DEVELOPMENT OF RESILIENT REINFORCED CONCRETE BUILDING STRUCTURE

Seitaro Tajiri, Hiroshi Fukuyama, Tomohisa Mukai
Building Research Institute

Toshikazu Kabeyasawa
The National Institute for Land and Infrastructure Management
Introduction

Targets of current earthquake resistant standards

(1) A building should be resilient in the case of a moderate earthquake, and its restoration should not be particularly required.

(2) A building should not collapse and human life should be secured in the case of a great earthquake.
Great Hanshin-Awaji Earthquake in 1995

Many buildings avoided collapse and saved people’s lives as required by the law

- Dwelling functions were lost.
- Restoration costs were so expensive that these buildings were demolished and rebuilt.
Mid Niigata Prefecture Earthquake in 2004

• A lot of semiconductor factory production facilities were damaged.
  -> The other companies which the factories had provided products suffer the impact.

• In hospitals, there arose a situation where medical operation could not continue due to the damage to facilities and equipment.

Niigataken Chuetsu-oki Earthquake in 2007

• A precision instrument factory for car engines was damaged.
  -> Domestic motorcar manufacturers were forced to stop all their production lines.
The 2011 Great East Japan Earthquake

- Government buildings, which should have become on-site countermeasure centers, were damaged.
- Gymnasiums expected to be used as evacuation sites were damaged.
- Apartment houses were so badly damaged that the dwelling functions were lost.
"How to ensure the resiliency of a building after an earthquake" and "How to promptly restore functions deteriorated by an earthquake" have been strongly required.

**Requirements from the society**
Buildings should be resilient and usable enough in the case of a great earthquake.

**Requirements by the law**
Not collapsing and protecting human lives

Major gap
Most RC buildings, which have nonstructural walls separated from the adjacent beams and columns with structural slits, are designed as ductile type.

-> The deformation or the damage will be large.
The proposed structure aims to reduce its damage or deformation with increasing strength and rigidity.

- Reinforced concrete structure
- Nonstructural walls are integrated with the adjacent beams and columns without setting slits.
- These walls also have adequate thickness and reinforcement like a structural wall in order to increase strength and ductility.
- Construction will be easier than the conventional.

Proposed Resilient Structure
Comparison with Conventional and Proposed

The strength of the specimen without slits showed more than twice as high as those with slits.
Types of Proposed Structures

High Strength
High Rigidity

[Proposal 2] Frame with wall
Strength: $D_s > 0.55$
Deformation: $R < 1/200$

[Proposal 1] Wing-wall Frame
Strength: $D_s > 0.40$
Deformation: $R < 1/100$

Conventional Frame (3-way slit)
Strength: $D_s > 0.30$
Large Deformation

Design to prevent damage is needed.
Slits are arranged leaving wing-walls on columns.
Non-structural walls are detached from a frame.
Damage grows
# Feasibility Study of Proposed Structure

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Shape</td>
<td>2x1 Span, 5 Stories</td>
</tr>
<tr>
<td>Span</td>
<td>6.0 m</td>
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<tr>
<td>Story Height</td>
<td>3.5 m</td>
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<tr>
<td>Concrete</td>
<td>30 N/mm$^2$</td>
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<tr>
<td>Column Section</td>
<td>700x700 mm</td>
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<tr>
<td>Column Main Reinforcement</td>
<td>16-D25 (SD345)</td>
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<tr>
<td>Beam Section</td>
<td>500x700 mm</td>
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<tr>
<td>Beam Main Reinforcement</td>
<td>6-D25 (SD345) (5F and RF), 8-D25 (SD345) (2-4F)</td>
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<tr>
<td>Wall Thickness</td>
<td>200 mm</td>
</tr>
<tr>
<td>Wall Vertical and Horizontal Reinforcement</td>
<td>D10@200 double (SD295)</td>
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<tr>
<td>End Reinforcing Bar</td>
<td>4-D13 (SD295)</td>
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<tr>
<td>Slab Thickness</td>
<td>200 mm</td>
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<tr>
<td>Slab Bar Arrangement</td>
<td>D10@150 double (S295)</td>
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<tr>
<td>Wing-Wall Length</td>
<td>700 mm</td>
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<tr>
<td>Opening 1</td>
<td>2000×1800 mm</td>
</tr>
<tr>
<td>Opening 2</td>
<td>1000×1800 mm</td>
</tr>
</tbody>
</table>

(a) Plan

(b) Elevation
Pushover Curves and Responses

(a) The 3-way slit frame

Maximum Story Drift: 1/64 rad.

C₀ = 0.3

(b) The column with wing-wall moment frame

C₀ = 0.45

Maximum Story Drift: 1/118 rad.

(c) The frame with wall

Maximum Story Drift: 1/254 rad.

C₀ = 0.55
Beam and Column with Nonstructural Walls

- It is necessary to develop member models which define beams and columns with nonstructural walls for structural designs.

  -> Experimental study to clarify structural properties of beams and columns with nonstructural walls.

A column with side-walls

A beam with side, hanging and standing walls
Frame with Nonstructural Walls

• It is necessary to decide rigid zones at the end of a beam and at the end of a column.
• In the case that a mullion-wall is attached, it is necessary to consider its influence.

-> Experimental study to evaluate the structural properties of frames with nonstructural walls.
Full-scale Test

Five-story full-scale test will be conducted soon.
Concluding Remarks

• The damage which cause the loss of building’s functions was shown in recent earthquakes.

• “How to ensure the resiliency of a building” and “How to promptly restore” have been strongly required.

• The RC structure which has thick nonstructural walls integrated with columns and beams is proposed for a resilient building. Its damage or deformation is expected to be lower than those of the conventional.

• The progress of research to achieve the practical use of the proposed structures was introduced.