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FRP STRENGTHENING – SHEAR MECHANISM OF BRICK MASONRY VAULTS

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Experimental tests carried out at Padova University

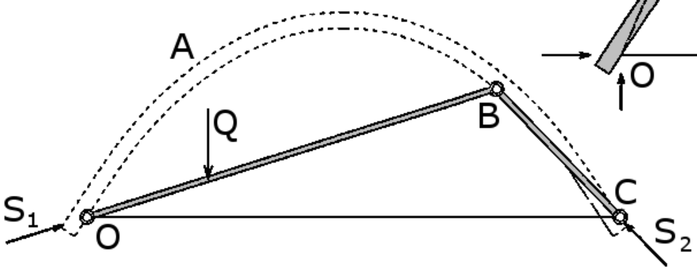
Six barrel vaults tested under eccentric line-load

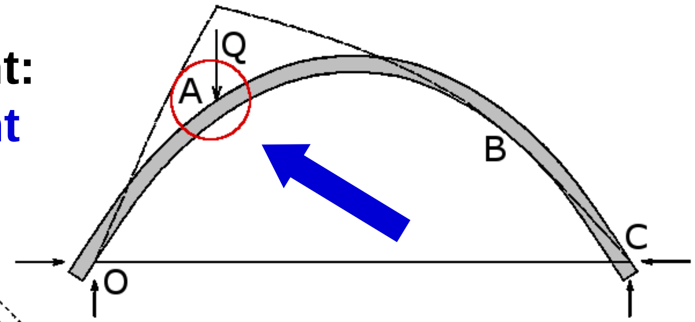
- ❑ **intrados + Carbon FRP (2)**
- ❑ **extrados + Carbon FRP (2)**
- ❑ **extrados + Glass FRP (2)**

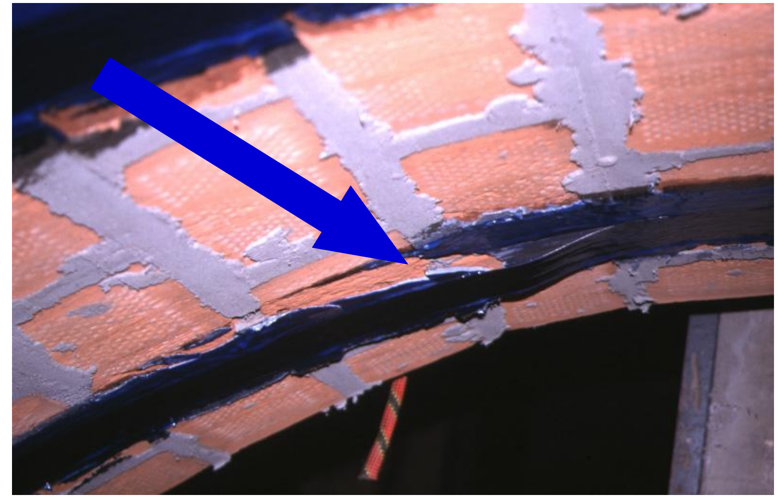
Valluzzi M.R., Valdemarca M., Modena C. (2001). *Behaviour of brick masonry vaults strengthened by FRP laminates*, International Journal of Composites for Construction 5(3), 163-169

Collapse mechanisms highlighted by tests

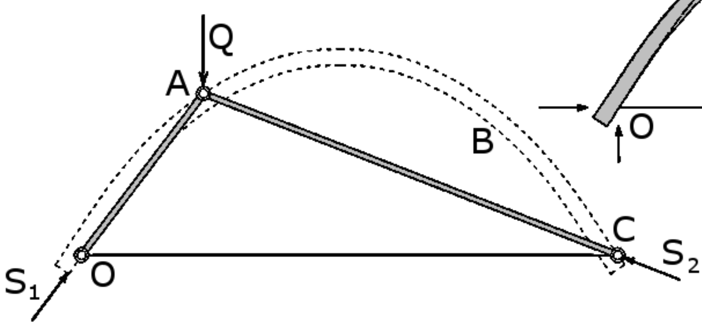
Intrados reinforcement:
composite detachment

