mitigation performance is the multiple of a structure's recovery curve, both electrical and mechanical. For building's functional recovery, structural recovery is the first priority, and the electric power supply will be the basis for recovery of the mechanical and electric equipment. Fig. 4 shows the AIJ proposed measurement of resilience performance of buildings.

The most difficult part is the quantitative evaluation of "recovery performance." It is difficult to quantitatively evaluate recovery performance. Recovery performance can delay the start of business resumption and building reconstruction. If we do not have a "safety check mechanism after the event," or we did not know how to operate the set BCP because of a lack of "training," or we do not have "data for recovery," those things can delay the kickoff of recovery. Thus, we set recovery performance as the factor delaying the start of recovery.

The resilience performance of a building is defined as its mitigation performance and the number of delay days for recovery performance. Now, we can quantitatively evaluate the resilience performance of a building by using the categories shown in Table 1.



Total resilience performance is composed of structure, electricity, and mechanical performance

$$\frac{dF(t)}{dt} = \frac{df_s}{dt} + \frac{df_e}{dt} + \frac{df_m}{dt}$$

Fig. 4 Quantitative measurement of the resilience performance of buildings: AIJ proposal

Table 1 Elements of resilience performance

	Mitigation Performance			Recovery Performance			
	Structural Element	Non-structural Element	Mechanical and Engineering Component	Safety Check Mechanism		Training	Data for Reconstruction
	Hardware			Software			
High	No Damage Type 1	No Damage (Deformation followability)	Earthquake Proof × System Reliability＝I	・Health Monitoring System ・Maintain Record ・Safety check by Building Manager	Deformation performance	Regular training	Dynamic Structural Analysis Data (Drawing)
	No Damage Type 2	No Damage ～ Minor Damage	Earthquake Proof × System Reliability＝II	・Safety Check Sheet ・Safety Check by inhouse engineer	–	No	Static Structural Analysis Data (Drawing)
	Minor Damage Type 2	Minor	Earthquake Proof × System Reliability＝III	・Safety check by outside engineers	–		Static Structural Analysis Data (Drawing)
Low	Moderate ～ Major Minimum Building Code Compliance Type 3	Moderate～Major Damage	Earthquake Proof	No	–	–	No Structural Analysis Data (Drawing)
–	Major ～ Severe Minimum Building Code Compliance Type 3	Major Damage	None	No	–	–	No Structural Analysis Data (No Drawing)

・Type 1-3 on Structural Element referring from MLIT guideline, 2013
・I, II, III on ME components referring from Kimura, T, et.al., 2016

4.5 Trial for evaluating the resilience of midrise reinforced concrete structure office buildings

We propose a simplified method to evaluate the resilience performance of an RC midrise office building, based on the AIJ proposed resilience performance concept.

There are five levels of structural performance, non-structural performance, and ME performance, as shown in Table 1, and we can write 125 recovery curve patterns, following the definition in Fig. 4.

Though it is necessary to validate the reliability of these recovery curves, we do not have sufficient data. We propose a simplified method by setting recovery days for each component, based on experts' empirical knowledge (Table 2).

The resilience performance of a building is defined as recovery time. We can rate the BCP level of a building by set categories: three stars = one week, two stars = one month, one star = six months. The following is an example of how to evaluate the recovery time or the resilience performance of a building based on the AIJ scheme.

<Mitigation performance>

Structural element: No damage, Type 1

Non-structural element: No damage (deformation followability)

ME element: Earthquake Performance × System Reliability＝II

<Recovery performance>

Safety Check Mechanism (structure): Health Monitoring System

Safety Check Mechanism (ME): Monitoring System

Training: None

Data for Reconstruction: Dynamic Structural Analysis Data (Drawing)

zero day (mitigation performance structure) + 7 days (mitigation performance ME) + 1 day (recovery performance training) = 8 days

The building will be evaluated as a two-star BCP level building because of the 8-day resilience performance.

4.6 Discussion

The AIJ Special Investigation Committee proposed a framework to measure the resilience performance of buildings and a building rating system from the perspective of BCP.

This system should be expanded to include multiple hazards and other building types. We should also evaluate the liability of the proposed method by checking the recovery time of impacted buildings.

Table 2 Simplified evaluation matrix of resilience performance for an RC midrise office building

	Mitigation Performance			Recovery Performance			
	Structural Element	Non-structural Element	Mechanical and Engineering Component (M&E)	Safety Check Mechanism (structure)	Safety Check Mechanism (M&E)	Training	Data for Reconstruction
	Hardware			Software			
High	No Damage Type 1 0 day	No Damage (Deformation followability) 0 day	Earthquake Proofing × System Reliability ＝I 0 day	･Health Monitoring System ･Maintain Record ･Safety check by Building Manager 0 day (delay)	Monitoring System ･Maintain Record ･Safety check by Building Manager 0 day (delay)	Regular training 0 day (delay)	Dynamic Structural Analysis Data (Drawing) 0 day (delay)
	No Damage Type 2 0 day	No Damage ～ Minor Damage 7 days	Earthquake Proofing × System Reliability ＝II 7 days	･Safety Check Sheet ･Safety Check by inhouse engineer 1 day (delay	･Safety Check Sheet ･Safety Check by inhouse engineer 1 day (delay	No 1 day (delay)	Static Structural Analysis Data (Drawing) 3 day (delay)
	Minor Damage Type 2 30 days	Minor Damage 14 days	Earthquake Proof × System Reliability＝III 14 days	･Safety check by outside engineers 7 days (delay)	･Safety check by outside engineer s 7 days (delay)		Static Structural Analysis Data (Drawing) 3 day (delay)
Low	Moderate ～ Major Minimum Building Code Compliance Type 3 90 days	Minor～Major Damage 30 days	Earthquake Proof 60 days	No 14 days (delay)	No 14 days (delay)	–	No Structural Analysis Data (Drawing) 14 days (delay)
–	Major ~ Severe Minimum Building Code Compliance Type 3 180 days	Major Damage 90 days	None 90 days	No 14 days (delay)	No 14 days (delay)	–	No Structural Analysis Data (No Drawing) 90 days (delay)

Recovery(day)=(Structure Component (day)+max (Non-structure, M&E)(day)+max(delay)(day)
Recovery(day)<1 week; three star, <1 month; two star, <6 months; one star

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5. Role of structural health monitoring system in improving building resilience performance

5.1 Introduction

In a business continuity plan (BCP) for companies and organizations after natural disasters, the building resilience performance for maintaining and restoring the functions of buildings and business activities has been attracting public attention in recent years. Here, BCP aims to develop plans necessary to continue business activities after disasters, and it can be a means to improve resilience. Resilience is a concept proposed by Bruneau and Reinhorn (2006), and one of its key components is 'rapidity', the ability to respond immediately (Bruneau et al. 2003, Bruneau and Reinhorn 2006, Cimellaro et al. 2010). The rapidity is defined as 'the ability to recover to a normal state of building functions in a short period of time after disasters.' A structural health monitoring (SHM) system can provide vital information for enhancing rapidity.

Recent earthquake disasters, e.g. those caused by the 2011 off the Pacific coast of Tohoku Earthquake and the 2016 Kumamoto Earthquakes, have led to the need to present more accurate information on the safety-related performance of buildings right after disasters. Under these circumstances, the SHM system, evaluating and grasping the soundness of buildings after disasters, has attracted much attentions from the viewpoint of its applications for BCP (Takahashi et al. 2007). The SHM system is defined as 'a system detecting and evaluating structural damage, or monitoring the structural soundness based on the information obtained from sensors.'

The Special Investigation Committee in the Architectural Institute of Japan (AIJ) on Building Resilience and BCP Level Index (Chairman: Prof. Izuru Takewaki of Kyoto University), hereinafter referred to as 'this committee', has considered quantitatively indicating the building resilience performance in three ways as: (1) performance where buildings possess just before a disaster, (2) performance declining right after a disaster according to damage degrees, and (3) performance transitioning from right after a disaster until recovery to a normal state (AIJ 2020). Here, the SHM system is a technology that can function as a mechanism to rapidly confirm the damage degree right after disasters in (2) and to promote the performance recovery after disasters in (3). The SHM system is useful to improve the resilience performance of a building.

The Working Group on SHM Utilization, hereinafter referred to as 'WG', established under this committee has investigated to present the application examples of the SHM system for BCP, improving the building resilience performance (AIJ 2020). In this study, mainly focusing on the applications of the SHM system for BCP, we first present the general outline of the SHM system. Next, we introduce the practical application examples of the SHM system to manage earthquake disasters based on the results of interview surveys to public and private sectors in Japan. Then, we discuss effective implementations of the SHM system in BCP based on the survey results. Finally, we identify the problems to be addressed in its practical use. In this paper, we focus on an earthquake as external disturbance, an office building with their related organizations, and functions of the SHM system for the objective of BCP.

5.2 Outline of SHM system

This chapter presents the general outline of the SHM system. The SHM system objectively and quantitatively analyzes and evaluates the building soundness, and assists to manage it with appropriate measures based on the evaluation results.

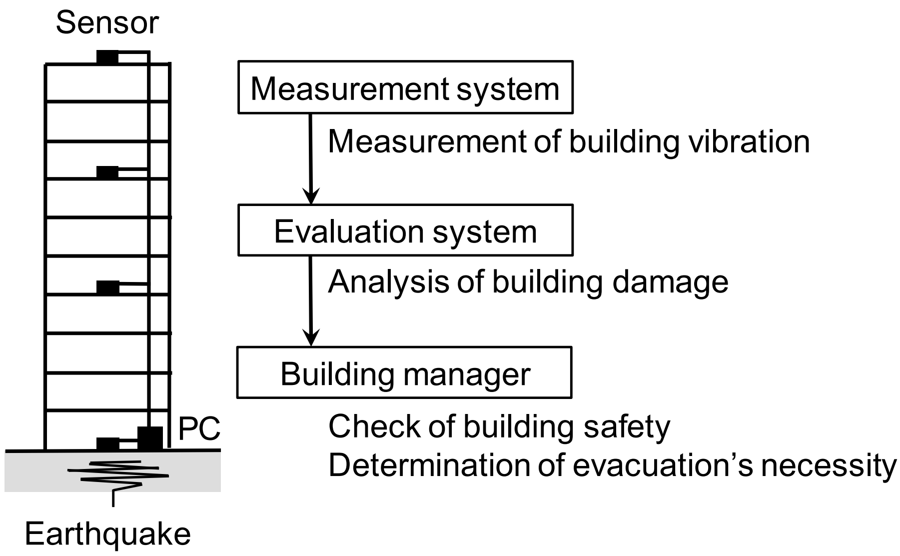

Fig.1 Overview of the SHM system

Fig. 1 shows the overview of a typical SHM system. The SHM system consists of a measurement system measuring building vibration and an evaluation system analyzing building damage. By utilizing the information obtained from the evaluation system, building managers can easily check the building safety right after earthquakes, and immediately determine whether building users need to evacuate (Hamamoto 2007, Hatada et al. 2018, Miura et al. 2016, National Institute for Land and Infrastructure Management 2008). The technologies composing the SHM system are described below.

5.2.1 Measurement systems: Sensing technology

The measurement system consists of sensing technology to obtain the information to evaluate the soundness of an objective building. Here, the sensing technology includes the acquisition of information and the processing of the obtained information data. The typical information to be obtained in the measurement system is the record of structural responses to earthquake ground motion measured by electrical sensors. In addition to the sensing technology, the information and communication technology, which collects and processes the measured information using networks, is also a key component of the measurement system, and can be applied for remote monitoring.

5.2.2 Evaluation system: Damage analysis technology

The evaluation system consists of damage analysis technologies to objectively and quantitatively evaluate the soundness of the objective building from the information obtained by the measurement system. For example, for the diagnosis on structural deteriorations during the building life-span, the material soundness evaluation is the main focus, and for the diagnosis on structural damages of the building right after earthquakes, the evaluations of main structures, non-structural elements, and building facilities are required. The latter case is the main focus on this study.

5.3 Utilization of SHM system

In this chapter, we present the results of interview survey to extract the effective application ways of the SHM system and the problems in its practical use for BCP.

The purpose, the object, and the method of the interview survey are as follows. First, the survey purpose is to clarify the actual situation of the introduction and the applications of the SHM system. For the survey objects, six companies were selected as potential users of the SHM system among public and private sectors in Japan as: three real estate companies, one infrastructure company, one government agency, and one media company. The survey was conducted in the form of individual interviews with the personnel involved in the implementation or operations of the SHM system. First in the interview survey, we have obtained their understanding of the survey purpose on the applications of the SHM system for BCP in the WG activities of this committee, and requested their cooperation to the extent that they could disclose the information. The following is an overview of the results of interview survey, indicating that each item is a questionnaire response from a company.

5.3.1 Application situations of SHM system

As for the application situations of the SHM system of the survey companies, four of the six companies are currently installing and operating the SHM system in their buildings based on the measurement of their acceleration responses to earthquakes, while the remaining two companies are not currently introducing the SHM system.

5.3.2 Introduction of SHM system

(1) Motivation for introduction

・The disaster experience of the Niigataken Chuetsu-oki Earthquake in 2007 and the 2011 off the Pacific coast of Tohoku Earthquake motivated the introduction or full-scale operations of the SHM system.

・The time to provide monitoring results in response to tenant requests in the 2011 off the Pacific coast of Tohoku Earthquake motivated us to introduce the system currently in operation.

(2) Opinions and issues for system introduction

・The introduction of the SHM system was smooth because of the proactive investment in safety and security of the company.

・The intentions of the executive and the financial situation of the company will determine whether to introduce the SHM system.

・Securing the budget for introduction is an issue.

・Since the usefulness of the system introduction is not clear, the budget securing and the operation management department are not clearly determined.

・Cost-effectiveness is a common factor in implementation.

・The SHM system is effective only for earthquakes, but the merits of its introduction are considered as an insurance policy.

・Considering the maintenance of the SHM system, a lease contract is considered instead of a purchase.

・If there were incentives for the introduction of the SHM system, e.g. subsidies from the government, the applications of the SHM system could be expanded.

(3) Reasons for not implementing the system (responses from companies that have not introduced the system)

・Low and mid-rise buildings are mainly dealt, and the building conditions after earthquakes can be checked by visual inspections based on manpower. Since the merits of the system introduction are unclear, it has not yet been applied.

・Since ensuring earthquake resistance is the most important factor, it is difficult to give a clear reason or explanation for the introduction of the SHM system.

・It is desirable to invest in hard countermeasure technologies such as seismic isolation and vibration control, which have clear implementation effects, rather than soft countermeasure technologies such as the SHM system.

・There is possibility that the introduction of the SHM system stirs up anxiety among building users since they don't fully understand the effects of the SHM system.

・It is particularly difficult to introduce to buildings other than the own, e.g. jointly owned buildings.

(4) Summary of the system introduction

While there were answers that the earthquake experience was a major motivator for the introduction of the SHM system, many respondents pointed out that the cost was an important factor in the introduction of the SHM system. From the results of this survey, we can see that the clarification of the introduction merits is an important indicator for companies to decide whether to introduce the system.

5.3.3 Operation and utilization of SHM system

(1) Method of operation and utilization

・It is used to distribute information to executives.

・The information obtained from the SHM system is being used for seismic retrofitting after earthquakes.

・The information is used to make decisions on whether to establish an emergency headquarter.

・The SHM system has been incorporated into the post-earthquake building inspection manual in the BCP, and an efficient post-earthquake response plan has been formulated.

・The application of the SHM system is described in the disaster response manual. However, only the persons in charge are aware of this.

・Post-disaster response consists of a primary rapid response by disaster prevention staff and a secondary response including on-site inspections by structural engineers, each of which utilizes information from the SHM system.

・The information from the SHM system is used as a supplementary tool for the building engineers to determine whether the building can continue to be used. However, in the future, the SHM system will be developed allowing security guards and other people other than building engineers to check the information.

・At present, the system is not used for BCP but is used as an earthquake monitor, but its application for BCP is currently considered.

・Since the rapid action is important for the problem of building facilities, the contractors, i.e. the professional engineers, are to be contacted to visually check the problem as soon as possible after earthquakes. However, there is always a concern about whether the contractor can respond immediately.

(2) Communications of information on system introduction and operations to tenants and building users

・Among the building users, the people who will be informed about the introduction of the SHM system are narrowed down.

