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Enhanced shear punching capacity by the use of post installed concrete screws

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A B S T R A C T

In the field of reinforced concrete structures, there is a growing need for structural engineers to develop methods that raise the shear punching capacity of existing flat slabs. Unfortunately, current structural solutions that aim to enhance the shear punching capacity suffer from many technical and economic problems. The aim of this paper is to develop a new and more efficient method for raising the shear punching capacity of existing concrete structures. The main idea behind this new strengthening method is to use post installed concrete screws as a punching reinforcement. This new strengthening method was analysed within an experimental framework performing shear punching tests on samples containing post-installed concrete screws. In addition to experimental tests, numerical simulations, based on the finite element method, were executed to derive a simplified model to calculate the shear punching capacity of strengthened slabs. In comparison to currently available structural methods, this new method, based on the use of post installed concrete screws, satisfies much of the criteria required for effective structural reinforcement. Along with robustness and economic efficiency, this new strengthening method leads to a significant increase in shear punching capacity.

1. Introduction

In the field of reinforced concrete structures, there is a growing need for structural engineers to develop methods that raise the shear punching capacity of existing flat slabs. Reasons for this need are for example changes of usage of existing structures that lead to higher live loads, inaccurately executed constructions (e.g. forgotten shear punching reinforcement; too low concrete covering or concrete strength), mistakes of construction engineers or different design rules due to the introduction of new regulations, like the EN 1992-1-1 in Europe. Additionally, increasing the deformation capacity in order to avoid integrity reinforcement is also a decisive reason for placing punching shear reinforcement. Moreover, recent building failures caused by a local punching failure like the breakdown of the Pipers Row Carpark in Wolverhampton 1997 or the collapse of the Sampoong-Department-Store in Seoul (South Korea) 1995, lead to a worldwide discussion concerning the safety of existing flat slabs. The threat of a punching failure is the brittle structural behaviour that can lead, especially in case of flat slabs without punching reinforcement or flat slabs without an additional collapse-reinforcement, to a progressive collapse of the whole load-bearing structure.

To raise the shear punching capacity of existing concrete structures only a few structural solutions are in use. Unfortunately, these solutions suffer from many technical and economic problems. A common solution to raise the shear punching capacity of existing flat slabs is to enlarge the supporting area by the use of a reinforced column cap. The enlargement of the supporting area raises the shear loaded area of the flat slab and leads to a significant raise of the maximum shear punching load capacity. But this solution suffers from economic problems in terms of material usage/costs and installation time. Additionally the installation of the described reinforcement method itself affects the usage of the building and next to aesthetic effects leads to changes of the structural clearance.

Another well-known solution to raise the shear punching capacity of existing concrete structures is the method based on the enhancement of the flexural capacity of the concrete structure by using post installed and pre-stressed Carbon-Fiber-Reinforced-Polymer strips (CFRP-strips) or by the use of an additional post installed reinforced concrete layer. A theoretical explanation for the positive correlation of the flexural capacity and the shear punching capacity is given by Regan [1]. The enhancement of the flexural capacity, especially an increase of the reinforcement amount, leads, according to Regan [1], to an increasing depth of the uncracked compressive zone of the flat slab. Furthermore, the width of shear cracks declines and as a result the maximum forces transferred by

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Variables

α	angle between the shear reinforcement element and the horizontal plane of the slab
b	variable, taking the material degradation within the definition of the compressive behaviour into account (b = 1, 0 represents no damaged material)
d_{eff}	effective depth of the flat slab
d_g	maximum diameter of the aggregate
ε_c	concrete strain, corresponding to the average, uniaxial compressive strength of concrete
E_c	modulus of elasticity of concrete
E_s	modulus of elasticity of reinforcement
$f_{c,cube}$	average compressive strength of concrete (cube)
$f_{ct,BZ}$	average bending tensile strength
f_{yk}	characteristic yield strength of flexural reinforcement
f_y	average yield strength of concrete screws
f_{1ct}	average, uniaxial tensile strength of concrete
f_{1c}	average, uniaxial compressive strength of concrete
G_f	fracture energy of concrete
G_{cl}	localised crushing energy of concrete
l_{eq}	equivalent element length of the finite elements
ν	Poisson's ratio

aggregate interlock increase. Due to the comparatively higher dead load in case of an additional post installed reinforced concrete layer, this reinforcement method lacks from efficiency problems. Furthermore the enhancement of the shear punching failure by raising the flexural capacity is limited. As a result, the described solutions only make sense in case of a low flexural reinforcement ratio.

