Toward Improvement of the Seismic Resilience Performance of RC Structures

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1. Introduction

First, I would like to express my heartfelt condolences to all those who lost family members or loved one in the 2024 Noto Peninsula Earthquake.

This earthquake damaged approximately 99,000 structures in the three prefectures of Niigata, Toyama and Ishikawa (as of February 14, 2024). The majority of the damaged structures were wood-frame houses, but overturning, tilting and other damage were also seen in reinforced concrete (RC) structures.

When victims are forced to live as evacuees due to building damage, their quality of life is reduced, and disaster-related deaths are possible. For this reason, the Building Department is conducting research on improvement of “seismic resilience performance” from the viewpoint of the structural performance of RC structures to enable continuing use, even in the event of a large-scale earthquake. This report presents an overview of those efforts.

2. Damage of RC Structures in 2024 Noto Peninsula Earthquake

An RC structure with 7 above-ground stories in Wajima City overturned in the 2024 Noto Peninsula Earthquake (**Photo 1**). The Building Dept. conducted a damage survey of the RC structures in Wajima, including this building (Jan. 10, 2024) [1]. As a result, no conspicuous damage was seen in the superstructures of multistory RC structures, but tilting of entire buildings was observed. Therefore, we set up a joint expert committee with the Housing Bureau to analyze the causes of structural damage of buildings and study directions for countermeasures based on the results [2].

Photo 1 Overturned RC building
(photographed from south side)

3. Framework for Evaluation of Seismic Resilience Performance

The framework for evaluation of seismic resilience performance is shown in **Fig. 1**. To enhance seismic resilience performance, first, it is necessary to encourage widespread adoption of buildings that secure earthquake-resistance performance, i.e., buildings that are damage-resistant and can easily be restored to use (in Fig. 1, reduce ① “Degree of functional decline” and shorten ③ “Recovery time”), and second, establish a method for quickly judging the continuing usability of buildings after an earthquake (shorten ② “Delay time.”)

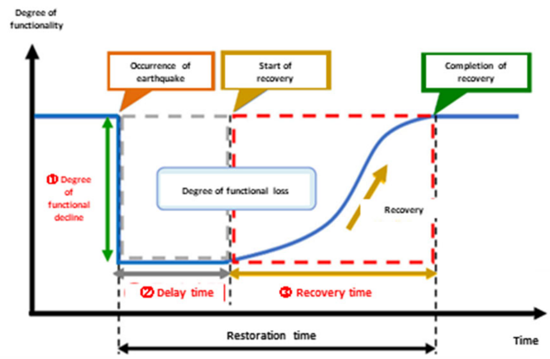


Fig. 1 Framework for evaluation of seismic resilience performance
(conceptual diagram of degree of functional loss in a disaster)

4. Development of Method for Evaluation of Seismic Resilience Performance

(1) Development of evaluation method for degree of damage in large-scale earthquake

From the viewpoint of structural performance, the most important factor which makes continuing use difficult when an earthquake occurs is serious damage of the structural skeleton. Even if a building avoided collapse or overturning, there are cases where the building was demolished owing to extremely severe damage of its beam-column joints.

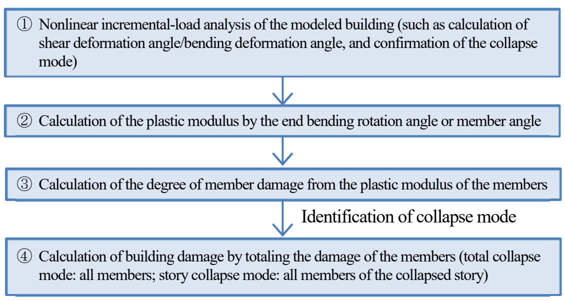


Fig. 2 Procedure for calculation and evaluation of building damage degree in an earthquake

Therefore, we will develop a technique for evaluating the damage of buildings assumed in a large-scale earthquake at the time of design (large-scale earthquake: earthquake that occurs extremely rarely (on the order of once in several hundred years)). Focusing on "damage" for judgment of the classification of the degree of damage, an evaluation by the procedure shown in **Fig. 2** is assumed [3], and the results will be made available as a "Damage evaluation Web program."