・Right after earthquakes, only the elevator operations and the fire information are broadcasted in the building, and the judgment about the building safety is not.

・The information obtained by the SHM system is scrutinized among the company staff before the data is reported to tenants.

・The company pays careful attention to the information disclosure to tenants.

・The information disclosure to tenants is permitted only upon request.

・The internet is utilized to communicate information to tenants.

(3) Publicity for SHM system

・Releasing observation data to public should be cautious.

・The publicity of hard countermeasure technologies such as seismic isolation and vibration control is positively planned as part of our efforts to ensure safety, but the publicity of soft countermeasure technologies such as the SHM system is not positively planned.

・The publicity after disasters should be cautious, taking into account how society would receive it.

(4) Current operation results

・The normal operations of the SHM system were confirmed in the Great East Japan Earthquake disaster in 2011. On the other hand, some part of the system did not work normally.

・In the Great East Japan Earthquake disaster in 2011, the validity of the response measurements was confirmed by comparing them with visual inspections.

・Measurement data in the Great East Japan Earthquake in 2011 was used for seismic reinforcement after the disaster.

・In the Great East Japan Earthquake in 2011, requests for information from tenants could be responded right after the disaster.

・For the Ogasawara Islands west offshore Earthquake in 2015, the system was used to guide the evacuation of visitors to the building.

・Although the SHM system has been confirmed operational, any earthquakes causing significant damage to the building has not been experienced and its effectiveness has not been confirmed.

・In seismically isolated buildings where the SHM system was not introduced, there were almost no inquiries from tenants even after the Great East Japan Earthquake in 2011.

(5) Education for personnel in charge of system operations

・The education of the personnel in charge of operating the SHM system is the most important issue in the system operations.

・As an educational measure for the system operation personnel, the operations of the SHM system are incorporated into normal operations.

・Educational training of SHM system operators has been thorough, and there have been no communication problem for system operations.

・Handover of the SHM system operations due to the departmental transfer of related staff has become an issue.

・Educational training on the SHM system is conducted according to the BCP manual for disaster prevention drills.

・Currently, the operations of the SHM system are not incorporated in disaster prevention drills.

(6) Summary of the SHM system operations

As operational methods, some respondents answered that they apply the SHM system in BCP. In addition, many respondents answered that they were careful in communicating information to building users for the operations of the SHM system. Similarly, many respondents pointed out that they were careful about the publicity of the system operations. In the results of interview survey on the system operations, there were answers that the effectiveness of the system had been confirmed; on the other hand, some respondents answered that the expected effects of the introduction have not been currently confirmed. In the results of interview survey on the educational training of SHM system operators, many respondents pointed out its importance.

5.3.4 General opinions on SHM system

(1) Effectiveness of the system

・The SHM system is effective to confirm the soundness of office buildings.

・Due to a large number of facilities under management, it is difficult to determine the emergency risk level by visual inspections right after earthquakes. A mechanical tool, i.e. the SHM system, is considered to be applied.

・Through the introduction of the monitoring, the SHM system is effective in terms of speeding up the immediate response to the earthquake disasters.

(2) Problems of the system

・It is difficult to shut down the operations of the building facilities based on the information from the SHM system due to the significant economic impact.

・Management of the SHM system equipment, such as system updates, is complicated.

(3) Future Requirements for SHM system in relation to technical and operational issues

・The SHM system is considered to be applied not only for evaluation of main structures, but also for evaluation of non-structural elements and building facilities.

・First of all, the situations of evacuation-related equipment are to be known after diasters, e.g. fire doors, escalators, elevators, and so on.

・To provide instructions to building users as real-time information right after earthquakes, reliable indices are necessary as decision criteria.

・In the future, if the standards and the terms relating the SHM system are defined and standardized by administrative agencies including the government or academic societies, the information from the SHM system can be effectively presented to building users.

・After earthquakes, it is important to secure the operations of building infrastructures. The monitoring scheme is considered to be introduced in relation to this issue.

・It is necessary to identify the areas where evacuation facilities, e.g. elevators, emergency stairs, and so on, are accessible right after earthquakes, and the damaged locations in the secondary disasters caused by the disruptions of window glasses and so on.

・The SHM system is considered to be introduced to identify the details of damaged locations in the damage evaluation.

・The information contents to be communicated to building users need to be examined in the future.

・It is necessary to establish an efficient information transmission network for disasters.

・The technical issues include reducing the number of sensors installed, making the system wireless, how to detect system failures, the equipment durability, and the measures for system maintenance and long-term operations.

・The SHM system and the monitoring system of building facilities are currently separate, but their unification is desired in the future.

・It is important to coordinate the evaluation of building soundness with the control judgment of building facilities such as in-house broadcasting and elevators.

5.4 Applications of SHM system to improve building resilience performance for BCP

In this chapter, based on the results of interview survey on the utilization of the SHM system, we present the application items by the SHM system for earthquakes, and discuss its utilization for BCP and the problems to be addressed in tis practical use.

5.4.1 Application items by SHM system for earthquakes

The immediate damage evaluation of buildings right after earthquakes by the SHM system can be used to support the rapid recovery of building functions in BCP, such as determining whether the buildings can continue to be used and whether building users need to be evacuated (Cabinet Office, Government of Japan, 2014). Fig. 2 shows an example of applications of the SHM system in the earliest stage after earthquakes.

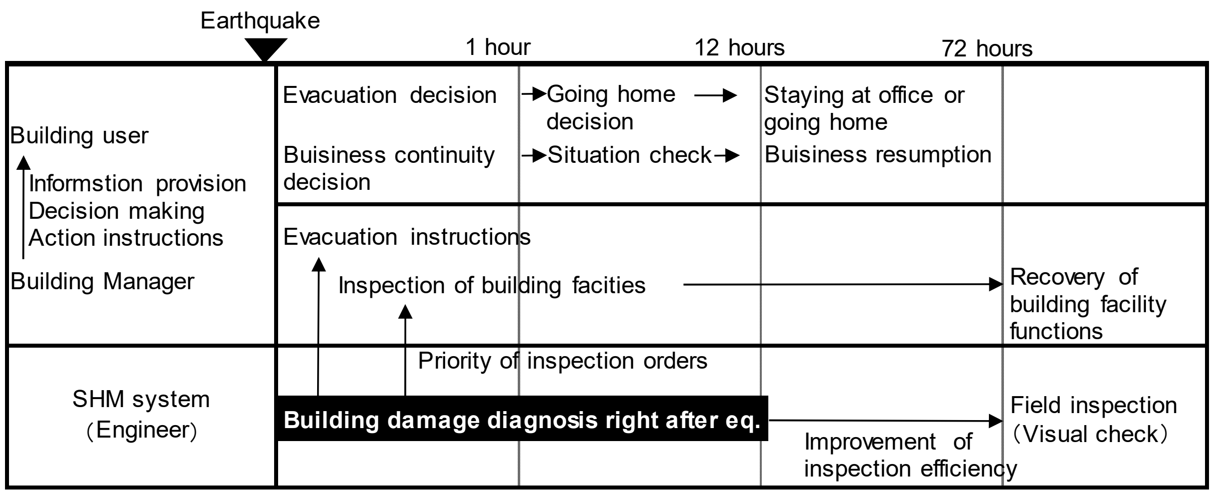

Fig.2 Example of applications of the SHM system in the earliest stage after earthquakes

Next, based on the results of interview survey on the applications of the SHM system, its main application items for earthquakes in terms of supporting early recovery of building performance after earthquakes are presented as follows.

・Provision of immediate information on the continuous availability of buildings.

・Provision of immediate information to help building users decide whether to evacuate.

・Provision of immediate information that contributes to the business continuity decisions of building users.

・Prioritization of inspections in post-disaster inspections of building facilities.

・Improvement of the efficiency of field surveys for visual inspections after earthquakes.

・Utilization for repair and reinforcement of buildings after earthquakes.

5.4.2 Application scheme of SHM system for BCP

Based on the application items by the SHM system for earthquakes, we discuss its application scheme for BCP. The building resilience performance proposed by this committee is defined as ‘the performance indicating the recovery degree of business operations within the target recovery period’. It includes the following building performances as: (1) performance where buildings possess until just before earthquakes, (2) performance declining right after earthquakes according to damage degrees, and (3) performance that transitioning from right after earthquakes until recovery to a normal state (AIJ 2020). Fig. 3 shows the concept of building resilience performance. In this figure, the vertical axis is the building performance ratio of the post-earthquakes’ to the pre-earthquakes’, i.e. the usable floor ratio of the revenue area portion after earthquakes, and the horizontal axis is the evaluation period, e.g. the elapsing time after the earthquake shock, and the relationship is illustrated as a recovery curve. The differential value of the recovery curve indicates the building recovery capability at each time point.

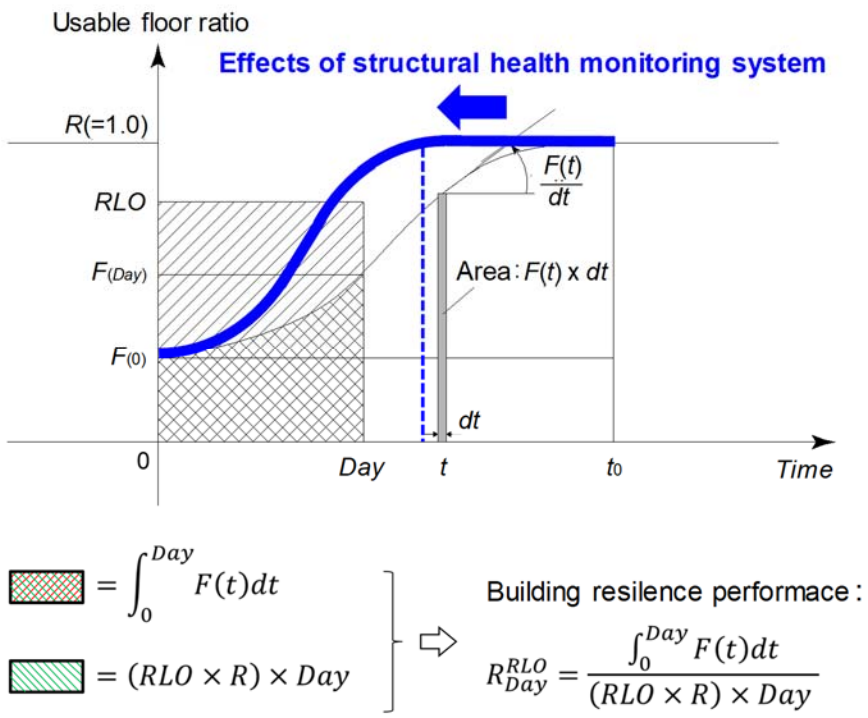

Fig.3 Concept of building resilience performance

Here, we define the building resilience performance as a recovery level of buildings in a certain period of time, expressing the ratio of the actual amount of available services after earthquakes to the service demand of the objective buildings. In Fig. 3, a function F(t) denotes a building performance level at time t and RLO represents a recovery level objective during an evaluation period, Day. The amount of available services is expressed as the integral value of the curve F(t) up to Day. The service demand is expressed as the product of a normalized recovery level objective RLO×R and the period Day, where R is a building performance before earthquakes setting to 1. The building resilience performance is measured by a ratio between area under F(t) and (RLO × R) × Day. This committee is attempting to classify the building rank of the BCP level based on the building resilience performance as an evaluation index.

The introduction of the SHM system to the BCP and its proper operation can function as a mechanism to rapidly confirm the damage degree of buildings right after earthquakes in the above-mentioned performance (2) and to promote the performance recovery after earthquakes in the above-mentioned performance (3). In Fig. 3, the effectsof the SHM system introduction is shown in the recovery curve. The introduction of the SHM system can accelerate the early recovery of building functions right after earthquakes. As a result, the building resilience performance can be improved, leading to the rise of the building rank of the BCP level.

5.4.3 Problems in the practical use of SHM system for BCP

The following is a list of problems cleared from the results of interview survey on the utilization of the SHM system for BCP to improve the building resilience performance.

(1) Developing and verifying technologies composing the SHM system

To ensure the reliability of technology components of the SHM system, i.e. sensing technology and damage analysis technology, verifications for actual buildings are important with the development of each technology, requiring the continuous accumulation and the quantitative analysis of verification data based on observations and experiments.

(2) Securing the SHM system reliability

In practical applications of the SHM system, it is important to secure the system reliability, being more pronounced for the monitoring of short-time responses to earthquakes. To deal with this issue, it is necessary to build a robust system and establish a reasonable and systematic maintenance and a management system, including emergency action plan based on the system operations.

(3) Setting the appropriate costs

The SHM system can be considered as an optional value-added technology in BCP. Considering this fact, we need to assume that the requirements of building users for the application cost of the SHM system are more stringent. The application cost of the SHM system consists of the cost of each technology component, the cost of integrating each technology component, and the cost of maintenance and management of the system. In its applications, each of cost elements should be carefully considered in light of the social and economic situations. In the answers of interview survey on the system applications, there are ideas of lease contracts and requests for cost incentives from the government for the introduction of the SHM system.

(4) Consensus building in the introduction of the SHM system

The SHM system is expected to be used as a tool for decision making in the event of earthquakes. To improve its introduction effect, it is important to build a consensus between the system suppliers, i.e. engineers, and the system users, i.e. building managers, particularly based on the understanding of the users regarding its technical features, application method, and application ranges. To accommodate these conditions, it is necessary for the system suppliers to provide reasonable explanations to the building users with clarifying the terms and conditions of applications, e.g. handling instructions, warranty coverage, and disclaimers of liability.

(5) Clarifying the benefits of the SHM system introduction

To introduce the SHM system for BCP and utilize its effects effectively, it is important to clarify the benefits of the SHM system introduction. For this purpose, when introducing the SHM system, it is necessary to understand the characteristics of the objective buildings, e.g. their size, usage and structural form, and their users, e.g. their purpose of use and the number of users, and to clarify the introduction purpose, e.g. decision on whether the building can be used continuously and decision on whether the building users need to evacuate, and its effect. e.g. the recovery level objective of building performance and the evaluation period. In addition, the relevance of these factors needs to be carefully examined.

(6) Proper operations of the SHM system

To improve the building resilience performance through the introduction of the SHM system for BCP, its proper operations are prerequisite. To achieve this condition, it is necessary to clarify the personnel in charge of system operations and their roles, to establish the information communication network including its contents and communication channels among the building managers or between the building managers and its users, and to improve the communication about system operations. As a means to achieve this purpose, the proper educational training of the personnel in charge of SHM system operations in normal times is effective and important.

5.5 Conclusions

In this chapter, we mainly focused on the applications of the SHM system to improve the building resilience performance for BCP. Based on the results of interview survey on the applications of the SHM system, we presented the application items by the SHM system for earthquakes and its applications for BCP, and identified the problems to be addressed in its practical use.

The immediate determination of damage degree of buildings by the SHM system right after earthquakes is applicable to support the rapid recovery of building functions in BCP, such as determining whether the building can be used continuously and whether building users need to evacuate. By introducing the SHM system for BCP, we can improve the building resilience and promote the early recovery of building performance after earthquakes. As a result of its introduction, the building resilience performance can be improved and the building rank of the

BCP level can be raised. To achieve this purpose, the proper operations of the SHM system are prerequisite, where it is important to establish the information communication network between the building managers and its users, to improve the communication about system operations, and to educate the personnel in charge of SHM system operations in normal times. In addition, to effectively utilize the effects of the SHM system in BCP, it is important to clarify the purpose and its introduction benefits.

Through the interview survey on the applications of the SHM system, we have found out many needs among the building managers for information provisions related to decision making according to the situations for earthquake disasters. The applications of the SHM system for BCP have a great potential as one of the most effective means to that end. The role of SHM system will become more important to improve the building resilience performance for BCP in the future.

Acknowledgments

We would like to express our gratitude to the companies that cooperated in the questionnaire survey on the system applications. The problems in the practical use of SHM system became clear through the discussions with ‘Subcommittee on Structural Health Monitoring (Chairman: Dr. Kouichi Sato of Taisei Corporation)’ and ‘Subcommittee on Earthquake Strong Motion Observation (Chairman: Prof. Susumu Ohno of Tohoku University)’ under ‘Managing Committee on Engineering Seismology and Structural Dynamics’ of ‘Research Committee on Structures’ in AIJ. Their cooperations are greatly appreciated.

