Continuity and/or Resiliency of Building Function after Disasters

by

Hiroshi Fukuyama[1], Koichi Morita[2], Tomohisa Mukai[2], Taiki Saito[1], Hitomitsu Kikitsu[4], Yoshihiro Iwata[3], Yoshio Wakiyama[3], and Seitaro Tajiri[3]

ABSTRACT

Building Research Institute (BRI) has started research project on "Development of Performance-Based Structural Design System for Evaluating Continuity and/or Resiliency of Building Function after Disasters" in 2007 as a 3-year research project. The expected final results of the project are research and development of (1) Structural design framework and (2) Structural design data base for evaluation of "Continuity and/or Resiliency of Building Function, and (3) Guidebook for dissemination of the concept on "continuity and/or resiliency of building function after disasters" .

KEYWORDS: Functional Continuity, Disaster Resiliency, Structural Performance Evaluation, Structural Design Framework, Database, Accountability

1. INTRODUCTION

Securing human life in disasters is one of the most important objectives of the design of buildings, and the Building Standard Law of Japan which specifies the minimal requirements contains the provisions to be observed for securing the human life in disasters. In earthquake disasters in recent years, however, there occurred serious damages of losing the functions of buildings as the dwelling and as the field of human activities. Thus, adding to the safety viewpoint, the design has recognized the necessity of the viewpoint of "how to maintain the building functions" or "how rapidly recover the deteriorated functions". The recognition also relates to the request of the Central Disaster Prevention Council of the Cabinet Office for the business enterprises to establish their Business Continuity Plan (BCP), along with the increase of achievement rate of earthquake-resistant structures, in order to decrease the amount of damages by about half at the expected Tokai Earthquake, Tonankai Earthquake, Nankai Earthquake, strong local earthquake in the Tokyo metropolitan area, etc.

Building Research Institute (BRI) began the 3-year research and development project "Development of Performance-based Structural Design System for Evaluating Continuity and/or Resiliency of Building Function after Disasters" in 2007, aiming at not only the safety evaluation in disasters but also the difficulty evaluation in social, economic, and human activities after disasters. A Framework and a database system for structural design, and guidebooks for dissemination information for general users, etc. will be developed as useful outputs of building design allowing functional continuity and disaster resilience. This paper describes the overview of the research project and the individual research subjects.

2. BACKGROUND OF PROJECT RESEARCH

The Southern Hyogo Earthquake (Kobe Earthquake) occurred in 1995 resulted in collapse of large number of buildings, killed many people, and also paralyzed variety of city functions to force citizens to live at emergency evacuation areas outside their home for a long period. This is because many residential buildings lost their functions as the "dwelling". In addition, there appeared not a small number of cases that, although the buildings designed

1 Chief Research Engineer, Building Research Institute, Tsukuba, Ibaraki 305-0802, JAPAN
2 Senior Research Engineer, ditto
3 Research Engineer, ditto
4 Senior Research Engineer, National Institute for Land and Infrastructure Management, MLIT, Tsukuba, Ibaraki 305-0804, JAPAN

according to the current seismic code did not collapse as requested by the codes and protected the human life, the damages of structural frame were serious, which needed very large restoration cost, thus the damaged buildings were finally tore down and reconstructed, (refer to Photo 1 as an example.) The cases show the importance of design to have a viewpoint of damage control and of functional resilience. The Geiyo Earthquake in 2001, the Tokachi-Oki Earthquake in 2003, and the Southern Miyagi Earthquake in 2005 generated damages caused by dropping large scale space ceiling. The West-Off Fukuoka Earthquake in 2005 generated damages of window glass of office buildings and of walls and fittings of condominiums (Photo 2). Thus, there appeared the cases that also the damages of those nonstructural members induce danger of human life similar to the cases of damages of structural framework, and that the loss of building function and of dwelling ability results in the difficulty of continuous use of the buildings after disasters.

Review of the cases of building damages in the earthquakes occurred in recent years clearly showed the actual state that owners and residents of buildings do not expect the conditions of disasters, and they do not prepare action plan after the disasters. On that matter, the suppliers of buildings might also lack the efforts to convey information and special field knowledge to the owners and the residents. The Kobe Earthquake drew attention about the damages of nonstructural members and equipment and fixtures, whose damages were relatively not recognized in the past hidden by the serious damage or collapse of structural framework. Furthermore, the Kobe Earthquake showed a feature that the residents of damaged buildings emphasized not only the direct loss of the building structure but also the indirect economic loss resulted from the disaster.