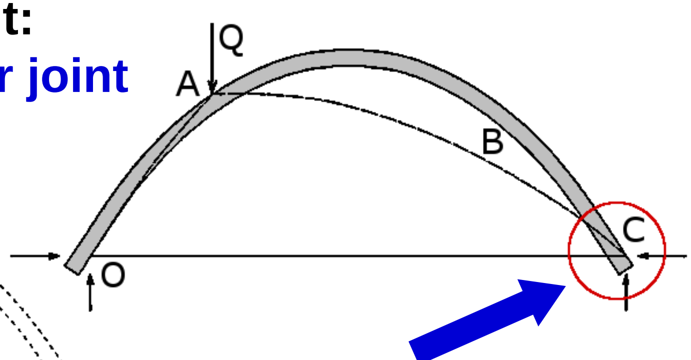




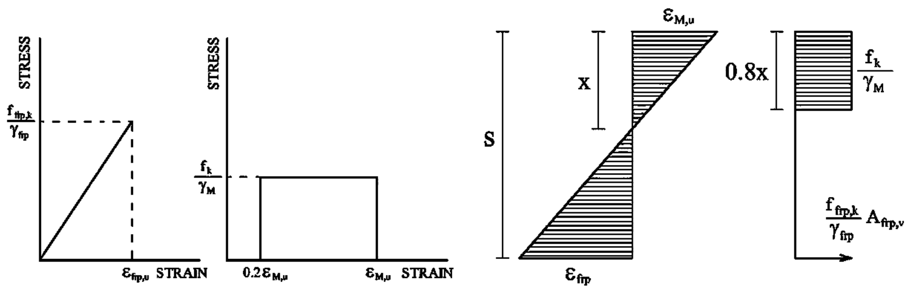


Extrados reinforcement:
shear sliding on mortar joint





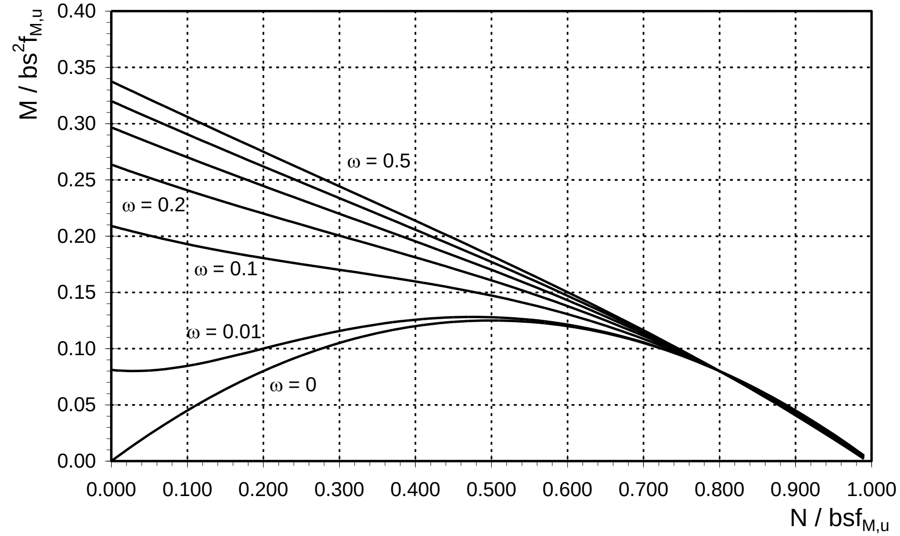
(a) Modeling of the masonry crushing mechanism



composite masonry strain stress

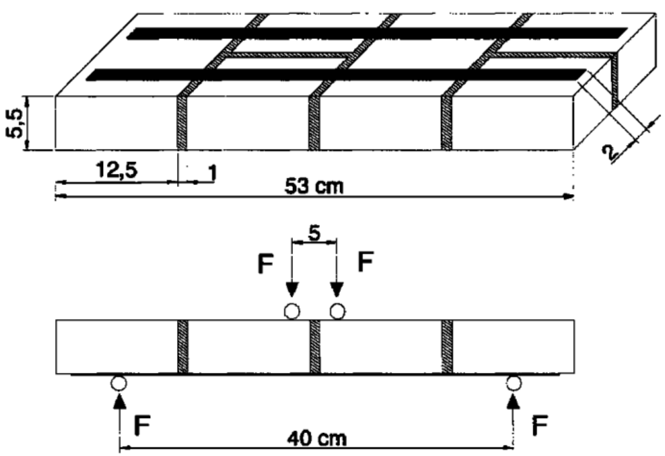
Constitutive laws Stress and Strain Distribution

