WHE-PAGER Project

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Seismic assessment of building stock and prediction of losses

• Input
  – Classification of buildings
  – Assignment of capacity curves
  – Definition of damage states
  – Definition of demand spectra
  – Evaluation of building response

• Output
  – Fragility curves
  – Damage scenarios
General Methodology

- Building classification by building typology
- If typologies are codified then capacity curves deduced from design standards
- Damage thresholds more difficult but theoretical correlation between damage and drift available for engineered structures
- Correlation of drift capacity and demand from displacement spectra possible
- Distribution of building stock from census by typology and use of lognormal distribution around mean average damage
- Possible calibration of fragility curves with direct damage observations.
Analytical push-over curves for non-HAZUS structures types

- Identify experimental/analytical curves existing in literature
- Document type of test/analytical procedure, representativeness, etc.
- Use FaMIVE database to extract a number of region/structure specific curves
- Compare with curves in literature
- Produce fragility curves
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>PAGER-STR</th>
<th>Description of Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>RS3</td>
<td>Local field stones with lime mortar.</td>
</tr>
<tr>
<td>9</td>
<td>RS4</td>
<td>Local field stones with cement mortar, vaulted brick roof and floors</td>
</tr>
<tr>
<td>10</td>
<td>DS2</td>
<td>Rectangular cut stone masonry block with lime mortar</td>
</tr>
<tr>
<td>11</td>
<td>DS4</td>
<td>Rectangular cut stone masonry block with reinforced concrete floors and roof</td>
</tr>
<tr>
<td>12</td>
<td>MS</td>
<td>Massive stone masonry in lime or cement mortar</td>
</tr>
<tr>
<td>14</td>
<td>UFB1</td>
<td>Unreinforced brick masonry in mud mortar without timber posts</td>
</tr>
<tr>
<td>15</td>
<td>UFB3</td>
<td>Unreinforced brick masonry in lime mortar</td>
</tr>
<tr>
<td>16</td>
<td>UFB5</td>
<td>Unreinforced fired brick masonry, cement mortar, but with reinforced concrete floor and roof slabs</td>
</tr>
</tbody>
</table>
Literature - Experimental

Benedetti et al. 1998

Brick masonry UFB3

Rubble masonry DS2
Rubble stone
RS4

Model A: without wall ties
Model C: with wall ties
\[ \sigma_v = 0 \text{ MPa} \]

\[ \sigma_v = 0.075 \text{ MPa} \]

Earthquake Engineering Research Institute

Griffith et al. (2004)

(a) 110 mm thick wall

(b) 50 mm thick wall

PGD = 16.6 mm

PWD = 32.5 mm

PGD = 107.6 mm

PWD > 110 mm

(a) 4 x Nahini

(b) 0.66 x El Centro

(c) 0.8 x Pacoima Dam

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Literature Analytical

Literature Push-over Curves

UFB5 Analytical/Experimental

- Barbat, 2006
- Benedetti et al, 1998
- Tomazevic, 2007

UFB3 Analytical/Experimental

- D’Ayala, 2005
- Salonikios et al, 2003
- Yi, Moon, Leon and Kahn, 2006
- Griffith, Lam, Wilson, Doherty, 2002/2004
Regions

- Italy
- Turkey
- Iraq
- Nepal

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Mechanisms of collapse

- Friction, identification of cracks by sliding or overturning
- Connections with other structural elements

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</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B1</td>
<td>B2</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>VERTICAL OVERTURNING</td>
<td>OVERTURNING WITH 1 SIDE WING</td>
<td>OVERTURNING WITH 2 SIDE WINGS</td>
<td>CORNER FAILURE</td>
<td>PARTIAL OVERTURNING</td>
<td>VERTICAL STRIP OVERTURNING</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>G</th>
<th>H</th>
<th>I</th>
<th>H2</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>HORIZONTAL ARCH</td>
<td>IN PLANE FAILURE</td>
<td>VERTICAL ADDITION</td>
<td>IN PLANE PIER FAILURE</td>
<td>ROOF/FLOORS COLLAPSE</td>
</tr>
</tbody>
</table>