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6. Example of assigning building resilience performance indicators (indices)

6.1 Introduction

The special committee "Investigation on index of building resilience and BCP level" has been studying building resilience performance indicators (indices) that evaluate the performance of buildings not only before but also after a disaster. This is required for future buildings. In this chapter, we examine the essential differences between the proposed indices and those that have been proposed so far. Furthermore, we present and analyze the characteristics of the proposed indices applied for model buildings.

6.2 Difference from previously proposed indicators (indices)

As representative examples of existing indicators proposed from the architectural viewpoint in Japan, the following standards and indicators [1)-11)] exist.

- Basic performance criteria for government facilities
- Guidelines for ensuring the functionality of government facilities for business continuity
- Comprehensive Seismic and Tsunami Resistance Planning Standards for Government Facilities
- Guidelines for Function Continuity in Buildings Used as Disaster Prevention Bases, etc.
- Guidelines for BCP-compliant buildings (draft)

When designing buildings, the classification of performances in accordance with the “Basic Performance Standards for Government Facilities” is common. Many other indicators are also defined in accordance with this. However, in this basic performance criteria, the classification is made from the viewpoint of "what level of performance should be set before the disaster?” In other words, the performance indices focus on the situation before the disaster, and there is no specific statement on the situation after the disaster. On the other hand, the "Draft Guidelines for Buildings with BCP" is examined from the perspective of "the extent of damage after a disaster and how long it takes to recover. In other words, the performance indicators focus mainly on business continuity after a disaster. Most of the other indices have been studied by focusing on either before or after the disaster, and there are few cases where the continuity of performance before and after the disaster has been discussed.

The performance index proposed in this committee is expressed in the form shown in Fig. 1, and is characterized by the fact that it attempts to comprehensively evaluate three types of performance: (1) performance of the building before the disaster, (2) damage after the disaster, and (3) performance from just after the disaster until restoration, by classifying the performance of the building before the disaster.

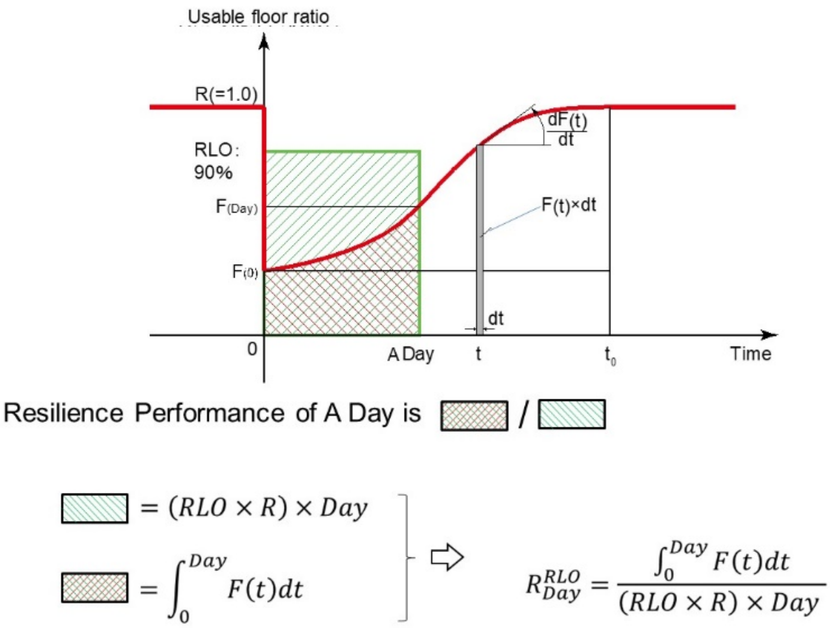

Fig. 1 Building resilience performance

6.3 Proposed performance indicators (indices)

6.3.1 Summary of proposed performance indicators (indices)

In the performance indices proposed by this committee, the building resilience performance is explained in three major categories: resistance-specific, balanced, and recovery-specific. All of them are classified based on the unified performance evaluation of "RLO-Resilience Performance in Period" (hereinafter referred to as RRPP for convenience). The number of ★ is determined by (1) the number of days (Day) and (2) the percentage of the initial performance (RLO: Recovery Level Objective) that can be recovered. However, the RRPP can be defined by (1) a certain resilience assessment period (Day), and (2) (RLO) % of the resilience performance at the original design (R=1.0), using the recovery performance $F(t)$ that the building possesses, as follows:

$$R_{Day}^{RLO} = \frac{\int_0^{Day} F(t)dt}{(RLO \times R) \times Day} = \frac{\int_0^{Day} F(t)dt}{RLO \times Day}$$

The recovery performance curve $F(t)$ is assumed as shown in Fig. 2. This is due to the following facts.

1) A period of preparation and ordering is required from immediately after the disaster until the performance is improved.
2) For example, in order to carry out facility restoration work, the structural performance of the target area must be restored, and the work can only proceed in stages.
3) A considerable amount of repair work is required to improve the performance to 100% after improving it to 90%.

To actually obtain the recovery curve $F(t)$, it is necessary to evaluate and simulate the performance of each building, and it is very difficult to calculate it in detail. However, the study by Torisawa et al.[12] can be used as a reference for quantification. In this chapter, a good example is given of the fact that quantification is possible even for equipment that tends to be considered difficult to quantify. This is discussed in detail in Appendix. It is also possible to evaluate the performance of the equipment based pseudo-quantitatively on the simple method described below.

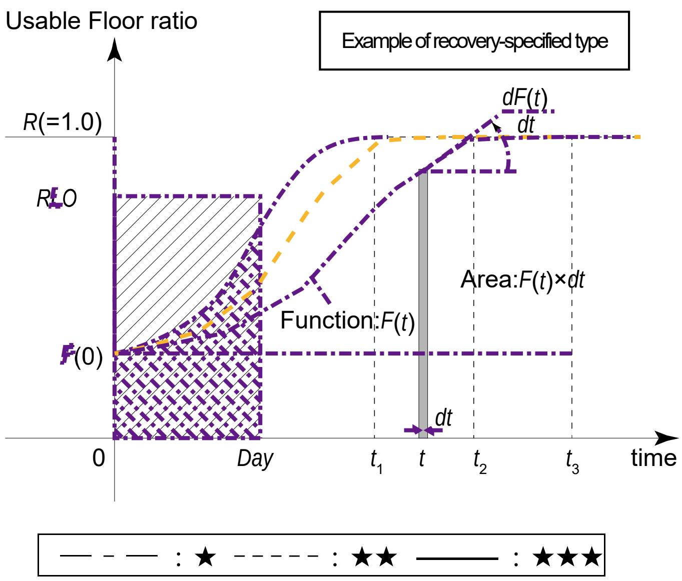

Fig. 2 Characteristics of each performance

6.3.2 Qualitative trends of the proposed performance indicators (indices)

Consider a comparison of ★ to ★★ within each type. We take the resilience performance as the vertical axis and the resilience evaluation period as the horizontal axis. When the resilience evaluation period and type (we use the resilience-focused type as an example) are fixed, the RRPP increases as the number of ★'s increases. But as shown in Fig. 2, the amount of increase is not linearly related to the improvement in building performance. As shown in Fig. 1, the increment is not linearly related to the improvement of building performance.

On the other hand, as shown in Fig. 3, when the resilience evaluation period and type (we use the resistance-specific type as an example) are fixed, the RRPP increases as the number of ★'s increases. But as shown in Fig. 2, the amount of increase is not linearly related to the improvement in building performance. As shown in Fig. 1, the increment is not linearly related to the improvement of building performance.

On the other hand, as shown in Fig. 3, when the resilience performance evaluation period and the number of ★'s are fixed and the resistance-specific type, balanced type, and recovery-specific type are compared, the RRPP of the resistance-specific type tends to be larger in the short evaluation period, that of the recovery-specific type in the long evaluation period, and that of the balanced type in the intermediate evaluation period. In the intermediate evaluation period, the RRPP of the balanced type tended to be larger. However, it is clear that the RRPP of the resistance-focused type is larger throughout the entire evaluation period. This results from the intuitively obvious fact that the time required for recovery can be shortened without compromising the seismic performance of the building after the initial disaster.

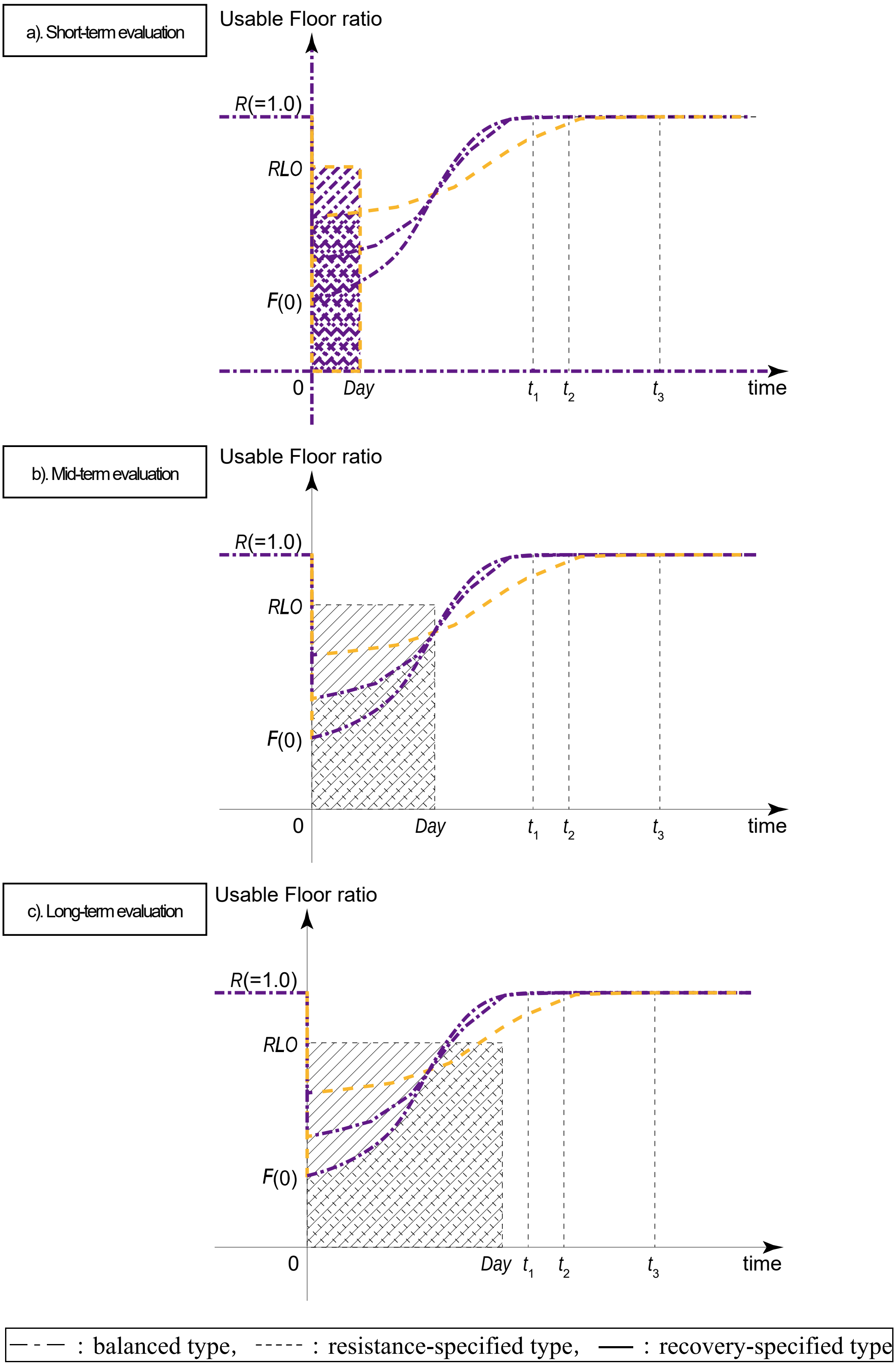

Fig. 3 Resilience performance evaluation by evaluation period

6.3.3 Simplified performance evaluation (simplified method)

As described in Section 6.3.1, even though it is possible to calculate the recovery curve $F(t)$ by quantifying the building performance, it is desirable to simplify it. Therefore, a simplified method was illustrated. The calculation method is largely as follows.

・As shown in Fig. 4, it is assumed that the resistance is the amount of drop in performance (vertical axis) and the recovery force is the amount of shift in the number of days required to start recovery (horizontal axis), and the recovery curve is assumed to be the same for all types.

・The RRPP is more simply evaluated by RLO recovery days, and the recovery days are calculated by the following formula

$$RD_{eq} = \{D_{ms} + max(D_{ss} + D_f)\} + \max(D_d)$$

Here, each variable indicates the following;

RD_{eq}: number of days of recovery,
D_{ms}: number of days of recovery of main structural parts,
D_{ss}: number of days of recovery of non-structural parts,
D_f: number of days of recovery of equipment,
D_d: Number of days of delay due to recovery power

・Assuming that the recovery curve is a straight line, as shown in Fig. 4.

In order to calculate precisely, it is necessary to determine whether the resilience performance is 0.8 or higher in one week. But the simple method evaluates the number of recovery days, which is intuitively very easy to understand. If a probabilistic evaluation is added to the above, the approximation method of the recovery curve is not a simple straight line, and thus the evaluation can be done in a form closer to the actual situation.

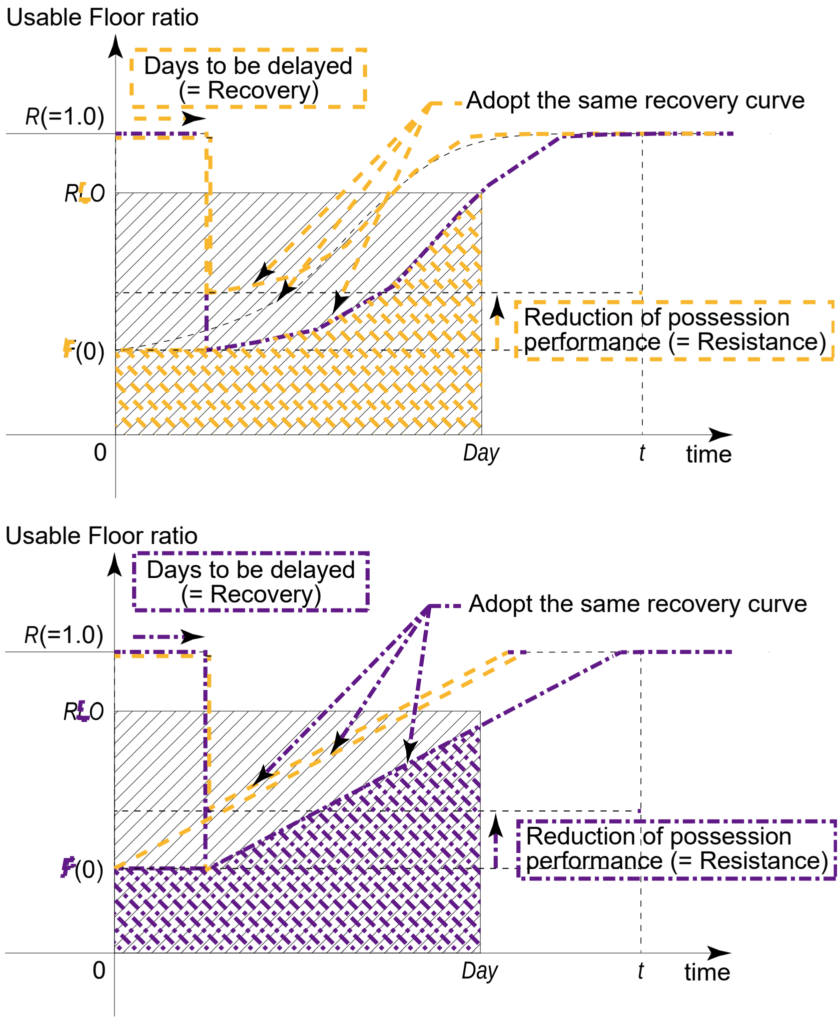

Fig. 4 Concept of the simplified method

6.4 Examination by model case

6.4.1 Model case

This section illustrates how the qualitative trends described in Section 6.3 appear in practice by using a simplified method to evaluate the performance of each case shown in Table 1 as a model. The followings are assumed as common preconditions.