Assumptions on materials and section behaviour



Out-of-plane moment capacity versus axial load

Flexural test on reinforced masonry panels



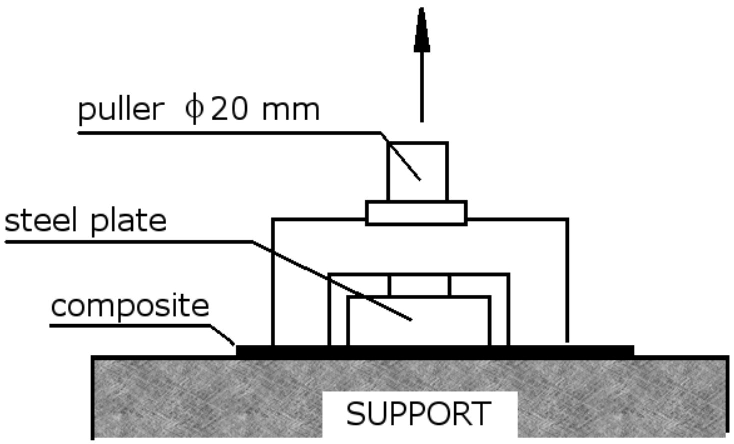
(Triantafillou, 1998)

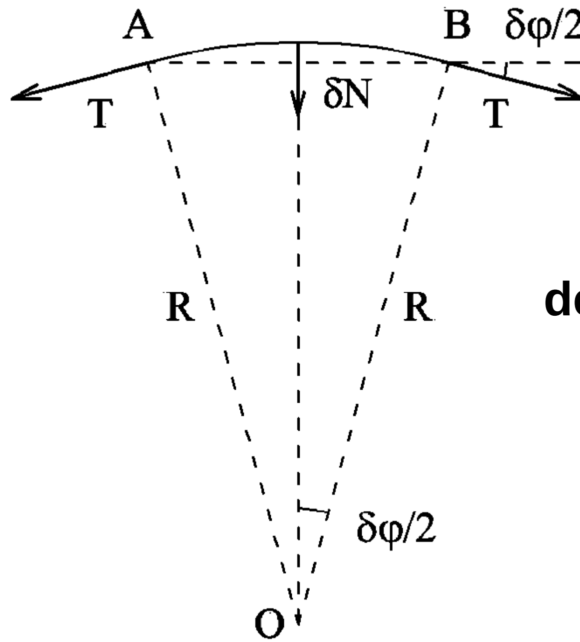
$$\frac{M_{Rd}}{ls^2 f_k} = \frac{1}{2}\omega \frac{\left(1-\frac{x}{s}\right)}{\frac{x}{s}} + \frac{0.4}{\gamma_M}\frac{x}{s}\left(1-0.8\frac{x}{s}\right); \quad \frac{x}{s} = \frac{\gamma_M}{1.6}\left(\frac{N_{Rd}}{lsf_k} - \omega + \sqrt{\left(\omega - \frac{N_{Rd}}{lsf_k}\right)^2 + \frac{3.2}{\gamma_M}\omega}\right)$$

MEAN RESISTING MOMENT

evaluated – measured: difference less than 8%

(b) Detachment of the reinforcement from the support





design formulation

$$\frac{\delta N}{\delta s} = \frac{T}{R}$$

Based on the results of local orthogonal pull-off tests:

