CoMa-Walls Project

Shake table test of a half-scaled building with RC and URM walls

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• Morandi Frères S.A. for manufacturing the half-scale bricks
Problem statement

• Mixed RC-URM wall structures
  • RC walls for retrofitting existing URM buildings
  • New construction of buildings with RC and URM walls

• Open design issues are:
  • Assumptions concerning the distribution of base shear forces between the two structural systems
  • Performance-limits for mixed structures
  • Choice of the q-factor
  • Effective slab width
  • Out-of-plane boundary conditions of URM walls
Concrete-Masonry Wall Structure (CoMa-Walls)

Shake-table test on a mixed RC-URM wall structure at the TREES laboratory. Test unit built at half-scale.
Concrete-Masonry Wall Structure (CoMa-Walls)

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Ing. Claudio Gatti
+ many more
Outline

• Shake table test unit
• Quasi-static cyclic tests carried out to prepare the shake table test
• Instrumentation of the shake table test unit
• Results of the shake table tests
• Summary and outlook
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Test unit:
4 storeys
Half-scale

Principal Dimensions:
Total height: 6.60 m
Storey height: 1.40 m
Length: 5.56 m
Width: 3.20 m

Structural elements:
2 RC walls
6 URM walls
RC slab
Symmetrical in plane
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Construction of test unit outside the laboratory

Transportation of test unit into the laboratory on sliders.
Scaling law

Scaling law «Artifical Mass Simulation» requires:

• Installation of additional masses

• Identical behaviour of model and prototype material

→ This is particularly important here since two materials are used (URM, RC)

→ Scaling of RC by a factor of two is not problematic (scale bar diameter and aggregates by two) + RC walls are not expected to undergo large ductility demands

→ Literature review shows: Scaling of URM is difficult (often too stiff but less strong),

→ Carry out tests on bricks and URM piers at half- and full-scale.
Scaling of bricks

Findings:

• Small and full-scale brick produced in same manufacturing plant with equal clay and equal production procedure (cutting, burning)

• Perforation at small scale with similar void ratio, similar effective width and similar web and shell thickness

• No remarkable improvement reached with modification of mortar

• Void ratio

• Effective width
  … important for lateral resistance of brick

• Thickness of web and shell
  … important for burning procedure
Scaling of bricks

Comparison of properties of half- and full-scale brick

<table>
<thead>
<tr>
<th>Average dimensions of a brick</th>
<th>Full scale brick</th>
<th>Half scale brick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>mm</td>
<td>297</td>
</tr>
<tr>
<td>Width</td>
<td>mm</td>
<td>194</td>
</tr>
<tr>
<td>Height</td>
<td>mm</td>
<td>189</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average mass and density of a brick</th>
<th>Full scale brick</th>
<th>Half scale brick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass / brick</td>
<td>kg</td>
<td>9.9</td>
</tr>
<tr>
<td>Volumetric mass</td>
<td>kg/m³</td>
<td>901</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Void ratios and effective length / width of a brick</th>
<th>Full scale brick</th>
<th>Half scale brick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void ratio</td>
<td>-</td>
<td>49.3</td>
</tr>
<tr>
<td>Effective length *)</td>
<td>-</td>
<td>30.6</td>
</tr>
<tr>
<td>Effective width *)</td>
<td>-</td>
<td>28.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average strength and deviation</th>
<th>Full scale brick</th>
<th>Half scale brick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression, parallel to perforation</td>
<td>MPa</td>
<td>35.0 ± 7%</td>
</tr>
<tr>
<td>Compression, perpendicular to perforation</td>
<td>MPa</td>
<td>9.4 ± 8%</td>
</tr>
<tr>
<td>Tensile strength, perpendicular to perforation</td>
<td>MPa</td>
<td>1.27 ± 38%</td>
</tr>
</tbody>
</table>

Excellent agreement of compression and tensile strength of half- and full-scale bricks
Quasi-static cyclic tests on URM piers

Test stand for full-scale piers

Test stand for half-scale piers

Quasi-static cyclic tests on full- and half-scale URM piers
Quasi-static cyclic tests on URM piers

