

# Experimental and numerical assessment of reinforced concrete joints subjected to shear loading

**Diogo André de Oliveira Figueira da Silva**

Afonso de Serra Neves, Rui Calçada, Carlos Sousa

2016



# Contents List

1. Experimental assessment
2. Design recommendations
3. Numerical assessment
4. Conclusions

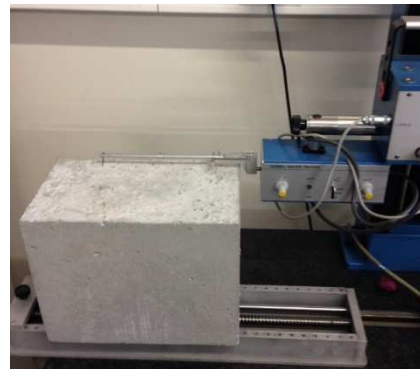


## 1. Experimental assessment

Monotonic and cyclic push-off tests with LVDT's measuring slip and crack opening.

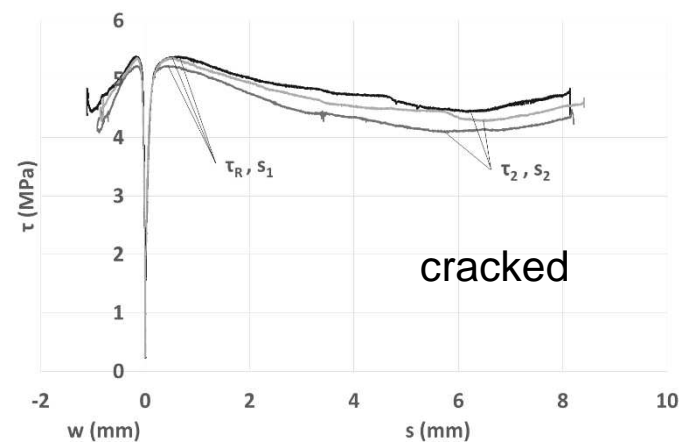
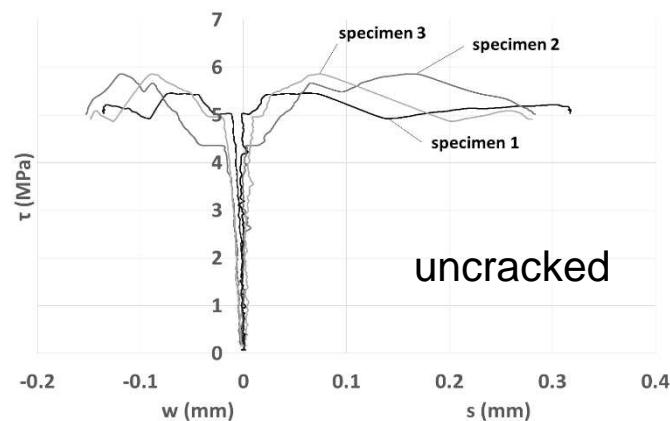
Specimens cast in 3 stages in order to create a concrete joint.

Interface roughness measured with a mechanical contour plot instrument.



	$\tau_{\min} / \tau_R$ (%)	$\tau_{\max} / \tau_R$ (%)	quantity
monotonic	-	-	$\times 3 = 3$
cyclic	5	80	$\times 3 = 12$
	25	80	
	5	70	
	5	60	

Results for interfaces subjected to monotonic shear loading:

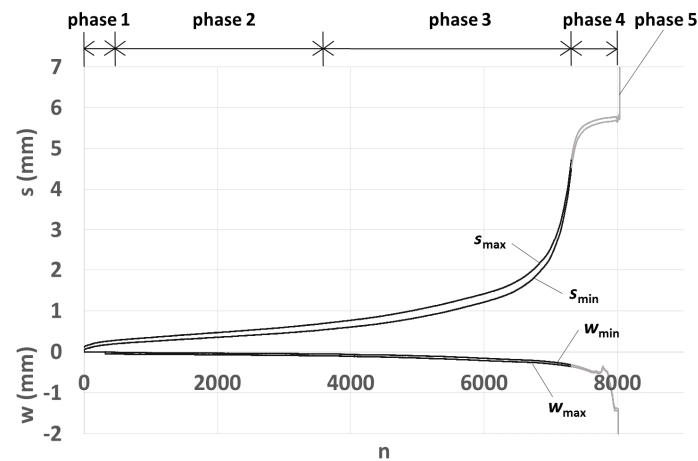


$$R_a = 0.352 \text{ mm}$$

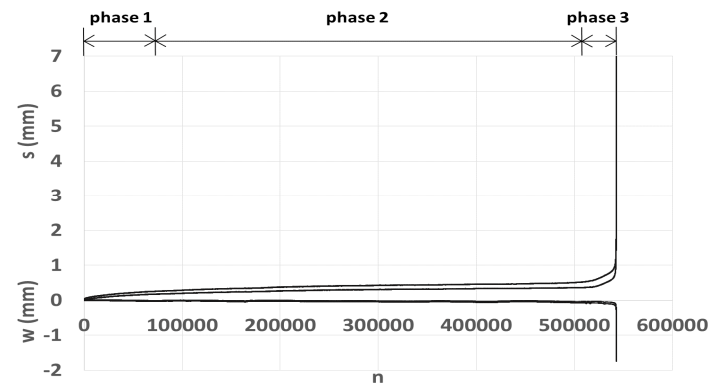


# 1. Experimental assessment

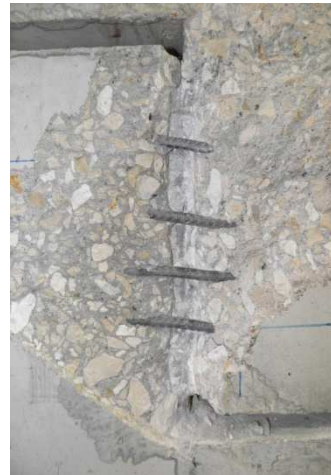
Results for cracked interfaces subjected to cyclic shear loading:



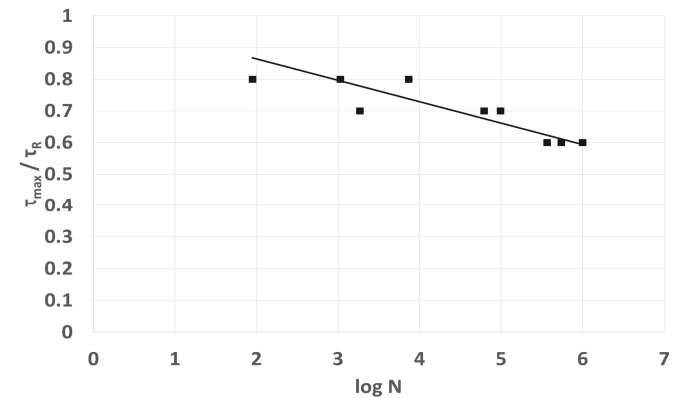
low cycle loading



high cycle loading



S-N curve

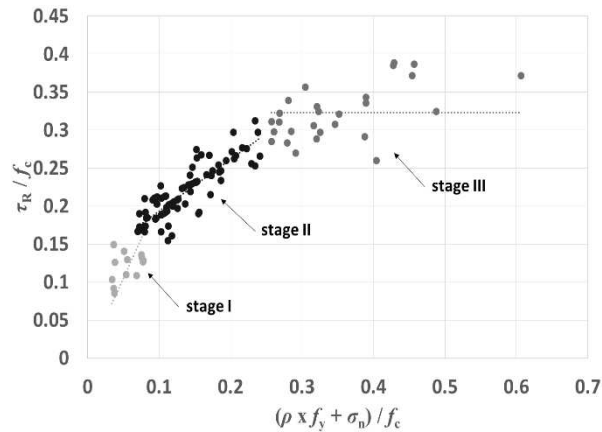


$$\frac{\tau_{\max}}{\tau_R} = 1 - 0.0677 \times \log N$$

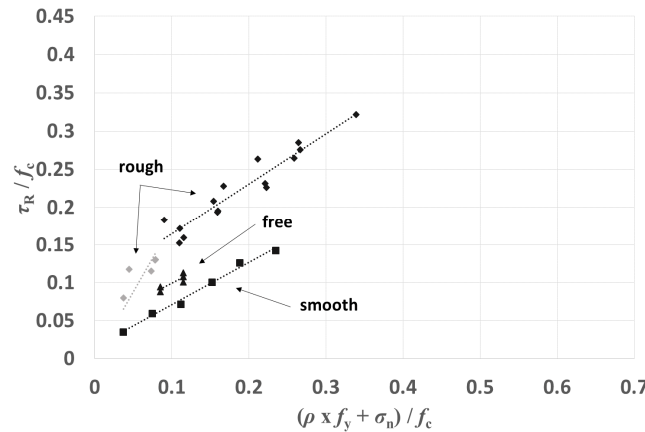


## 2. Design recommendations

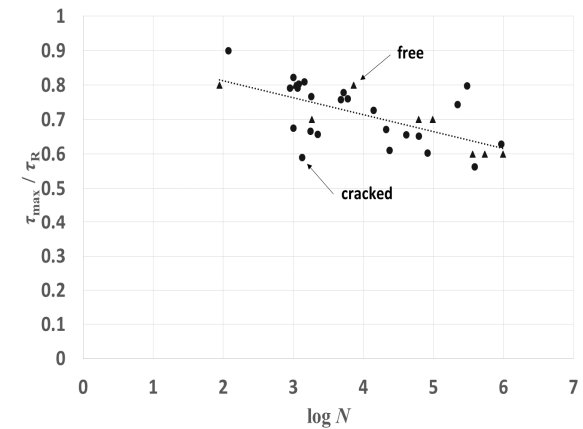
Analysis of experimental test data available in literature:



monolithic concrete cracked surfaces

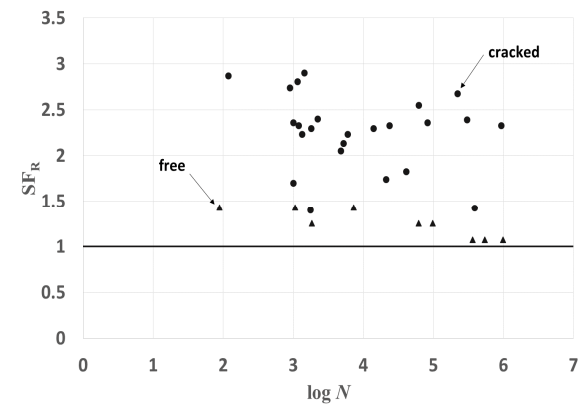
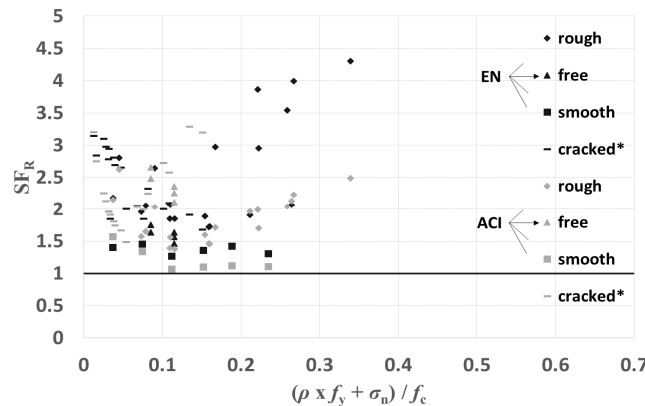
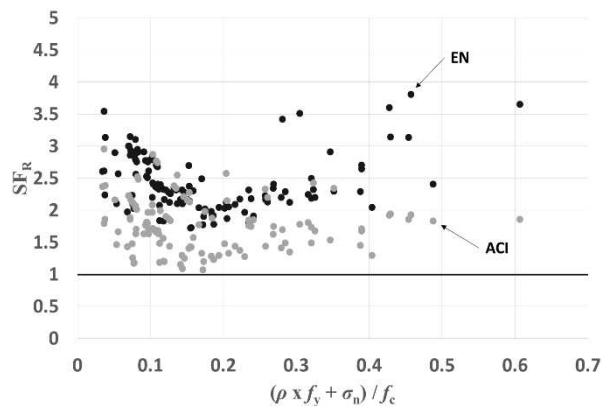


concrete joint surfaces



cyclic tests

Analysis of design code recommendations (EN 1992 and ACI 318-05):



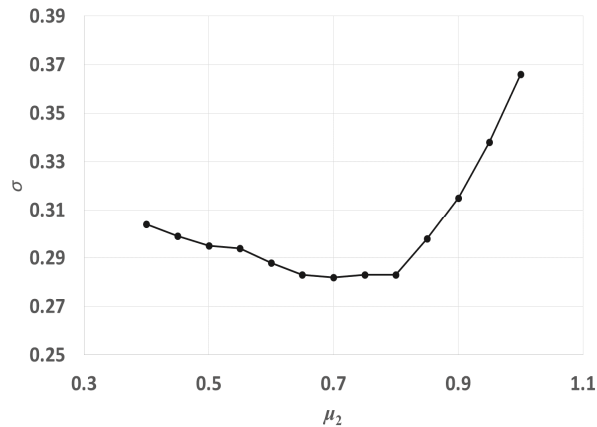
$$\tau_{Rd,EN} = c \times f_{ctd} + \rho \times f_{yd} \times (\mu \times \sin \alpha + \cos \alpha) + \mu \times \sigma_n \leq 0.5 \times v \times f_{cd}$$

$$\tau_{Rd,ACI} = \rho \times f_y \times (\mu \times \sin \alpha + \cos \alpha) \leq 0.2 \times f_c' \text{ and } 5.5 \text{ MPa}$$

