An Overview for Practicing Engineers

SEISMIC REHAB OF RC STRUCTURES

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Of my two alternative proposals, namely,
- A report on recent scientific research or
- An overview for practicing engineers,
the latter was preferred. Thus,

In this talk, existing information will be presented in a classified manner.

Nothing sophisticated, nothing impressive...
OUTLINE

- Introduction
- Rehabilitation Strategy
- Rehabilitation Technologies
- OFR—Occupant Friendly Rehabilitation (if time allows)
- Concluding Remark
INTRODUCTION
INTRODUCTION

Earthquake is a natural phenomenon

- It is **tolerable** in countries where people and built environment are prepared for it;
- It leads to a **disaster** in countries where built environment is not prepared for it and people just wait and do nothing.
INTRODUCTION

Earthquake Preparedness consists of

- **Disaster Management** (post-quake) – Search & rescue, sheltering, food, medical care etc. *(Tip of the iceberg, easy but ineffective)*

- **Risk Management** (pre-quake) – Safe towns, safe structures, well educated public, well trained engineers, effective financing etc. *(Body of the iceberg, hard but very effective)*
Risk Mitigation is a multi-dimensional activity having various aspects such as,

- Earth sciences
- **Civil engineering**
- Educational
- Psychological
- Financial
- Legislative
- Urban planning
- Environmental
- Social
- Administrative
- Economic
- Political etc.
INTRODUCTION

- A huge seismically unsafe building stock
- A systematic assessment will reveal that
  - A small number seismically safe,
  - A certain portion to be demolished,
  - The majority to be rehabilitated. So,
- **Seismic rehabilitation is one of the most critical aspects of risk mitigation.**
INTRODUCTION

Risk mitigation unavoidably requires

- A well defined Damage Mitigation Strategy
- A realistic and well organised Action Plan
- A consistent and insistent implementation for decades
- And plenty of political will
REHAB STRATEGY
Development of an efficient rehabilitation strategy requires careful considerations of
- Common deficiencies observed;
- Performance levels to aim at;
- Rehab technologies available.
Common Deficiencies
COMMON DEFICIENCIES

RC framed building structures with hollow brick masonry infill are common in SEE.

- **Low-rise** (1~2 floor) are not vulnerable;
- **High-rise** (> 10~12 floor) buildings are carefully designed and constructed;
- **Mid-rise** (3~8 floor) bldgs of inferior material, design & construction quality are a problem.
COMMON DEFICIENCIES

Mid-rise buildings of inferior quality

- Constitute the majority in small towns;
- Collapse in the pancake mode; thus
- Are responsible for the high number of human losses and severe damage,
- Are generally too good for demolition;
- Are greatly in need of rehabilitation.
COMMON DEFICIENCIES

Common deficiencies of such buildings:

- Insufficient lateral stiffness

- Deficient reinforcement detailing
  - Insufficient confinement & anchorage
  - Inadequate joint reinforcement etc.

- Deficient design practice
  - Horizontal/vertical irregularities
  - Short columns; soft storeys etc.

- Poor concrete; poor workmanship etc.
Performance Levels
PERFORMANCE LEVELS

Generally accepted performance levels:

- **Functional** – Slight or no damage *(in the code earthquake)*; continued serviceability
- **Immediate occupancy** – Light damage; serviceability after inspection
- **Life safety** – Moderate damage
- **Collapse prevention** – Severe damage, no collapse, no casualties
PERFORMANCE LEVELS

Most of the current seismic codes

- Were developed for new structures;
- Aim at a performance level above life safety without explicitly mentioning;
- Apply to repair and strengthening besides new construction;
- No flexibility for “performance level” and “remaining service life” considerations.
PERFORMANCE LEVELS

- Special code provisions are needed for rehabilitation providing flexibility for
  - **Performance level** and
  - **Remaining service life** considerations.

- Designer should be given the choice of
  - **Life safety** or **collapse prevention**
  - **20 or 40 or >60 yrs** service life.
Rehab Technologies
Available
Member strengthening techniques are available for

- **Columns** (axial load & bending)
- **Beams** (bending & shear)
- **Beam-column joints** (shear)
- **Slabs** (diaphragm action)
REHAB TECHNOLOGY

System behaviour improvement techniques are also available

- **Lateral stiffness** increasing elements
  *(To relieve members from seismic effects)*

- **Base isolation**, dampers etc.
  *(To minimise seis action transfer to structure)*
Rehab Strategy
Proposed
REHAB STRATEGY

- **Member strengthening is preferred** when
  - Structural weakness is localised or
  - A small number of members are deficient.