Through the experiences of above earthquake damages, business enterprises strongly recognized the importance of preventive measures to enable the business to continue in disaster and to enable the core business operation to rapidly recover to the level before the disaster. In this regard, the "Business Continuity Plan (BCP)" has drawn attention inside and outside Japan. The BCP is a strategy of protection of business enterprise from critical profit loss and from deterioration of enterprise rating by avoiding stop operation of important business in disaster and by, even when the business operation is stopped, resuming the important function within a target restoration period. In Japan, "Special Field Survey Committee relating to the Disaster Preventive Power Improvement utilizing Private Sector Power and Market Power", organized under the Central Disaster Prevention Council of the Cabinet Office, published the 1st edition of the Business Continuity Guidelines and the Check List in August 2005, and the Committee requested all the business enterprises to prepare their own BCP. Not limited to the activities of the government, the general constructors have recently begun practical application of earthquake risk evaluation system which supports BCP of, for example, semiconductor production facilities. In this manner, the development of structural design technology proceeds targeting not only the damage evaluation but also the evaluation of restoration period and of cost-effectiveness. Many of the above activities, however, use the statistical data of past earthquake damages, and do not reach the level of evaluation in depth to the response of individual buildings and to the relation between the damages and the deterioration of functions.

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

3.1 Definition of "Functional Resiliency"

On the background of Chapter 2, this section newly defines the "Functional Resiliency" as the performance indicating the easiness of disaster resilience of building function after disasters, especially earthquakes.

BRI selected three basic structural performances of buildings in the performance design, "Serviceability", "Safety", and "Reparability", in the "Development of New Building Structural System (hereinafter referred to as the "New Structural System Project") as one of the Comprehensive Technological Development Project of the Ministry of Construction, and promoted the practical application of the design process based on these three basic structural performances. The concept of the "Functional Resiliency" defined in the research, however, is the one with an extension of the concept of "Reparability" defined in the New Structural System Project. Therefore, those two concepts differ from each other on the following points.

・The concept of "Reparability" in the New Structural System Project: The main object is the "property preservation" for buildings after earthquake; the easiness of restoration of buildings after the earthquake is secured by suppressing the building damages within a physical restoration limit of the building specified in each performance evaluation article.

・The concept of "Functional Resiliency" in this research: Easiness of functional resilience of buildings after earthquake is secured by, adding to the concept of "Reparability" of the New Structural System Project, keeping the restoration cost and the restoration period of the building after the earthquake within the target restoration cost and the target restoration period, respectively, determined by the owner (with an agreement with the designer) in view of functions of the building. Although the Business Continuity Plan (BCP) expects the damages of surrounding area of the building and the damages of lifeline, the concept of "Functional Resiliency" of the research deals with the controllable range in the design of individual buildings, and the influence caused by the variables other than those of the building is considered afterward as an additional condition

3.2 Design Verification Flow Scheme Based on the "Functional Resiliency"

The design verification flow scheme based on the "Functional Resiliency" is illustrated in Fig. 1. Main articles of the flow are outlined below.

i) *Uses of buildings ("Occupancy category" in Fig.1)*

Since the functions of buildings have close relation mainly with their uses, and since the applied structural methods and specifications of every position of the building depend on the uses, the design verification based on the "Functional Resiliency" positively counts the building uses.

ii) *Process up to the 1st level verification*

The cross sectional dimensions of structural members are firstly determined. Then, the model of structural members is prepared, and the earthquake motion is determined. Next, the response evaluation is given to thus prepared model to calculate the response values of engineering indexes (such as maximum story drift and response acceleration) necessary to the damage evaluation. Also to the nonstructural members and the building equipment and contents, detail specifications are prepared, and their response values of engineering indexes required in the damage evaluation are calculated based on the values of maximum story drift and of response acceleration derived from the response evaluation of the structural members. Finally, using the database relating to the damage conditions, the physical restoration limit state of individual positions of the building, determined at the target performance level, is converted into the limit value of corresponding engineering index, thus comparing the limit value with the response value to complete the 1st level verification of the Reparability. The 1st level verification is a verification based on the performance evaluation article of the conventional Reparability.

iii) *Process up to the 2nd level verification*

On the basis of the damage condition of each position of the building, revealed up to the 1st level verification, firstly the restoration target of entire building is determined, and the method for restoration is determined. Then, the restoration cost and the restoration period, corresponding to the determined restoration method, are calculated using the database relating to the restoration method. Finally, these values are compared with the target restoration cost and the target restoration period expected by the owner and the resident in their Business Continuity Plan, etc. to complete the 2nd level verification. If the result of the 2nd level verification gives NG, the preparation of restoration plan is executed again, and the same procedure is applied again. (If the second time of the 2nd level verification gives NG, and if the sole change of the restoration plan is judged as non-effective, the design itself has to be changed from the beginning.)

iv) *Indication of performance*

The evaluation result of the "Functional Resiliency" of the building, confirmed through the 1st and the 2nd level verifications, is explained to the owner and the resident in an understandable format. The "database relating to the damage condition corresponding to the occupancy category of building" given in the flow was prepared gathering experimental data and other findings to give a total image of the relation between [the damage conditions of each position of structural members, nonstructural members, and equipment and fixtures] and [the engineering indexes describing the damages, based on the experimental data, etc.] The "database relating to the restoration method" is the collected data relating to the restoration cost and the restoration period for each restoration method, based on the existing findings and knowledge.

