

## IMPACT OF PLASTIC AND STEEL FIBRE REINFORCEMENT ON THE STRENGTH OF STEEL ANCHORS

Daniel Dudek✉, Kazimierz Konieczny

Building Research Institute (ITB), Warsaw, Poland

### ABSTRACT

The paper describes changes of strength of steel anchors depending on the diameter of the drill hole, the crack width and presence of plastic and steel fibres. Tests were carried out on C20/25 concrete bases with two specific fibre admixtures. Two types of anchors were selected for the tests: stud and sleeve anchors with M12 diameter, for their frequent application in construction. Steelbet 50/0.8 fibres affect the strength of the connections which use stud anchors, reducing the pullout resistance by ca. 10% in non-cracked C20/25 concrete. For cracked concrete with crack width of 0.30 mm and connections using stud anchors, no effect of using steel fibres was found, a 30% increase in strength was found for connections using stud anchors and the minimum drill hole diameter and a 20% reduction in strength for the maximum drill hole diameter, as compared to the minimum diameter. For sleeve anchors, reductions and an increase of 10% in strength were observed. The obtained results indicate a need to develop assessment criteria for effects of external factors in the form of steel fibre admixtures.

**Key words:** fibre concrete, steel anchors, plastic and steel, concrete, crack

### INTRODUCTION

With newer, innovative construction technology and fast economic growth, new issues emerge related to the strength of steel anchors in structural elements. Steel anchors used for structural connections have a structure for which target application is specified (Dudek, 2017). Currently, anchors are commonly used for connections in non-cracked and cracked concrete (Pregartner, 2009). With adopted installation parameters, characteristic strengths are calculated depending on the condition of the base. Requirements applicable to new and existing buildings keep becoming more strict as new execution technologies and new fastening systems force a change of approach to specific engineering solutions (Eligehausen & Fuchs, 1992). This is related to changing economy conditions and requirements of building owners and users. Variable actions on anchors

installed in structural elements cause changes which affect the final strength of the anchors and result in technical, engineering and usage issues (Eligehausen, Mallée & Silva, 2006). Torque-controlled anchors used for structural connections transfer tensile loads through friction (International Federation for Structural Concrete [fib], 2011). The friction force occurs between the anchor's side surface and the surface of the opening drilled in the base (Dudek & Kadela, 2016). The force acting along the circumference of the anchor keeps it in place. Expansion of the anchors occurs as a result of applying torque, which will be referred to as installation torque (Fuchs, Eligehausen & Breen, 1995). Steel sleeve anchors differ in build. Their working principle is similar to stud anchors. The range of applications allowed by the sleeve, which increases the connecting surface, makes them more appropriate and frequently used for heavy loads. Pullout resistance is tested for

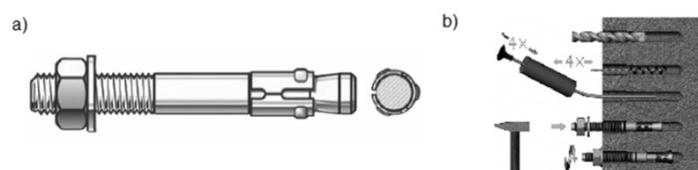
non-cracked and cracked concrete in specialised test laboratories. The static crack width used, without seismic actions, was equal to 0.80 mm. Typically however, tests are carried out with crack width of 0.30–0.50 mm (Hoehler & Eligehausen, 2008). Plastic and steel fibres are increasingly used as modification of concrete base elements despite the facts that this admixture technology is over 20 years old. This modification of concrete base elements modifies strength properties and the result is referred to as fibre reinforced concrete (Balaguru & Shah, 1992). The aim of preparing the fibre reinforced concrete is to increase resistance to cracking and propagation of cracks. To this end, admixtures in the form of fibres, meshes and mats are used. After the process of adding the right fibres the propagation of cracks is stopped (Bentur & Mindess, 2006). For the purposes of this paper plastic and steel fibres were used. Polyethylene fibres are manufactured through fibrillization of low density polyethylene. Low density polyethylene is obtained from ethylene in a process of polymerisation under pressure. These fibres have been commonly used in construction for the past 15 years, where their strength parameters are constantly being improved. Polypropylene fibres effectively prevent cracks and shrinkage damage, they reduce permeability of concrete and mortar and improve their performance (Brandt, 2009). They are very easy to use and do not require any changes to the methods of mixing the concrete or mixing time. They are compatible with all surface finishes. After the concrete has hardened and has been smoothed, the fibres are practically invisible. They increase resistance to frost and weather conditions, reduce corrosion of reinforcement steel and they are highly resistant to acids and salts. They are packaged in specially manufactured, soluble bags, which makes it possible to mix the fibres together with their packaging. The fibres' impact is purely mechanical and they work well with all concrete mixes and additions without the need to change proportions of