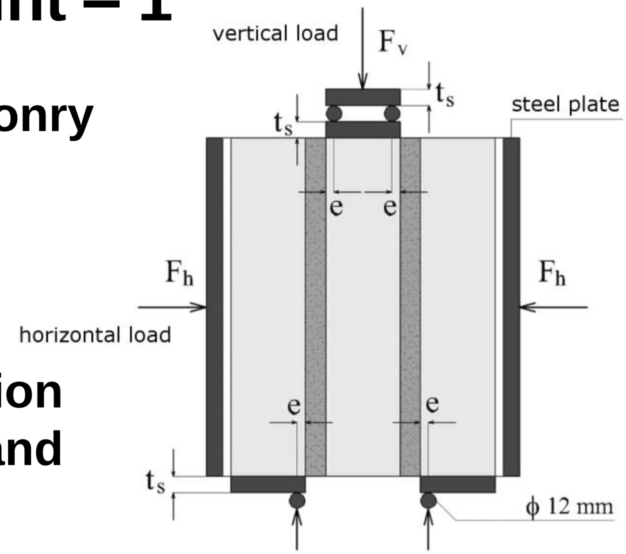
VAULTS' MEAN COLLAPSE LOAD

evaluated – measured: difference less than 7%

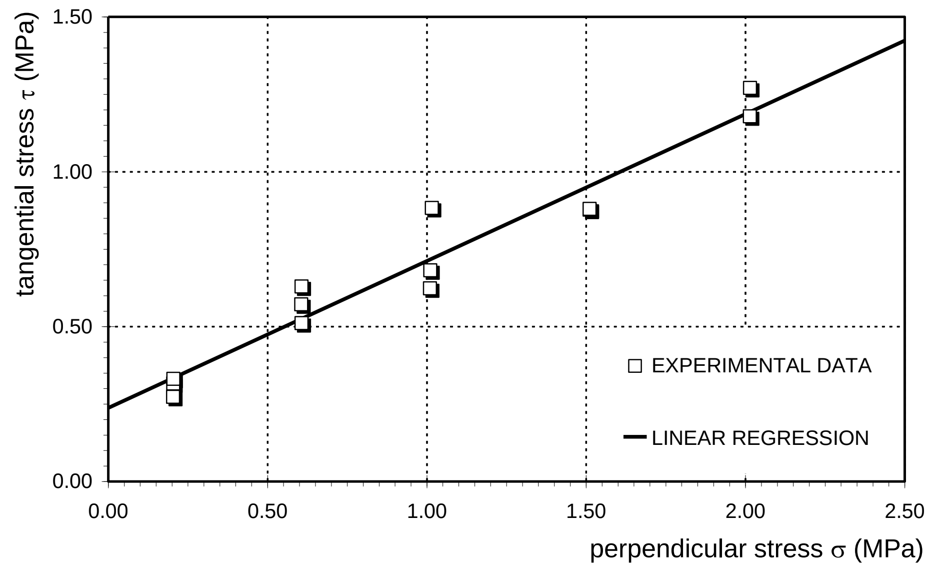
(c) Shear sliding on mortar joint – 1

Frictional strength of masonry (post-critical phase):

$$R_m = \mu C$$

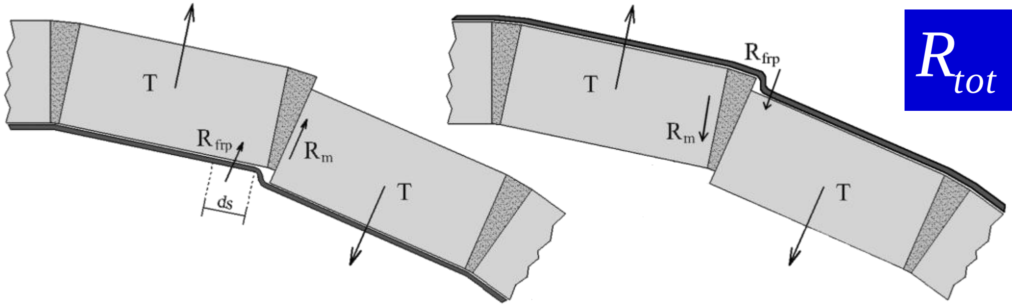


Triplet Tests: linear relation between tangential (τ) and compressive (σ) stresses



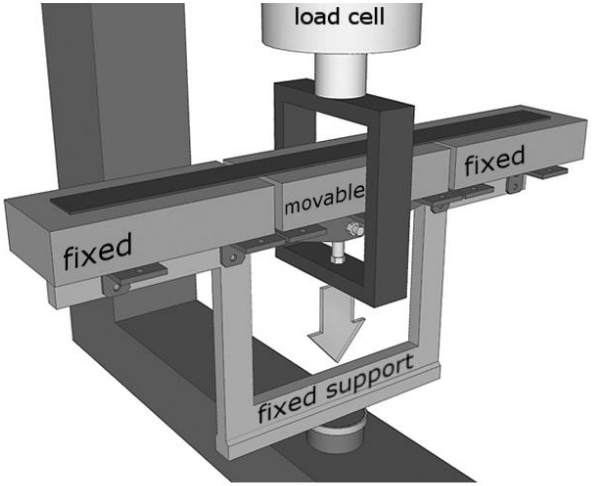
(c) Shear sliding on mortar joint – 2

Could the reinforcement (if adequately anchored) offer any contribution to the joint's shear resistance?



