“Seismic Design and Rehabilitation of Buildings” Conference, Tbilisi, May 31, 2014

An Overview for Practicing Engineers

SEISMIC REHAB OF RC STRUCTURES

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FOREWORD

- 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)*

INTRODUCTION

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

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** (3~8floor) 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 from 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

REHAB TECHNOLOGY

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

SYSTEM IMPROVEMENT

Lateral stiffness increasing elements such as

- Cast-in-place **reinf conc infilled** frames
- Steel **cross bracing**
- **Post tensioning**
- **External rigid frame** to support the str
- **Masonry infills converted to shear walls**

Member Strengthening Techniques

COLUMN 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.

BEAM STRENGTHENING

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 CHALLANGE

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

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

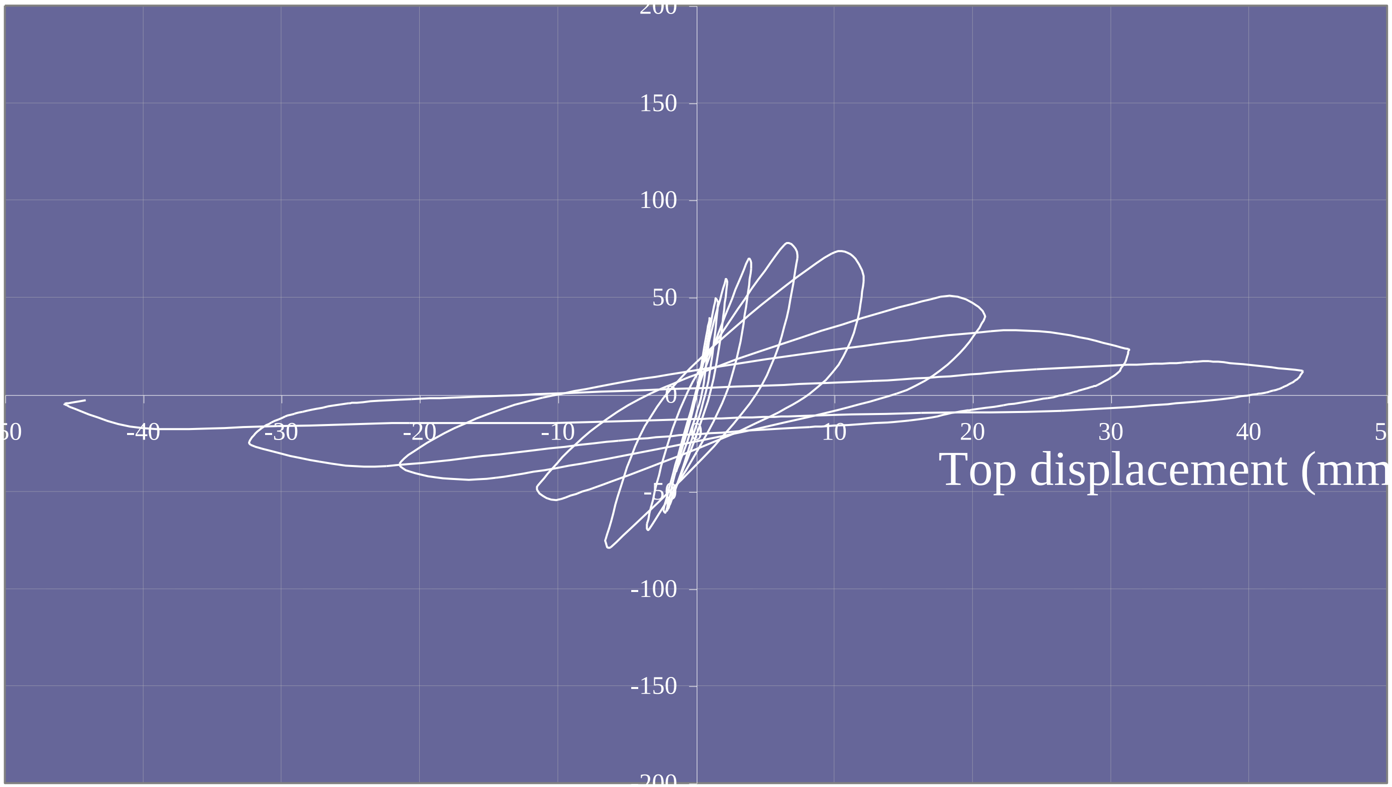
THE IDEA

- 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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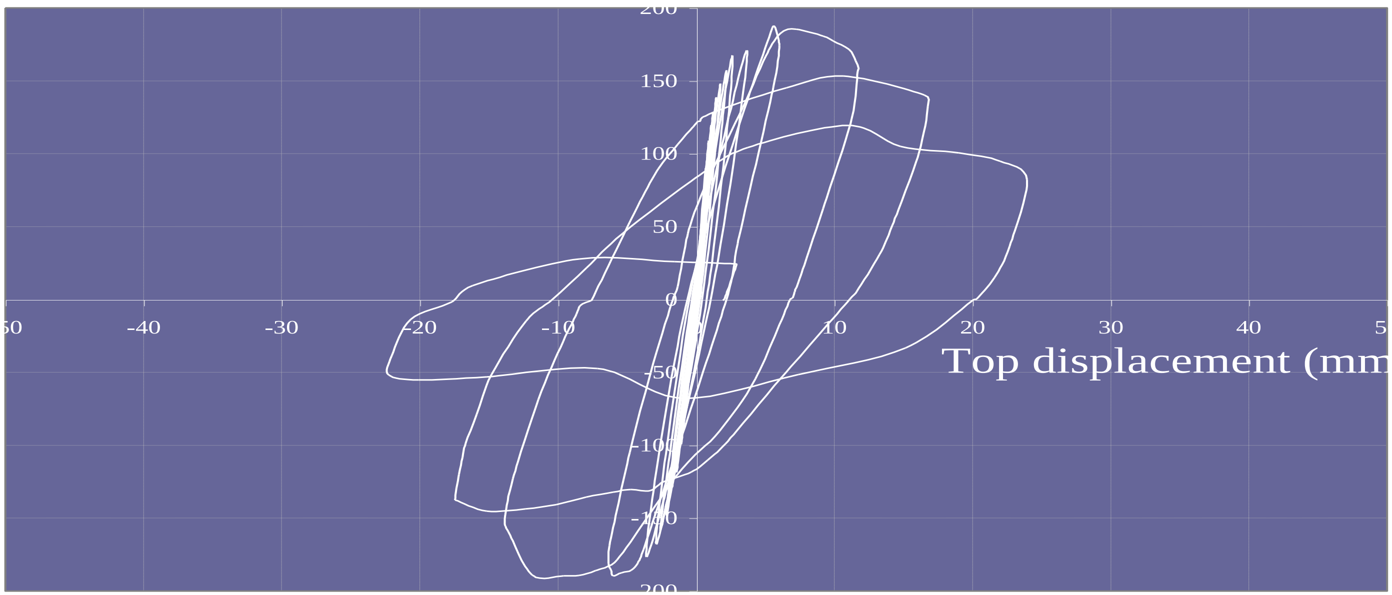
Top displacement (mm

STRENGTHENED (SQUARE)



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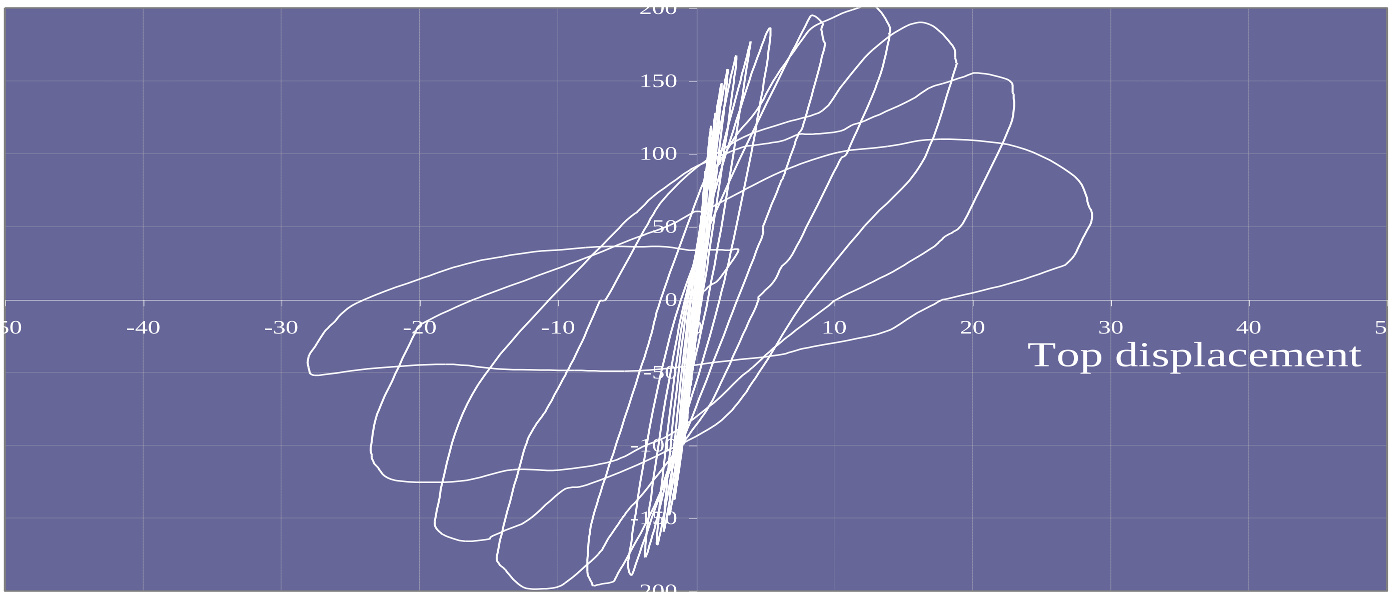

