Experimental investigation into the behaviour of injection anchors in stone masonry

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Seismic behaviour of URM buildings

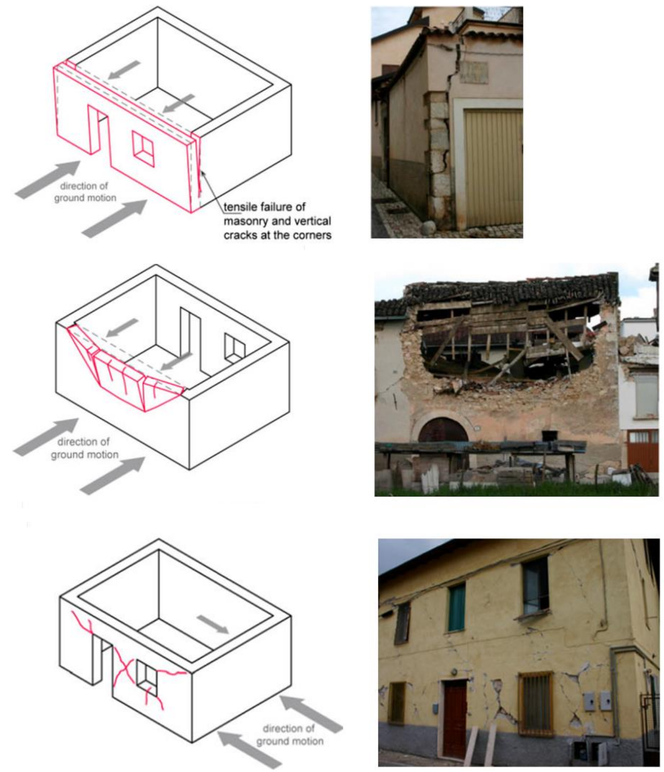
Local out-of-plane overturning

Global mechanism

- Interaction between out-of-plane and in-plane walls

Vulnerabilities

- Low material properties
- Unfavourable geometrical layout
- Inappropriate diaphragm stiffness
- Poor connections



Ortega et al. (2018)

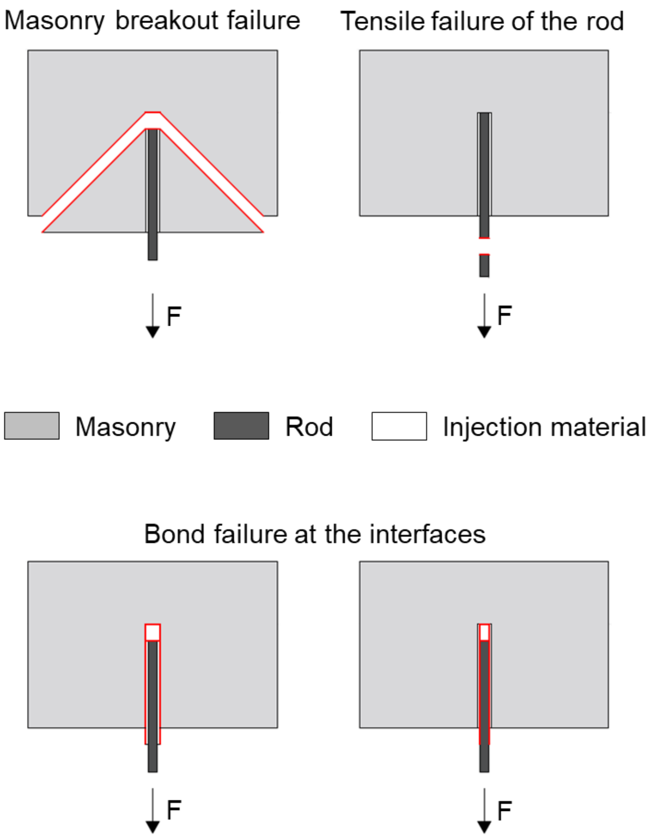
Injection anchors

Common technique to improve WTD connections

Several possible failure modes

When used in stone masonry:

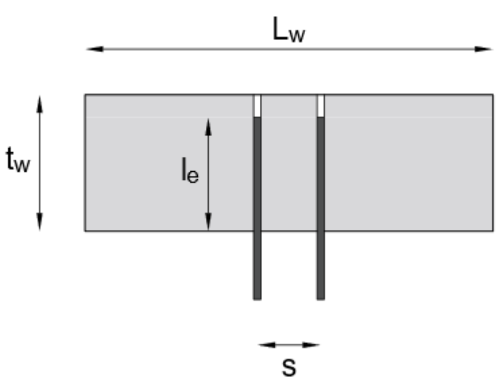
- Little experimental evidence of their structural behaviour
- No specific design formulas in current building codes and guidelines