1) The building is designed for extremely rare earthquake ground motion.
2) The building is assumed to be a mid-rise office building (about 14 stories).

The numbers in parentheses in Table 1 show the assumed values of the number of days required for recovery. Each case is based on the following assumptions.

- Case 1 : Ideal highest specifications
- Case 2-4 : Comparison of specialization for each type
- Case 2, 5 : Comparison of specialization in resistance
- Case 6 : A type that claims to specialize in resistance, but has unbalanced specifications

6.4.2 Comparison result

As described in Table 1, we calculated the number of recovery days based on the settings of each item and evaluated the resilience performance. In the following sections, we discuss the results by focusing on specific cases and by comparing the results among cases.

1) Focusing on Case 1

Even if one or both of the items of "nonstructural components" and "seismic resistance of equipment and systems" are dropped by one grade, recovery within one week is possible, and the case falls under the category of ★★★ (specialized recovery capability). Similarly, even if the judgment of either "structure" or "equipment" or both is outsourced, it can be confirmed that recovery is possible within one week and that the system is classified as ★★★ (specialized in resilience).

2) Comparison of Cases 2-4

It can be confirmed that the number of days required for recovery of the resistance-specialized type is greatly reduced compared to the balanced type and the recovery-specialized type. On the other hand, the number of recovery days of the balanced type and the specialized recovery power type is almost the same as each other. This is based on the obvious logic that, since it takes the longest time to restore the performance of the main structural frame, the time required for restoration can be drastically shortened without compromising the seismic performance of the building after the disaster. This shows that the resistance-specific type is the easiest to improve building resilience performance. Conversely, it can be judged that in order to improve building resilience performance, it is essential to increase the resistance (especially the seismic performance of the main structure). However, this is a high hurdle to achieve because the initial cost is very high, and the other costs are lower than those for improving the main structural frame performance. This is consistent with the overall balance of performance indicators.

3) Comparison of Case 2 and 5

As shown in Case 5, the number of recovery days increases rapidly when the seismic performance of the main structural frame is reduced, even for the same resistance-specialized type. In addition, more recovery days are required for both Cases 2-4 because the recovery force is reduced. This indicates that it is essential to improve the seismic performance of the main structure in order to enhance building resilience.

4) Comparison of Cases 5 and 6

In contrast to Case 5, Case 6 assumes a case where the performance of "equipment seismic resistance x system reliability" is to be secured, but the seismic performance of the main structure to ensure this performance is low and the design does not fully utilize the performance of the equipment. In order to achieve this goal, the seismic performance of the main structure and non-structural components must be improved. Thus, if the seismic performance of the equipment is set high, but the performance of the main structure and nonstructural components supporting it is low, the number of recovery days will increase as if dragged by the lower performance, and the number of recovery days will not always be less than Case 5. In this way, by evaluating the value by $\max(D_{ss}+D_f)$, a penalty is applied to the inconsistent design. Similarly, there is a case that a building is claimed to be resistance-specific and the seismic performance of the equipment is improved. However, a case can be seen that SHM is only added because it is expensive to improve the performance. If only SHM is added and there is no evidence of the improvement of the equipment, a penalty is applied.

The proposed thresholds of one week, one month, and three months have been adopted here. But it goes without saying that these thresholds need to be reviewed in accordance with further deepening. As the number of items increases with depth, the number of delay days may increase further. For example, this performance index does not cover infrastructure restoration because of the large regional characteristics, but it is essential in order to make it closer to the actual situation. In some cases, it may be necessary to revise the threshold of the performance indicator in conjunction with the above.

Table 1 Model case for examination

Case			Case 1		Case 2		Case 4		Case 3		Case 5		Case 6	
Type			Balanced type		Resistance-specified Type		Recovery-specified Type		Balanced type		Resistance-specified Type		Resistance-specified Type※	
Resistance		Structural element	Type I (No damage)	(0)	Type I (No damage)	(0)	Type II (Minor damage)	(30)	Type II (Minor damage)	(30)	Type II (Minor damage)	(30)	Type II (Minor damage)	(30)
Resistance		Non-structural element	No damage	(0)	No damage	(0)	Minor damage	(7)	Minor damage	(7)	Minor damage	(7)	Minor damage	(7)
Resistance		Earthquake proofing × System reliability	I	(0)	II	(7)	II	(7)	II	(7)	II	(7)	I	(0)
Resistance	Example of performance	Electricity	Providing 100% private power generation		No private power generation		No private power generation		No private power generation		No private power generation		Providing 100% private power generation	
Resistance	Example of performance	Water	Groundwater available With water tank		With water tank		With water tank		With water tank		-		Groundwater available With water tank	
Resistance	Example of performance	Air conditioning	Temperature control (72h.)		Ventilation (24 h.)		Ventilation (24 h.)		Ventilation (24 h.)		Ventilation (24 h.)		Temperature control (72h.)	
Resistance	Example of performance	EV	Deformation tracking possible		Deformation tracking possible		Minor damage		Deformation tracking possible		Minor damage		Deformation tracking possible	
Recovery		Safety check mechanism (Structure)	SHM System Safety check by in-house engineer	(0)	Safety check by outside engineer	(7)	SHM System Safety check by in-house engineer	(0)	By infiltration tactics	(1)	Safety check by outside engineer	(7)	SHM System Safety check by in-house engineer	(0)
Recovery		Safety check mechanism (M&E)	Maintain record Safety check by building manager	(0)	-	(14)	Maintain record Safety check by building manager	(0)	Safety check by outside engineer	(7)	-	(14)	-	(14)
Recovery		Training	Regular training	(0)	-	(1)	Regular training	(0)	Regular training	(0)	-	(1)	-	(1)
Recovery		Data for reconstruction	Dynamic analysis data	(0)	Static analysis data	(3)	Static analysis data	(3)	Static analysis data	(3)	Static analysis data	(3)	Static analysis data	(3)
Recovery		Presence of Drawing	Yes		Yes		Yes		Yes		Yes		Yes	
Recovery day			0		21		40		44		51		51	
Resilience performance			★★★		★★		★		★		★		★	

6.5 Conclusion

In this chapter, the following two points were presented.

a) We attempted to evaluate the qualitative characteristics of the proposed index through a model case from the difference with the existing proposed index.
b) A simplified method was applied to the model cases to confirm three points: 1) the characteristics of the proposed performance index, 2) the correspondence with actual performance, and 3) the importance of the overall sense of balance. Although the study is based on bold assumptions, it is confirmed that relatively reasonable results can be obtained.

On the other hand, the following issues remain unresolved in the actual application of the proposed performance index.

- Since it is a performance index that links the performance from before the disaster to recovery, it is very important to classify it more appropriately so that the performance before the disaster can be evaluated after the disaster. The current classification is at the level of a proposal for a model case, and needs to be improved in more detail through examination of actual cases.
- In the quantitative evaluation, it is necessary to accumulate data continuously and review the evaluation.
- It is necessary to clarify the relationship between the simplified method and the detailed evaluation method.
- Since it is necessary to evaluate the deterioration of building performance over time, it is necessary to review each building level once every few years to avoid overestimation.

From these facts, it is desirable to clarify the parts that can be evaluated approximatively in the future and to work on accumulating data in the entire industry. Currently, in the structural engineering field, JSCA is playing a central role in organizing and proposing a performance-based design[13)] for organizing comprehensive structural seismic criteria. It is obvious that, when a high specification is required for one part of a building, the minimum performance required for that high specification to be achieved is also required for other parts. From the perspective of performance-based design, it is important to evaluate the performance from the total perspective of the building provision period, so as not to evaluate a so-called "fake design" that is poorly balanced and inconsistent in terms of building performance. We hope that the proposed performance index, which is a method to evaluate buildings from pre-disaster to recovery, will help to properly evaluate the performance of buildings as an economic activity and to improve the quality of buildings.

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Appendix：**Calculation flow of the detailed evaluation method**

The concept and general flow of the detailed evaluation method based on the method shown in Reference 12) are shown here. FTA (Fault Tree Analysis), ETA (Event Tree Analysis), and PRA (Probabilistic Risk Assessment), which is a risk assessment method that combines these two methods, are used in the study.

FTA is a method to systematically investigate the causes of undesirable outcomes of a system in a top-down manner. As shown in Fig. A-1, a fault tree (FT) is a tree-like logic development diagram in which undesirable results of the target system are defined as top events, and their causes are hierarchically developed from higher to lower levels, and their causal relationships are connected with logic symbols such as AND and OR. The lowest level is the events (causal events) that cause undesirable results of the system, such as failures of equipment constituting the target system, human error events, and external factor events, etc. By using FT, it is possible to derive the combination of causal events that cause the top event, and by accumulating this combination and the probability of occurrence of each causal event, the probability of occurrence of the top event (undesirable result of the system) can be quantified. There are AND gates and OR gates in the diagram due to the relationship of causal events.

ETA is a method to investigate multiple latent outcomes of a system resulting from one cause. As shown in Fig. A-2, an event tree (FT) is a tree-like diagram starting from the left causing point and developing multiple measures for preventing affairs caused by the staring cause.

We use the same method to calculate the amount of resilience proposed in this report. Specifically, it is as follows. We take the stability of equipment as an example.

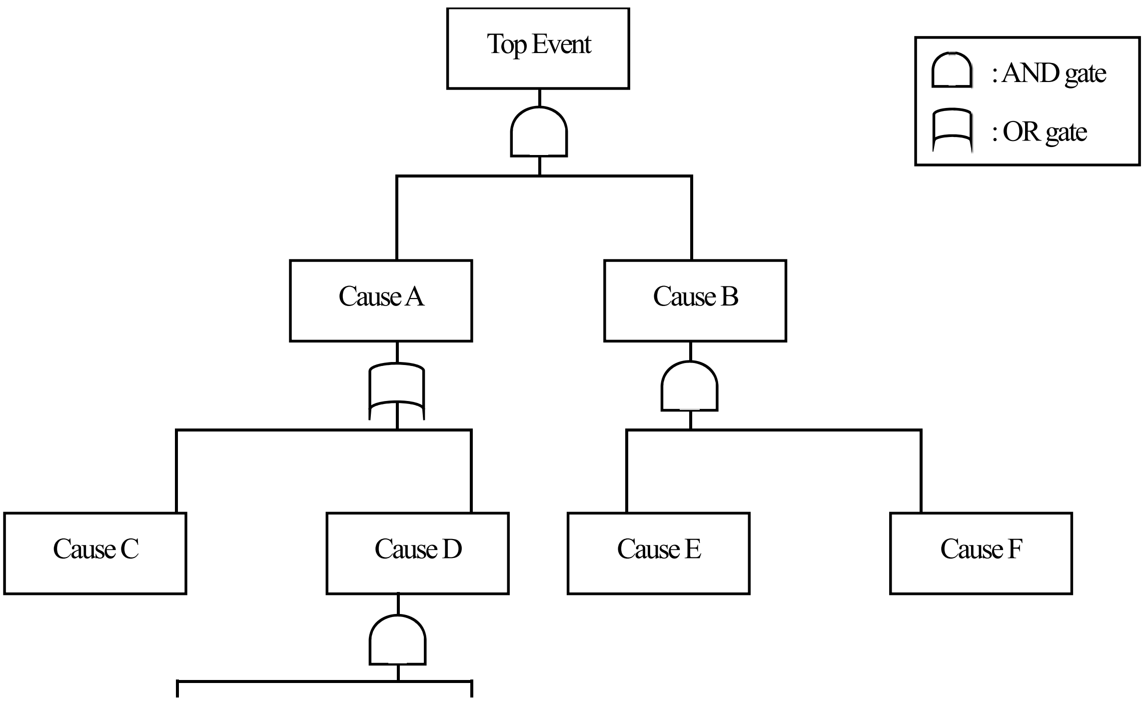


Fig. A-1 Fault tree

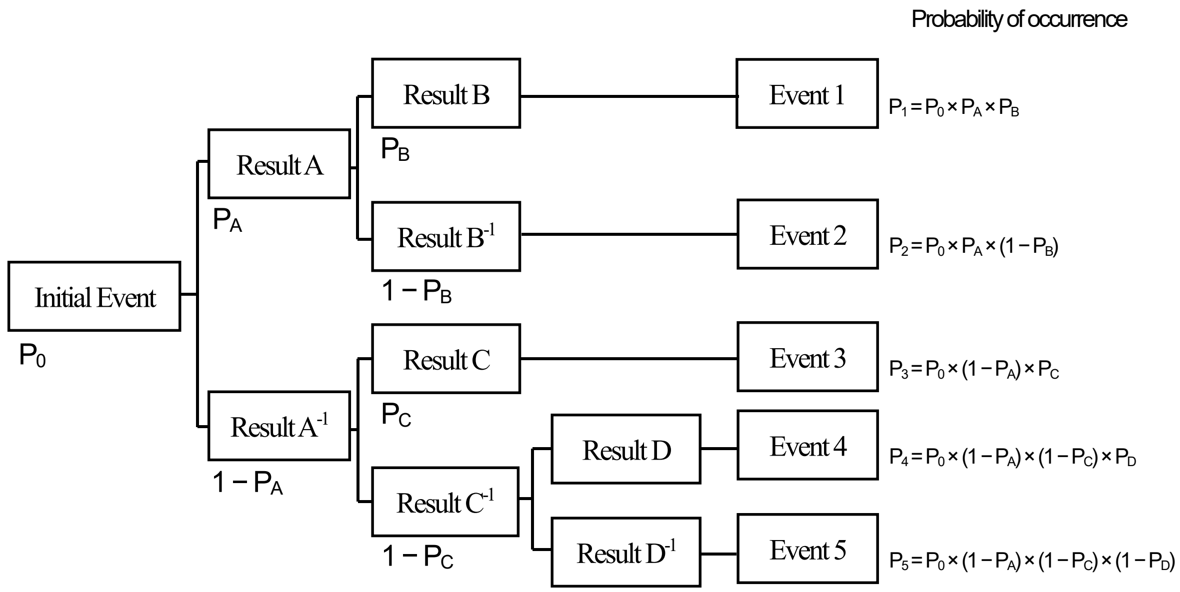


Fig. A-2 Event tree

The probability $G_i(x)$ that equipment i stops when the seismic intensity is x can be expressed by the following equation assuming that the bearing capacity of equipment i follows a lognormal distribution.

$$G_i(x) = \Phi\left(\frac{\ln(x/\theta_i)}{\beta_i}\right)$$

Here, $\Phi(\cdot)$ is the standard normal distribution function, θ_i is the median of the bearing capacity of equipment i, and β_i is its logarithmic standard deviation.

The probability $H_i(t)$ that the recovery period will be less than or equal to t when equipment i is stopped can be expressed by the following equation assuming that the recovery period of equipment i follows a lognormal distribution.

$$H_i(t) = \Phi\left(\frac{\ln(t/q_i)}{b_i}\right)$$

The probability distribution function of the probability that the recovery period of equipment i will be less than or equal to t when the earthquake motion strength x occurs is "probability that equipment i will not stop" and "probability that equipment i will be recovered when it stops.

From the above, the probability distribution function of the probability that the recovery period of equipment i will be less than or equal to t when seismic intensity x occurs is the sum of the "probability that equipment i will not stop" and the "probability that the recovery period will be less than or equal to t when it stops," and can be expressed as follows

$$F(t|x) = (1 - G_i(x)) + G_i(x) \cdot H_i(t)$$

Using this, the probability distribution function of the functional shutdown period of the entire facility system is expressed by the following equation

$$\text{AND gate: } F(t|x) = \prod_{i=1}^{n} F_i(t|x)$$

$$\text{OR gate: } F(t|x) = 1 - \prod_{i=1}^{n}\big(1 - F_i(t|x)\big)$$

The functional shutdown period of the entire facility system is calculated by accumulating these data based on FT. The same concept can be used to calculate the structure. The probability of structural damage $T_i(x)$ when the seismic intensity is x can be expressed by the following equation, assuming that the bearing capacity of structural element i follows a lognormal distribution.

$$T_i(x) = \Phi\left(\frac{\ln(x/\theta_i)}{\beta_i}\right)$$

Here, $\Phi(\cdot)$ is the standard normal distribution function, θ_i is the median of the bearing capacity of structural element i, and β_i is its logarithmic standard deviation.

