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# Composite model for predicting the punching resistance of R-UHPFRC-RC composite slabs

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# ABSTRACT

Adding a thin layer of Ultra-High Performance Fiber Reinforced cement-based Composite (UHPFRC), with or without steel rebars, over a Reinforced Concrete (RC) slab is an efficient reinforcement method for existing structures. The thin layer of UHPFRC serves as a tensile reinforcement for the RC slab, creating a composite element. A recent experimental campaign showed that the layer of UHPFRC significantly increases the rigidity and the punching shear resistance of a RC slab submitted to a point force. An analytical composite model is developed herein to predict the global bending behavior of the composite slab and the punching shear resistance. A multilinear moment-curvature relation for composite sections is proposed to calculate the global force-rotation behavior of a slab which can then be used in combination with a composite failure criterion to predict the punching shear resistance. The contribution of the concrete section to the punching shear resistance is obtained with existing models from the literature. The UHPFRC layer resists to punching shear by out-of-plane bending over a limited length equal to its height. This mechanism induces tensile stresses perpendicularly to the interface with the concrete. The contribution of the UHPFRC layer to the punching shear resistance thus depends on the tensile strength of concrete. The results of this analytical composite model are in good agreement with the experimental result. A method is also proposed to consider pre-existing deformation of the RC section for a post-installed UHPFRC layer.

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# 1. Introduction

The use of a thin layer of Ultra-High Performance Fiber Reinforced cement-based Composite (UHPFRC) as an external tensile reinforcement for Reinforced Concrete (RC) slabs is a spreading technique for strengthening existing structures [1]. UHPFRC layers reinforced (or non-reinforced) with small diameter steel rebars (R-UHPFRC) have a typical thickness of between 25 and 50 mm and are cast in place over RC slabs, creating a composite RU-RC section (Fig. 1a).

This reinforcement method was proven effective to strengthen one-way elements in bending and in shear [3,4].With its high tensile properties, the UHPFRC layer contributes to the resistance of the element by its in-plane tensile resistance and deformability as well as its out-of-plane bending resistance and rotation capacity [5,6].

In a previous paper by the authors [2], an experimental campaign on the punching shear resistance of composite RU-RC slabs submitted to a point force was presented. The tests showed that the layer of UHPFRC can increase the punching shear resistance of a RC slab by at least 69% without modifying its rotation capacity as it would be expected for a slab with added flexural reinforcement. As for one-way shear, the layer of UHPFRC resists to punching shear by out-of-plane bending (Fig. 1b), meaning that it activates a bending mechanism perpendicular to the plane of the deflected shape of the composite slab.

Over the last century, punching shear resistance of RC slabs has been the object of extensive research [7]. Various analytical models were developed to predict the punching shear resistance of RC slabs using elasticity and plasticity theories. A full review of the existing models can be found in [8].

A sector model was developed in 1960 by Kinnunen and Nylander [9]. Their model allowed simulating the behavior of an axisymmetric slab by assuming that slab sectors rotate around the edge of the column. With the assumed kinematic, the force-rotation curve of the slab is obtained and combined to a failure criterion to predict the punching shear resistance (Fig. 2). The proposed failure criterion is expressed as the ultimate tangential strain in the concrete near the column. The punching shear resistance is thus related to the state of deformation in the slab due to bending.





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# Nomenclature

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$ \begin{array}{c} V_{calc} \\ V_{exp} \\ U \\ W_{exp} \\ W_{u} \\ W \\ $	V <sub>C</sub> V.	Calculated shear force	κ	curvature when the layer of LIHPERC is added to a RC
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	V calc	Measured shear force	Nadd	section
Latin lower case b beam width b_0 critical perimeter for punching shear set at $d_{sc}/2$ from the column face b_1 distance between two force introduction points in the square test slab b_2 distance between force introduction point and nearest slab side $\lambda$ remaining ratio of $f_{Utu}$ $\rho$ reinforcement ratio $\rho_{TC}$ reinforcement ratio in the tension chord $\sigma$ stress $\psi$ rotation $\psi_{add}$ rotation when the layer of UHPFRC is added to a RC slab	V exp V.	LIHPERC layer contribution to punching resistance	Kre	reduction in the curvature due to tension stiffening
Latin lower case $\rho$ reinforcement ratiobbeam width $\rho_{TC}$ reinforcement ratiobcritical perimeter for punching shear set at $d_{sc}/2$ from the column face $\rho_{TC}$ reinforcement ratio in the tension chordbdistance between two force introduction points in the square test slab $\psi_{add}$ rotationbdistance between force introduction point and nearest slab sidesiderotation	•0	of the layer contribution to puncting resistance	$\lambda$	remaining ratio of fu
$\begin{array}{cccc} p & \text{reinforcement ratio} \\ b & \text{beam width} & \rho_{TC} & \text{reinforcement ratio} \\ b_0 & \text{critical perimeter for punching shear set at } d_{sc}/2 \text{ from} & \sigma & \text{stress} \\ & \text{the column face} & \psi & \text{rotation} \\ b_1 & \text{distance between two force introduction points in the} & square test slab \\ b_2 & \text{distance between force introduction point and nearest} \\ & \text{slab side} \end{array}$	Latin Journ case		0	reinforcement ratio
$ \begin{array}{c} b \\ b_{0} \\ critical perimeter for punching shear set at d_{sc}/2 \text{ from} \\ distance between two force introduction points in the square test slab \\ b_{2} \\ distance between force introduction point and nearest \\ slab side \\ \end{array} $	LULIII IOV	been width	Р Отс	reinforcement ratio in the tension chord
$ \begin{array}{c} b_{0} \\ b_{1} \\ b_{2} \\ b_{2} \\ b_{3} \\ b_{4} \\ b_{2} \\ b_{3} \\ b_{4} \\ b_{2} \\ b_{3} \\ b_{4} \\ b_{5} $	D h	Detail willing char set at $d/2$ from	$\sigma$	stress
$b_1$ distance between two force introduction points in the $\psi_{add}$ rotation when the layer of UHPFRC is added to a RC slab $b_2$ distance between force introduction point and nearest slab side	<i>D</i> <sub>0</sub>	the column face	Ŵ	rotation
<ul> <li>b<sub>1</sub> additional and a square test slab</li> <li>b<sub>2</sub> distance between force introduction point and nearest slab side</li> </ul>	h.	distance between two force introduction points in the	T Vada	rotation when the laver of UHPFRC is added to a RC slab
<i>b</i> <sub>2</sub> distance between force introduction point and nearest slab side	<i>v</i> <sub>1</sub>	source between two force infroduction points in the	7 uuu	
slab side	h <sub>2</sub>	distance between force introduction point and pearest		
	52	slab side		

The sector model served as a basis for further model developments [10-12]. Hallgren [10] modified the failure criterion using fracture mechanics. Muttoni [12] used the sector model to develop the critical shear crack theory (CSCT) in which the failure criterion is a function of the slab rotation. The CSCT is now the basis for the punching shear resistance calculation in the *fib* Model Code 2010 [13] as well as the Swiss standards for the design of concrete structures [14].

The objective of the presented work is to develop analytical models to include the contribution of the UHPFRC layer to the punching shear resistance calculation of a composite slab. First, a multilinear moment–curvature relation is proposed to predict the Download English Version:

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