INFLUENCE OF BOREHOLE DIAMETER AND CRACK WIDTH ON THE CAPACITY OF SCREW ANCHOR

EINFLUSS DES BOHRLOCHDURCHMESSERS UND DER RISSBREITE AUF DIE TRAGFÄHIGKEIT VON BETON-SCHRAUBEN

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SUMMARY

In fastening technology, the precise fit between screws and drilled holes is critical for ensuring the load-bearing capacity of structural components. Inaccurate planning or execution during the drilling process can lead to production delays and increased costs, making the process inefficient from both economic and ecological perspectives. This study investigates whether a standard drill cutting diameter can be substituted with a smaller diameter in combination with controlled crack expansion. The proposed method involves pre-drilling with a smaller, readily available drill cutter, followed by borehole enlargement using the wedge cracking method. A displacement transducer is employed to incrementally widen the crack until the target borehole diameter is achieved. Tensile tests are conducted to evaluate the influence of borehole diameter and crack width on the fastening's load-bearing capacity. The results aim to determine the feasibility of this alternative method as a cost-effective and sustainable solution in fastening applications.

ZUSAMMENFASSUNG

In der Befestigungstechnik ist die präzise Abstimmung von Schraube und Bohrlochdurchmesser entscheidend für die Tragfähigkeit. Fehlerhafte Planung oder Ausführung führen zu Verzögerungen und wirtschaftlichen Nachteilen. Ziel dieser Arbeit war es zu untersuchen, ob ein größerer Bohrschneidedurchmesser durch eine Kombination aus kleinerem Bohrdurchmesser und zusätzlicher Rissbreite ersetzt werden kann. Dazu wurde das Bohrloch zunächst mit einem kleineren Bohrschneider vorgebohrt und anschließend mithilfe der Keilrissmethode auf den Ziel-Bohrdurchmesser erweitert. Durch Zugversuche wurden die Einflüsse von Bohrlochdurchmesser und Rissbreite auf die Tragfähigkeit systematisch analysiert.

1. INTRODUCTION

Concrete screws are an integral component of modern fastening systems in reinforced concrete construction, valued for their ease installation, removability, and high load-bearing capacity. Their performance depends significantly on the precision of the borehole geometry, particularly the fit between the screw and the borehole wall. These fasteners are equipped with specially hardened threads that actively cut a thread into the concrete surface during installation, forming a mechanical interlock that facilitates load transfer through friction and thread engagement [1].

Due to their versatility, concrete screws are used in a broad spectrum of applications. In structural contexts, such as in bridges, high-rise buildings, and heavy industrial components, they are employed to carry substantial loads. In contrast, they also serve non-structural roles in supporting lightweight systems, including conduits, piping, and suspended equipment. Regardless of the application, correct borehole preparation is essential to ensure consistent mechanical performance.

A key requirement for effective fastening is that the borehole diameter must be smaller than the outer thread diameter of the screw, allowing the threads to cut and engage with the surrounding concrete material [2]. Furthermore, a minimum embedment depth must be maintained to prevent thread stripping and shaft failure due to excessive driving torque [1]. Load transfer is achieved via the cutting action of each engaged thread, with the full thread length contributing to anchorage strength [3].

This study explores a novel approach to borehole preparation by investigating whether a larger borehole diameter—typically achieved through standard drilling can be substituted with a smaller initial drill diameter in combination with a controlled crack expansion. This alternative method involves the use of a wedge-splitting technique to incrementally increase the borehole diameter by inducing radial cracks. The objective is to evaluate whether this process can replicate or enhance the mechanical interlock achieved by traditional drilling methods, offering potential benefits in terms of tooling flexibility, sustainability, and installation efficiency. The findings are intended to contribute to the optimization of design and execution strategies for concrete screw installations.

2. METHODOLOGY

A total of 60 experimental tests were performed to investigate the influence of borehole preparation on the load-bearing behaviour of concrete screw fastenings. The tests utilized W-BS/S galvanized concrete screws in nominal diameters of M8, M10, and M12, which were installed in concrete slabs of strength class C20/25. The testing procedure was conducted in accordance with the European Assessment Document (EAD) 330232-00-0601 and included two defined series, designated as F1 and F2 [4].