The probability $U_i(t)$ that the recovery period will be less than or equal to t when structural element i is stopped can be expressed by the following equation, assuming that the recovery period of equipment i follows a lognormal distribution.

$$U_i(t) = \Phi\left(\frac{\ln(t/q_i)}{b_i}\right)$$

The probability distribution function of the probability that the recovery period of structural element i will be less than or equal to t when earthquake motion strength x occurs is given by the following equation. From the above, the probability distribution function of the probability that the recovery period of structural element i will be less than or equal to t when the seismic intensity x occurs is the sum of the "probability that structural element i will not be damaged" and the "probability that the recovery period will be less than or equal to t when it is damaged," and can be expressed as follows

$$S(t|x) = (1 - T_i(x)) + T_i(x) \cdot U_i(t)$$

Using this, the probability distribution function of the recovery period of the entire structural system is expressed by the following equation

$$\text{AND gate: } S(t|x) = \prod_{i=1}^{n} S_i(t|x)$$

$$\text{OR gate: } S(t|x) = 1 - \prod_{i=1}^{n}\big(1 - S_i(t|x)\big)$$

The other performances can be calculated by accumulating them in the same way.

However, for the detailed evaluation method, it is necessary to obtain the "median and standard deviation of bearing capacity" and the "median and standard deviation of recovery agency" for each element. For equipment, examples are given in the literature[15)], but of course not for all equipment. As for the structural elements, how to set them will be a future issue. In this paper, we have tried to eliminate the complications and ambiguities of the abbreviated calculation method, and to grasp the major trends while making bold assumptions.

7. Aiming to spread BCP activities

7.1 Introduction

The special investigation committee on index of building resilience and BCP level organized in Architectural Institute of Japan (AIJ)" investigated a procedure to enable the quantitative evaluation of the resilience performance of buildings, paying special attention to mitigation and recovery performance[1)]. Consequently, the committee proposed a Resilience Performance Index (RPI) and a Business Continuity Plan Level Rating (BCPLR) of buildings.

The committee also established the working group (WG) investigating a way to spread activities related to BCP in April 2018, and conducted the following studies:

❶ To further promote the spread of BCP activities by referring to existing incentives such as financing and insurance systems.

❷ To create pamphlets and other materials in order to spread and raise awareness of BCP activities because it is important to educate building owners, managers, and users.

This chapter reports the investigation results by the WG of AIJ committee. Firstly, we analyze some existing systems that are expected to serve as incentives for the spread of BCP activities and/or improvement of the seismic performance of buildings.

Secondly, we focus on buildings, which are the foundation of BCP activities, and report the results of our study on measures to disseminate RPI and BCPLR. BCP activities here refer to activities that should be carried out during normal times and emergencies in order to enable the continuation or early recovery of core business operations while minimizing damage to business assets in the event of a disaster or accident.

Thirdly, we introduce representative examples of consulting services to support corporate BCP activities provided mainly by risk consulting companies in recent years.

Finally, based on the above investigation results, a leaflet is created to make a better understanding of RPI and BCPLR in order to promote BCP activities.

7.2 Existing systems for promoting BCP activities

(1) Existing Systems and incentives

Various systems have been developed to promote BCP activities. We analyze some existing systems that are expected to serve as incentives for the spread of BCP activities and/or the improvement of the seismic performance of buildings. BCP activities here refer to activities that should be carried out during normal times and emergencies in order to enable the continuation or early recovery of core business operations while minimizing damage to business assets in the event of a disaster or accident.

Table 1 shows an overview of the nine existing systems we collected. The underlined sentences in Table 1 correspond to the incentives for the spread of BCP activities. It is found that the main incentives in each system can be categorized into the following three types:

❶ Promotion and improvement of BCP activities by providing risk information.

❷ Improve the external appeal of BCP activities and provide stakeholders with a sense of security through certification by a third-party organization.

❸ Improve the utilization rate of the system through economic incentives (conditions for bidding, financing, insurance discounts, etc.).

Table 1 – Overview of nine existing systems

Name of System	Overview
(1) Accreditation of BCMS conformity[2)] (by Japan Information Processing and Development Center: JIPDEC)	An accreditation system by a third-party certification body based on conformity with ISO 22301. This accreditation assures stakeholders that_a mechanism for the continuation of critical operations has been established and maintained.
(2) Resilience certification system[3)] (by Association for Resilience Japan)	The purpose of this certification is to promote the resilience of society by spreading the proactive business continuity efforts of various organizations. By obtaining certification, organizations can increase their external appeal, improve their business continuity efforts, and receive preferential treatment in bank loans.
(3) Certification system for business continuity of the construction industry for disaster[4)] (by Regional Development Bureau, Ministry of Land, Infrastructure, Transport, and Tourism: MLIT)	In order to promote the formulation of BCPs by construction companies, the regional development bureaus evaluate the BCPs, issue certificates, and make them public. The effect will be to improve the disaster response capability of the regional development bureau and the disaster prevention capability of the region. Certified construction companies will be given points when bidding in the comprehensive evaluation bidding system.
(4) SMBC Business Continuity Assessment Loan[5)] (by Sumitomo Mitsui Banking Corporation: SMBC)	BCP/BCM/BCMS will be evaluated based on the original criteria established by SMBC and other organizations. The conditions for financing will be set according to the results. Funding methods can be selected from loans and private placement bonds.
(5) DBJ BCM rated loan[6)] (by Development Bank of Japan)	This is a loan program that introduces the BCM rating system, which uses an original evaluation system developed by the Development Bank of Japan (DBJ) to evaluate companies that have made outstanding efforts in disaster prevention and business continuity measures, and sets loan conditions according to the evaluation.
(6) Housing performance indication system[7)] (by the Association for Evaluating and Labeling Housing Performance)	An evaluation of a building's seismic performance (grade 1 to 3) according to the Housing Performance Indication Standard. This may be a condition for receiving greater incentives such as mortgage tax reductions and discounts on earthquake insurance premiums by earthquake resistance grades.
(7) Certification system of conformance with earthquake resistance standards[8)] (by MLIT)	This certification certifies that existing houses built according to the old seismic standards have been retrofitted to conform to the current seismic standards. The certificate can be used to receive mortgage tax reductions and discounts on earthquake insurance premiums for seismic retrofitting.

Table 1 – Overview of nine existing systems (cont.)

Name of System	Overview
(8) System for indicating seismic certification mark[9] (by MLIT and competent administrative agency)	Following the Law Concerning the Promotion of Seismic Retrofitting of Buildings (revised in 2013), an earthquake safety labeling system has been established. Owners of buildings that have been certified by a competent administrative agency as being earthquake-resistant can display the mark. It is expected to have the effect of bringing a sense of security when using buildings and when buying and selling used properties.
(9) CASBEE Evaluation and Certification System (Resilient Housing Checklist) [10] (by Institute for Building Environment and Energy Conservation: IBEC)	The CASBEE (Comprehensive Assessment System for Built Environment Efficiency) is a method for evaluating and rating the environmental performance of buildings. One of the various evaluation tools is the Resilient Housing Checklist, which was developed to be used as a "trigger" for thinking about and improving the resilience of houses.

(2) Why are incentives necessary?

This section discusses the reasons why the above-mentioned incentives are necessary to spread BCP activities. To begin with, Japan is a country that has experienced many natural disasters such as earthquakes and typhoons, and there should be relatively abundant information and scientific knowledge about the disasters and risks. There is, however, a current situation that does not easily lead to concrete actions. Some theories explain one of the reasons for this discrepancy between risk perception and behavior, leading to irrational behavioral choices, such as the dual-process theory[11), 12)]. The dual-process theory is explained that humans have two information processing systems, an intuitive type (system 1) and an analytical type (system 2).

Nagase[13)] pointed out that the risk of natural disasters striking infrequently is less certain and the time is less imminent, so we have more time to think about the trade-off between risk and benefit and generally process information in System 2. However, natural disaster risks have the following characteristics that tend to lead the human cognitive system to underestimate the risk.

❶ It is difficult to evoke a vivid image like a physical entity.

❷ The existence of risk is perceived as distant.

❸ The probability of the risk occurring is relatively small, and even if it does occur, it seems to be far away.

❹ We are exposed to risks for a long time.

❺ There is room for cost-benefit calculations on whether risk-avoidance actions should be taken or not.

Therefore, in order to spread BCP activities, it is necessary to reduce the bias in risk perception and provide incentives for people to lead making rational choices.

7.3 Incentives for disseminating proposed quantitative measurements

(1) Results of the interview survey

For the purpose of collecting opinions on the possibility of using RPI and BCPLR proposed by the special investigation committee of AIJ and expectations for the effects of its use, an interview survey was conducted with related organizations and companies. The targets are (1) real estate companies (developers), (2) construction companies, (3) non-life insurance companies, (4) news media, and (5) local governments. The results of the interview survey are shown in Table 2.

Table 2 – Possibility of utilization and expectations for the effectiveness of proposed Resilience Performance Index and BCP Level Rating

Organization	Possibility of utilization	Expectations for the effectiveness
Real estate companies (Developers)	It could be used to appeal to institutional investors and attract tenants.	It would be better if it were directly linked to corporate profits, such as tax reduction or linking to rents. It would be good if the number of periodic inspections and other inspections required by the Building Standards Law and the Fire Service Act could be reduced.
Construction companies	If a customer requests for evaluation using the indicators by own expense, there is a possibility that the indicators will be adopted to building design.	Although direct benefits are difficult to find at present, it is easy to shift to use the indicators when developers take the lead in introducing them.
Non-life insurance companies	It could be used as an internal reference when examining the premiums for comprehensive corporate expenses and profits insurance.	It is expected to have the effect of increasing interest in business continuity to reduce the risk of profit loss.
News media (Facilities Department)	It can be used to promote the understanding of the people around the building to renovation work that leads to improved performance, including seismic reinforcement.	If social interest increases, it may be possible to broadcast a program on the indicators.
Local governments	In the case of municipal buildings, the potential for direct utilization is not high.	It will be more effective if it is linked to a system that improves the performance of the building rather than just the indicators.

From the results of the interview survey, if the proposed quantitative performance measurements are disseminated to a certain level, it is clarified that there is a possibility that various organizations and companies can be utilized except for the local governments.

As for the effects of the use of the proposed measurements, in addition to economic incentives, opinions from real estate companies pointed out that the measurements are expected to reduce the number of periodic inspections and other inspections required by the Building Standard

Law, Fire Service Act, etc. It is also revealed that the overall reduction of workload, including coordination with other systems and schemes, could be an incentive. It is also suggested that pamphlets and other materials should be prepared to raise awareness of the measurements and that they should be linked to specific measures to improve building performance.

(2) Potential of non-life insurance service for the incentive

Based on the results of the survey of existing systems and interviews with related organizations and companies, it was confirmed that there are high expectations for economic incentives. Therefore, the WG of AIJ focused on non-life insurance and examined its potential.

a) Relationship between the mitigation performance and non-life insurance products

Fig. 1 shows the proposed definition of building resilience performance and BCP level measure using the Bruneau's resilience triangle[14), 15)]. As shown in Fig. 1, the proposed RPI has two evaluation axes: (1) the mitigation performance and (2) the recovery performance which are the two major constituent factors for resilience and the combination of these two factors is the overall resilience performance.

Mitigation performance is an indicator related to the seismic performance of buildings and facilities, and buildings with high seismic performance have a smaller risk of property damage (property risk), which means that insurance premiums can be considered for reduction. In fact, earthquake insurance in Japan for residential buildings includes discounts for a high grade of seismic performance and seismically isolated buildings[16)], which serve as incentives for improving seismic performance. On the other hand, there is no explicit discount system for earthquake insurance for commercial buildings and factories, although each non-life insurance company can consider certain discounts at its discretion.

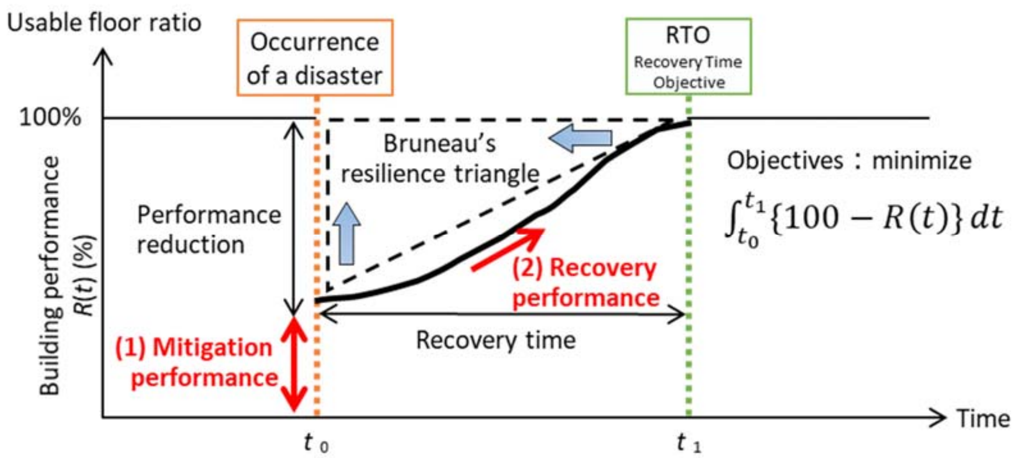


Fig. 1 – Definition of performance of building resilience and BCP level measure

b) Relationship between the recovery performance and non-life insurance products

Recovery performance is an indicator related to the business interruption period, and if the period is shortened, the loss of profit opportunities can be avoided. In response to this business interruption risk, non-life insurance companies, for example, provide comprehensive insurance for corporate expenses and profits[17)]. This insurance provides coverage against a decline in sales and operating profit, fixed expenses (ordinary expenses), and extraordinary expenses. Premiums are calculated based on a predetermined assumed business interruption period, so the shorter the assumed period, the lower the premiums will be provided. However, it is important to keep in mind the possibility of inadequate compensation if the assumed suspension period is exceeded.

c) Challenges for non-life insurance services as an incentive to spread BCP activities

It was clarified that there is a possibility of reducing insurance premiums for buildings with high mitigation and recovery performance. In other words, insurance can be expected to function as one incentive to disseminate the proposed index as well as spreading buildings with high resilience performance. On the other hand, it was found that the following issues need to be addressed in order to make such incentives work:

- The Financial Services Agency's approval may be required to sell new insurance products that offer a higher discount rate if the grade of business interruption risk is higher.
- The participation rate of profit-based insurance products is relatively low compared to that of property-based products, and the incentive effect is currently limited.
- The risk of business interruption due to earthquakes can lead to huge losses, and non-life insurance companies are taking a cautious approach.
- Insurance payment is not based on the period of business interruption, but on the actual decrease in sales, which may not be consistent with the quantitative measurements for resilience performance of buildings proposed by the special investigation committee of AIJ.

(3) Examination of incentives based on the behavioral economics

As discussed in section 7.2, there is a discrepancy between risk perception and behavior, and economic rationality may not always induce appropriate behavior. Inherently, it is considered that people living in Japan, where disasters occur frequently, do not ignore the risk of natural disasters. Therefore, we examined the possibility of providing such people with a mechanism that would induce them to take appropriate actions on their own. Specifically, we studied incentives based on the nudge theory, which has recently attracted attention in behavioral economics[18)]. The results of the study are shown in Table 3. In the future, it will be necessary to examine the feasibility and effectiveness of each incentive proposal.