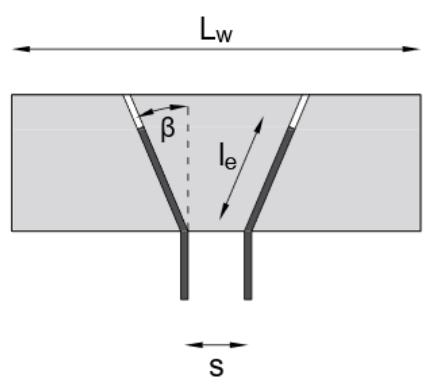
Pull-out tests

Behaviour of anchors in stone masonry using epoxy resin, when masonry breakout failure occurs

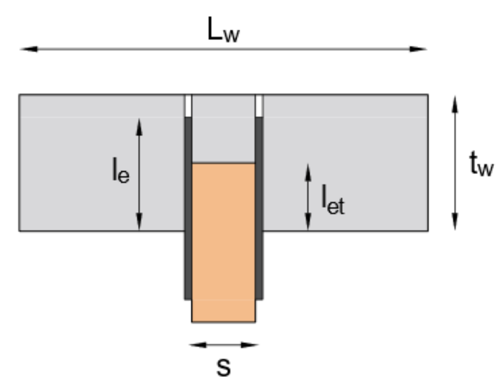
- 3 series - 4 specimens per series
- Anchoring detail - Overburden stress - Presence of a joist pocket



PA specimens



IA specimens



PAT specimens

Specimens

Double-leaf rubble stone masonry

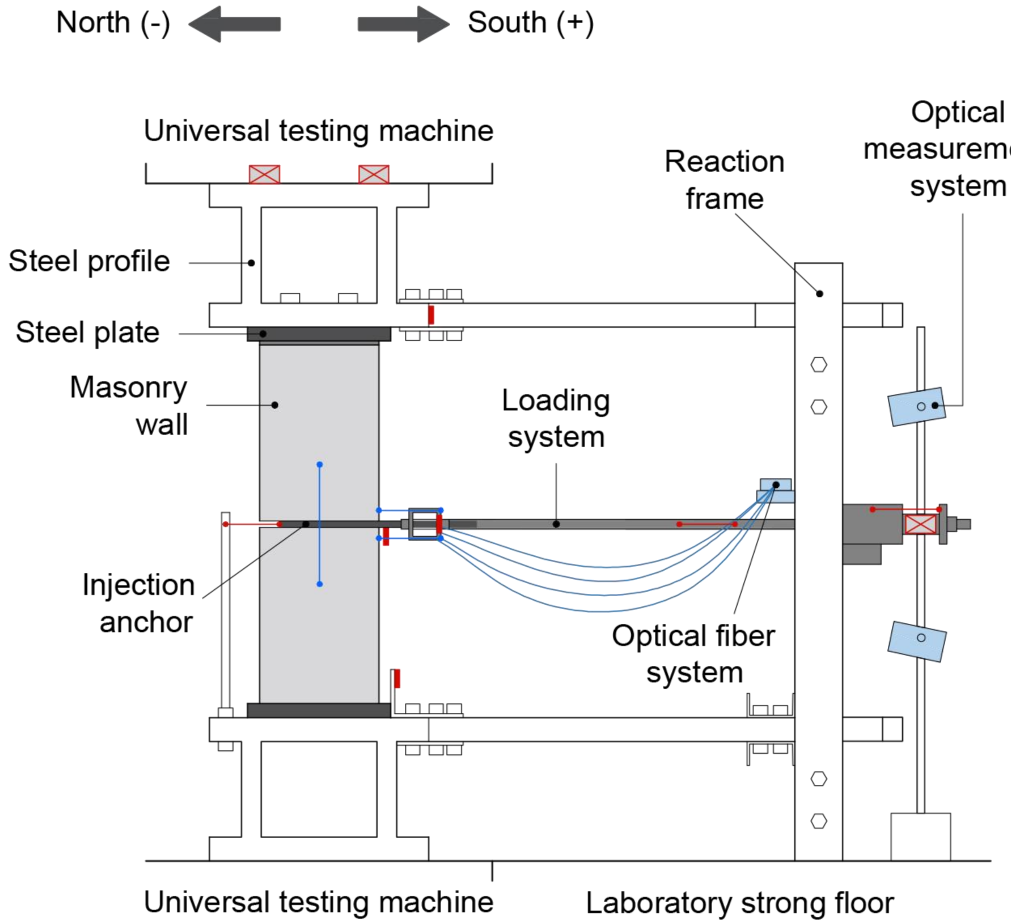
- 0.9 x 0.9 x 0.3 m^3
- Mortar: f_{ft} = 0.91 MPa, f_c = 4.36 Mpa
- Stone: f_c = 116.3 MPa