4. APPLICATION EXAMPLE OF EVALUATION SYSTEM BASED ON "FUNCTIONAL RESILIENCY"

4.1 Buildings for Evaluation

The target building is an existed hospital in Niigata Prefecture. Table 1 shows the outline of the building. The room arrangement of each floor is: 1st and 2nd basement for machinery of core equipment; 1st and 2nd floor for diagnostic and treatment departments; 3rd floor for operation of each medical section; 4th and upper floors for wards; and roof top for elevated water tank and cooling tower. The building suffered damage due to the Niigata-Chuetsu Earthquake in 2004, and the restoration was conducted, thus the building is still in operation as hospital. After the earthquake, a survey of building damages was given, and detail records exist including the analysis of restoration work. The hospital was selected as the target building because these records are effective reference materials in the research.

4.2 Time history response analysis

The applied vibration analysis model was an equivalent shear model with seven mass points, giving the 1st floor as the fixed end. The viscosity damping was assumed as an instantaneous stiffness proportional type of 3% to the primacy natural period. The earthquake motion for the study was selected to the simulated earthquake motion 3 wave which was prepared using the phases of EL CNTRO NS (1940), TAFTEW (1952), and HACHINOHE NS (1968), in accordance with the "extremely rarely occurring earthquake motion" specified in the Notification No. 1461.

The maximum response acceleration and the maximum drift at each floor are given in the following, (Figs. 3 and 4). The response acceleration distributes in a range from 300 to 700 gal. The maximum story drift angle is almost 1/200 or less, though it gives about 1/140 at the maximum in the Y direction at lower floors.

4.3 Evaluation of Functional Resiliency

(1) Evaluation of damage conditions

Degree of damages is evaluated for structural frame, exterior/interior, building equipment, lift facility, and medical equipment and devices. As of these, the medical equipment and devices were subjected to on-site sampling survey focusing on the fixing conditions, and confirmed 6 units of fixed-to-floor type, 21 units of direct-positioned (nonfixed) type, and 19 units of mobile type. If only the fixed type equipment and devices were designed according to the Design and Construction Guidelines of Building Equipments (2005) published by the Building Center of Japan, etc., they are judged not to induce sliding or falling at the response acceleration of this research. For the equipment and devices of direct-positioned type, the possibility of falling is calculated based on the equipment dimensions and the maximum response acceleration, (adding 0.30 of vertical seismic intensity), to give the possibility of falling of 17 units among 21 units. Therefore, the direct-positioned type equipment and devices and the mobile type equipment and devices presumably suffer damages. To estimate the amount of damages, there are needed materials relating to the characteristics and the purchased price of the equipment and devices, which materials are however difficult to obtain at present. Accordingly, the medical equipment and devices are limited to obtain the above damage estimation, and the expected amount of damages is left as an issue. Thus, the targets of the research are limited to the building and the building equipment. The damages of targets other than that of medical equipment and devices were evaluated based on the vibration analysis result, the report of damage survey, and the above literature. Responding to the degree of damage, the necessary restoration period was speculated. The result is given in Table 2.

(2) Estimated amount of damages

The fractional damages of building caused by earthquake, (the ratio of the restoration work cost for the damage to the initial investment), is calculated by the following equation.

$$L_T = \sum_i p_i \cdot L_i \qquad (1)$$

where L_i : the fractional damage at each position based on the vibration analysis result

p_i : the fraction of work cost at each position to the total work cost

Table 3 shows the breakdown of cost ratio for each work article at the initial construction. The table does not contain temporary work expenses and miscellaneous expenses.

The fractional damage (Li) corresponding to the degree of various damages for each article is defined corresponding to the five damage stages: large damage; medium damage; small damage; slight damage; and non-damage.

The values used in the damage evaluation are assumed as given in Table 4. From the above assumptions, the fractional damage is expected to:

$$L_T = 0.185 \times 0.200 + 0.078 \times 0.125 + 0.187 \times 0.010 + 0.366 \times 0.010 = 0.052 \qquad (2)$$

That is, the damage is determined to that of 5.2% of the initial investment. Based on the current building price level, if the total construction work (including miscellaneous expenses and temporary work expenses) is assumed to 2,114,000,000 yen, the restoration work cost is estimated to 109,900,000 yen.