→ Excellent agreement of shear stress-drift envelope.
Quasi-static cyclic tests on a mixed RC-URM substructure
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INSTRUMENTATION
• 20 accelerometers
• 49 LVDTs
• 24 omega gauges
• Optical measurement system with ~500 markers
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INSTRUMENTATION - LVDTs

- Deformation of first storey walls (RC and URM)
- Out-of-plane deformation of URM walls
INSTRUMENTATION – Omega gauges

- Slab deformation of first storey slab (effective slab width)
INSTRUMENTATION – Optical measurement system
• In-plane deformation of URM piers and spandrels
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Input ground motion

- 1979 Montenegro record, Herceg-Novi station
- Scaled in time by $\sqrt{2}$
- Peak acceleration scaled to 0.05g, 0.1g, 0.2g, 0.3g, 0.4g, 0.6g, 0.7g, 0.9g
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TEST 8 – 0.7 g

<table>
<thead>
<tr>
<th>Location</th>
<th>Crack width</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES1</td>
<td>0.8 mm</td>
</tr>
<tr>
<td>WS1</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>EN1</td>
<td>0.6 mm</td>
</tr>
<tr>
<td>WN1</td>
<td>0.8 mm</td>
</tr>
</tbody>
</table>
TEST 9 – 0.9 g
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TEST 9 – 0.9 g
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TEST 9 – 0.9 g
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RESULTS

• Drift Profiles from Optical Measurement System
Summary & Outlook

- Test up to near collapse
- A large amount of data on
  - In-plane behaviour of URM and RC walls
  - Out-of-plane behaviour of URM walls with different boundary conditions
  - Effective slab width
- Different behaviour in the two loading directions
- Different behaviour from URM wall buildings
- Different boundary conditions on out-of-plane loaded URM walls
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Summary & Outlook

- **Completed:** Report on test unit properties and test observations
- **Ongoing:**
  - Report on test data
  - Updating of numerical models and predictions
- **Outlook:**
  - Comparison of static and dynamic test results
  - Design guidelines for mixed RC-URM wall structures
  - Preparation of test data as benchmark test for analysis of mixed RC-URM wall structures
Thank you
Quasi-static cyclic tests on a mixed RC-URM substructure

Reference structure

Test unit

PhD Student: Alessandro Paparo
Quasi-static cyclic tests on a mixed RC-URM substructure
Pushover analysis of the structure

Modelling approach:
RC walls and slabs:
• Nonlinear material model; longitudinal reinforcement modelled as truss elements shear reinforcement as smeared reinforcement.

URM walls and spandrels:
• Simplified micro model (bricks as elastic, joints as interface elements)

Analysis program:
• Atena (Cervenka Consulting)
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Pushover analysis of the structure

![Graph showing pushover analysis](image)

- Positive direction (RC wall in compression)
- Negative direction (RC wall in tension)
Pushover analysis of the structure

Positive loading direction (RC wall in compression)

Negative loading direction (RC wall in tension)
Prediction – Capacity spectrum method

At PGA = 0.7g: 0.3% average drift = drift capacity of masonry piers

At PGA ≈ 0.9 g
PRELIMINARY RESULTS

- Relationship Base Shear/PGA - Base Shear/Arias Intensity

- Significant level of acceleration ($\approx 1.45$ g)

\[
\delta_{\text{Prototype}} = \frac{2}{3} \delta_{\text{Model}}
\]

\[
\delta_{u,SD} = \frac{2}{3} \delta_{u,NC}
\]  
(EC8, Part 3)

\[
\delta_{u,SD,Prototype} = \frac{2}{3} \cdot \frac{2}{3} \delta_{u,NC,Model}
\]

- The expected acceleration capacity for the model is around half the observed value
RESULTS

• Relationship Base Shear/PGA - Base Shear/Arias Intensity
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RESULTS

• Deformations Profiles from Optical Measurement System
CoMa WallS Project

RESULTS

• Deformations Profiles from Optical Measurement System