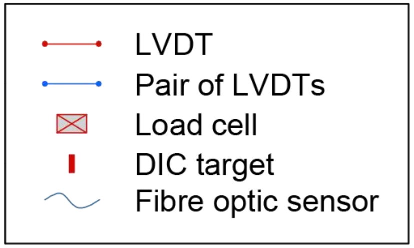
A pair of steel threaded bars with epoxy resin adhesive

- Hilti HIT-RE 500
- l_e = 250 mm
- d = 16 mm
- s = 140 mm

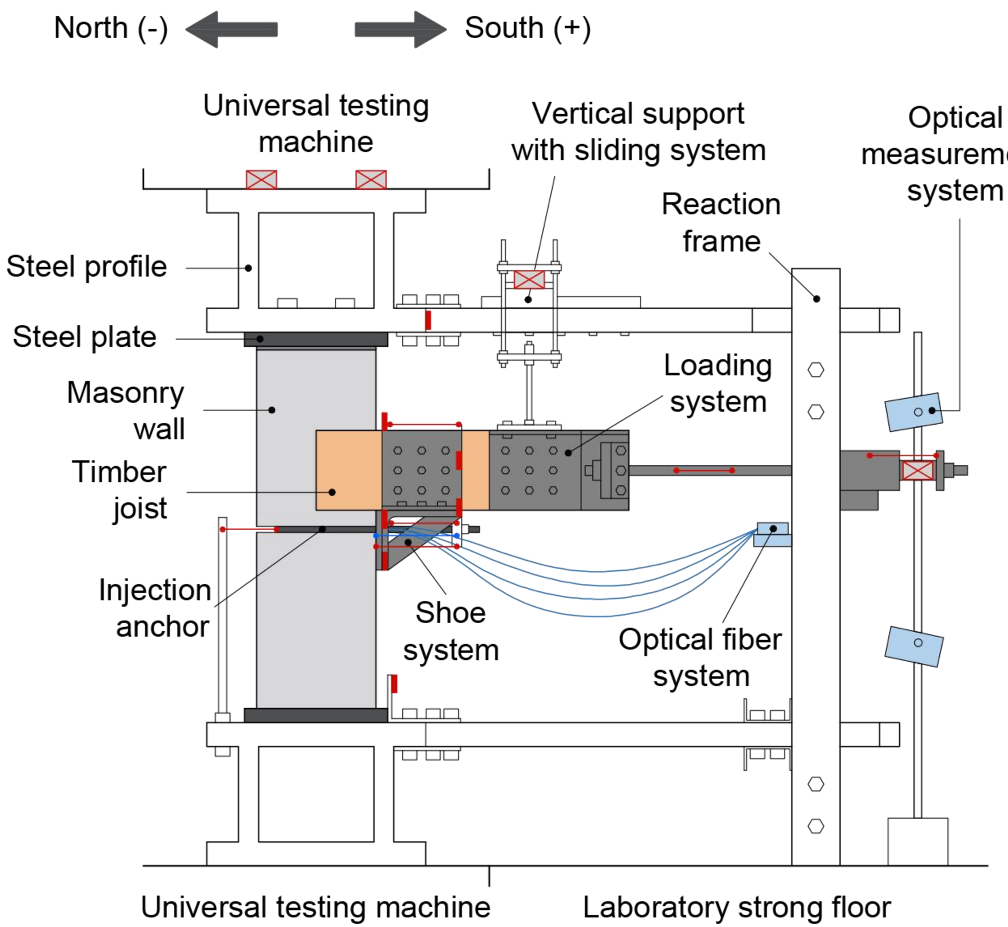
Crack repair for PAT specimens

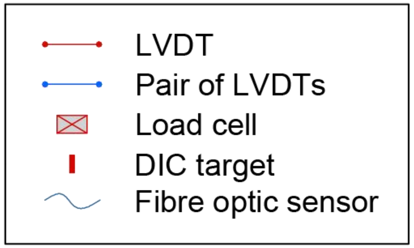
Test setup – PA & IA specimens

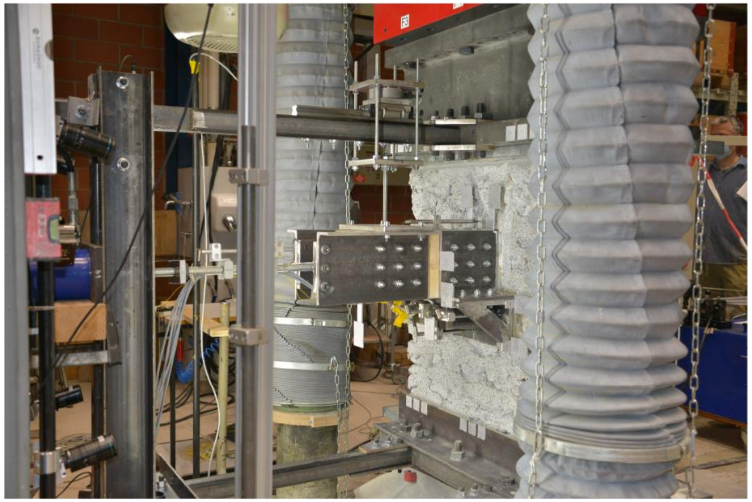




Test setup – PAT specimens

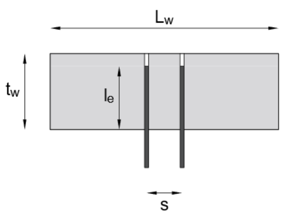




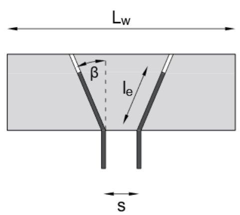


(b)

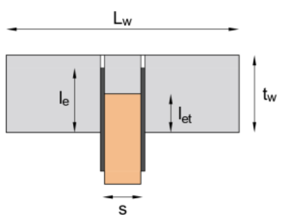
Pull-out load capacities



Specimen name	σ_v [MPa]	F_{max} [kN]	Δ_{Fmax} [mm]
PA1	0.1	-	
PA2	0.1	42.4	0.7
PA3	0.2	50.3	1.1
PA4	0.2	57.1	2.6



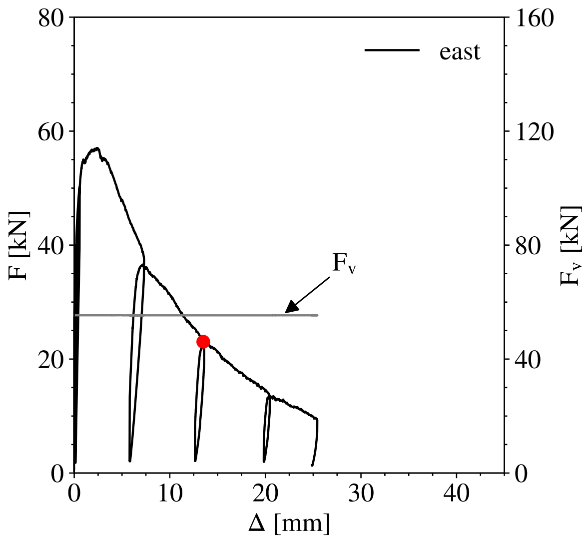
Specimen name	σ_v [MPa]	F_{max} [kN]	Δ_{Fmax} [mm]
IA1	0.2	51.7	0, 89, 0.93
IA2	0.2	55.5	0.66, 1.28
IA3	0.2	55.1	0.93, 1.05
IA4	0.3	64.6	0.86, 0.90