(3) Period of restoration

As shown in Table 2, the restoration period can be determined mainly by the period for restoring the structural frame. The period of complete restoration of the hospital from the Niigata-Chuetsu Earthquake was slightly more than 5 months. The level of the earthquake under research is presumably lower than the level of the Niigata-Chuetsu Earthquake, thus the expected restoration period of 3.5 months is considered reasonable.

5. DATABASE FOR EVALUATING THE “FUNCTIONAL RESILIENCY”

The database developed in the project has a structure largely classifying the building elements, relating to “Functional Resiliency”, into four: (structural members, nonstructural members, equipment (including piping), and furniture). To obtain necessary data, individual positions are further grouped in detail, and the data relating to the following articles are collected for each of thus grouped in detail.

i) Engineering (response) quantity contributing to the damages
ii) Quantity of damages generated from a certain response, (specifically the damage relating to Reparability)
iii) Restoration method corresponding to the quantity of damage
iv) Cost and period for the restoration method
v) Period and cost of functional resilience taking into account the restoration cost and restoration period

Next, for structuring the database, the data of damage evaluation relating to the Reparability are collected from a vast amount of data, and thus collected data are reviewed to pick up the articles necessary for the “Functional Resiliency”. To this point, among the three stages of data, “Collection”, “Review”, and “Pick up”, the research conducts the “Review” by a work sheet, and the data reflecting the result of the “Pick up” are positioned to the “Database”, (refer to Fig. 5). The following is the description about the investigation method and the progress of the investigation relating to the database structuring for evaluating damages at each position.

5.1. Structural Members

In principle, the target data are those for damage evaluation, which satisfy the following two requirements.

i) The damage article which allows estimating the restoration period and cost shall be clearly given: for example, an RC member has the description of damage information about the quantity of cracks and the yield of reinforcing bars.

ii) The article which allows calculating stiffness (including stiffness reduction ratio) and proof stress shall be given: for example, there shall be described cross section, reinforcement arrangement, strength of applied material, and loading conditions (degree of end-fixation and loading history).

To prepare the work sheet, there is specifically necessary the information of damages required for the restoration. Furthermore, the degree of influence of the damages of structural members on the other positions and on the building functions will be considered.

5.2 Nonstructural Members

A questionnaire survey was conducted on manufacturers and suppliers of nonstructural members to collect data for the damage evaluation. The collected data are then arranged in the work sheet. In addition, investigation on papers, academic or related guidelines and standards is also conducted.

5.3 Equipment and Devices

Similar to the nonstructural members, a questionnaire survey is given to the related manufacturers to collect data relating to the damage evaluation, which collected data are then arranged in the work sheet. In addition, investigation on papers, academic guidelines and standards collected data are also conducted.

5.4 Furniture (Contents)

On the existing papers, guidelines and standards are reviewed to collect the data having clear indication of the input magnitude and the response value, which are then arranged in the work sheet.

6. OCCURRENCE OF EARTHQUAKE DAMAGE AND MEANS OF FUNCTIONAL RESILIENCE

According to the research articles, the object is to review the information relating to the building damages of earthquake and to the functional resilience after earthquake, and to investigate the preparation of explanation and expression tool to convey the information to general users in an understandable format.

In the first fiscal year of the research project, there was reviewed the expectedly occurring damages of earthquake and means of functional resilience on the examples of houses, hospitals, and offices. Since the functions required to buildings differ with the uses of buildings, the research assumed the three uses of buildings: houses, hospitals, and offices. Then the possible damages on earthquake and the means of functional resilience were reviewed. As the method of review, the damage phenomena were divided along the time axis into I (immediately after the earthquake), II (within several days after the earthquake), and III (afterward), and there were reviewed the influence of each phenomenon on the functions, the hardware measures, and the software measures including human actions. In addition, the software measures were further divided into the pre-measures applying before appearing the earthquake damages and the post-measures applying immediately after the earthquake.

