Seismic Retrofitting of RC Frames with RC Infilling

RC Infilling of Existing RC Structures for Seismic Retrofitting

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Seismic Retrofitting of RC Frames with RC Infilling (SERFIN) Partners

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Statement of the problem

• Large number of structures designed without seismic design provisions
• Multi-storey reinforced concrete buildings can be most effectively and economically retrofitted by the construction of new walls
Suggested solution

Original Frame

Retrofitted Frame
Parameters investigated

- Percentage of the reinforcement in the RC infill
  - different percentages of infill wall reinforcement have been studied

- Connection between the RC infill and the surrounding RC frame
  - two types of connection between the infill and the bounding frame (epoxy grouted dowels and/or wall reinforcement starter bars)
Fulfillment of objectives through a testing campaign

- Test a structure (consisting of two parallel retrofitted RC frames) using the pseudo-dynamic method
- The frame corresponds to frames designed for gravity-loads only in the 1970’s
Specimen dimensions

Elevation of test structure

Perspective of mock-up
Design of frame

- The proposed structure represents typical construction of the late 70's and beginning of the 80's in Cyprus
- Structures at that time were designed for gravity loads only, since there were no provisions for earthquake loading
- Use the provisions of BS8110 which is very close to those of CP110 with very minor differences
- Reinforcement details used for the design were according to CP110:1972 and BS8110:1983
Design of frame: Prototype structure

- 4 frames
- Columns
  - 25cmx40cm
  - Long dim. along plane of loading
- Beams
  - 25cmx50cm
- Slab
  - 15cm thick
Design of frame: Mock-up without infills

- 2 end-frames of the prototype structure
- Columns
  - 25cmx40cm
  - Long dim. along plane of loading
- Beams
  - 25cmx50cm
- Slab
  - 15cm thick
Design of frame: Material properties

- **Concrete:**
  - C20/25 for both the frame and the walls
  - Unit weight 25 kN/m³
  - $E = 30000$ MPa

- **Reinforcing steel**
  - $f_{yk} = 400$ MPa ribbed bars for both bending and shear reinforcement for the frame (existing structure)
  - $f_{yk} = 450$ MPa ribbed bars for the RC infill and the dowels to be used for connecting the wall to the bounding frame members
The frame was designed for gravity loads only. The loads used were the following:

- **Self-weight**: this was calculated using the unit weight of concrete specified above
- **Imposed dead load**: 3 kN/m² including the load of infills
- **Live load**: 1.5 kN/m²

**Partial factors of safety for loads**
- 1.4 for self-weight and imposed dead-load, and
- 1.6 for live load.

**Material partial factors**
- 1.5 for concrete and
- 1.15 for steel
Design of frame: Resulting reinforcement details

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RC infills

- Made of reinforced concrete
- Connected to the bounding frame by starter bars and/or dowels
• By design the dimensions are such, so as to have high aspect ratio
  ➢ Bending dominated behaviour
  ➢ Higher modes involved after yielding of the wall at the base

• The RC infill wall has the same thickness as the width of the frame members
  ➢ Try to avoid
    • diagonal cracking of the wall
    • failure of the interface connection
**RC infills – Parameters to be investigated**

- Percentage of the reinforcement in the RC infill
  - different percentages of infill wall reinforcement was studied

<table>
<thead>
<tr>
<th>Story</th>
<th>Web Bars</th>
<th>Embedment of Web Starter Bars, mm</th>
<th>Dowels</th>
<th>Embedment, mm</th>
<th>S Wall</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>in wall in frame</td>
<td></td>
<td>bottom &amp; east in:</td>
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<td></td>
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<td>Φ16</td>
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</table>
RC infills – Parameters to be investigated

• Connection between the RC infill and the surrounding RC frame

  ➢ epoxy grouted dowels and/or wall reinforcement starter bars

  ➢ two cases are examined

  • Continuity of web reinforcement is provided through lap splices and dowels are provided for shear
  
  • Web reinforcement is placed at the phase of the bounding members and dowels are provided which double as
  
    – dowels

    – anchorage of the web panel to the surrounding frame but violating the 50mm or 4Φ clear distance requirement for lapping
Reinforcement Details
Dowel details

Reinforcement at the interface (bottom side-section A1)

Dowels and starter bars

Reinforcement at the interface (top side-section C1)

Dowels only
Pictures of construction
Pictures of construction
Pictures of construction
Pictures of construction
Strengthening of ground floor columns

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Strengthening of ground floor columns
SERFIN - Instrumentation

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<table>
<thead>
<tr>
<th>Displacement</th>
<th>Gefran PZ12 100</th>
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<td>Inclination</td>
<td>Schaeffler AccuStar</td>
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<tr>
<td>Force</td>
<td>Piston Load Cell</td>
<td>8</td>
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</table>

128 channels

SERFIN INSTRUMENTATION
06/04/2011
3 tests were performed

- Pseudo-dynamic testing
  - 0.10g
  - 0.25g
- Cyclic testing
  - Displacement controlled triangular distribution
- Actuators
  - 2 x 1000 kN at the top two floors
  - 2 x 500 kN at the bottom two floors
0.25g Pseudo-dynamic

- The Hercegnowi transverse accelerogram was used, scaled to 0.25g
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Storey-shears vs. i-d for 0.25 g
Storey-shears vs. i-d for 0.25 g…
Base-shear vs. top displacement for 0.25 g...

North frame
(with more reinforcement)

South frame
(with less reinforcement)
Lap-splice failure – West column of North frame
Lap-splice failure – West column of South frame
Lap-splice failure – East column of South frame
Lap-splice failure – East column of South frame
Beam cracking
Wall cracking
Wall cracking
Ground beam cracking – South wall

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2011-11-30
Ground beam cracking – North wall
Cyclic testing

SERFIN ELSA [RC Building] (82: Controller Derived)
f21: Final cyclic test 07/12/2011

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SERFIN ELSA [RC Building]
f21: Final cyclic test 07/12/2011
NORTH

North frame
(with more reinforcement)

South frame
(with less reinforcement)
Cyclic testing

SERFIN ELSA [RC Building] (82: Controller Derived)  
f21: Final cyclic test 07/12/2011  
Level 1

South frame

North frame
Conclusions

• The structure managed to sustain an earthquake of 0.25g without significant damage

• Some column lap-splices failed with concrete spalling, but the structure continued to carry load

• The 3-sided FRPs protected the wall bounding columns at the 1st floor and prevented lap-splice failure
Conclusions…

• The “weak” frame behaved equally well as the “strong” frame
• There has not been visible movement at the interface between the wall and the bounding frame
• The behaviour of the wall was mainly flexural, although on the south-frame wall some diagonal cracks appeared
• Some vertical cracks appeared at the connection of the beams to both the exterior column and the wall columns
• A horizontal crack appeared at the ground beam of the walls, and it was the main reason for loss of strength of the south frame
• The proposed system seems to behave in a satisfactory manner
Thank you for your attention