$$R_{tot} = R_m + R_{frp} \,?$$

Experimental characterization of the influence of FRP composite on the joint shear strength:



Influence of FRP composite on the joint shear strength

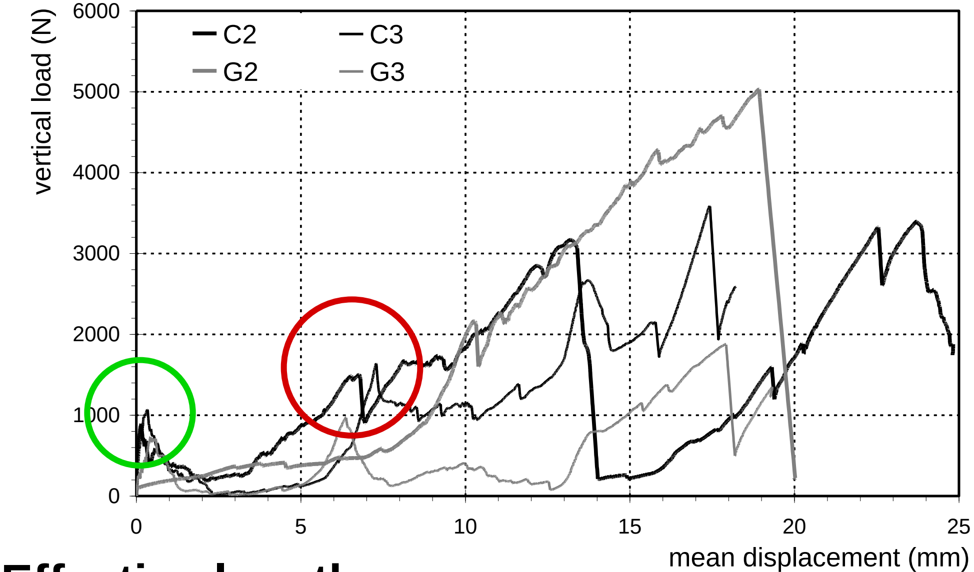
TESTS RESULTS

Progress of the vertical load →

1° peak: displacements lower than 0.7 mm

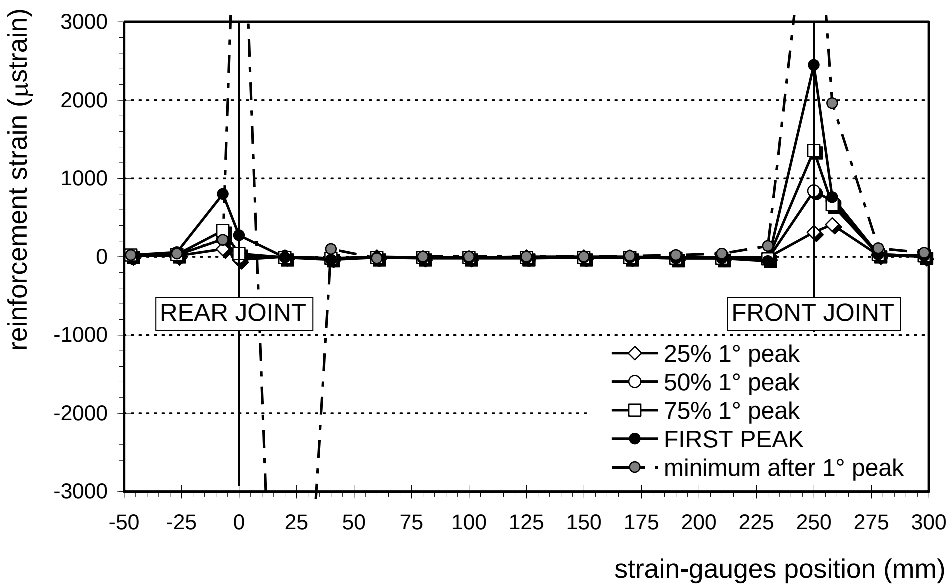
2° peak: displacements around 6 – 8 mm

subsequent peaks: not considered



Effective lengths ←

reasonably comparable with strain-gauges' spacing (20 mm)