6.1 Earthquake Damage of Houses and Means of Functional Resilience

The function requested for houses was determined as the maintaining of living, thus the recovery from the condition of difficulty in living after earthquake was determined as the functional resilience. Table 5 shows the generation of earthquake damages and outline of the means of functional resilience. The characteristics of houses include that the citizens suffered from earthquake are forced to live in an emergency evacuation area or temporary houses owing to the lack of substitute facilities, and that restoration cost becomes a heavy economical load. In the initial period of living in an emergency evacuation area, washroom is not available, and other damages of lifeline seriously affect the maintaining living

6.2 Earthquake damages in hospitals and means of functional resilience

The function requested to hospitals was determined as the continuity of medical activities, thus the recovery of medical activities was determined as the functional resilience. Table 6 shows the generation of earthquake damages and outline of the means of functional resilience. Since the assurance of life of patients and medical treatment take the priority, the characteristics of hospital include that transfer of patients to an emergency evacuation area or to other hospital is requested after the earthquake, and that, if dialysis patients exist, water stoppage becomes a critical problem. Furthermore, many of medical equipment and devices have casters, which need special care for the transfer under earthquake.

6.3 Earthquake Damage of Offices and Means of Functional Resilience

The function requested to offices was determined as the continuity of business, thus the recovery of the business was determined as the functional resilience. Table 7 shows the generation of earthquake damages and outline of the means of functional resilience. The features of office buildings include that substitute facilities for the head office building and the branch building are relatively easily available. Consequently, it is important that, as the preliminary measures, the Business Continuity Plan (BCP) in disaster is prepared assuming the use of substitute facilities. Since many kinds of business rely on computers, it is necessary to secure the earthquake resistance of computer facilities and to attain early restoration.

7. CONCLUSION

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

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

8. ACKNOWLEDGEMENT

This research was conducted as a part of “Development of Performance-Based Structural Design System for Evaluating Continuity and/or Resiliency of Building Function after Disasters”” of a research subject of BRI, (Chairman: Dr. Hitoshi Shiobara, Associate Professor of the University of Tokyo). We would like to express our appreciation to the related persons and organizations.

(a) Full view of the building (RC rigid joint structure)

(b) Shearing fracture and damage of pillar

(c) Damage of beams and joints of pillar with beam

Photo 1 Building designed in accordance with the New Earthquake Resistance Standards: Seriously damaged by the Southern Hyogo Earthquake in 2005, though not collapsed

Photo 2 Crack damage of nonstructural wall of corridor of a condominium by the West-Off Fukuoka Earthquake in 2005