**ASSOCIATED FAILURES**

- Insufficient cohesion in the fabric
Displacement based assessment

- Choice of appropriate non linear spectrum:
  - Deterministic event ⇒ site specific PGA
  - Ductility ⇒ Strength reduction factor
  - Displacement reduction factors:

\[
\begin{align*}
S_{dar} &= \begin{cases} 
\left[1 + (R - 1)T_g / T \right] / R & \text{if } T < T_g \\
1 & \text{if } T > T_g 
\end{cases} \\
S_{dar} &= 1 + \left( \frac{R_y - 1}{300} \right) + \frac{1}{10T^2} e^{-20\sqrt{T} / R_y} 
\end{align*}
\]

\[
R = \begin{cases} 
\frac{c_1(\mu - 1)}{T/T_g} + 1 & \frac{T}{T_g} \leq 1 \\
\frac{c_1(\mu - 1) + 1}{T/T_g} & \frac{T}{T_g} > 1 
\end{cases}
\]
Capacity curves for vulnerability classes

- Define peak strength as collapse load factor
- Define natural period as ratio of effective stiffness and mass
- Define elastic limit displacement as
- Define $\Delta_u$ as loss of equilibrium for given mechanism
- Typical ductility range $3 < \mu < 10$

$$a_y = \lambda$$

$$T = \sqrt{\frac{m_{\text{eff}}}{K_{\text{eff}}}}$$

$$\Delta_y = \frac{a_y}{4\pi^2} T^2$$
Italy, Serravalle

Serravalle sample

- DS4
- DS2
- Benedetti et al, 1998
- RS3
- RS4
- Tomazevic, 2007
- UFB3
- UFB5
- Tomazevic, 2007
Serravalle, Italy, Correlation of FaMIVE and EMS’98, Stonework

<table>
<thead>
<tr>
<th>Procedure</th>
<th>EMS98 grade A</th>
<th>EMS98 grade B</th>
<th>EMS98 grade C</th>
</tr>
</thead>
<tbody>
<tr>
<td>VULNUS</td>
<td>High and Very High</td>
<td>Medium</td>
<td>Low and Very Low</td>
</tr>
<tr>
<td>FaMIVE</td>
<td>Estreme and High</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>

Damage distribution \(\geq D3\) for buildings of class A

Damage distribution \(\geq D3\) for buildings of class B

Damage distribution \(\geq D3\) for buildings of class C

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Turkey, Fener-Balat

Fener-Balat Sample

- DS2
- DS4
- UFB3
- UFB5
- Griffith, Lam, Wilson, Doherty, 2002/2004
- Tomazevic, 2007
- Benedetti et al, 1998
Displacement based damage scenario
L’Aquila, Italy

![Graph showing data points and lines for various studies in L’Aquila, Italy](image)

- **DS2**
- **DS4**
- **Benedetti et al, 1998**
- **RS3**
- **Tomazevic, 2007**
- **UFB3**
- **UFB5**
- **Tomazevic, 2007**
Comparison FaMIVE experimental for UFB5

![Graph showing comparison of FaMIVE experimental results for UFB5 with different locations and data sources.]

- Erbil
- L'Aquila
- Fener Balat
- Nocera
- Serravalle
- Benedetti et al, 1998
- Tomazevic, 2007
Cumulative total damage probability

Serravalle cumulative damage by PAGER TYPE

Cumulative Damage Probability

Spectral displacement in mm

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Cumulative distribution over the whole sample for UFB3 and UFB5
Indian Data Concrete

Northern Indian non-ductile Concrete Frames

- Non-Ductile Reinforced Concrete Frame with Open First Storey
- Non-Ductile Reinforced Concrete Frame with Masonry Infill Walls in all Storeys
- Non-Ductile Reinforced Concrete Frame without Masonry Infill Walls
- Non-Ductile Reinforced Concrete 4 Storey Residential Building with Open First Storey
- Non-Ductile Reinforced Concrete 4 Storey Residential Building with Masonry Infills in all Storeys