Table 3 – Proposed incentives based on the nudge theory in behavioral economics

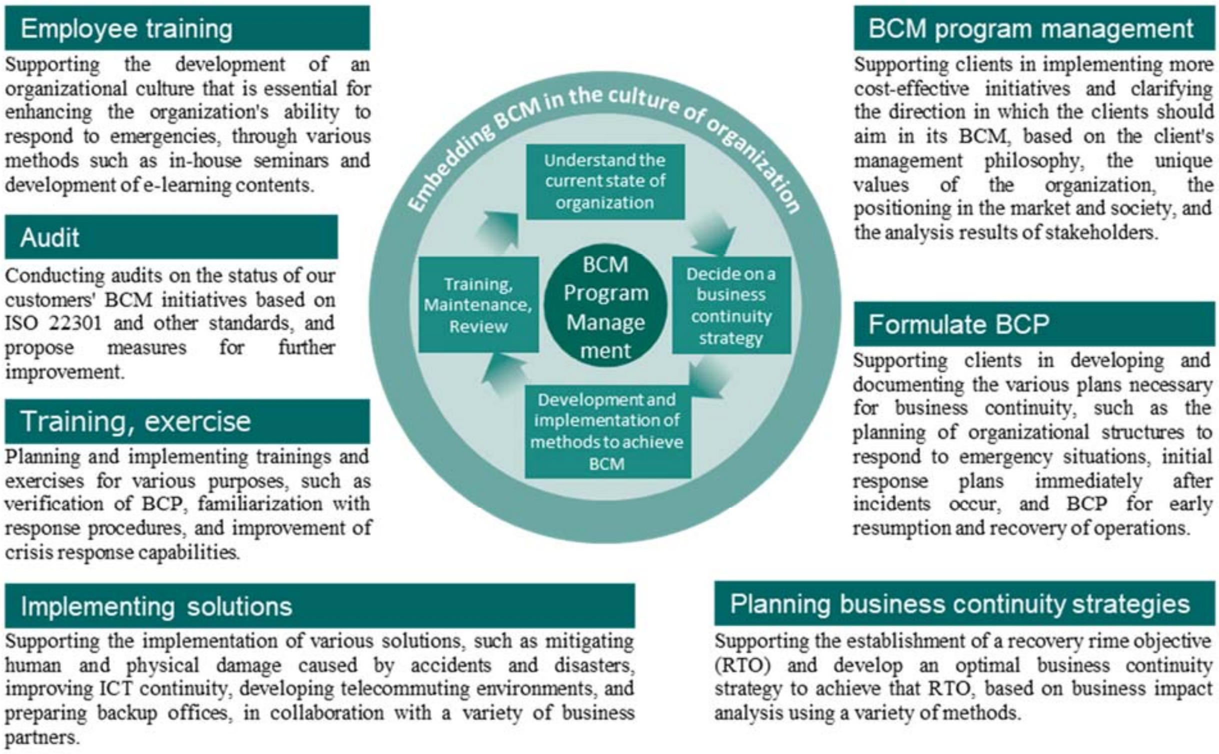
<table>
<tr><th>Name</th><th>Overview</th><th>Incentives</th></tr>
<tr><td>Prospect theory</td><td>・In situations of profit, people try to avoid risk to gain profit.
・In situations of loss, people try to avoid loss by taking risks.</td><td>・Conduct a free campaign for the evaluation of resilience performance to make people think it is beneficial to take the evaluation.
・If no evaluation is taken, the default rating will be evaluated as no star.</td></tr>
<tr><td>Placebo effect</td><td>・The effect of creating influence through some kind of assumption, despite the lack of effect.</td><td rowspan="2">・By referring to the opinions of celebrities and others, people will get a sense of the high value and compromise on the negative aspects of the evaluation such as the complexity of the procedure.</td></tr>
<tr><td>Halo effect</td><td>・The effect of a conspicuous feature distorting the evaluation of other features, when evaluating a person or an object.</td></tr>
<tr><td>Bandwagon effect</td><td>・Provide a mechanism to make people aware that many people are using the evaluation.</td><td>・Promote evaluation cases through mass media and social networking sites to let people know that many buildings are being evaluated.</td></tr>
<tr><td>Sunk cost,
Concorde effect</td><td>・The effect of psychological inability to cut losses against embedded costs.</td><td>・Distribute discount coupons for in-house power generation, etc., if the evaluation is received
・Distribute discount coupons for the evaluation in the case that the structural health monitoring system is installed.</td></tr>
</table>

7.4 Examples of consulting services related to BCP activities

Consulting services to support corporate BCP activities are being provided mainly by risk consulting companies. As representative examples[19), 20)], we introduce (1) support for establishing a system to implement business continuity management (BCM), (2) support for implementing Business Continuity Management System (BCMS), (3) support for business continuity plan (BCP) training, and (4) Support for determining the continued use of buildings in the event of an earthquake.

(1) Support for establishing a system to implement BCM

BCM is an initiative to plan and prepare for the resumption of core business operations within a recovery time objective (RTO) set as a goal in advance, assuming that normal business activities are interrupted as a result of an accident or disaster. Many accidents and disasters that occurred in the past resulted in significant decreases in profits, suspension of operations, or even bankruptcy of companies. However, it is considered that many cases could have been avoided if BCM had been properly implemented. Based on this background, consulting services that provide comprehensive and multifaceted support for overall BCM activities, including BCP formulation, are being offered as shown in Fig. 2.

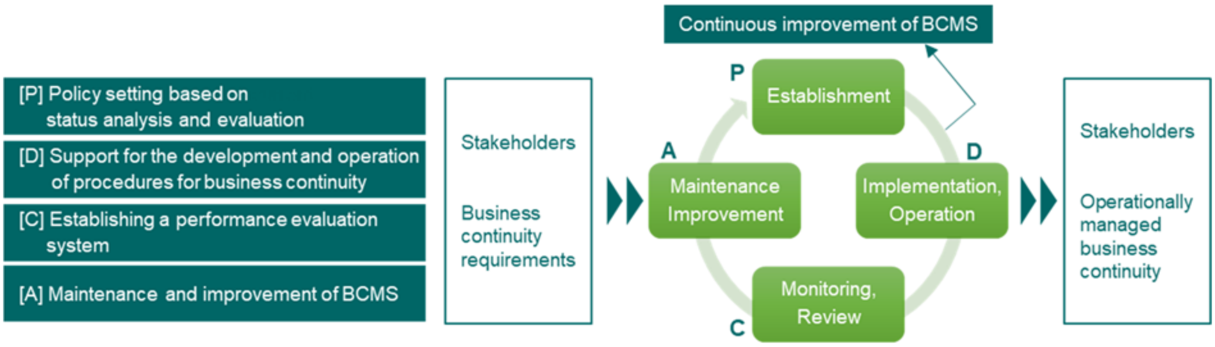


(Source: Based on material by MS&AD InterRisk Consulting and Research, Inc., with additions and English translation by AIJ)

Fig. 2 – Overall of the support service for establishing a system to implement BCM

(2) Support for implementing BCMS

BCMS is the part of an enterprise management system that establishes, practices, and operates the business continuity, as well as maintains and improves it through monitoring and review. The typical model is shown in ISO 22301:2012 "Social security - Business continuity management systems - Requirements" which applies the same management system concepts as ISO 9001 and ISO 14001, such as the PDCA cycle. Through the operation of this model, the BCMS aims to prevent incidents such as accidents and disasters that cause disruptions and interruptions to business, reduce the probability of such incidents occurring, and respond and restore business when they do occur. Besides, risk consulting companies provide support services for the establishment, maintenance, operation, and continuous improvement of a BCMS that is most suitable for a company, according to the company's needs, as well as full backup services for efforts to obtain BCMS certification as shown in Fig. 3.



(Source: Based on material by MS&AD InterRisk Consulting and Research, Inc., with additions and English translation by AIJ)

Fig. 3– Overall of the support service for implementing BCMS

(3) Support for BCP training

In recent years, consulting services have been provided to prepare BCPs for large-scale earthquakes, as well as floods, new influenza, and supply chain disruptions. Training based on the formulated BCPs is an essential process to enhance the effectiveness in business continuity response, including (1) understanding and establishing the BCPs, (2) identifying issues in the BCPs, and (3) improving the decision-making and response capabilities of those involved. Recently, services are being offered to provide the most effective training for companies from the various methods shown in Table 4. In addition to those methods, services have been provided to support "self-driven training" so that companies can continue to implement training on their own.

Table 4 – Examples of BCP training methods

Method	Outline	Features and effects
Simulation with the given situation	Participants will be given the disaster situation one after another and asked to respond and make decisions based on the BCP.	Effective in verifying whether the BCP will work in the event of a disaster
Practical exercise	This is a practical exercise in which participants are asked to carry out the actions planned in the BCP. (e.g., operation of the safety confirmation system, establishment of the emergency response headquarters, gathering of disaster responders, operation of communication devices, operation of the backup system, etc.)	Effective in mastering procedures
Quizzes, workshop	Group discussion on what to do based on the BCP under the various situations presented.	Effective in understanding the contents and procedures of BCP
Checklist	Using a checklist that shows the items to be implemented and the order in which they should be done in the event of a disaster, actually perform based on each procedure and check them.	Effective for training conducted at multiple remote locations (branch offices, etc.)
Reading out and verifying	Participants conduct a reading of the BCP document to verify whether it is effective and consistent.	Effective in understanding the contents of the BCP and raising awareness of those involved
Role-playing	By following a script prepared beforehand and having participants act out the BCP response, the effectiveness and consistency of the response are verified.	Effective in understanding the flow of action in the event of a disaster

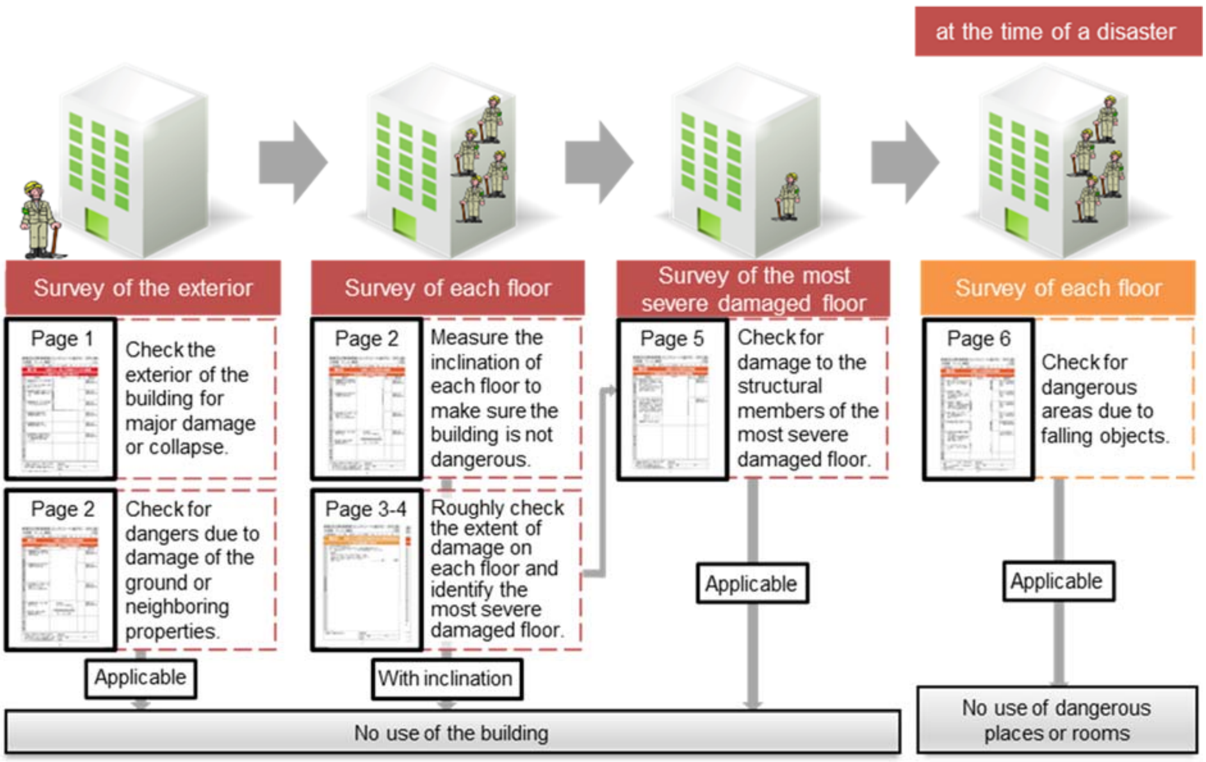
(Source: Based on material by MS&AD InterRisk Consulting and Research, Inc., with additions and English translation by AIJ)

(4) Support for determining the continued use of buildings in the event of an earthquake

In the event of a large-scale earthquake or other disaster, building owners and users need to immediately confirm the safety of their buildings and make decisions on whether to stay or evacuate. One of the issues is the possibility of expanding secondary disasters by continuing to use the building without being able to assess its condition. Also, it may take a long time to confirm the safety of the building because the experts requested to survey the building may not be able to come immediately.

In response to these issues, in February 2015, Cabinet Office[21)] published “Guidelines for Emergency Inspections of Buildings by Facility Managers and Others Immediately after a Large-Scale Earthquake”. This guideline is a compilation of safety confirmation methods for buildings in order to accept people who have difficulty returning home in the event of a large-scale earthquake. It describes specific methods of preparation and safety confirmation for building managers and others who do not have expertise in construction to check the safety of buildings in emergencies.

A service to support the determination of the continued use of buildings using the "safety confirmation chart" and "check sheet" posted in the guideline by the Cabinet Office is available as shown in Fig. 4.



(Source: Based on material by MS&AD InterRisk Consulting and Research, Inc., with additions and English translation by AIJ)

Fig. 4– Flow of safety check in the event of a disaster in the support service for the determination of the continued use of buildings

7.5 Publication of a leaflet for disseminating resilience performance index and BCP level rating

As the results of the aforementioned interview survey to related organizations and companies, the opinion was expressed that it was necessary to create pamphlets and other materials in order to increase awareness of RPI and BCPLR. Therefore, we have created a leaflet targeting the persons to be evaluated, such as building owners, managers, and users, as well as those who conduct the evaluation[22)].

(1) Composition of the leaflet for persons receiving the evaluation

The leaflet has been created using both sides of an A3 size paper, which becomes A4 in size when folded. The front side of the A3 size paper, as shown in Fig. 5, contains information for the person receiving the evaluation. On the front cover (right half), the Bruneau's resilience triangle diagram is used to express the concept of quantitative evaluation methods for resilience performance of buildings, as well as an overview of the two evaluation axes: mitigation and recovery performances. On the back cover (left half), we have included six types of images of buildings with resilience performance of mitigation-oriented and recovery-oriented types. These illustrations make it easy to understand the general correspondence between the resilience performance of each building and BCPLR. In addition, we have included images of envisioned use in each institution and organization.