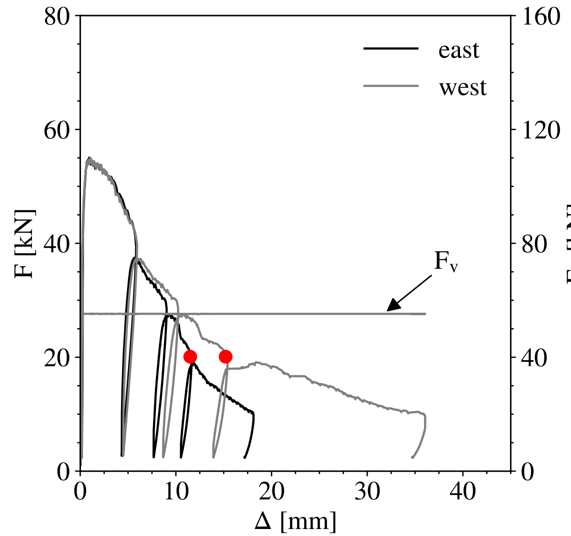
Specimen name	σ_v [MPa]	F_{max} [kN]	Δ_{Fmax} [mm]
PAT1	0.2	60.9	2.71
PAT2	0.2	75.9	1.72
PAT3	0.1	41.9	1.44
PAT4	0.3	57.4	2.86