MEAN PEAK LOADS (strips 50mm wide)

CFRP:	**511 N (1st)**	**810 N (2nd)**
GFRP:	**393 N (1st)**	**808 N (2nd)**

Influence of FRP composite on the joint shear strength

ANALYSIS

Starting assumptions:

Tested vaults → **geometry; materials' properties**

Local characterization test → **2° peak loads (reinforcement contribution)**

Significant parameters → **s – model vault's thickness (55mm ÷ 250mm)**
Q – failure load related to masonry crushing

Comparison:

Frictional contribution → **Coulomb law:** $R_m = \mu C$

"Reinforcement" contribution → **experimental calibration:** R_{frp}

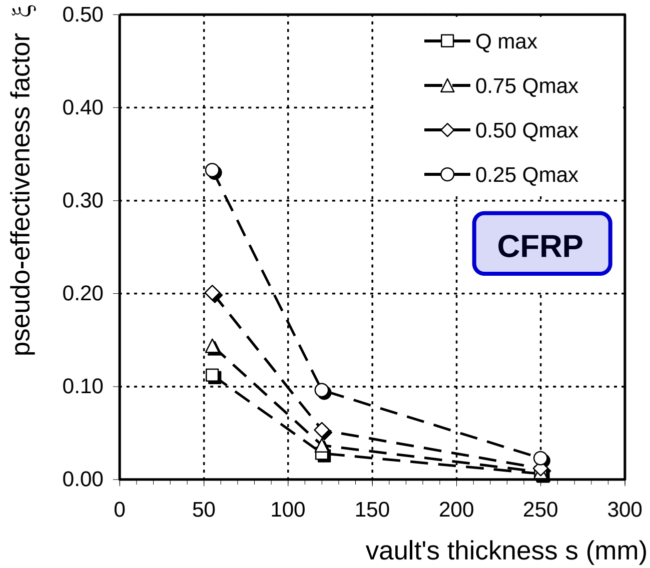
Frictional vs. reinforcement contribution ratio:
the *pseudo-effectiveness factor* ξ