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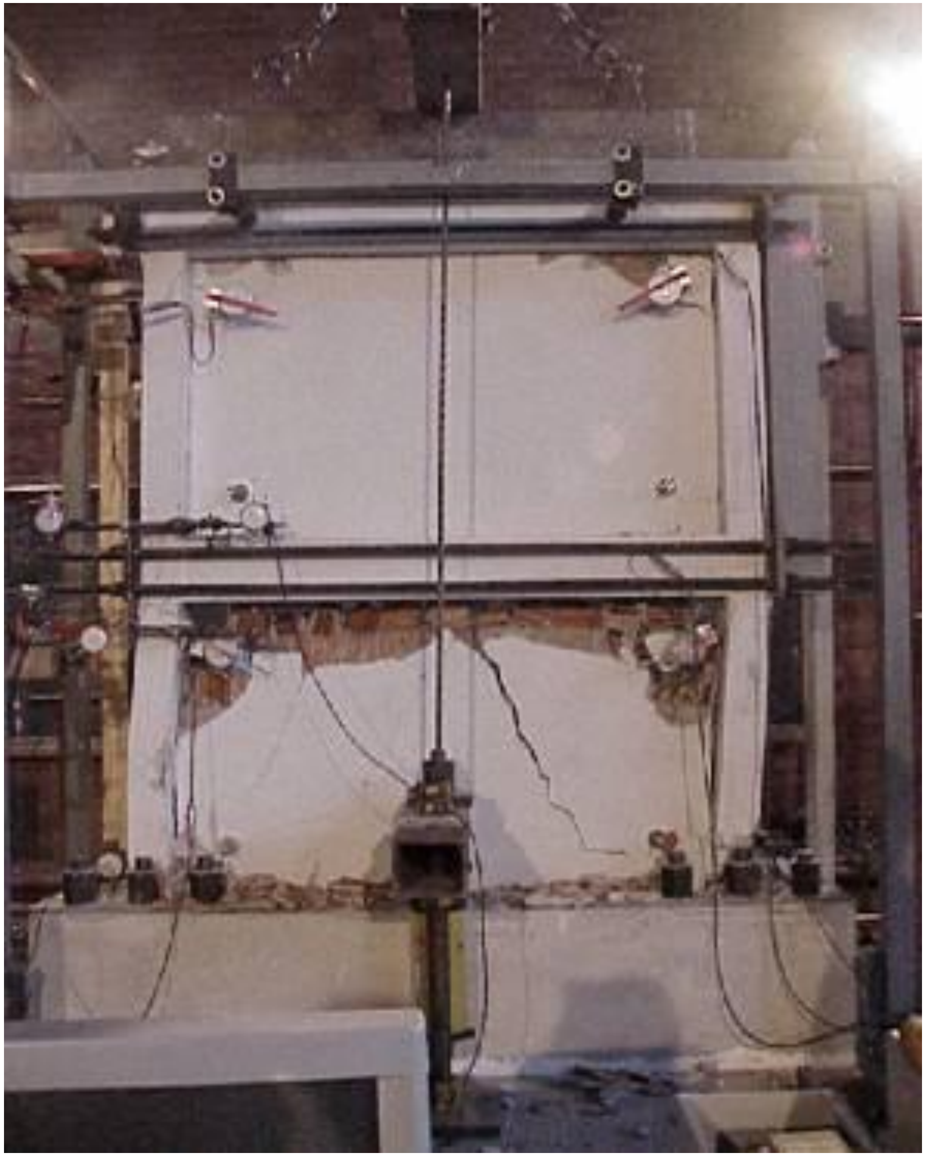
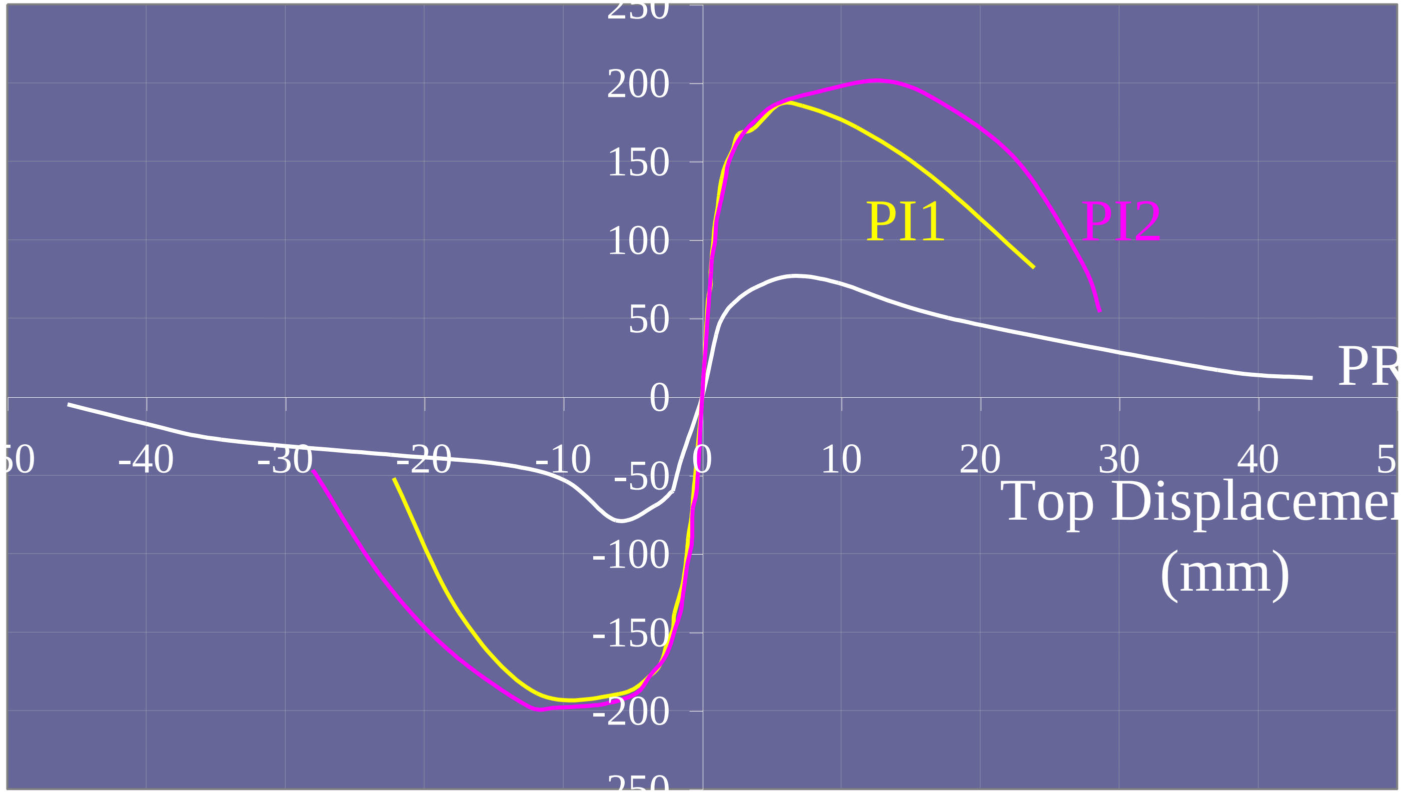


STRENGTHENED (SQUARE)

STRENGTHENED (STRIP)

ENVELOPES



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PERFORMANCE IMPROVEMENT

	Relative to masonry infilled frame	Relative to bare frame
Lateral load capacity	~2.5 times	~ 15 times
Lateral stiffness	~ 3 times	~ 20 times
Ductility	~ 2 times	~ 0.2 times
Energy dissipation	~ 3 times	~ 60 times

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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