Force-displacement curve and failure mode

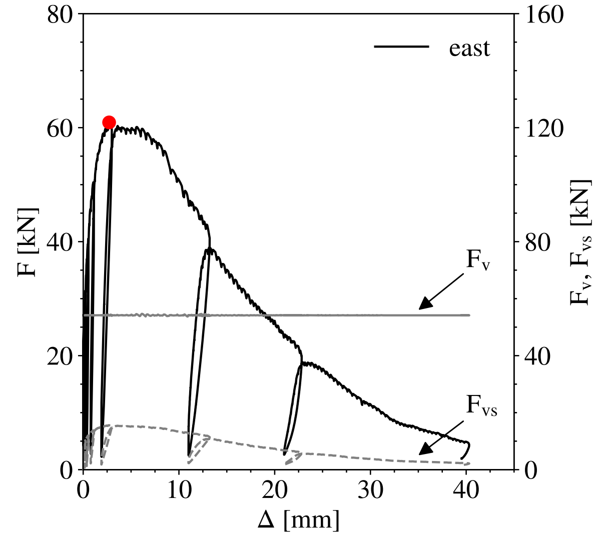
PA4

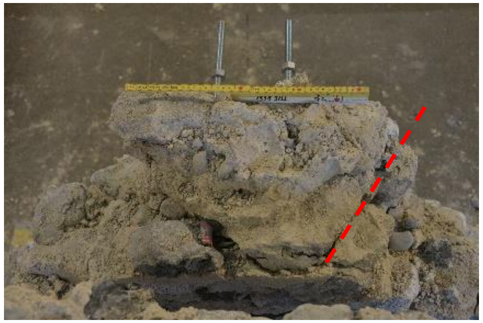


IA3

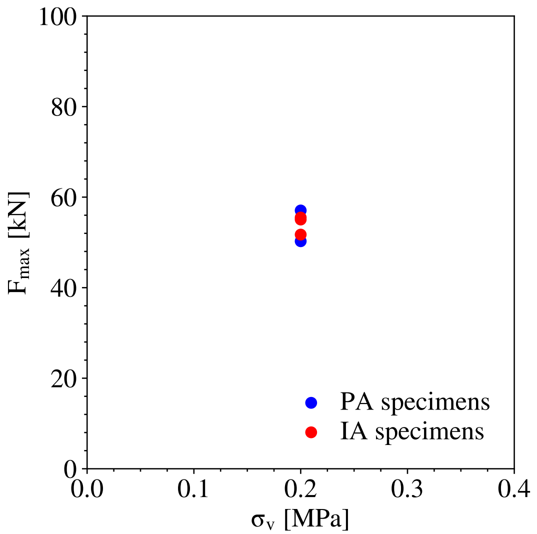


PAT1

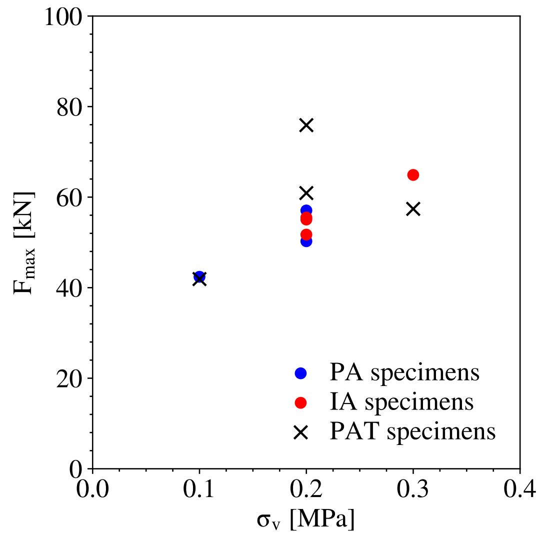




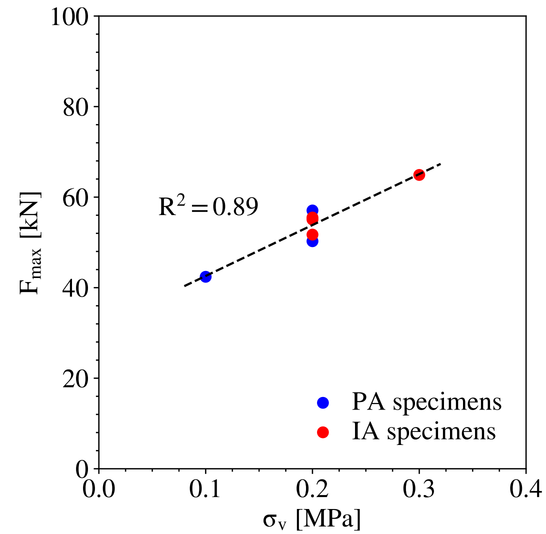
Investigated parameters on F_{max}



When σ_v = 0.20 MPa,