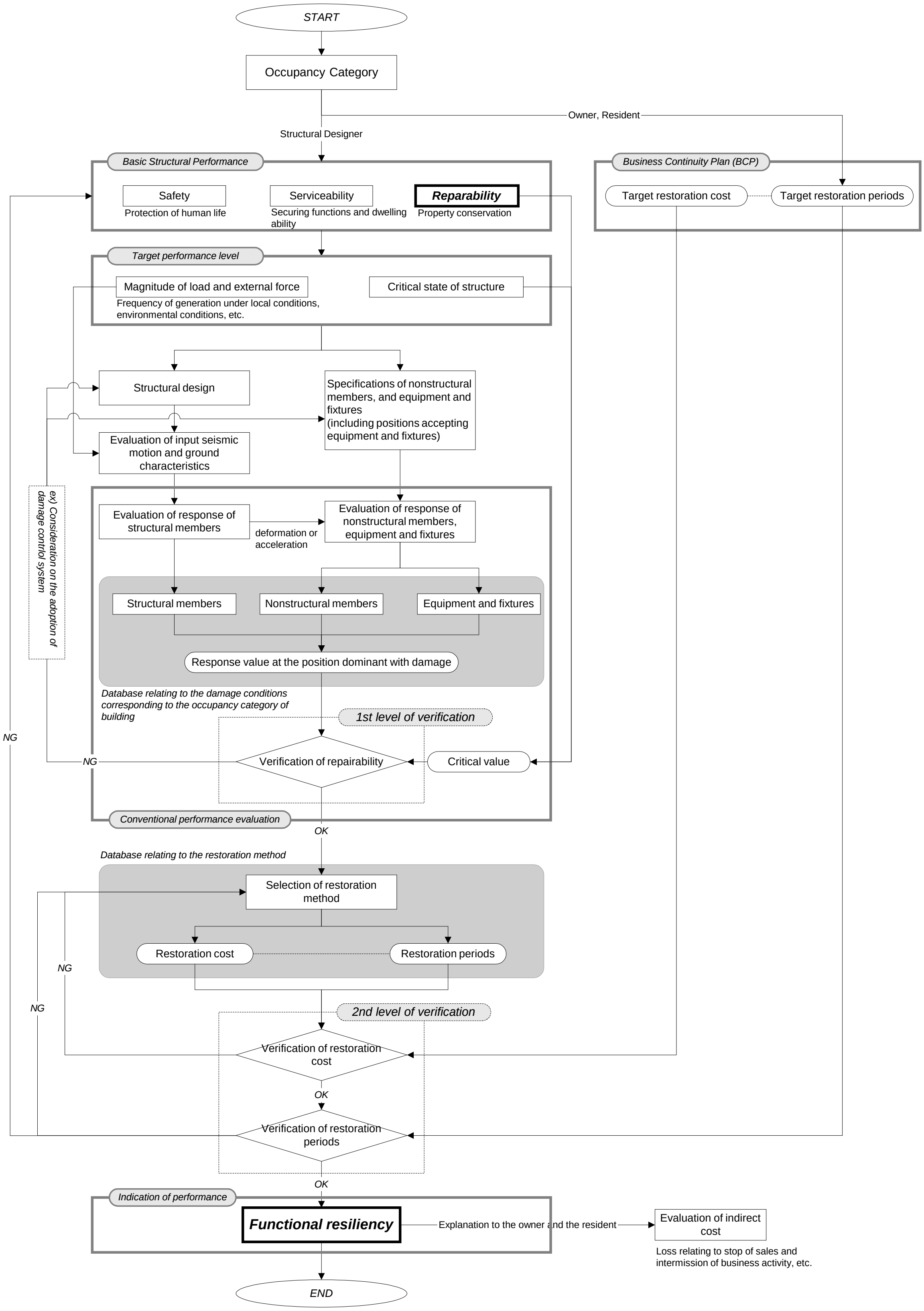

Figure 1 Design verification flow scheme based on the “Functional Resiliency”

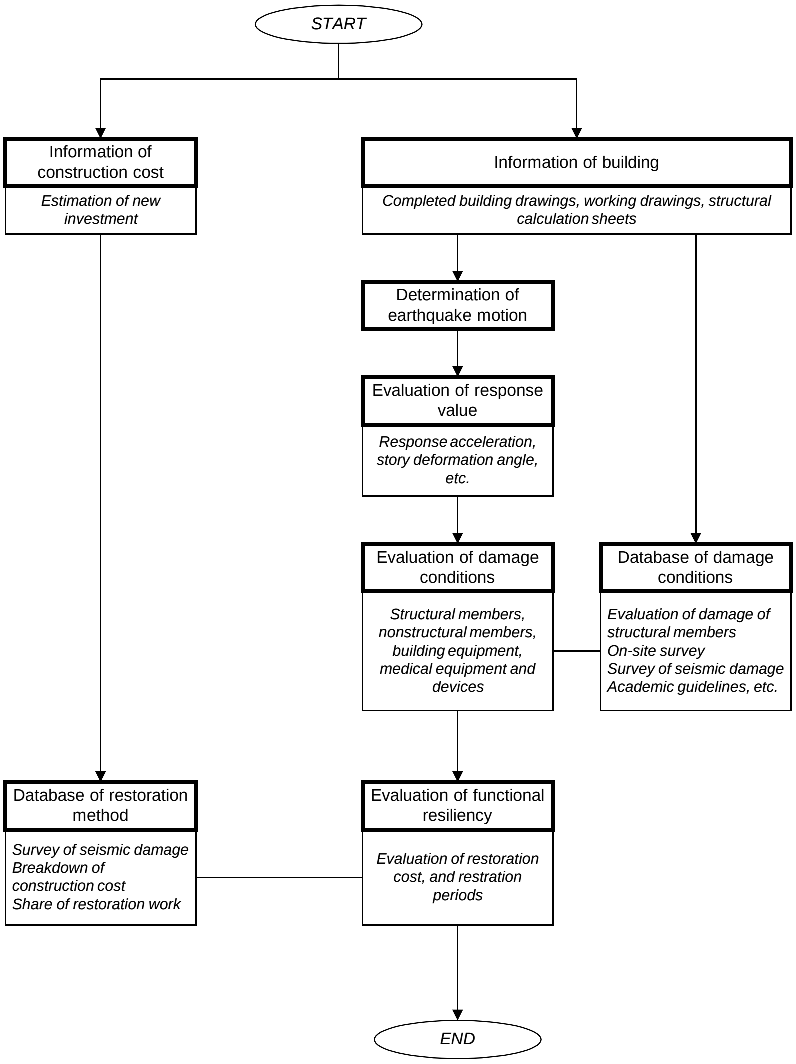

Figure 2 Evaluation flow diagram

Table 1 Outline of building

Time of construction	September, 1980
Scale	1st and 2nd basements and 1st to 8th floors, with a penthouse
Total floor area	7,974m^2
Structure	SRC (from 2nd basement to 3rd floor), RC (from 4th floor to penthouse)
Foundation structure	Direct foundation