mix ingredients. Steel fibres, as an addition modifying strength parameters of concrete, eliminate plastic cracking and increase residual strength (Maidl, 1995). Forces are transferred by the fibres from the moment of damage in the cement matrix. One disadvantage of steel fibres is the occurrence of rust on the concrete surfaces. Apart from corrosion, some difficulties have been found in obtaining a homogenous concrete mix, proportional to the amount of fibre admixture. The material used for these fibres is steel with high tensile strength of up to 1,200 MPa. A special shape of the fibres allows good anchoring in the hardened concrete. This leads to increased adhesion to the cement matrix. Steel fibres are typically used to reinforce industrial floors, heavily loaded traffic surfaces and concrete precast elements. The main features of steel fibres for which they are used are: elimination of cracks, improving strength parameters of concrete floors, improving fatigue resistance, simple dosage methodology, allowing reduction of the thickness of concrete floors while maintaining their performance parameters, allowing to abandon the traditional reinforcement with welded mesh. This solution eliminates the problems related to installing the mesh and keeping it at the right height in the concrete slab.

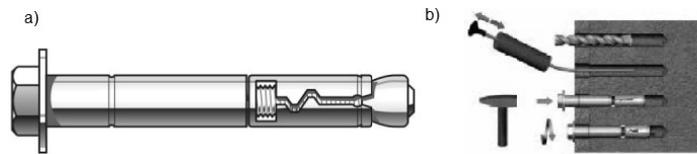
## MATERIAL AND METHODS

Two types of expansion anchors were chosen for the tests: M12 stud anchors and M12 sleeve anchors. Figures 1 and 2 present the structure of the anchors along-side methods of drilling and cleaning the openings.

The tests consisted in determining the maximum pullout force for steel expansion anchors in C20/25 concrete bases (Kim, Yu & Yoon, 2014). The anchors were installed in drill holes with three different diameters  $d_{cut}$ : minimum, nominal and maximum. Pullout strength, without accounting for spacing, distance of the anchors from the edge and the thickness of the base



**Fig. 1.** Steel anchor – stud/expansion: a – construction; b – installation



**Fig. 2.** Steel anchor – sleeve/expansion: a – construction; b – installation

(Nilforoush et al., 2016a; 2016b), determined based on tests of steel expansion anchors subjected to static or quasi-static load is described by the formula (American Concrete Institute Committee, 2001; 2008):

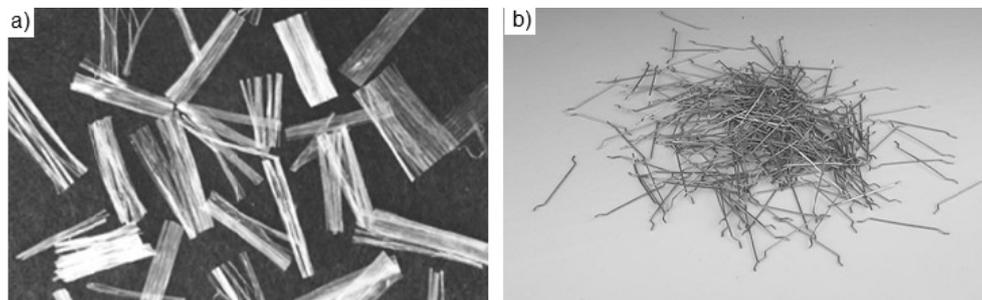
$$F_{Ru, \text{cone}} = F_{Ru}^t \cdot \left( \frac{f_c}{f_{c, \text{test}}} \right)^{0.5}$$

where:

- $F_{Ru, \text{cone}}$  – mean failure load in the event of failure of the concrete base [kN],
- $F_{Ru}^t$  – test failure load [kN],
- $f_c$  – standard compressive strength of the concrete base [MPa],
- $f_{c, \text{test}}$  – compressive strength of the concrete base obtained from tests [MPa].