F_{max} = 54.0 kN (CoV = 5%)



Influence of grouting



For PA and IA specimens,
R^2 = 0.89

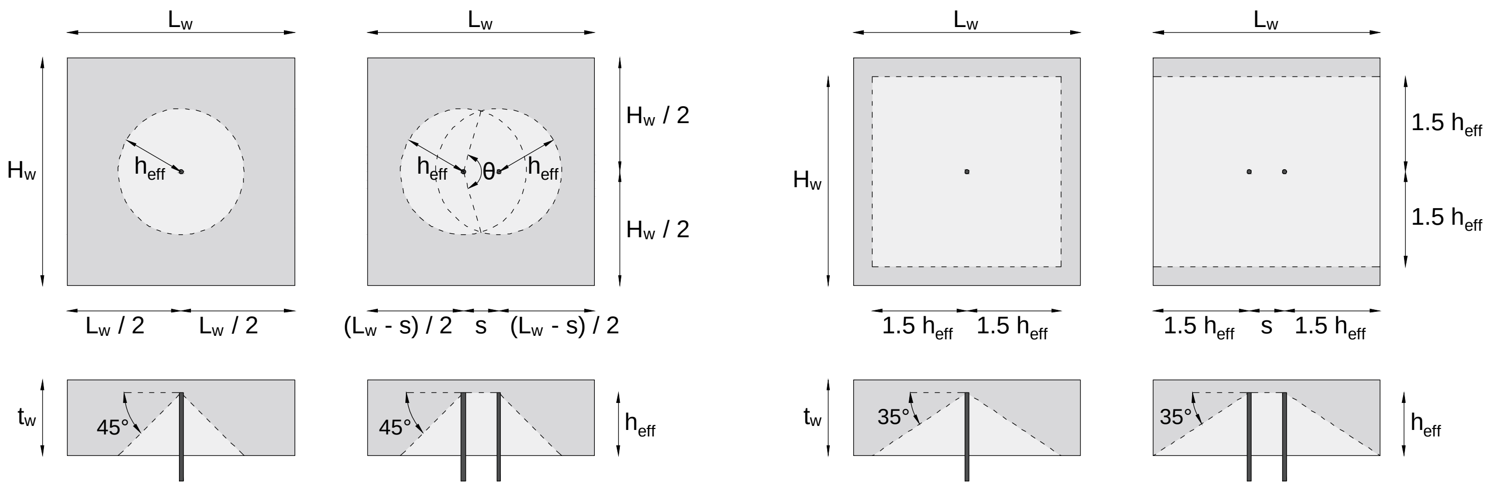
Prediction of pull-out load capacity

Semi-empirical formulas

$$F^{p}_{max} = (A/A^0)\, \kappa \sqrt{f_c}\, h^{\alpha}_{eff},$$

with: $\kappa = \kappa_1 \kappa_2$ and $\alpha = 2.0,$ (plasticity-based models)