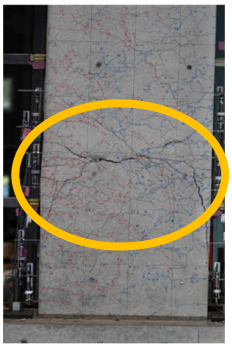
(2) Evaluation of the allowable degree of damage

In order to evaluate the allowable degree of damage related to seismic resilience performance, the Building Dept. is performing loading tests of techniques that are considered promising for damage mitigation and collecting data on damage properties, etc. The following **Table** shows ① Hinge relocation beam (technique in which the amount of main reinforcement of beam-column joints is increased, and the damage point is controlled to the central part of the beam; hereinafter, "HRC beam") and ② Unbonded precast prestressed concrete beam (technique in which damage is reduced by passing PC steel material through precast column-beam members and unifying the members by forming a prestressed joint by the tension of the PC steel; hereinafter, PcaPC beam). The following presents an example of the results of a loading test of the PcaPC beam (distortion angle: 1/50, 2nd cycle, negative side loading/unloading).

The HRC beam could control the damage position (plastic hinge). However, since the damage in that position was very large, it was found that a quite large reduction of deformation (horizontal displacement) was necessary in order to ensure seismic resilience. It was also found that the P_CaPC beam was effective in controlling cracking of the tensioning system, but damage of the compressive system occurred instead.

Based on the damage characteristics identified in these loading tests, in the future, we plan to clarify the distortion angle needed to keep beam damage within the allowable range and study the degree of repairability corresponding to the damage characteristics.

Table Examples of results of loading tests of beams for RC structures

①HRC beam	② PcaPC beam
	
The damage position is controlled. However, the concentration of damage in the central part of the beam is severe.	Damage of the compressive system (concrete flaking) occurred.

5. Development of Method for Quick Judgment for Continuity of Use

To expand continuing use of buildings when a large-scale earthquake occurs, quick judgment for the continuity of use (integrity) of the damaged structures is demanded. Therefore, we are working to develop a quick and highly accurate judgment method utilizing positioning satellite data.

Fig. 3 shows an overview of the development. The aim is to develop ① a system that can directly measure the horizontal displacement of buildings during and after an earthquake by acquiring positioning satellite data at the building rooftop floor and ground surface, and combining it with seismographs installed in buildings, and ② a system that enables judgment of the degree of damage, etc. of buildings from a remote location based on the measured horizontal displacement.

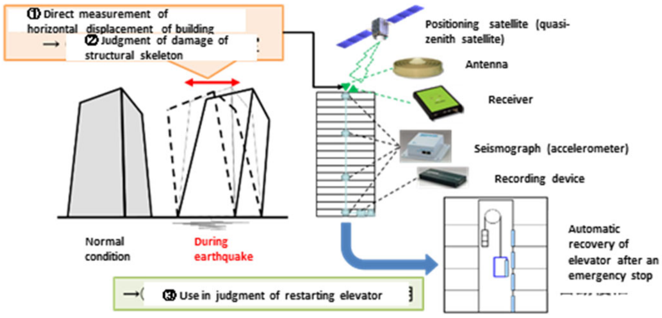


Fig. 3 Overview of development of quick judgment method for continuity of use of damaged structures utilizing positioning satellite data

6. Conclusion

Securing seismic resilience performance in large-scale earthquakes has become an important issue in the building earthquake-resistance field. While clarifying the causes of damage to RC structures in the 2024 Noto Peninsula Earthquake, the Building Dept. hopes to contribute to mitigating damage of buildings in large-scale earthquakes and speeding up post-disaster recovery through continuing research toward improvement of seismic resilience performance and social implementation of the results.

☞For more information

1) "Report of site survey of foundation and ground damage of structures by the 2024 Noto Peninsula Earthquake (bulletin)"
https://www.nilim.go.jp/lab/bbg/saigai/R5/notojishin04.pdf

2) Objects of study by the committee include wood-frame structures, etc. in addition to RC structures.
"Meeting of committee to analyze causes of building structural damage in 2024 Noto Peninsula Earthquake"
https://www.nilim.go.jp/lab/bcg/kisya/journal/kisya20240209.pdf

3) "Development of Method for Evaluating the Continuing Usability of RC Structures after a Large-Scale Earthquake," pp. ____