The concrete bases were prepared using the formula and aggregate grading curve prescribed in EADs and Eurocodes for steel anchors. Different concrete bases were prepared for the test – non-cracked and cracked (Karmažinova, Melcher & Štrba, 2009) with crack width of 0.3 mm. Apart from variance in condition of the base (cracks) additionally concrete bases were made with an admixture of plastic and steel fibres, both non-cracked and cracked. Figure 3 shows admixtures in the form of plastic and steel fibres.

The results of five tests in total were distributed in the range of 3–10%. Installation parameters of anchors are presented in Tables 1 and 2. Technical details of plastic and steel fibre admixtures are contained in Table 3.



**Fig. 3.** Applied fibre admixtures: a – plastic (PP); b – steel

**Table 1.** Installation parameters of M12 stud anchors made of galvanised carbon steel ( $R_m \geq 800$  MPa)

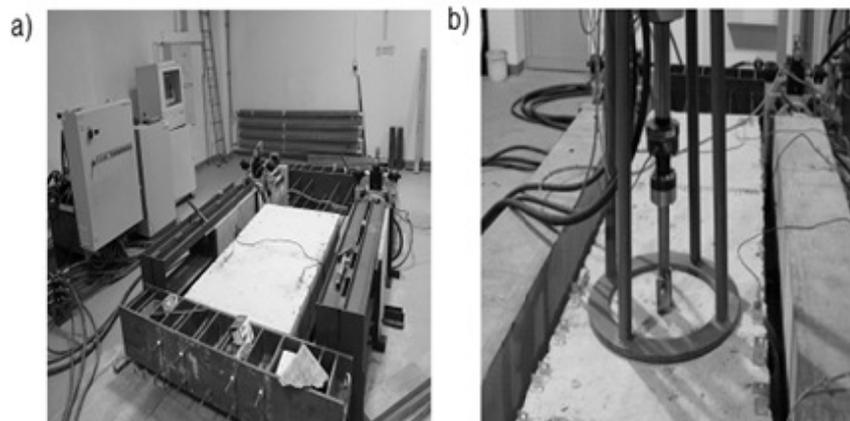
Compressive strength on C20/25 concrete base ( $f_{c, \text{test}, \text{C20/25}}$ ) [MPa]	Nominal embedment depth ( $h_1$ ) [mm]	Effective embedment depth ( $h_{ef}$ ) [mm]	Installation torque ( $T_{inst}$ ) [Nm]	Drill hole diameter ( $d_{cut, \text{min}}$ ) [mm]
30	80	60	80	12.15
				12.30
				12.45

**Table 2.** Installation parameters of M12 sleeve anchors made of galvanised carbon steel ( $R_m \geq 800$  MPa)

Compressive strength on C20/25 concrete base ( $f_{c, \text{test}, \text{C20/25}}$ ) [MPa]	Nominal embedment depth ( $h_1$ ) [mm]	Effective embedment depth ( $h_{ef}$ ) [mm]	Installation torque ( $T_{inst}$ ) [Nm]	Drill hole diameter ( $d_{cut, \text{min}}$ ) [mm]
30	95	60	80	20.15
				20.30
				20.45

**Table 3.** Technical details of fibres used as admixtures in concrete bases

Fibre type	Amount in the concrete base [kg m <sup>-3</sup> ]
Plastic: PP Fibermesh 300-e3	0.90
Steel: Steelbet 50/0.8	25.00