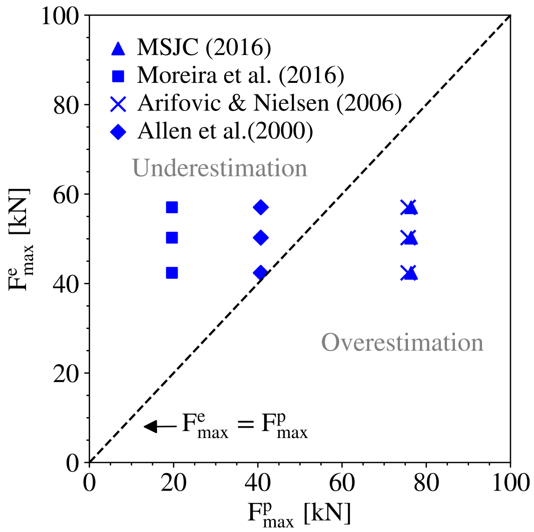
$\kappa = \kappa_1 \kappa_2 \kappa_3$ and $\alpha = 1.5.$ (CCD method)



Prediction of pull-out load capacity

Semi-empirical formulas

- Calibrated for brick masonry
- Scattered results
- Do not account for the effect of overburden stress

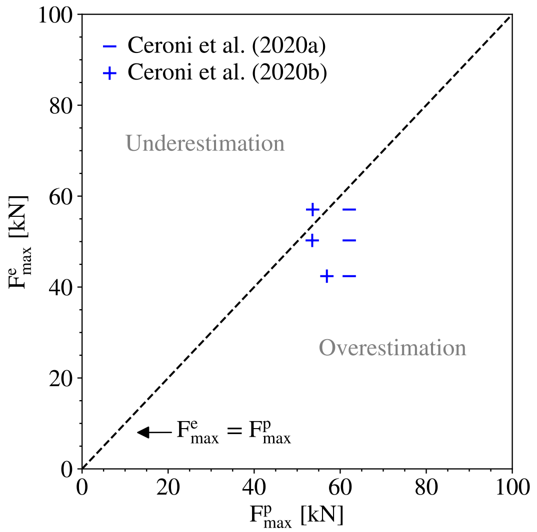


Author	Formula	MAE [kN]	MAPE [-]
MSJC (2016)	$F^p_{max} = (A_{pt}/A^0_{pt})\ 0.33\ \pi \sqrt{f_m}\ h^2_{eff}$	26.4	0.55
Moreira et al. (2016)	$F^p_{max} = (A_{pt}/A^0_{pt})\ \kappa_1\ \pi \sqrt{f_m}\ h^2_{eff}$ with $0.08 \leq \kappa_1 \leq 0.33$	30.3	0.60
Arifovic & Nielsen (2006)	$F^p_{max} = (A_{pt}/A^0_{pt})\ 0.96 \sqrt{f_m}\ h^2_{eff}\ (1 + d/h_{eff})$	25.7	0.54
Allen et al. (2000)	$F^p_{max} = 1.4 \left[(A_{cN}/A^0_{cN})\ 7.11 \sqrt{f_m}\ h^{1.5}_{eff}\right]$	9.3	0.17

Prediction of pull-out load capacity

Empirical formulas

- Pull-out tests database
- Effect of overburden stress
- Failed in predicting the $F_{max} – \sigma_v$ relationship observed in this study



Author	Formula	MAE [kN]	MAPE [-]
Ceroni et al. (2020a)	$F^{p}_{max} = k\,\alpha\left(\frac{d}{d_0}\right)^{\beta} l_e^{\gamma}\, d_0^{\delta}\, 0.25\, f_{cg}^{\varepsilon},$	12.1	0.26
Ceroni et al. (2020b)	$F^{p}_{max} = k\left[\alpha\,\frac{(0.67\,f_t + 0.4\,\sigma_v)^{\beta}}{f_m^{\theta}} + \gamma\, d_0^{\delta}\, l_e^{\xi}\,(0.67\,f_t + 0.4\,\sigma_v)^{\eta}\right]$	7.1	0.11

Final remarks & Work in progress

- Pull-out tests to investigate anchoring detail, presence of joist pocket and vertical loading (σ_v)
- For all specimens:
  - $F \leq F_{max}$ → near-linear branch & no visible damage on the wall surface
  - After F_{max} → significant decrease in force & rapid cracking propagation
  - F_{max} = 41.9 kN – 75.9 kN
  - Masonry breakout failure
- Significant influence of σ_v on F_{max}
- Need for an analytical formulation which includes σ_v as a governing parameter when estimating F_{max}

Thank you

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