Each screw size was assigned a specific target borehole diameter, applied consistently across four different test series (see Table 1). In series F1, the target borehole diameter was achieved through conventional pre-drilling using larger drill bits. In contrast, series F2 employed an alternative approach: initial pre-drilling with smaller diameter cutters, followed by controlled enlargement of the borehole using the wedge-splitting method. This method involved inducing and expanding hairline cracks radially from the pilot hole using a wedge and a displacement transducer, allowing precise adjustment of the final crack width and thus the effective borehole diameter.

After installation of the concrete screws, the induced cracks were carefully widened to the specified width and continuously monitored using high-resolution displacement sensors to ensure consistency across specimens. The fastening assemblies were then subjected to axial tensile loading in displacement-controlled pull-out tests. During testing, both the applied load and the axial displacement of the screw were recorded until complete failure of the connection occurred.

Upon failure, each specimen was examined to document the failure mode and the geometry of the breakout surface. This detailed evaluation enabled a comparative analysis of the structural performance of fastenings installed with different borehole preparation methods, providing insights into their effect on load-bearing capacity and failure mechanisms.

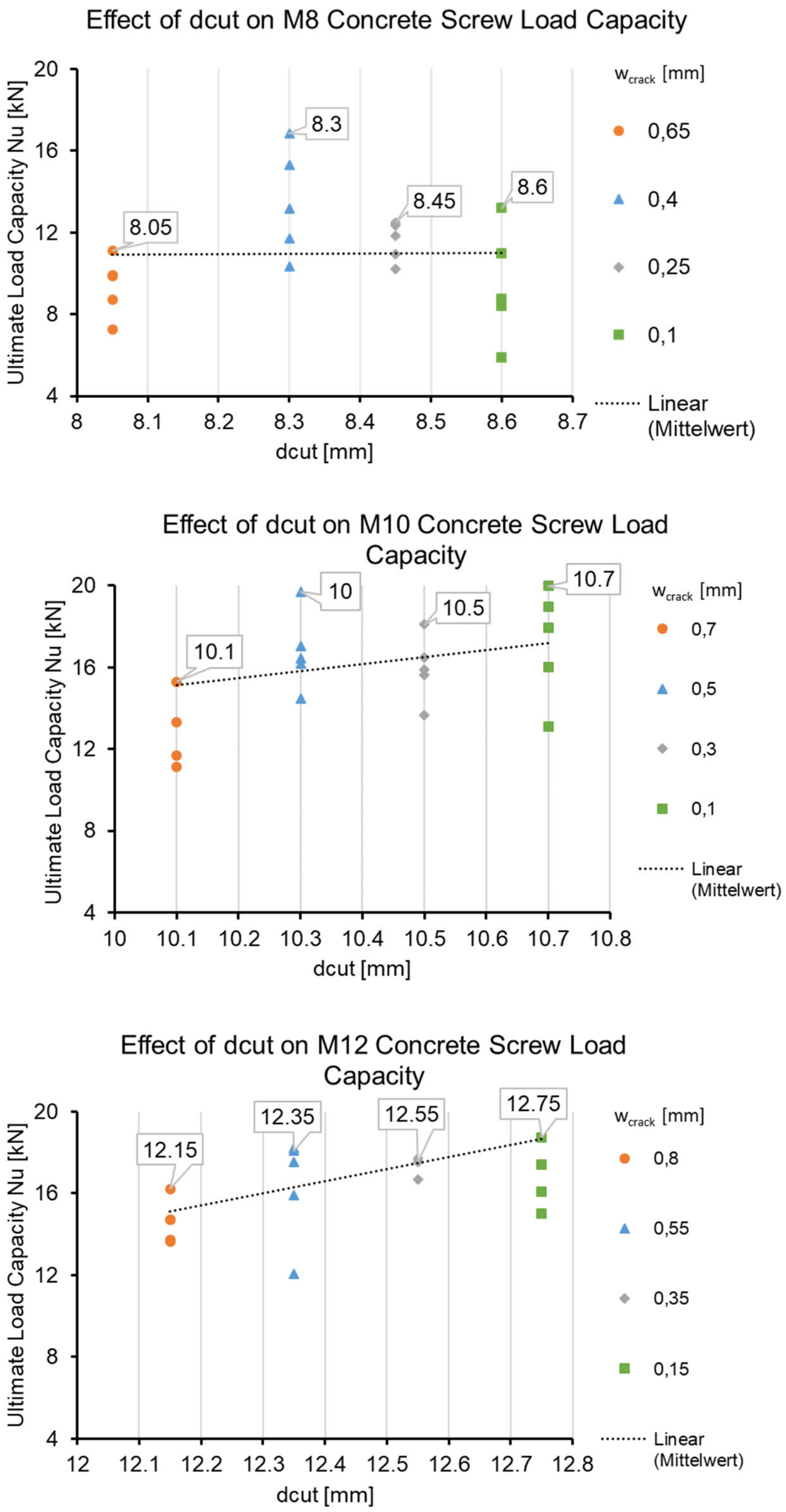
Table 1: Test program - Cutting diameter and Crack widths