Moreover there are solutions that lead to an increase of the shear punching capacity by strengthening the shear cracking zone. One common solution is based on drilled through and pre-stressed threaded rods. This method has the disadvantage that both sides of the slab need to be accessible for the installation of the system and as a result affects the usage of the flat slab. Another well-known solution works with post installed inclined bonded anchors [2,3], installed from the soffit of the slab. To maximise the bond length, the post installed elements are installed inclined with an angle of $\alpha = 45^\circ$. The main disadvantage of this system is that the maximum stress of the epoxy adhesive material is temperature-dependent and gradually declines with rising temperature starting at approximately 60 °C [4–6]. This has an impact on the efficiency of the system in case of a fire. Furthermore the drilling of the inclined boreholes often leads to a collision with the tensile reinforcement of the flat slab.

The aim of the research presented in this paper is to develop a new and more efficient method for raising the shear punching capacity of existing concrete structures. The main idea behind this new strengthening method is to use post installed concrete screws as a punching reinforcement. Due to the convenient anchoring behaviour, based on mechanical interlock, these screws can anchor high loads over a short embedded length and equally ensure a defined load capacity in case of fire. This new strengthening method was analysed within an experimental framework performing shear punching tests on samples containing vertically post-installed concrete screws. In addition to experimental tests, numerical simulations, based on the finite element method (FEM), were executed to derive a simplified model to calculate the shear punching capacity of strengthened slabs.

In comparison to currently available structural methods, this new method, based on the use of post installed concrete screws, satisfies much of the criteria required for effective structural reinforcement. Along with robustness and economic efficiency, this new strengthening method equally leads to a significant increase in shear punching capacity.

2. Experimental research

2.1. Specimens

Within the frame of four experimental shear punching tests P01–P04 the new reinforcement system has been tested. To reduce the costs of the tests, the shear punching tests were executed on circular flat slab sector elements including a part of the column underneath. All geometrical dimensions were kept constant for the specimens P01–P04. Based on a span width between 5 and 6 m and a common slenderness of the slab of $l/d = 35$ the diameter of the specimens was set to 2700 mm in plane and to a thickness of 200 mm. The part of the column underneath had a diameter of 300 mm and a height of 100 mm. To avoid an early bending failure of the flat slab, the flexural reinforcement was designed for a calculated load of 1.65 times the calculated shear punching resistance of the flat slab without any shear reinforcement according to ÖNORM B 1992-1-1 [7]. As a result the flexural reinforcement ratio was, dependent on the direction of the bars, $\rho_x = 2.10\%$ and $\rho_y = 2.39\%$ respectively, which is usual for flat slabs of this thickness. All specimens had the same amount and positions of flexural reinforcement (Fig. 2). The effective depth d_{eff} of the slab was 155 mm. To ensure exactly the same effective depth, the positions of the flexural reinforcement bars of all specimens were individually adjusted with plastic spacers. The lower layer of the flexural reinforcement consisted of straight bars with a diameter of 10 mm and a distance of 100 mm. To avoid a shear failure in the area of the twelve local load application positions, these areas were strengthened by additional stirrups.

Specimen P01 served as a reference specimen and was executed without any concrete screws. The specimens P02, P03 and P04 were strengthened with post installed concrete screws. The amount and the position of the screws were identical for all three strengthened specimens P02, P03 and P04 (see Fig. 5). Specimen P02 was strengthened with TSM B16 concrete screws in combination with a high-performance epoxy adhesive. Specimen P03 was executed with TSM B16 concrete screws without any composite material and specimen P04 was strengthened with TSM B22 concrete screws in combination with a high-performance epoxy adhesive.

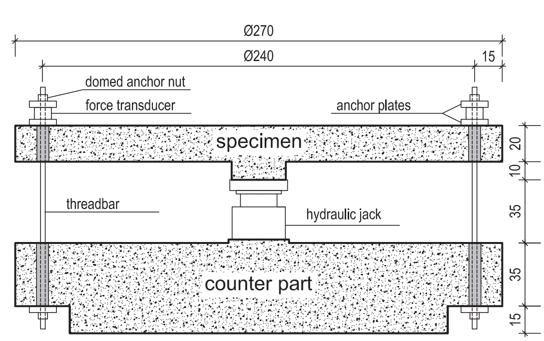

Fig. 1. Test set-up of the shear punching tests (cm).