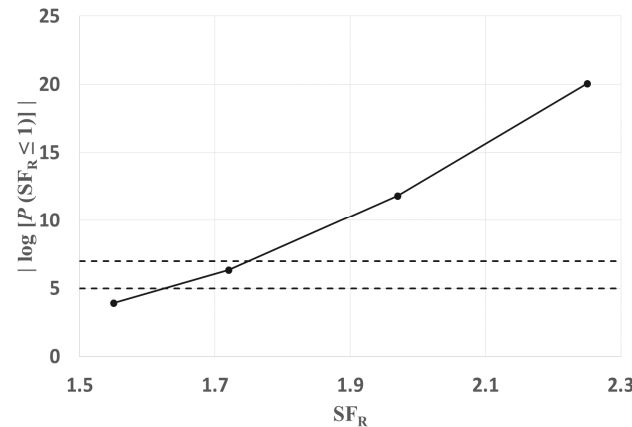


## 2. Design recommendations

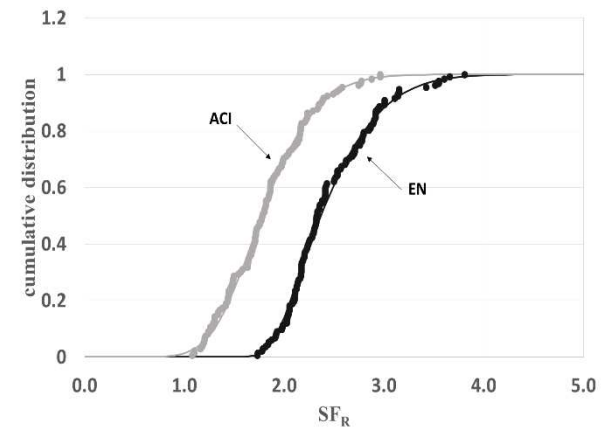
Criteria and procedures adopted to reach new design recommendations:



minimize variability in SFR values



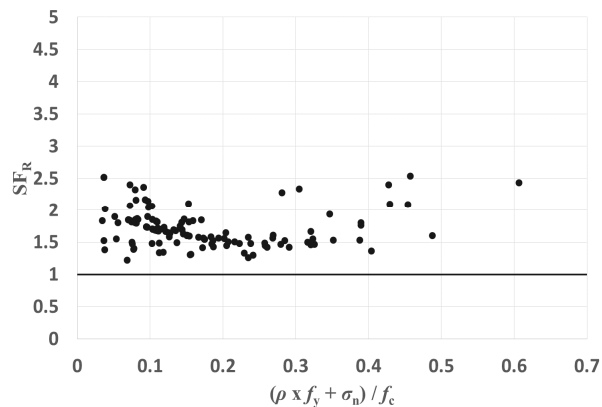
$P(SFR \leq 1)$  within the target range



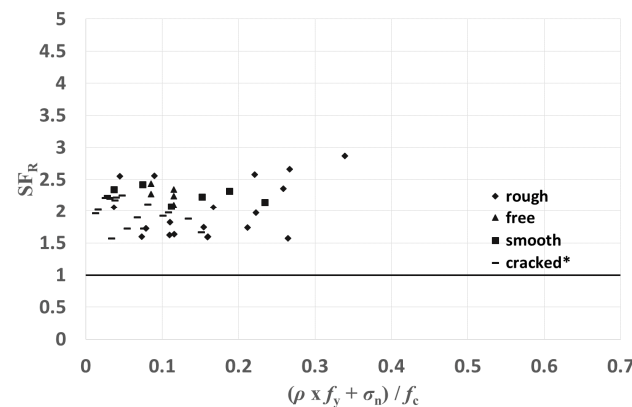
statistical hypothesis testing

New design proposal:

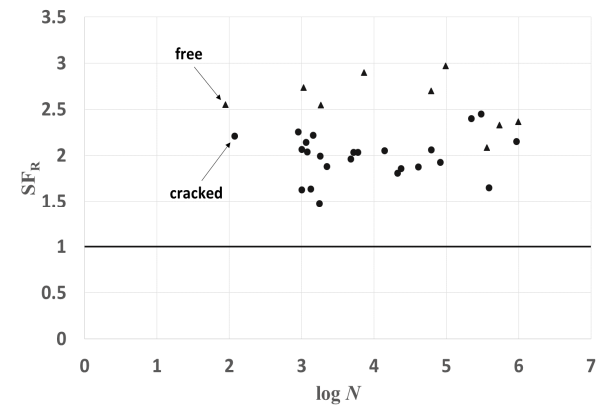
$$\tau_{Rd} = \min\{\tau_{Rd1}, \tau_{Rd2}, \tau_{Rd3}\} \quad \tau_{\max} / \tau_{Rd} = 0.80 - 0.045 \times \log N$$



$$\tau_{Rd1} = \mu_1 \times (\rho \times f_{yd} + \sigma_n)$$



$$\tau_{Rd2} = c \times f_{cd} + \mu_2 \times (\rho \times f_{yd} + \sigma_n)$$

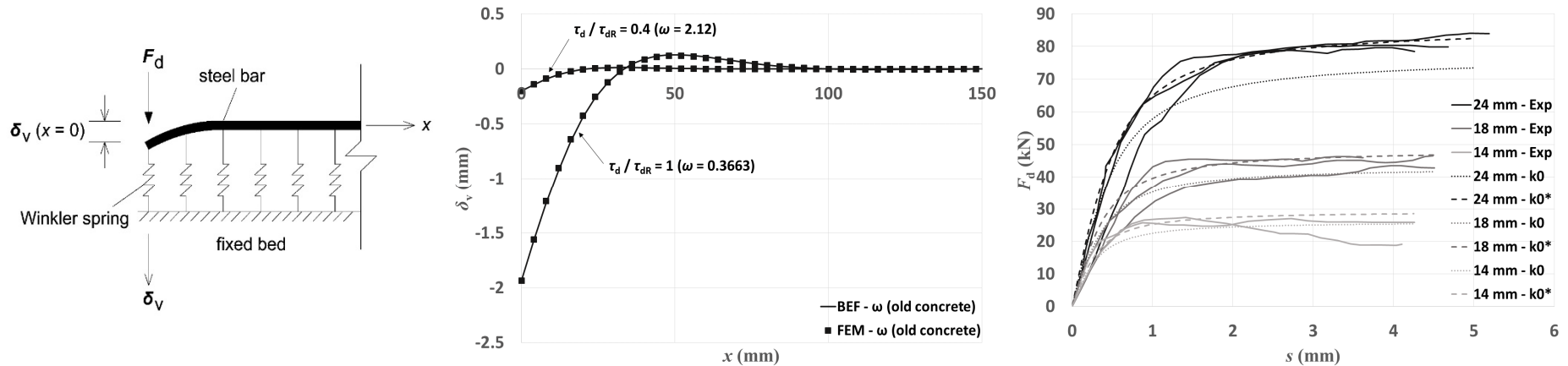


$$\tau_{Rd3} = d \times v \times f_{cd}$$



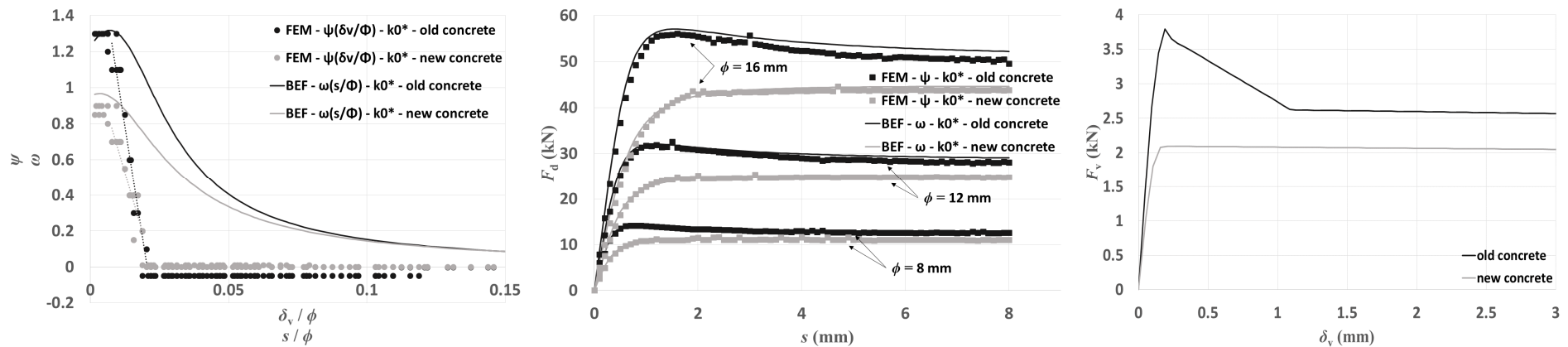
### 3. Numerical assessment

Dowel action non-linear finite element modeling:



spring elements for concrete    class III beam elements for reinforcement    Brenna et al. model for dowel action

Expressions were determined for the non-linear behavior of the Winkler springs:

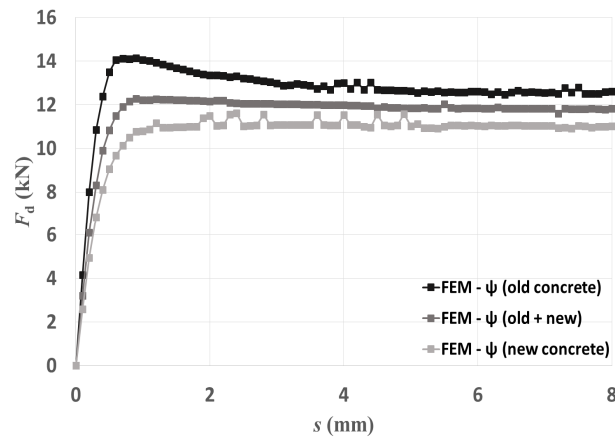


$$\psi = a \Leftrightarrow \frac{\delta_v}{\phi} \leq 0.0065 \quad \psi = b \times \left( \frac{\delta_v}{\phi} \right) + c \Leftrightarrow 0.0065 < \frac{\delta_v}{\phi} \leq 0.022 \quad \psi = d \Leftrightarrow 0.022 < \frac{\delta_v}{\phi} \leq 0.117 \quad \psi = 0 \Leftrightarrow \frac{\delta_v}{\phi} > 0.117$$

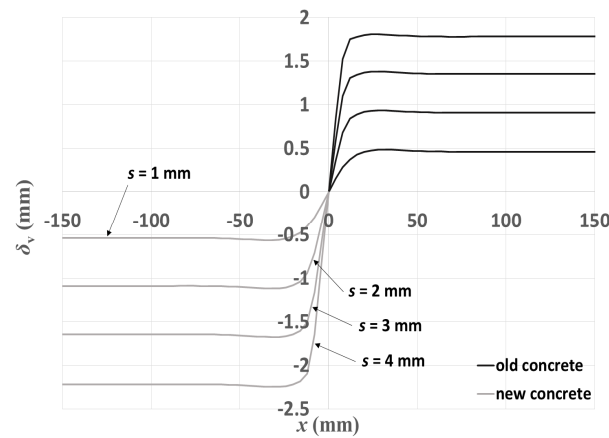


## 3. Numerical assessment

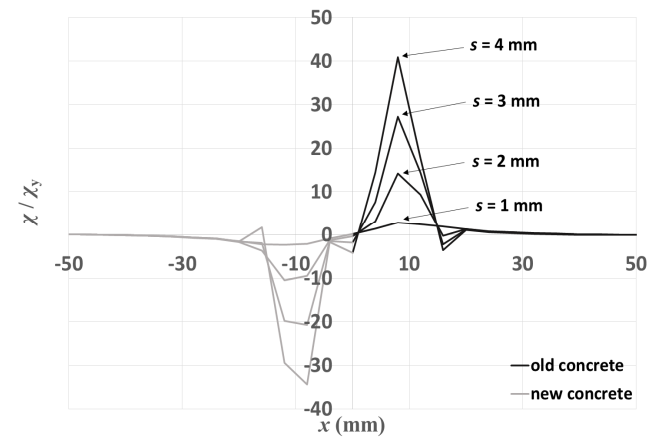
Dowel action behavior in a concrete joint:



dowel force

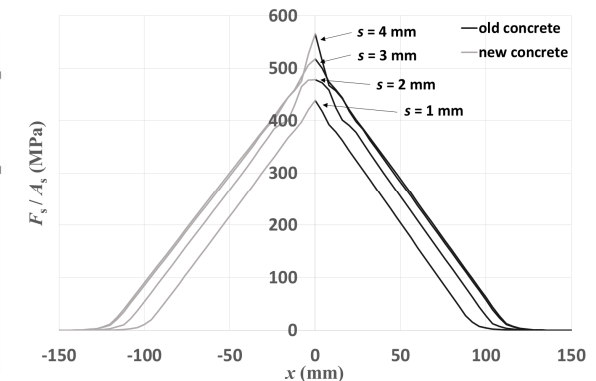
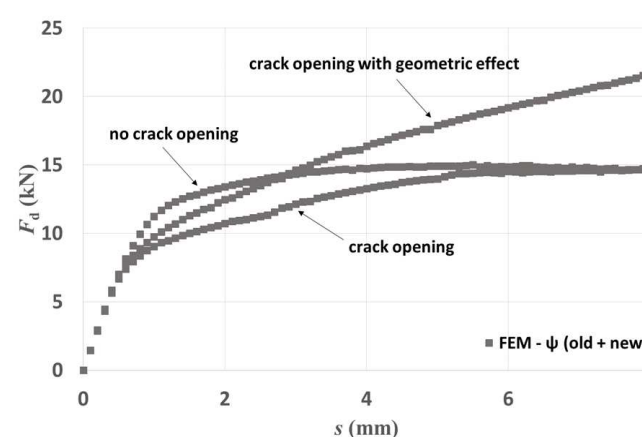
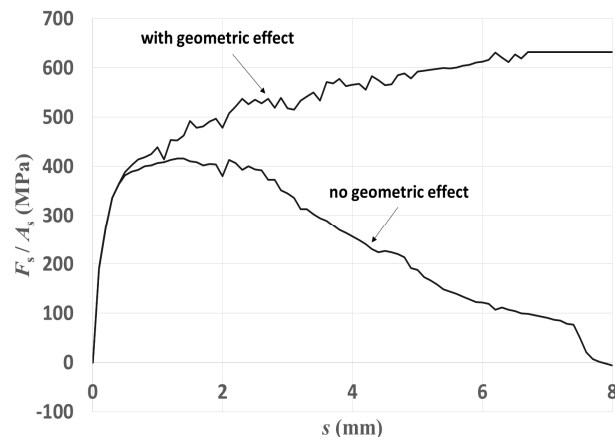


vertical displacements



curvatures

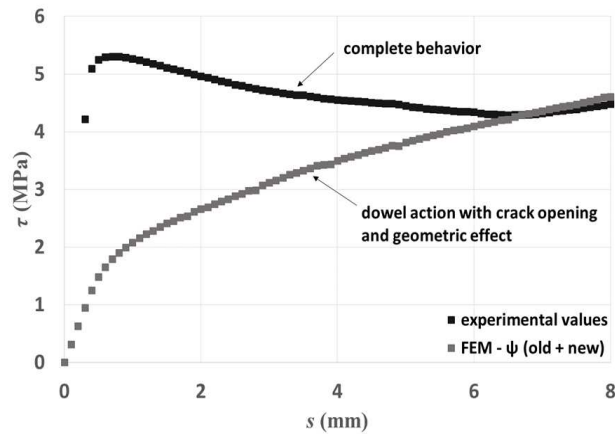
Tangential springs were added in order to simulate steel/concrete bond behavior. Interface crack opening was applied and geometric non-linearity effect activated.