Concrete screw size	M8			M10			M12		
Test series	d_{cut} [mm]		w_{crack} [mm]	d_{cut} [mm]		w_{crack} [mm]	d_{cut} [mm]		w_{crack} [mm]
	Target	Actual		Target	Actual		Target	Actual	
1	8,05	8,05	0,65	10,10	10,10	0,70	12,15	12,17	0,75
2	8,30	8,29	0,40	10,30	10,30	0,50	12,35	12,33	0,55
3	8,45	8,46	0,25	10,50	10,51	0,30	12,55	12,57	0,35
4	8,60	8,62	0,10	10,70	10,67	0,10	12,75	12,79	0,15

3. RESULTS

3.1 Influence of borehole diameter

The results show that smaller borehole diameters increase the undercut between the thread and the borehole wall, thereby enhancing the load-bearing capacity, particularly at shallow embedment depths. With larger borehole diameters, the load-bearing capacity decreases due to reduced mechanical interlocking. Interestingly, at greater embedment depths, a slight increase in load-bearing capacity with increasing borehole diameter was observed, especially for screw sizes M10 and M12 (see Fig, 1).



Fig, 1: Effect of Drill Cutter Diameter on Maximum Load Capacity

3.2 Influence of Crack Width

With increasing crack width, the mechanical interlocking between the screw and the concrete decreased significantly. This effect was particularly pronounced for screw sizes M10 and M12. In contrast, a slight increase in load-bearing capacity was observed for M8 screws, possibly due to the lower embedment depth and the resulting rough crack surface, which may have improved adhesion (see Fig. 2).