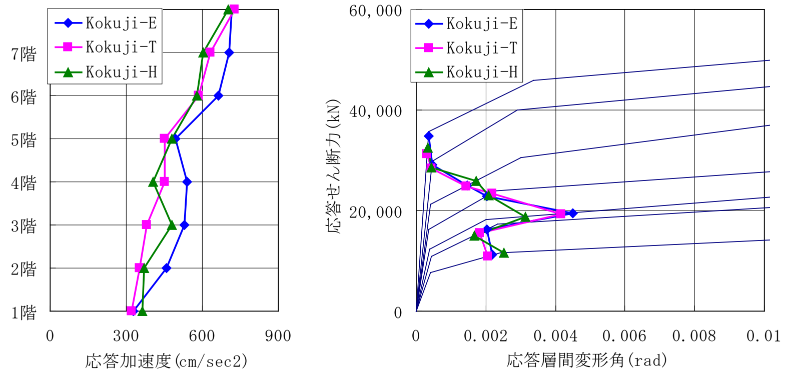

Figure 3 Result of time history response analysis (X direction)

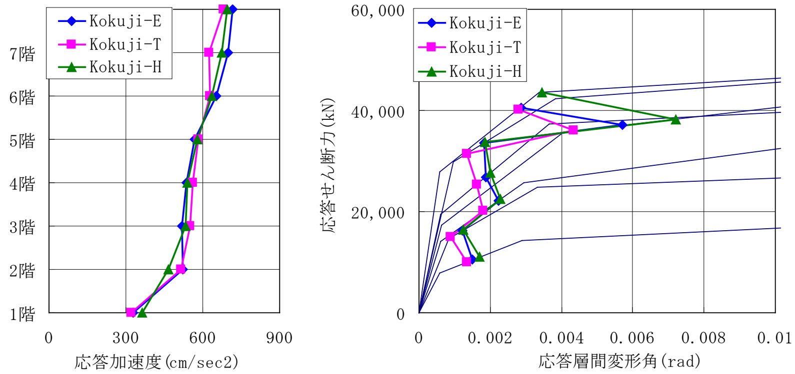

Figure 4 Result of time history response analysis (Y direction)

Table 2 Evaluation of damage condition

Position	Damage evaluation	Restoration work period
Structural frame	Medium damage	within 3 months
Exterior non-structural member	Small damage – Medium damage	within 3 weeks
Interior non-structural member	Slight damage	within 3 days
Air conditioning and hygiene equipment	Slight damage	within 3 days
Electric equipment	Non-damage	
Lift equipment	Non-damage	

Table 3 Breakdown of construction work

Work article	Share of work cost, p_i
Structural member	0.185
Exterior non-structural member	0.078
Interior non-structural member	0.187
Air conditioning and hygiene equipment	0.366
Electric equipment	0.160
Lift equipment	0.023
Total	1.000

Table 4 Fractional damage of each position responding to the degree of damage

Position	Degree of damage				
	Large damage	Medium damage	Small damage	Slight damage	Non-damage
Structural member	0.50	0.20	0.05	0.02	0.00
Exterior non-structural member	0.50	0.20	0.05	0.01	0.00
Interior non-structural member	0.50	0.20	0.05	0.01	0.00
Air conditioning and hygiene equipment	0.50	0.20	0.05	0.01	0.00
Electric equipment	0.50	0.20	0.05	0.01	0.00
Lift equipment	0.50	0.20	0.05	0.01	0.0

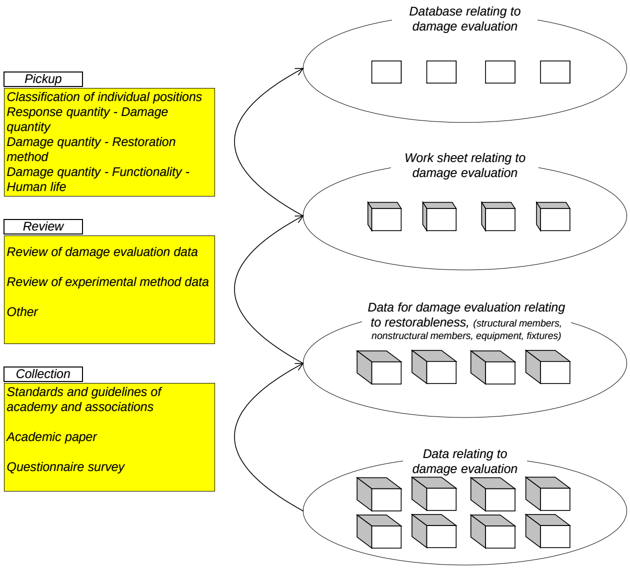

Figure 5 Method for developing structuring database

Table 5 Earthquake-induced damage and means of functional resilience (Houses)