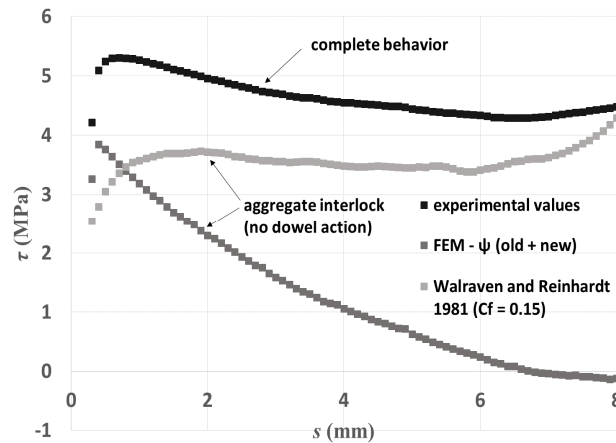


### 3. Numerical assessment

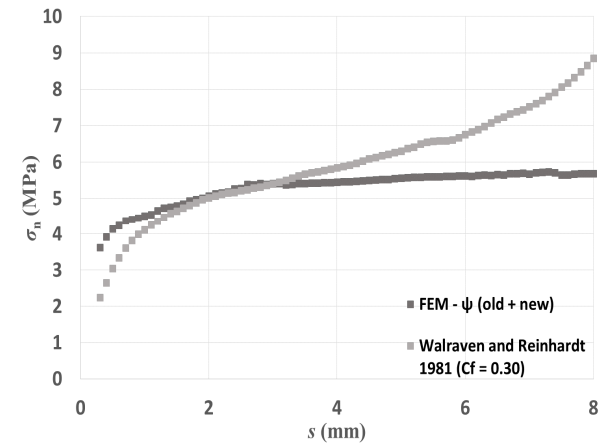
Aggregate interlock contribution and comparison with Walraven (1981) expressions:



dowel action contribution

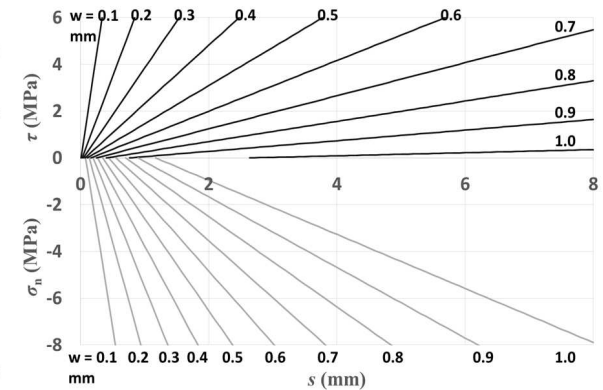
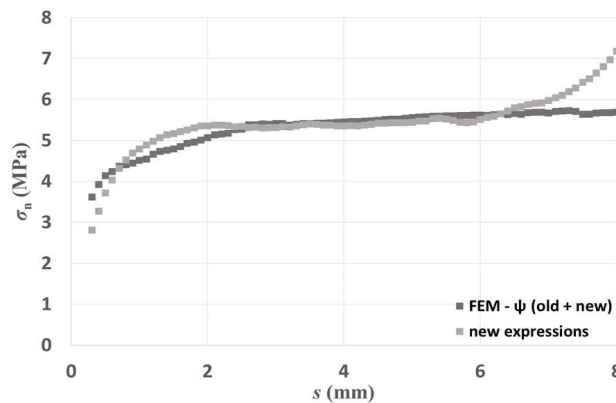
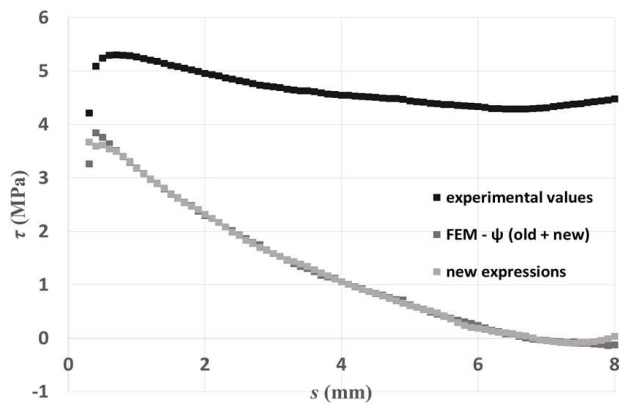


aggregate interlock (shear stress)



aggregate interlock (normal stress)

New expressions were determined to calculate aggregate interlock contribution:



$$\tau_{\text{agg}} = 0.075 \left\{ -0.04 f_c + \left[ -1.555 w^{-0.8} + (0.292 w^{-1.205} - 0.25) f_c \right] s \right\} \quad \sigma_n = 0.389 \left\{ -0.06 f_c + \left[ -0.040 w^{-0.63} + (0.242 w^{-0.597} - 0.19) f_c \right] s \right\} \quad \text{PhD 2016 | 9}$$



## 4. Conclusions

1. Interface response is very different depending on the applied cyclic shear load amplitude due to reinforcement behavior.
2. An experimental S-N curve was obtained for concrete joints subjected to cyclic shear loading.
3. Code provisions for the design of concrete interfaces can be significantly improved in terms of safety and reliability.
4. New design expressions were derived for concrete interfaces subjected to monotonic and cyclic shear loading.
5. Finite element modeling allowed to determine new expressions to simulate the non-linear behavior of reinforcement concrete substrate through Winkler springs.
6. Geometric non-linearity effect has a main influence in interface dowel action contribution.
7. New expressions were derived to calculate aggregate interlock contribution to shear transfer in a concrete joint.