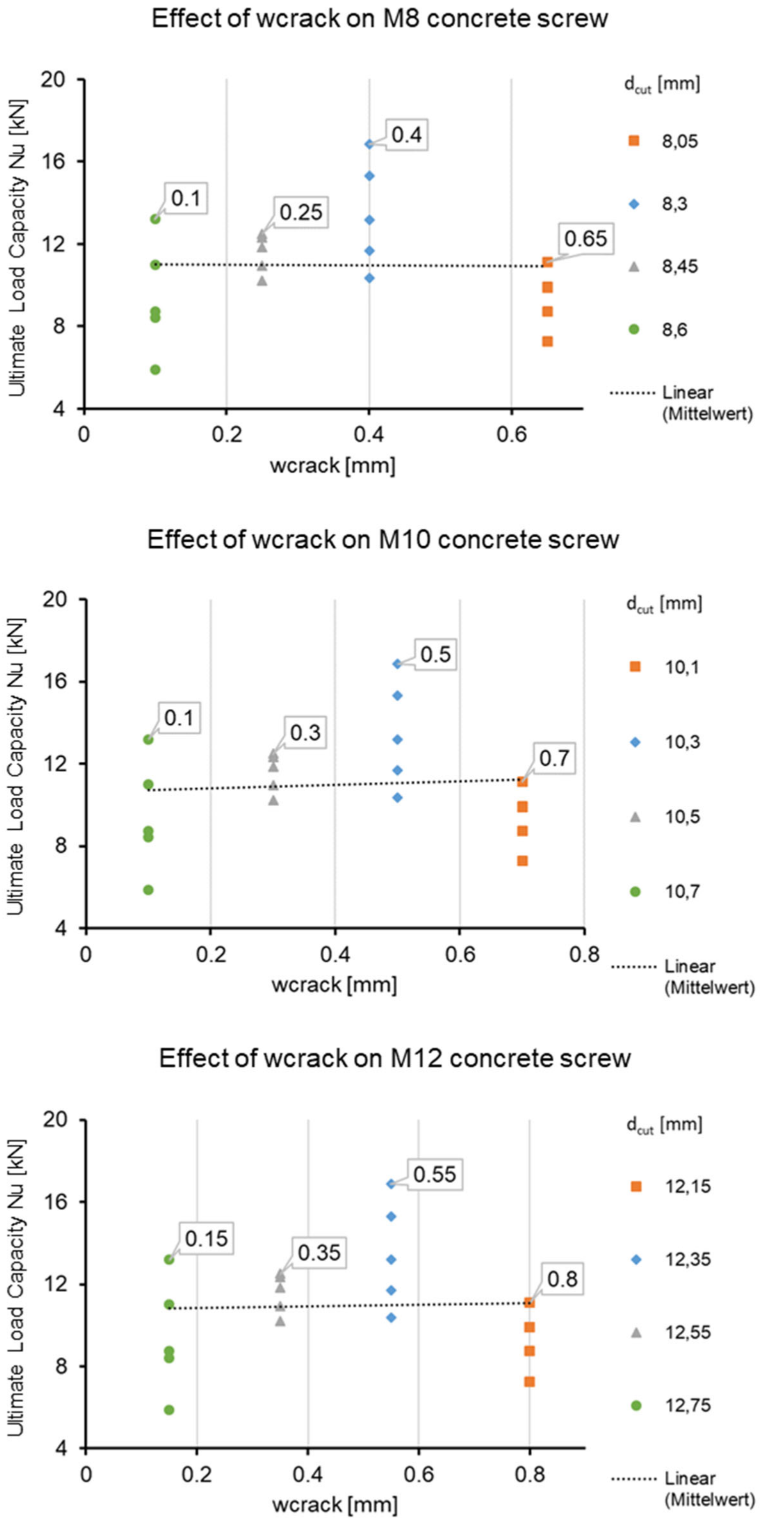


Fig. 2: Effect of Crack Width in Relation to the Ultimate Load

3.3 Regression Analysis

To quantitatively evaluate the test results, a linear regression analysis was performed to accurately model the relationship between the calculated undercut x_i and the experimentally determined ultimate load N_u (see Fig. 3). The purpose of this analysis was to investigate whether comparable load-bearing capacities could be achieved using different drill cutter diameters and crack widths.

The calculation is based on the following formula for determining the linear undercut:

$$x_i = d_S - (d_{cut} + w_{crack})$$

with:

x_i	[mm]	Linear undercut of the thread flanks
d_S	[mm]	External thread diameter
d_{cut}	[mm]	Drill cutter diameter
w_{crack}	[mm]	Crack Width

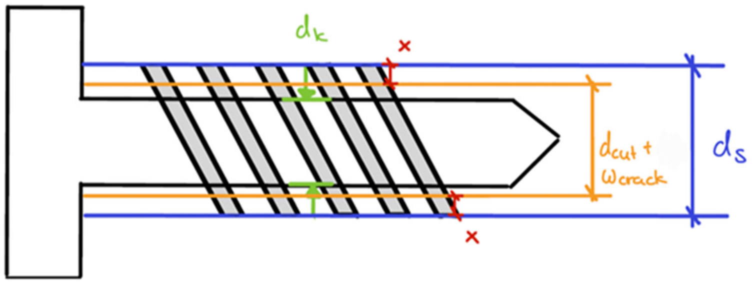


Fig. 3: Schematic illustration of the undercut x

Since the calculation of the undercut can be based on different theoretical approaches, seven variations of this formula were developed. These formulas differ in the consideration of various influencing factors, such as the weighting of borehole diameter, crack width, or geometric adjustment factors. The Seven Formular are systematically presented in Table 2.

