In-Plane Fragility Assessment of Masonry Infill Panels

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Drift-Based Fragility Functions for In-Plane Loaded Masonry Infill Panels
Introduction and motivation

- **Masonry infills** are one of the most prevailing types of non-structural elements in both Eastern and Western architecture.

- Damage to non-structural components often accounts for most of the earthquake induced economic losses.
  
  - Non-structural components represent a large portion (70-90%) of the total cost of buildings.
  
  - Their damage is generally triggered at much lower levels of structural response than those required to initiate structural damage.

- Nonstructural masonry infill walls are commonly used for exterior enclosures as well as for interior partitions in low to mid-rise reinforced concrete (RC) or steel frame buildings.
Masonry infills are typically made of either solid or hollow clay or concrete bricks, joined with cement or lime mortar.

Most of current seismic codes are force-based and, therefore, primarily rely on checking on the strength of structural elements giving a secondary importance to lateral deformations and the performance of nonstructural components.

For this reason, whilst an important body of work has addressed the assessment of the strength of masonry infill walls and their influence on building response, very few studies have been devoted to estimating the progression of in-plane damage as a function of lateral deformations being imposed on them.
Introduction and motivation

In-plane damage to masonry infills after the Ecuador 2016 earthquake:
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In-plane damage to masonry infills after the Ecuador 2016 earthquake:
PBEE APPROACH:

In the **PEER-PBEE framework**, the expected annual loss (EAL) can be computed as the sum of expected losses in each component at a given level of ground motion intensity and then integrating over the mean annual frequencies of exceeding of all possible intensities:

\[
EAL = \sum_{i=0}^{\infty} \sum_{j=1}^{n} E[L_j | IM = im] \left| \frac{d \nu(IM)}{d(IM)} \right|_{im} d(IM)
\]

\[
E[L_j | IM = im] = \sum_{i=1}^{m} E[L_j | DS = ds_i] P[DS = ds_i | EDP_j = edp] dP[EDP_j > edp | IM = im]
\]

**FRAGILITY FUNCTION**
The aim of the present study is to obtain drift-based fragility functions relying on a wide and up-to-date survey of experimental results contained in the literature on in-plane loaded infilled frames.

EXPERIMENTAL DATABASE:

- 32 Experimental studies from literature
- 152 masonry infilled frame specimens
- Cyclic lateral loading
- Different brick types (solid/hollow clay/concrete)
- Different compressive strength for masonry blocks and mortar joints
- Presence of openings
Damage states definition

DAMAGE STATE 1: Initiation of small hairline cracks in masonry,
Damage states definition

DAMAGE STATE 2: Beginning of significant cracks,
Damage states definition

DAMAGE STATE 3: Wide diagonal cracks (usually larger than 4mm) with significant sliding between joints and widespread crushing and spalling of masonry units.
In order to build fragility functions, a probability density function must be chosen which adequately fits the obtained experimental cumulative frequency distribution. The **log-normal distribution** is a common choice in engineering applications when the values of the random variable are known to be strictly positive, as in the present study:

\[
P(DS \geq ds_i \mid IDR = \delta) = 1 - \Phi \left( \frac{\ln(\delta) - \mu_{\ln(\delta)}}{\beta} \right)
\]
FRAGILITY FUNCTIONS FOR DS1 – ALL SPECIMENS

FINITE-SAMPLE UNCERTAINTY
FRAGILITY FUNCTIONS FOR DS2 – ALL SPECIMENS

FINITE-SAMPLE UNCERTAINTY
FRAGILITY FUNCTIONS FOR DS3 – ALL SPECIMENS

FINITE-SAMPLE UNCERTAINTY
### Fragility Functions – All Specimens

Estimated parameters for the log-normal distribution:

<table>
<thead>
<tr>
<th>Damage State</th>
<th>$\overline{IDR}$ [%]</th>
<th>$\mu_{\ln(\sigma)}$</th>
<th>$\beta$</th>
<th>Number of Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS$_1$: light cracking</td>
<td>0.125</td>
<td>-2.078</td>
<td>0.325</td>
<td>100</td>
</tr>
<tr>
<td>DS$_2$: moderate cracking</td>
<td>0.327</td>
<td>-1.118</td>
<td>0.278</td>
<td>118</td>
</tr>
<tr>
<td>DS$_3$: heavy cracking</td>
<td>0.820</td>
<td>-0.198</td>
<td>0.320</td>
<td>132</td>
</tr>
</tbody>
</table>
WORKING HYPOTHESIS: information on brick type alone do not introduce any significant improvement on the dispersion of the original fragility functions. In order to ascertain this conjecture, all specimens have been grouped into three dataset corresponding respectively to masonry infills made with solid clay bricks, hollow clay bricks and concrete masonry units.
From two tailed t-tests, it turns out that whereas mortar compressive strength primarily influences damage states with low level of damage and, therefore, can be employed to refine fragility functions for DS$_1$, prism compressive strength significantly influences all three damage states. Here we recommend its use to correct/improve fragility functions for DS$_2$ and DS$_3$, whenever information of the prism compressive strength of the infill is available.
A more sophisticated approach to account for the influence of mortar and prism compressive strength on the IDR producing a given damage state is possible by plotting the linear regression of the IDR producing the damage state as a function of mortar compressive strength and 95% confidence bands on the regressed linear fit.
By varying continuously logarithmic mean and logarithmic dispersion, it is possible to obtain a bivariate fragility function (or FRAGILITY SURFACE).
Unfortunately, the number of specimens with openings in the initial dataset (i.e. 38) is rather limited compared to the number of specimens without openings (i.e. 114). Thus, the initial dataset has been subdivided into two subgroups. From a two-tailed $t$-test it is seen that presence of openings is statistically significant for reaching damage states DS1 and DS2 whereas no significant influence is detected on DS3.

![Graphs showing influence of openings on damage states DS1 and DS2](image)
Thank you for your kind attention