- **Member strengthening is not feasible** when
  - Deficiencies are widespread and
  - Lateral stiffness is insufficient
REHAB STRATEGY

Considering common deficiencies above, a sensible strategy can be formulated as;

- **System behaviour improvement is essential** and should be accompanied by

- **Strengthening of a limited number of deficient members**
REHAB TECHNOLOGIES
CLASSIFIED
System Improvement Techniques
Lateral stiffness increasing elements such as:
- Cast-in-place reinf conc infilled frames
- Steel cross bracing
- Post tensioning
- External rigid frame to support the structure
- Masonry infills converted to shear walls
Member Strengthening Techniques
COLUMNS STRENGTHENING

Reinforced concrete jacketing

- **Effective for axial load**, but complicated and not recommended for bending
- Full jacket is best, partial is acceptable
- Well confinement in jacket is essential
- Bar welding is recommended
COLUMN STRENGTHENING

Steel jacketing

- Only for axial load, never for bending
- Tight connection with base plates and
- Well confinement are essential
COLUMN STRENGTHENING

CFRP confinement

- Effective as confinement especially in circular columns; to a lesser extent in rectangular ones
- Effective to improve lap splice performance and capacity
BEAM STRENGTHENING

Additional layers with new steel

- Effective for bending
- Bar development is critical
- Welding is advisable
- Stirrups or Z-bars are essential
- CFRP applications to the same effect are also possible.
External clamps as shear reinforcement

- Effective for shear
- Limited prestressing is recommended
- CFRP applications to the same effect are also possible.
BEAM STRENGTHENING

Beams connected to new lateral stiffness elements become “coupling beams” and receive enormous bending and shear.

- **Hinging is unavoidable.** Make sure,
  - It is properly confined to tolerate hinging,
  - Shear capacity is higher than bending cap.
JOINT STRENGTHENING

Joints are critical under seismic action, and they are generally deficient

*(Required confinement is not usually provided)*

- Effective and practical strengthening techniques are not yet available
  *(Suggestions are ineffective or impractical)*.

- Another reason to endorse the system behaviour improvement approach
SLAB STRENGTHENING

Major contribution of the slab to the seismic performance is diaphragm action.

Additional layers with new steel

- Effective for bending & in-plane stress
- Rough connection surface and
- Shear connectors are essential
- Deformation recovery is not recommended
OCCUPANT FRIENDLY REHABILITATION
BASIC QUESTION

- Cast-in-place RC infilled frame technique is suitable for post-quake repair of the evacuated buildings;

- But it is not suitable for pre-quake rehabilitation of the buildings still in use.

- Suitable techniques should be developed.
THE CHALLENGE

To develop a rehabilitation method,

- Suitable for the common local building type (Hollow brick infilled RC frame)
- Practical & economical, and above all
- **Occupant friendly** (*no more disturbance than an ordinary painting job*)
The answer is OFR (occupant friendly rehab)

- To reinforce existing masonry infill wall with epoxy bonded PC panels, which are,
  - Light enough to be handled by two men
  - Relatively thin, 40~50 mm (high strength)
  - Connected to infill wall by epoxy, and to frame by epoxy bonded dowels
THE IDEA

- Cast-in-place reinforced concrete infill is known to improve the seismic structural performance.

- Why shouldn’t PC panel reinforced masonry infill do the same?
TEST FRAMES

- 1/3 scale, one-bay, two-storey inferior quality RC frames, 
  *(representing the actual practice)*
  - Strong beam-weak column
  - Insufficient confinement
  - Low quality concrete (C13~C16)
REFERENCE
STRENGTHENED (SQUARE)
STRENGTHENED (STRIP)
STRENGTHENED (SQUARE)
STRENGTHENED (STRIP)
<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>Relative to masonry infilled frame</th>
<th>Relative to bare frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral load capacity</td>
<td>~2.5 times</td>
<td>~15 times</td>
</tr>
<tr>
<td>Lateral stiffness</td>
<td>~3 times</td>
<td>~20 times</td>
</tr>
<tr>
<td>Ductility</td>
<td>~2 times</td>
<td>~0.2 times</td>
</tr>
<tr>
<td>Energy dissipation</td>
<td>~3 times</td>
<td>~60 times</td>
</tr>
</tbody>
</table>
INTERPRETATION

Significantly improved performance:

- Increased load carrying capacity
- Increased initial & final stiffness
- Delayed strength degradation
- Decelerated stiffness degradation
- Better ductility
- Much higher energy dissipation
CONCLUSION

PC panel technique is an effective & practical seis rehab method for existing buildings.

- Leads to a significant improvement in seismic performance
- Is easily applied to buildings in use with minimal disturbance
- Is cost effective

(Comparable to cast-in-place RC infills)
CONCLUDING REMARK
A REGRET

The speaker regrets

- For not being able to present the manuscript of this talk to be included in the proceedings.
- He was unable to finalise the manuscript in the “8 days” he was given by the authorities.

Lazy old man!..
THANKS for your attention...
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