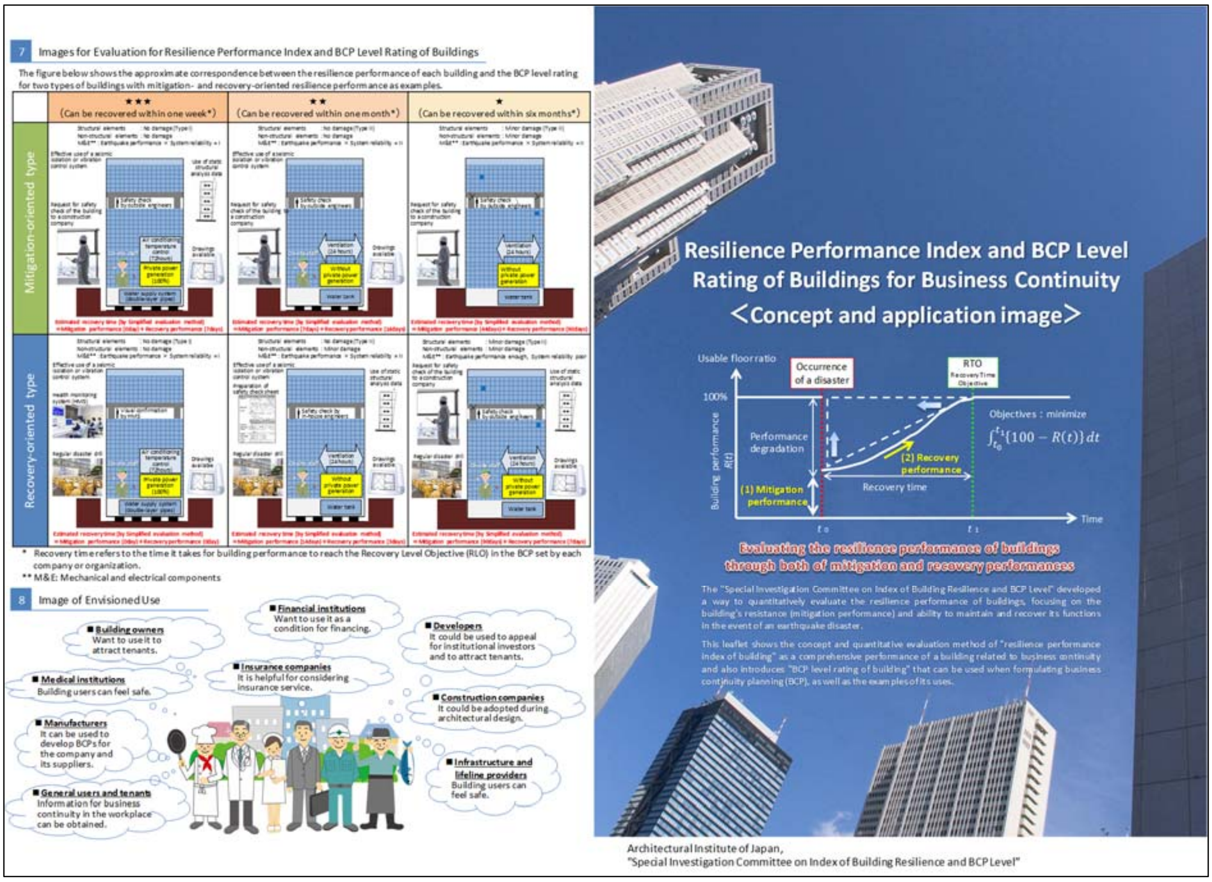
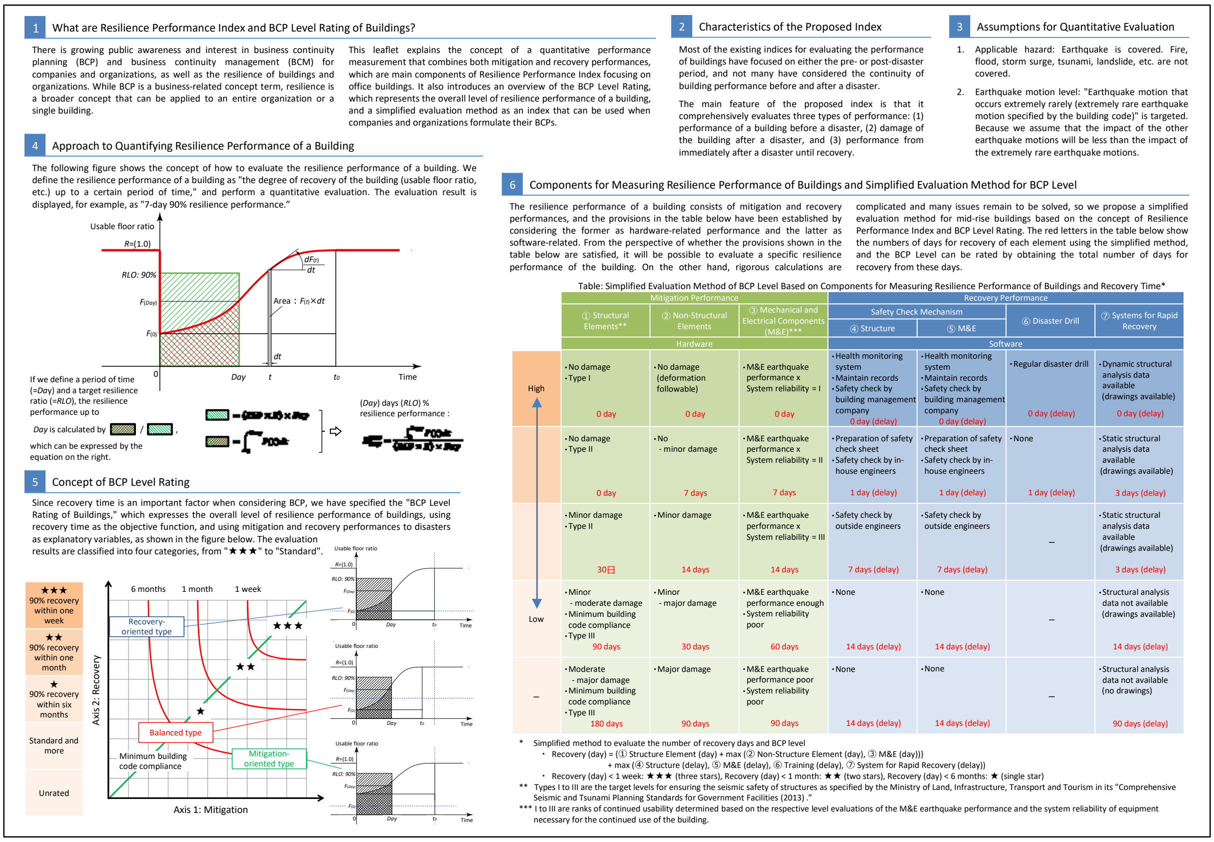


Fig. 5 – Composition of the leaflet (front side of the A3 size paper: front and back covers)

(2) Composition of the leaflet for evaluators

As shown in Fig. 6, the reverse side of the A3 size paper is facing pages used for the evaluator, which contains information for a more detailed understanding of RPI and BCPLR of buildings, as well as an overall picture of the evaluation method.

Specifically, the upper section of the leaflet explains the background and purpose of the creation of this leaflet. It also describes that the proposed index is characterized by the comprehensive evaluation of the following three performances: (1) performance of the building before a disaster, (2) damage immediately after the disaster, and (3) performance from immediately after the disaster until recovery. As assumptions for the quantitative evaluation, it is clearly stated that the applicable hazard is an earthquake and the seismic motion level is for “extremely rare seismic motions.” The middle and lower sections of the leaflet explain the concept of quantifying RPI and BCPLR of buildings, as well as the simplified quantification method proposed by the special research committee of AIJ, using charts and graphs.



1 What are Resilience Performance Index and BCP Level Rating of Buildings?

There is growing public awareness and interest in business continuity planning (BCP) and business continuity management (BCM) for companies and organizations, as well as the resilience of buildings and organizations. While BCP is a business-related concept term, resilience is a broader concept that can be applied to an entire organization or a single building.

This leaflet explains the concept of a quantitative performance measurement that combines both mitigation and recovery performances, which are main components of Resilience Performance Index focusing on office buildings. It also introduces an overview of the BCP Level Rating, which represents the overall level of resilience performance of a building, and a simplified evaluation method as an index that can be used when companies and organizations formulate their BCPs.

2 Characteristics of the Proposed Index

Most of the existing indices for evaluating the performance of buildings have focused on either the pre- or post-disaster period, and not many have considered the continuity of building performance before and after a disaster.

The main feature of the proposed index is that it comprehensively evaluates three types of performance: (1) performance of a building before a disaster, (2) damage of the building after a disaster, and (3) performance from immediately after a disaster until recovery.

3 Assumptions for Quantitative Evaluation

1. Applicable hazard: Earthquake is covered. Fire, flood, storm surge, tsunami, landslide, etc. are not covered.
2. Earthquake motion level: "Earthquake motion that occurs extremely rarely (extremely rare earthquake motion specified by the building code)" is targeted. Because we assume that the impact of the other earthquake motions will be less than the impact of the extremely rare earthquake motions.

4 Approach to Quantifying Resilience Performance of a Building

The following figure shows the concept of how to evaluate the resilience performance of a building. We define the resilience performance of a building as "the degree of recovery of the building (usable floor ratio, etc.) up to a certain period of time," and perform a quantitative evaluation. The evaluation result is displayed, for example, as "7-day 90% resilience performance."

If we define a period of time (=Day) and a target resilience ratio (=RLO), the resilience performance up to Day is calculated by [red hatched area] / [green hatched area], which can be expressed by the equation on the right.

(Day) days (RLO) % resilience performance :

5 Concept of BCP Level Rating

Since recovery time is an important factor when considering BCP, we have specified the "BCP Level Rating of Buildings," which expresses the overall level of resilience performance of buildings, using recovery time as the objective function, and using mitigation and recovery performances to disasters as explanatory variables, as shown in the figure below. The evaluation results are classified into four categories, from "★★★" to "Standard".

6 Components for Measuring Resilience Performance of Buildings and Simplified Evaluation Method for BCP Level

The resilience performance of a building consists of mitigation and recovery performances, and the provisions in the table below have been established by considering the former as hardware-related performance and the latter as software-related. From the perspective of whether the provisions shown in the table below are satisfied, it will be possible to evaluate a specific resilience performance of the building. On the other hand, rigorous calculations are complicated and many issues remain to be solved, so we propose a simplified evaluation method for mid-rise buildings based on the concept of Resilience Performance Index and BCP Level Rating. The red letters in the table below show the numbers of days for recovery of each element using the simplified method, and the BCP Level can be rated by obtaining the total number of days for recovery from these days.

Table: Simplified Evaluation Method of BCP Level Based on Components for Measuring Resilience Performance of Buildings and Recovery Time*

	Mitigation Performance			Recovery Performance			
				Safety Check Mechanism			
	① Structural Elements**	② Non-Structural Elements	③ Mechanical and Electrical Components (M&E)***	④ Structure	⑤ M&E	⑥ Disaster Drill	⑦ Systems for Rapid Recovery
	Hardware			Software			
High	・No damage ・Type I 0 day	・No damage (deformation followable) 0 day	・M&E earthquake performance x System reliability = I 0 day	・Health monitoring system ・Maintain records ・Safety check by building management company 0 day (delay)	・Health monitoring system ・Maintain records ・Safety check by building management company 0 day (delay)	・Regular disaster drill 0 day (delay)	・Dynamic structural analysis data available (drawings available) 0 day (delay)
	・No damage ・Type II 0 day	・No - minor damage 7 days	・M&E earthquake performance x System reliability = II 7 days	・Preparation of safety check sheet ・Safety check by in-house engineers 1 day (delay)	・Preparation of safety check sheet ・Safety check by in-house engineers 1 day (delay)	・None 1 day (delay)	・Static structural analysis data available (drawings available) 3 days (delay)
	・Minor damage ・Type II 30日	・Minor damage 14 days	・M&E earthquake performance x System reliability = III 14 days	・Safety check by outside engineers 7 days (delay)	・Safety check by outside engineers 7 days (delay)	–	・Static structural analysis data available (drawings available) 3 days (delay)
Low	・Minor - moderate damage ・Minimum building code compliance ・Type III 90 days	・Minor - major damage 30 days	・M&E earthquake performance enough ・System reliability poor 60 days	・None 14 days (delay)	・None 14 days (delay)	–	・Structural analysis data not available (drawings available) 14 days (delay)
–	・Moderate - major damage ・Minimum building code compliance ・Type III 180 days	・Major damage 90 days	・M&E earthquake performance poor ・System reliability poor 90 days	・None 14 days (delay)	・None 14 days (delay)	–	・Structural analysis data not available (no drawings) 90 days (delay)

* Simplified method to evaluate the number of recovery days and BCP level
- Recovery (day) = {① Structure Element (day) + max (② Non-Structure Element (day), ③ M&E (day))} + max (④ Structure (delay), ⑤ M&E (delay), ⑥ Training (delay), ⑦ System for Rapid Recovery (delay))
- Recovery (day) < 1 week: ★★★ (three stars), Recovery (day) < 1 month: ★★ (two stars), Recovery (day) < 6 months: ★ (single star)

** Types I to III are the target levels for ensuring the seismic safety of structures as specified by the Ministry of Land, Infrastructure, Transport and Tourism in its "Comprehensive Seismic and Tsunami Planning Standards for Government Facilities (2013) ."

*** I to III are ranks of continued usability determined based on the respective level evaluations of the M&E earthquake performance and the system reliability of equipment necessary for the continued use of the building.

Fig. 6 – Composition of the leaflet (reverse side of the A3 size paper: facing pages)

7.6 Conclusions

In this chapter, we presented the investigation results on measures to disseminate RPI and BCPLR proposed by the special investigation committee of AIJ. As confirmed through the studies of existing systems that were expected to improve the seismic performance of buildings and provide incentives for disseminating BCP activities, we confirmed that typical incentives including the provision of risk information, the establishment of certification systems by third-party organizations, and the application of economic incentives (tax reductions, rewards, preferential treatment, penalties, etc.). Through the interviews which were conducted with related organizations and companies, we found that there is a possibility to be utilized in various organizations and companies if the proposed quantitative performance measurements are disseminated to a certain level. We also clarified that insurance is expected to serve as one incentive to disseminate the proposed measurements and promote buildings with high resilience performance, although it faces some challenges. Besides, as a concrete measure for dissemination, we created and published the leaflet for persons receiving the evaluation and evaluators.

Currently, AIJ is working on a new committee, the Task Force for Resilient Buildings, based on the results of the activities of the special investigation committee. This new committee is studying the application of the proposed evaluation methods to various hazards other than earthquakes and various buildings other than office buildings. The committee is also investigating international standards to promote the use of the proposed RPI and BCPRL. We are planning to study the issues identified in this research, including the linkage of the proposed quantitative measurements with other systems and schemes, in order to effectively and efficiently disseminate them.

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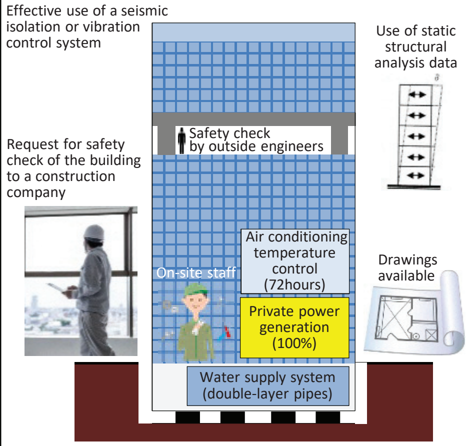
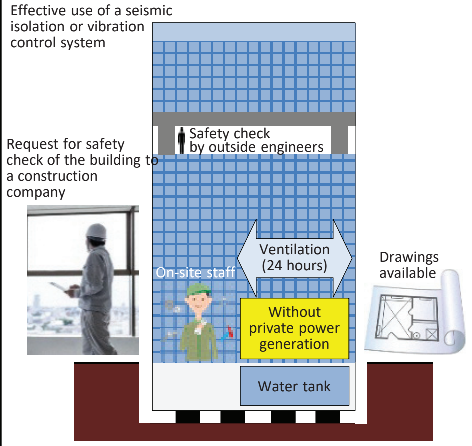
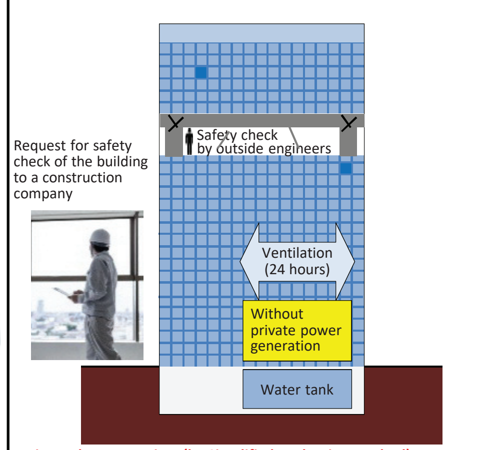
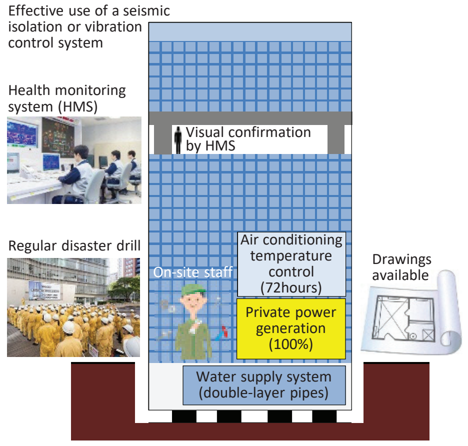
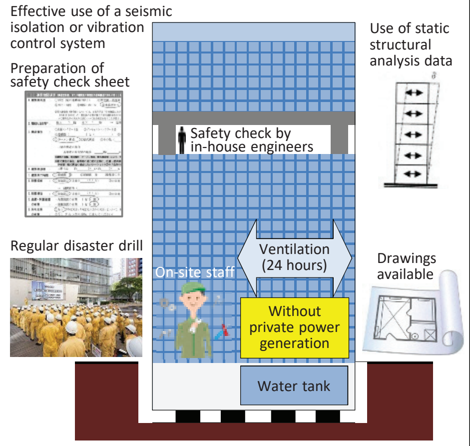
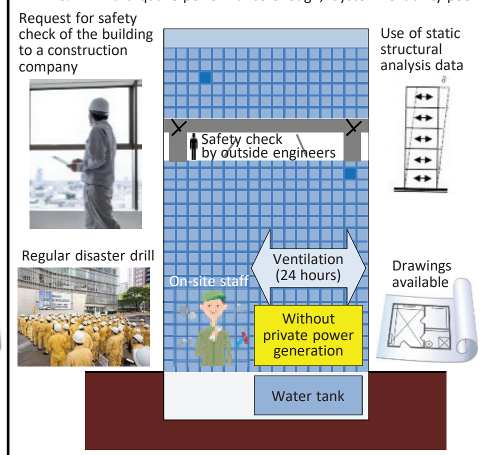
7 Images for Evaluation for Resilience Performance Index and BCP Level Rating of Buildings

The figure below shows the approximate correspondence between the resilience performance of each building and the BCP level rating for two types of buildings with mitigation- and recovery-oriented resilience performance as examples.