Table 2: Formulas for investigating the longitudinal undercut of the thread in concrete

Formula No.	Investigated Formula	General Formula	Conditions
1	$x_1 = d_S - (d_{cut} + w_{crack})$	-	-
2	$x_2 = d_S - (d_{cut} + 2 * w_{crack})$	$x_2 = d_S - (d_{cut} + 2n * w_{crack})$	$2n < d_a$, $n \in \mathbb{N}$
3	$x_3 = d_S - (d_{cut} + 3 * w_{crack})$	$x_3 = d_S - (d_{cut} + (2n+1) * w_{crack})$	$2n+1 < d_a$, $n \in \mathbb{N}$
4	$x_4 = d_S - (d_{cut} + w_{crack}{}^2)$	$x_4 = d_S - (d_{cut} + w_{crack}{}^n)$	$n=2k$, $k \in \mathbb{N}$
5	$x_5 = d_S - (d_{cut} + w_{crack}{}^3)$	$x_5 = d_S - (d_{cut} + w_{crack}{}^n)$	$n=2k+1$, $k \in \mathbb{N}$
6	$x_6 = d_S - (d_{cut} + w_{crack}{}^{-1})$	-	-
7	$x_7 = (d_S/d_k) * (w_{crack}/d_{cut})$	-	-

For each formula variation, a linear regression was performed using the method of least squares. In this analysis, x_i was plotted on the x-axis against the experimentally determined ultimate load N_u on the y-axis to evaluate the correlation. The regression equation is as follows:

$$N_u = a + b \times x_i + e$$

with:

a	[-]	Intercept (value at the y-axis)
b	[-]	Slope of the regression line
e	[-]	Residual

To evaluate the model accuracy, the coefficient of determination (r^2) was used. The analysis revealed (see Fig. 4):

- For screw sizes M10 and M12, formula x_7 showed the highest agreement with the experimental results.
- For M8, formula x_4 demonstrated the best correlation.