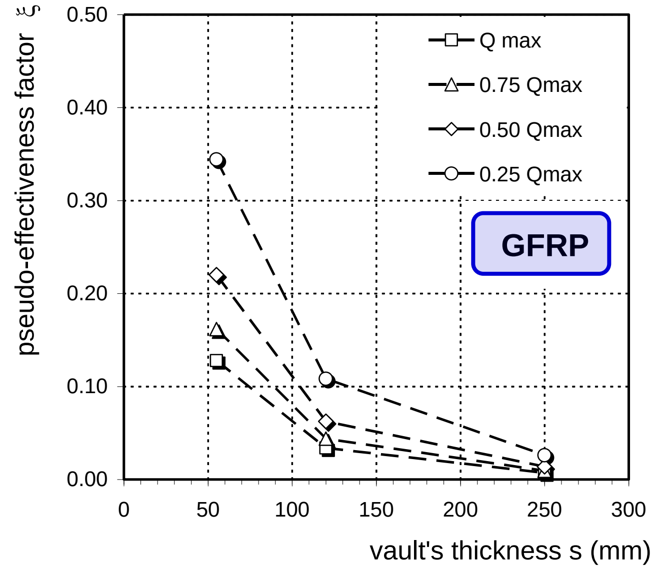
$$\xi = \frac{R_{frp}}{R_m}$$

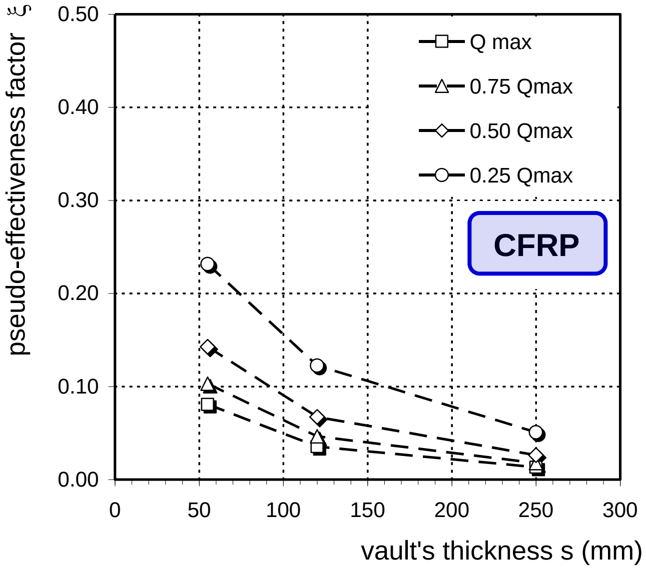
ANALYSIS RESULTS

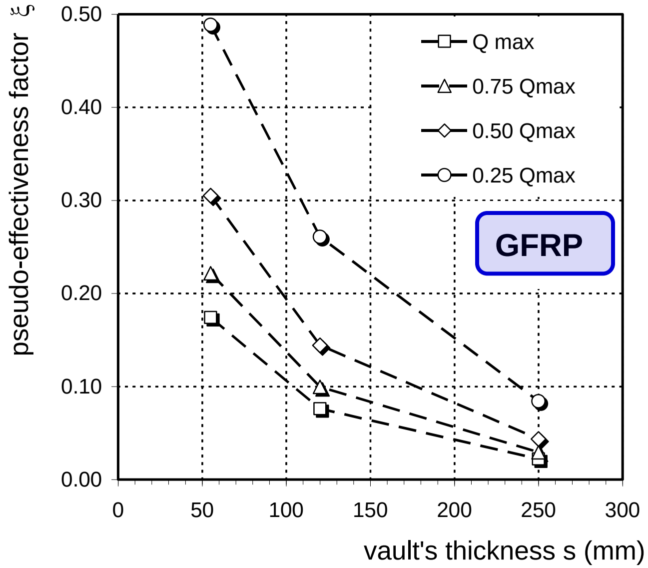
$$\xi = \frac{R_{frp}}{R_m}$$

Estimation of the ξ factor (constant width of the reinforcement)







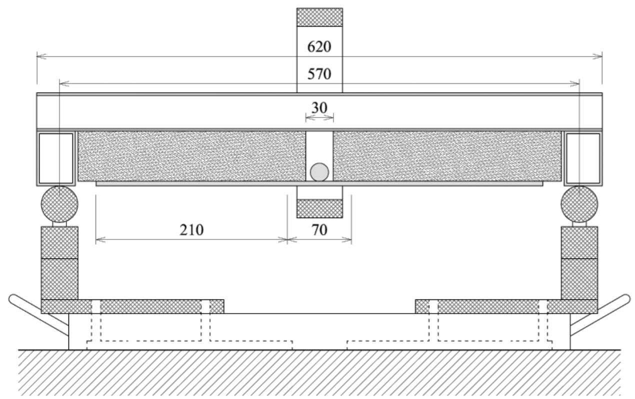


Estimation of the ξ factor (constant reinforcement normalized area fraction ω)

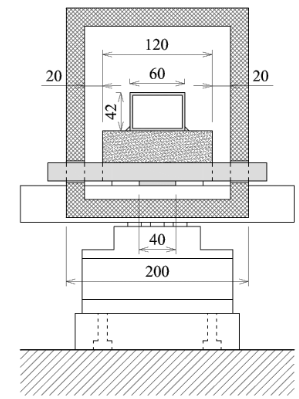
$$\omega = \frac{\varepsilon_{M,u} E_{frp}}{f_k} \frac{A_{frp}}{ls}$$

Conclusions

- a contribution offered by the reinforcement has been observed at the local test level;
- in case of thin vaults and second peak mechanism fully developed, the reinforcement influence on the joint shear resistance could be not irrelevant: for single skin vaults, it could vary from 8% to 18% of the frictional strength (μC) related to the failure load evaluated with respect to masonry crushing;
- the test set-up need to be simplified: possible improvements on the basis of the V-Shape Peel Test (*).



longitudinal section



transversal section

(*) Sun Z., Wan K.T., Dillard D.A. (2004). *A theoretical and numerical study of thin film delamination using the pull-off test*, Int. Journal of Solids and Structures 41, 717-730.

Wu Z., Yuan H. et al. (2005). *Experimental and analytical studies on peeling and spalling resistance of unidirectional FRP sheets bonded to concrete*, Composites Science and Technology 65, 1088–1097

SHEAR MECHANISM OF BRICK MASONRY VAULTS

THANK YOU FOR THE ATTENTION

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