	★★★ (Can be recovered within one week*)	★★ (Can be recovered within one month*)	★ (Can be recovered within six months*)
Mitigation-oriented type	Structural elements : No damage (Type I) Non-structural elements : No damage M&E** : Earthquake performance × System reliability = I  Estimated recovery time (by Simplified evaluation method) ＝Mitigation performance (0day)＋Recovery performance (7days)	Structural elements : No damage (Type II) Non-structural elements : No damage M&E** : Earthquake performance × System reliability = II  Estimated recovery time (by Simplified evaluation method) ＝Mitigation performance (7days)＋Recovery performance (14days)	Structural elements : Minor damage (Type II) Non-structural elements : Minor damage M&E** : Earthquake performance × System reliability = II  Estimated recovery time (by Simplified evaluation method) ＝Mitigation performance (44days)＋Recovery performance (90days)
Recovery-oriented type	Structural elements : No damage (Type I) Non-structural elements : No damage M&E** : Earthquake performance × System reliability = I  Estimated recovery time (by Simplified evaluation method) ＝Mitigation performance (0day)＋Recovery performance (0day)	Structural elements : No damage (Type II) Non-structural elements : Minor damage M&E** : Earthquake performance × System reliability = II  Estimated recovery time (by Simplified evaluation method) ＝Mitigation performance (14days)＋Recovery performance (3days)	Structural elements : Minor damage (Type II) Non-structural elements : Minor damage M&E** : Earthquake performance enough, System reliability poor  Estimated recovery time (by Simplified evaluation method) ＝Mitigation performance (90days)＋Recovery performance (7days)

* Recovery time refers to the time it takes for building performance to reach the Recovery Level Objective (RLO) in the BCP set by each company or organization.

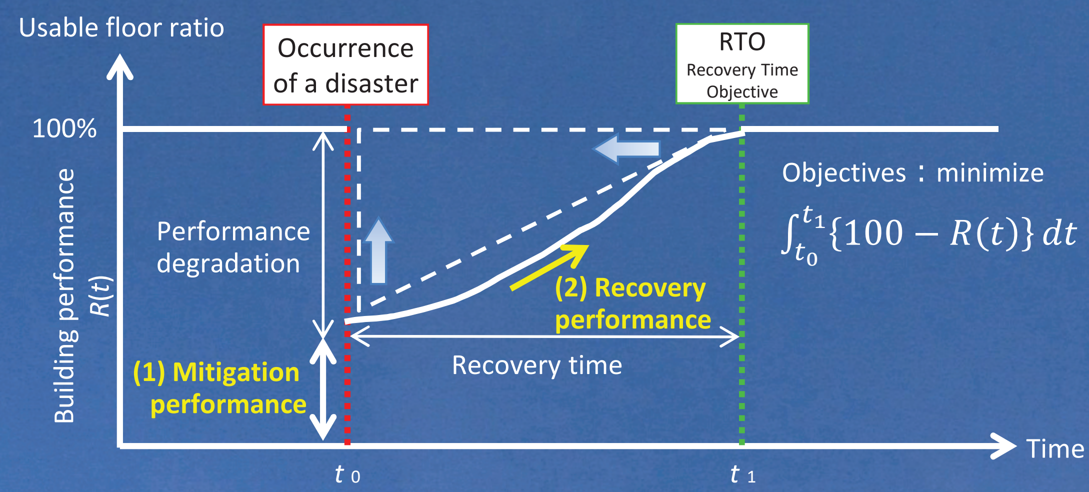
** M&E: Mechanical and electrical components

8 Image of Envisioned Use

- **Building owners** Want to use it to attract tenants.
- **Financial institutions** Want to use it as a condition for financing.
- **Developers** It could be used to appeal for institutional investors and to attract tenants.
- **Medical institutions** Building users can feel safe.
- **Insurance companies** It is helpful for considering insurance service.
- **Construction companies** It could be adopted during architectural design.
- **Manufacturers** It can be used to develop BCPs for the company and its suppliers.
- **Infrastructure and lifeline providers** Building users can feel safe.
- **General users and tenants** Information for business continuity in the workplace can be obtained.

Resilience Performance Index and BCP Level Rating of Buildings for Business Continuity

<Concept and application image>



Evaluating the resilience performance of buildings through both of mitigation and recovery performances

The "Special Investigation Committee on Index of Building Resilience and BCP Level" developed a way to quantitatively evaluate the resilience performance of buildings, focusing on the building's resistance (mitigation performance) and ability to maintain and recover its functions in the event of an earthquake disaster.

This leaflet shows the concept and quantitative evaluation method of "resilience performance index of building" as a comprehensive performance of a building related to business continuity and also introduces "BCP level rating of building" that can be used when formulating business continuity planning (BCP), as well as the examples of its uses.

Architectural Institute of Japan,
"Special Investigation Committee on Index of Building Resilience and BCP Level"

1 What are Resilience Performance Index and BCP Level Rating of Buildings?

There is growing public awareness and interest in business continuity planning (BCP) and business continuity management (BCM) for companies and organizations. While BCP is a business-related concept term, resilience is a broader concept that can be applied to an entire organization or a single building.

This leaflet explains the concept of a quantitative performance measurement that combines both mitigation and recovery performances, which are main components of Resilience Performance Index focusing on office buildings. It also introduces an overview of the BCP Level Rating, which represents the overall level of resilience performance of a building, and a simplified evaluation method as an index that can be used when companies and organizations formulate their BCPs.

2 Characteristics of the Proposed Index

Most of the existing indices for evaluating the performance of buildings have focused on either the pre- or post-disaster period, and not many have considered the continuity of building performance before and after a disaster.

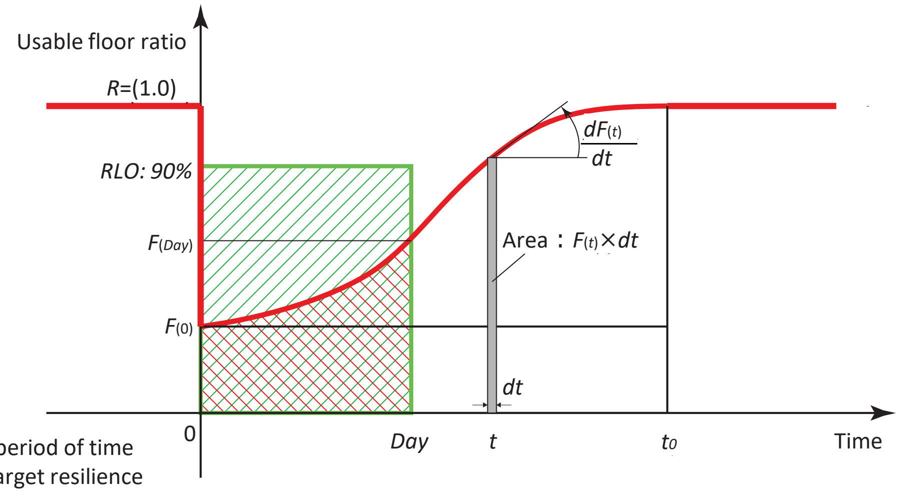
The main feature of the proposed index is that it comprehensively evaluates three types of performance: (1) performance of a building before a disaster, (2) damage of the building after a disaster, and (3) performance from immediately after a disaster until recovery.

3 Assumptions for Quantitative Evaluation

1. Applicable hazard: Earthquake is covered. Fire, flood, storm surge, tsunami, landslide, etc. are not covered.
2. Earthquake motion level: "Earthquake motion that occurs extremely rarely (extremely rare earthquake motion specified by the building code)" is targeted. Because we assume that the impact of the other earthquake motions will be less than the impact of the extremely rare earthquake motions.

4 Approach to Quantifying Resilience Performance of a Building

The following figure shows the concept of how to evaluate the resilience performance of a building. We define the resilience performance of a building as "the degree of recovery of the building (usable floor ratio, etc.) up to a certain period of time," and perform a quantitative evaluation. The evaluation result is displayed, for example, as "7-day 90% resilience performance."



If we define a period of time (=*Day*) and a target resilience ratio (=*RLO*), the resilience performance up to *Day* is calculated by [hatched area] / [green area], which can be expressed by the equation on the right.

[green area] $= (RLO \times R) \times Day$

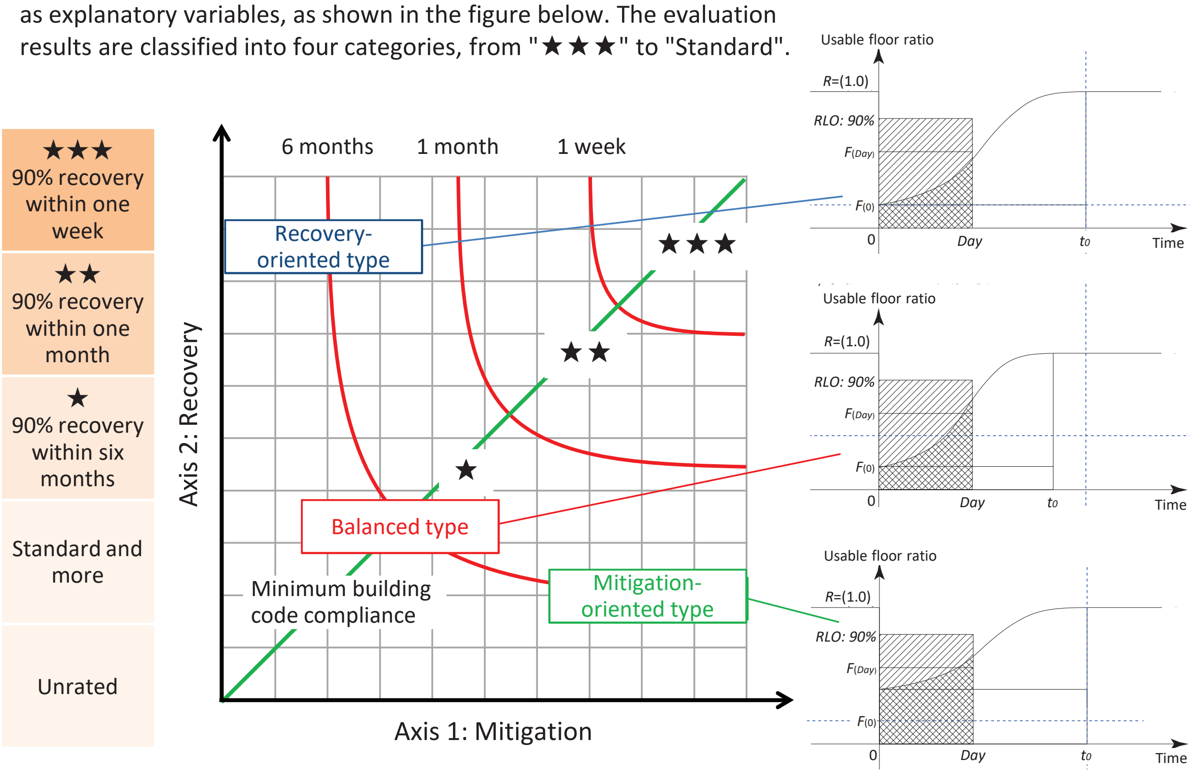
[hatched area] $= \int_0^{Day} F(t)dt$

⇨ (*Day*) days (*RLO*) % resilience performance :

$$R_{Day}^{RLO} = \frac{\int_0^{Day} F(t)dt}{(RLO \times R) \times Day}$$

5 Concept of BCP Level Rating

Since recovery time is an important factor when considering BCP, we have specified the "BCP Level Rating of Buildings," which expresses the overall level of resilience performance of buildings, using recovery time as the objective function, and using mitigation and recovery performances to disasters as explanatory variables, as shown in the figure below. The evaluation results are classified into four categories, from "★★★" to "Standard".



6 Components for Measuring Resilience Performance of Buildings and Simplified Evaluation Method for BCP Level

The resilience performance of a building consists of mitigation and recovery performances, and the provisions in the table below have been established by considering the former as hardware-related performance and the latter as software-related. From the perspective of whether the provisions shown in the table below are satisfied, it will be possible to evaluate a specific resilience performance of the building. On the other hand, rigorous calculations are complicated and many issues remain to be solved, so we propose a simplified evaluation method for mid-rise buildings based on the concept of Resilience Performance Index and BCP Level Rating. The red letters in the table below show the numbers of days for recovery of each element using the simplified method, and the BCP Level can be rated by obtaining the total number of days for recovery from these days.

Table: Simplified Evaluation Method of BCP Level Based on Components for Measuring Resilience Performance of Buildings and Recovery Time*

	Mitigation Performance			Recovery Performance			
	① Structural Elements**	② Non-Structural Elements	③ Mechanical and Electrical Components (M&E)***	Safety Check Mechanism		⑥ Disaster Drill	⑦ Systems for Rapid Recovery
				④ Structure	⑤ M&E		
	Hardware			Software			
High	・No damage ・Type I 0 day	・No damage (deformation followable) 0 day	・M&E earthquake performance x System reliability = I 0 day	・Health monitoring system ・Maintain records ・Safety check by building management company 0 day (delay)	・Health monitoring system ・Maintain records ・Safety check by building management company 0 day (delay)	・Regular disaster drill 0 day (delay)	・Dynamic structural analysis data available (drawings available) 0 day (delay)
↑	・No damage ・Type II 0 day	・No - minor damage 7 days	・M&E earthquake performance x System reliability = II 7 days	・Preparation of safety check sheet ・Safety check by in-house engineers 1 day (delay)	・Preparation of safety check sheet ・Safety check by in-house engineers 1 day (delay)	・None 1 day (delay)	・Static structural analysis data available (drawings available) 3 days (delay)
	・Minor damage ・Type II 30日	・Minor damage 14 days	・M&E earthquake performance x System reliability = III 14 days	・Safety check by outside engineers 7 days (delay)	・Safety check by outside engineers 7 days (delay)	–	・Static structural analysis data available (drawings available) 3 days (delay)
↓ Low	・Minor - moderate damage ・Minimum building code compliance ・Type III 90 days	・Minor - major damage 30 days	・M&E earthquake performance enough ・System reliability poor 60 days	・None 14 days (delay)	・None 14 days (delay)	–	・Structural analysis data not available (drawings available) 14 days (delay)
–	・Moderate - major damage ・Minimum building code compliance ・Type III 180 days	・Major damage 90 days	・M&E earthquake performance poor ・System reliability poor 90 days	・None 14 days (delay)	・None 14 days (delay)	–	・Structural analysis data not available (no drawings) 90 days (delay)

* Simplified method to evaluate the number of recovery days and BCP level
- Recovery (day) = {① Structure Element (day) + max (② Non-Structure Element (day), ③ M&E (day))} + max (④ Structure (delay), ⑤ M&E (delay), ⑥ Training (delay), ⑦ System for Rapid Recovery (delay))
- Recovery (day) < 1 week: ★★★ (three stars), Recovery (day) < 1 month: ★★ (two stars), Recovery (day) < 6 months: ★ (single star)

** Types I to III are the target levels for ensuring the seismic safety of structures as specified by the Ministry of Land, Infrastructure, Transport and Tourism in its "Comprehensive Seismic and Tsunami Planning Standards for Government Facilities (2013) ."

*** I to III are ranks of continued usability determined based on the respective level evaluations of the M&E earthquake performance and the system reliability of equipment necessary for the continued use of the building.