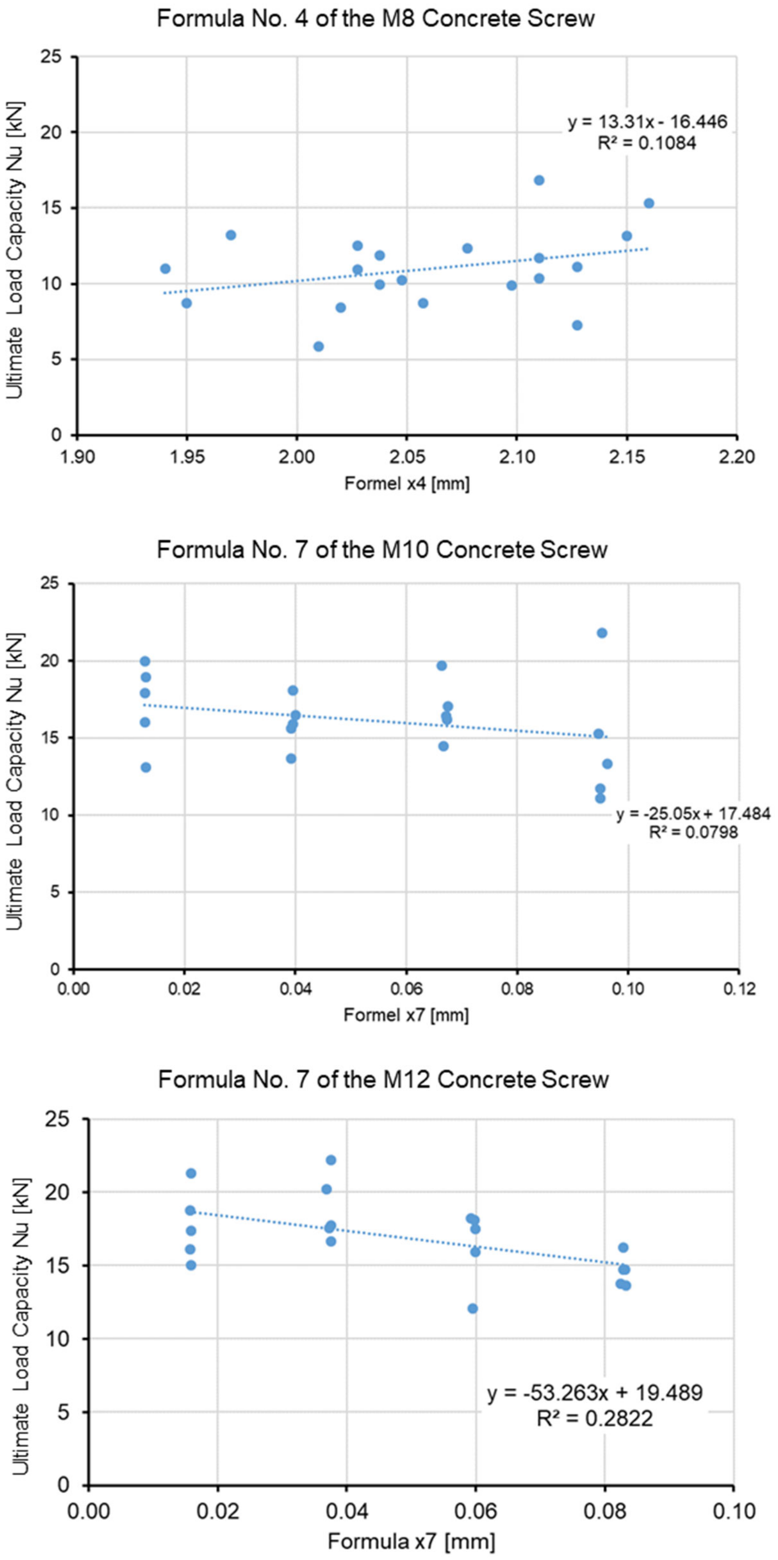


Fig.4: Effect of the x-formulas on the ultimate load capacity of the concrete screws (formula No. 4 for M8 and formula No. 7 for M10 & M12 sizes).

The nearly linear trends in the experimental data and the high r^2 values confirm the suitability of the developed formulas for predicting load-bearing capacity. Notably, the regression equations enable reliable predictions of the maximum load capacity for different combinations of drilling parameters and crack widths.

4. DISCUSSION

The results confirm that a larger drill cutter can be successfully substituted by combining a smaller borehole diameter with targeted control of the crack width. However, several additional factors are crucial for ensuring sufficient load-bearing capacity:

- **Borehole diameter**: Larger diameters reduce load-bearing capacity due to decreased mechanical interlocking.
- **Embedment depth**: Greater embedment depths compensate for the influence of borehole diameter and enhance load capacity.
- **Borehole quality**: Square-end drill bits produce more precise boreholes, improving load transfer.
- **Cleaning**: Residual drilling dust reduces adhesion and must be thoroughly removed.
- **Thread geometry**: An undamaged external thread diameter is essential for safe load transfer.

Furthermore, the study demonstrates that the undercut cannot be described by a single formula alone, but rather requires the interaction of multiple parameters. While medium crack widths may enhance adhesion due to increased surface roughness, they ultimately reduce the overall load-bearing capacity.

5. CONCLUSION

The combination of a smaller borehole diameter with a deliberately introduced crack width represents a practical alternative to using larger drill cutters, provided that additional influencing factors such as embedment depth, borehole quality, and thread condition are taken into an account. In practical applications, this means that the load-bearing capacity of concrete screws in cracked concrete can be specifically optimized through the precise selection and coordination of drilling parameters.

For future research, it is recommended to systematically record different parameter combinations in the form of design tables. This could serve as a basis for practice-oriented recommendations for the design and specification of concrete screw connections.

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