Phase	Damage phenomena	Influence on functions	Hardware measures	Software measures (preliminary action)	Software measures (after earthquake)
I	Collapse, half collapse, part damage of building	Occurrence of killed and injured citizens	Increase in the earthquake resistance of building	Diagnosis of earthquake resistance of building	Confirmation of safety of family Rescue operation
	Difficult for opening/closing door	Interference with evacuation	Making door earthquake resistant		
	Falling and dropping of furniture and fixtures	Injury by direct earthquake attack Interference with evacuation	Fixation and support of furniture and fixtures	Room safety check	
	Electric power failure	Interference with collecting information Inconvenience in living (especially at night)		Preparation of portable radio Preparation of flashlight and candle	
	Stop of lift	Interference with evacuation			Request for restoration of lift
I - II	Water stoppage, gas stoppage	Inconvenience in living (drinking water, toilet, face wash, bath)		Storing drinking water Storing water for toilet	
II	Unserviceable building	Poor living condition			Moving to an emergency evacuation area
	Fire	Occurrence of killed and injured citizens	Increase in the fire proof of building		Fire fighting
III	Worsened living environment	Psychological stress			Psychological care
	Elongation of period of living in an emergency evacuation area	Psychological stress			Moving to temporary houses
	Poor economical condition	Delay of building restoration		Joining earthquake insurance	Contribution, emergency aid

Table 6 Earthquake-induced damage and means of functional resilience (Hospitals)

Phase	Damage phenomena	Influence on functions	Hardware measures	Software measures (preliminary action)	Software measures (after earthquake)
I	Collapse, half collapse, part damage of building	Occurrence of killed and injured citizens	Increase in the earthquake resistance of building	Diagnosis of earthquake resistance of building	Confirmation of safety of patients and staffs Rescue operation
	Falling medical equipment and devices, etc. Break of glass	Injury by direct earthquake attack Interference with evacuation	Fixation and support of medical equipment and devices	Room safety check	Guiding evacuation of inpatients
	Stop of lift	Interference with evacuation		Acceptance of seriously ill patients at lower floors	Guiding evacuation through emergency staircases
	Electric power failure	Stopping functioning of medical equipment and devices Deletion of computer data Inconvenience in living (especially at night)	Securing emergency power source	Backup of data	
I - II	Water stoppage	Inconvenience in living (drinking water, toilet, face wash, bath) Interference with medical treatment (dialysis patients)	Securing emergency water source (groundwater, etc.)	Storing daily life water	Use of water tank trucks Moving patients to other hospitals
II	Unserviceable building	Stopping medical treatment activities	Preparation of temporary tents		Emergency medical treatment at temporary tents
	Increase in the number of sufferers	Stagnant medical treatment activities Shortage of acceptance area		Structuring network with other hospitals	Gathering staffs Request for other hospitals to accept patients
	Shortage of drugs and medicines		Cool storage of drugs and medicines	Securing drugs and medicines which can be stored in cool space	
III	Worsening hospital environment	Stress of patients			Psychological care for patients
	Lump of waste	Hygienic problems		Establishing cooperation scheme with local government	

Table 7 Earthquake-induced damage and means of functional resilience (Offices)

Phase	Damage phenomena	Influence on functions	Hardware measures	Software measures (preliminary action)	Software measures (after earthquake)
I	Collapse, half collapse, part damage of building	Occurrence of killed and injured citizens	Increase in the earthquake resistance of building	Preparation of BCP, Diagnosis of earthquake resistance of building	Confirmation of safety of staffs Rescue operation
	Drop of ceiling Break and scattering of window glass Difficult for opening/closing door Damage of sprinkler	Injury by direct earthquake attack Injury of passers-by Interference with evacuation Fire extinguishing unavailable	Preventive measure against falling of ceiling Protective film against scattering of glass Making door earthquake resistant Making equipment earthquake resistant		
	Moving and falling of heavy equipment such as copying machine	Injury by direct earthquake attack	Fixation and support of equipment	Room safety check	
	Failure of computer network	Stopping communication, deletion of data	Making computers seismic isolation	Backup of data	Request for restoration of network
	Stop of lift	Interference with evacuation			Evacuation through emergency staircases Request for restoration of lift
	Electric power failure	Deletion of computer data	Securing emergency power source		
I - II	Water stoppage	Inconvenience in living (drinking water, toilet, face wash, bath) Interference with medical treatment (dialysis patients)	Securing emergency water source (groundwater, etc.)	Storing daily life water	Use of water tank trucks Moving patients to other hospitals
II	Unserviceable building	Stopping sales activity	Securing substitute facilities	Preparation of BCP	Continuation of sales activity at substitute facilities

I: immediately after the earthquake
II: within several days after the earthquake
III: afterward