**Fig. 4.** Test station: a – side view; b – view during the tests

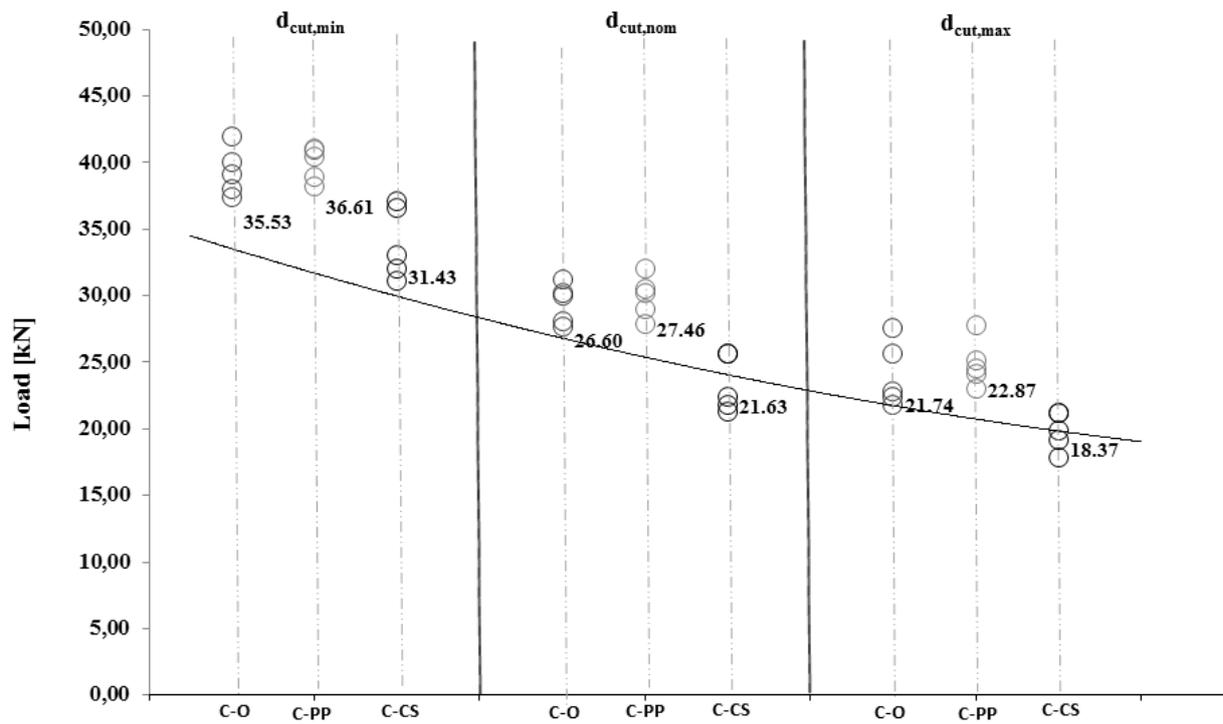
The tests were performed in a special test station enabling initiation of cracks with the width of 0.30 mm (Fig. 4).

## RESULTS AND DISCUSSION

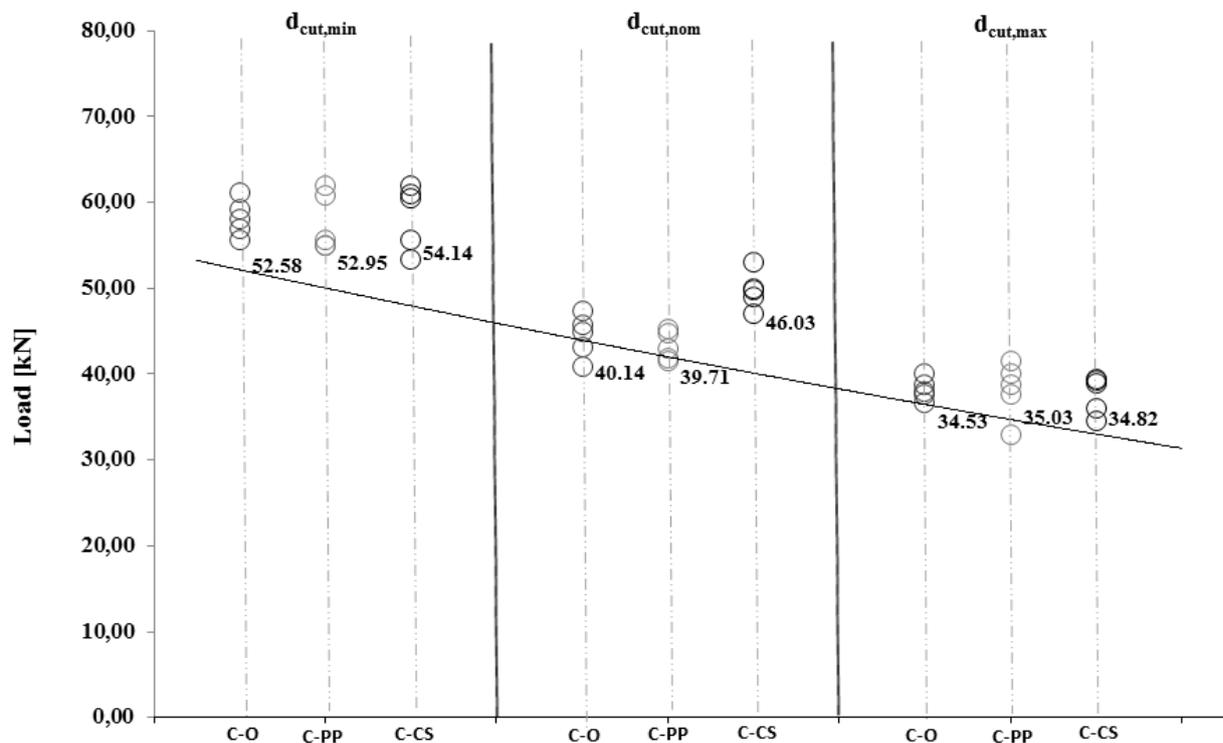
The obtained results of tests of pullout resistance for M12 sleeve and stud anchors in non-cracked concrete, for which mean failure loads were determined, are shown in Figures 5 and 6. The non-cracked concrete bases without any fibres were labelled C-O, those containing an admixture of PP Fibermesh 300-e3 fibres are labelled C-PP, and those containing Steelbet 50/0.8

fibres are labelled C-CS. The diameters of drill holes are shown in Tables 1 and 2. The curve represents the decrease in pullout resistance depending on the diameter of drill hole and the type of fibre admixture in the C20/25 concrete base. The curves marked in the Figures 5–8 are not approximated curves, the decrease in the load capacity in the entirety of the tests performed is presented graphically.

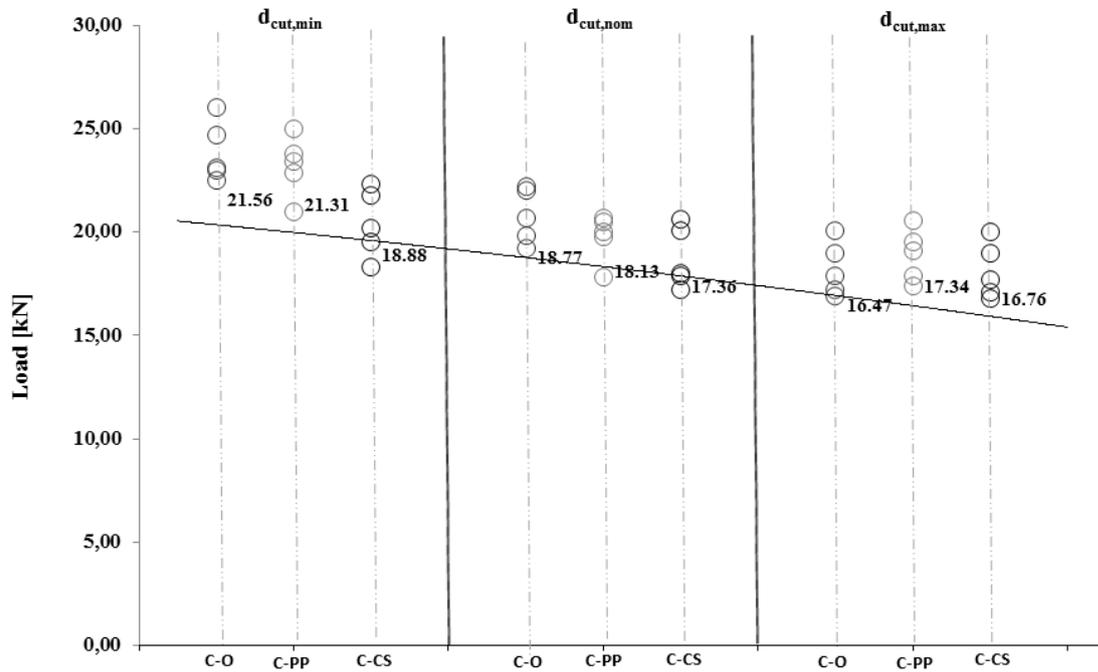
Results of tests of pullout resistance for M12 sleeve and stud anchors in cracked concrete bases where crack width of 0.30 mm, for which mean failure loads have been determined are shown in Figures 7 and 8. The admixture labels are described in Table 3.



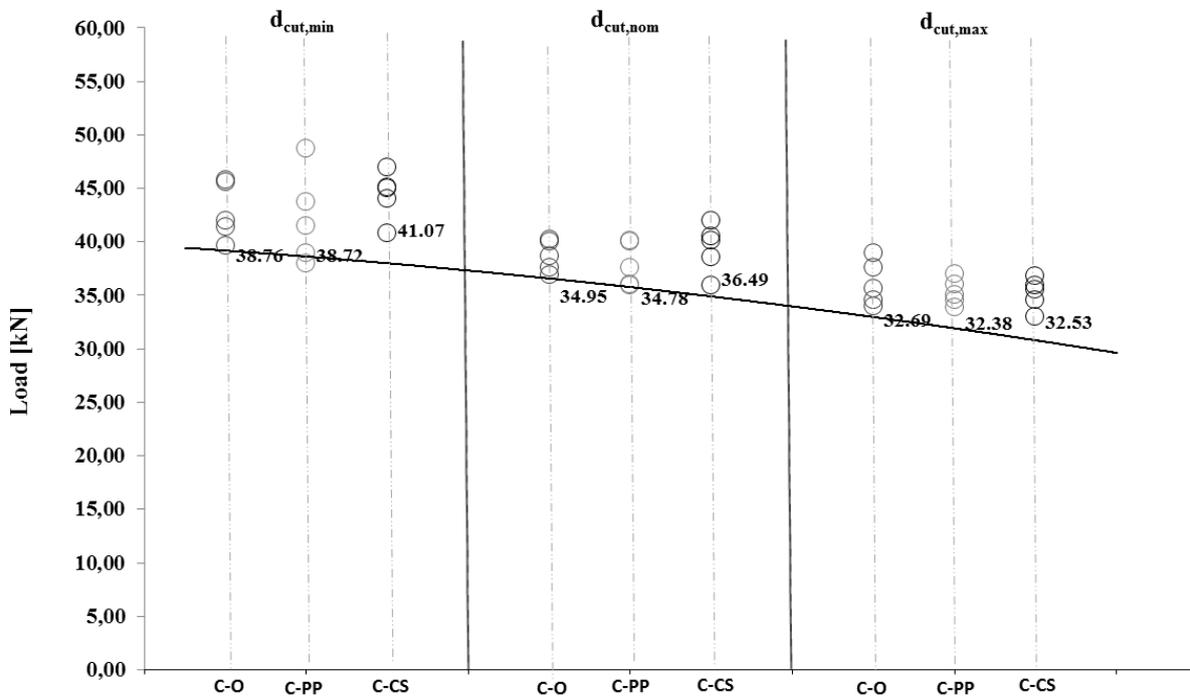
**Fig. 5.** Mean ultimate load in the test for non-cracked C20/25 concrete for M12 stud anchor



**Fig. 6.** Mean ultimate load in the test for non-cracked C20/25 concrete for M12 sleeve anchor



**Fig. 7.** Mean ultimate load in a test for C20/25 cracked concrete (crack width equal 0.30 mm) and M12 stud anchor



**Fig. 8.** Mean ultimate load in a test for C20/25 cracked concrete (crack width equal 0.30 mm) and M12 sleeve anchor

## CONCLUSIONS

Based on the conducted tests determining pullout resistance of steel M12 stud and sleeve anchors in C20/25 concrete both non-cracked and cracked with crack width of 0.30 mm and with admixtures of PP and steel fibres it can be concluded that:

- PP Fibermesh 300-e3 fibres do not affect the strength of connections for stud and sleeve M12 anchors, both in cracked and non-cracked concrete;
- steel Steelbet 50/0.8 fibres affect the strength of the connections which use M12 stud anchors, reducing the pullout resistance by ca. 10% in non-cracked C20/25 concrete;
- for cracked concrete with crack width of 0.30 mm and connections using M12 stud anchors no effect of using steel fibres was found (which means that it is within the spread of tests results);
- a 30% increase in strength was found for connections using M12 stud anchors and the minimum drill hole diameter and a 20% reduction in strength for the maximum drill hole diameter as compared to the minimum diameter;
- for sleeve anchors reductions and an increase of 10% in strength was found as compared to the nominal drill hole diameter;
- despite dispersed admixtures in the form of plastic and steel fibres no improvement in compressive strength was found in either cracked or non-cracked concrete bases;
- in all analysed test combinations the image of the pullout failure was observed.

This paper presents tests of pullout resistance conducted by the authors on M12 stud and sleeve anchors in non-cracked concrete and cracked concrete with crack width of 0.30 mm; failure loads and mean pullout resistance were determined. Additionally, it provides pullout resistance tests for the above mentioned fasteners in concrete bases containing admixtures in the form of PP and steel fibres. In doing so, it provides new, significant data regarding the behaviour of steel M12 stud and sleeve anchors installed in non-cracked concrete and in cracked concrete with crack width of 0.30 mm containing admixtures in the form of PP and steel fibres. The tests of steel expansion anchors have

been conducted in accordance with applicable testing rules. The anchors used for the tests were fasteners most commonly used in construction for structural connections – steel M12 stud and sleeve anchors. The obtained results indicate a need to develop assessment criteria for effects of external factors in the form of steel fibre admixtures.

## Authors' contributions

Conceptualization: D.D. and K.K.; methodology: D.D.; validation: D.D.; formal analysis: D.D.; investigation: D.D.; resources: D.D.; data curation: D.D.; writing – original draft preparation: D.D.; writing – review and editing: D.D.; visualization: D.D.; supervision: D.D.; project administration: D.D.; funding acquisition: D.D.

All authors have read and agreed to the published version of the manuscript.

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## WPLYW ZBROJENIA ROZPROSZONEGO W POSTACI WŁÓKIEN TWORZYWOWYCH I STALOWYCH NA NOŚNOŚĆ STALOWYCH ŁĄCZNIKÓW ROZPOROWYCH

### STRESZCZENIE

Współczesny fibrobeton to materiał złożony ze spoiwa, z kruszywa mineralnego, piasku, wody i włókien dodawanych do matrycy cementowej. Dodatek tych włókien do mieszanki betonowej zmienia w zasadniczy sposób zachowanie się kruchego tradycyjnego betonu na materiał quasi-plastyczny, co powoduje, że nawet po pojawieniu się pierwszych rys w konstrukcji nie występują kruche zniszczenia. Podstawowymi czynnikami zewnętrznymi, które mogą wpływać na odporność na obciążenie, są w szczególności różne parametry montażowe stalowych łączników, stan podłoża (możliwe pęknięcia), wielkość ziaren podłoża betonowych oraz dodatkowe zbrojenie w postaci rozproszonych włókien tworzywowych i stalowych. W pracy określono zmiany nośności stalowych łączników rozporowych w zależności od średnicy wierconego otworu, szerokości zainicjowanej rysy oraz domieszki włókien tworzywowych i stalowych. Badania przeprowadzono na podłożach betonowych klasy C20/25 z odpowiednimi domieszkami włókien. Do badań wybrano dwa powszechnie stosowane w budownictwie rodzaje stalowych łączników rozporowych: pierścieniowe i tulejowe o średnicy M12.

**Słowa kluczowe:** fibrobeton, stalowe łączniki rozporowe, włókna tworzywowe i stalowe, beton, zarysowania