Zukunft Bau

KURZBERICHT

Titel

Langfassung Titel: „Innovative high-performance fibre-reinforced concrete for a significant increase in the punching capacity of flat slabs “

Anlass/ Ausgangslage

kurze Beschreibung des Problems und des Lösungsansatzes

In the area of the slab-column connection of flat slabs, typically high bending moments in combination with considerable shear forces are being transmitted. To strengthen this critical node, various types of punching shear reinforcement have been established which, however, have numerous system-related disadvantages. The major goal of this project was to investigate the suitability and effectiveness of modern high-performance steel fibre reinforced concretes (SFRC) as an alternative to conventional punching shear reinforcements.

Gegenstand des Forschungsvorhabens

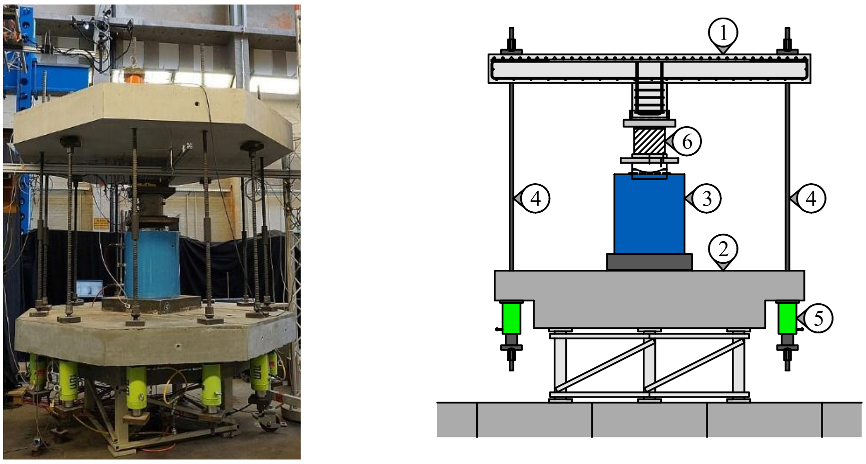
Beschreibung der Arbeitsschritte und des Lösungswegs

At the beginning of the research project, experimental work documented in the national and international literature with a total of 284 individual punching tests was thoroughly reviewed. It was found that in evaluated tests, mainly slab thicknesses below 150 mm and correspondingly small column dimensions were examined. An evaluation of a building database [1] showed that in building practice mostly slab thicknesses above 200 mm to 250 mm are being used, though these thicknesses are not covered by the database. Due to the expected negative influence of the formwork on the fibre orientation and distribution [2], an effect to be considered especially with low slab thickness, as well as further developments regarding the performance of steel fibres, the need for a review of the available knowledge and design approaches for practical slab thicknesses became apparent.

Figure 1: Reinforcement with formwork (left) and used steel fibres (right)

The test program included a total of ten punching tests on steel fibre reinforced flat slab specimens with thicknesses of 250 mm or 300 mm. The octagonal test specimens had a bracing radius of 2.40 m and were provided with conventional reinforcement layout in three different reinforcement grades of 0.75 %, 1.23 % and 1.75 % to prevent premature bending failure (Fig. 1, left). The average concrete compressive strength was in a range of 40 N/mm² to 50 N/mm². The used steel fibres, Dramix 4D and Dramix 5D, were provided by Bekaert GmbH and added to the concrete at 0.5 % and 1.0 % by volume. Both fibre types are end-anchored steel fibres with a diameter d_f of 0.9 mm and a length l_f of 60 mm. While the Dramix 4D fibre is a typical normal-strength steel fibre, Dramix 5D is a high-strength fibre with optimised end hook design (Fig. 1, right).

The tests were carried out utilising an existing test setup as shown in Fig. 2.



1. test specimen
2. abutment plate
3. centrical hydraulic cylinder
4. tie rods
5. hollow plunger cylinder in ring line
6. load cell

Figure 2: Used test setup

Figure 3 illustrates the force-deflection curves obtained in the tests with a degree of longitudinal reinforcement of 1.23 %. While the reference specimens (w/o fibres, ref. M0) showed a very brittle punching failure with a significant load decrease, a clearly ductile punching failure could be observed in all fibre-reinforced specimens (ref. M1 – M3). A comparison of the gained experimental loads with the calculated punching shear resistance of test specimens without fibres and punching shear reinforcement according to DIN EN 1992-1-1 is displayed in Figure 4 and proves load factors (i.e. increase of capacity) of up to 1.75 for steel fibre contents of 1.0 vol.% (ref. M3). As a result, the performance of steel fibres as punching shear reinforcement is very much comparable to conventional stirrups. The crack formation was also positively influenced by the addition of fibres in form of a larger number of cracks and therefore considerably smaller crack widths. The result is an improved serviceability and load-bearing behaviour.

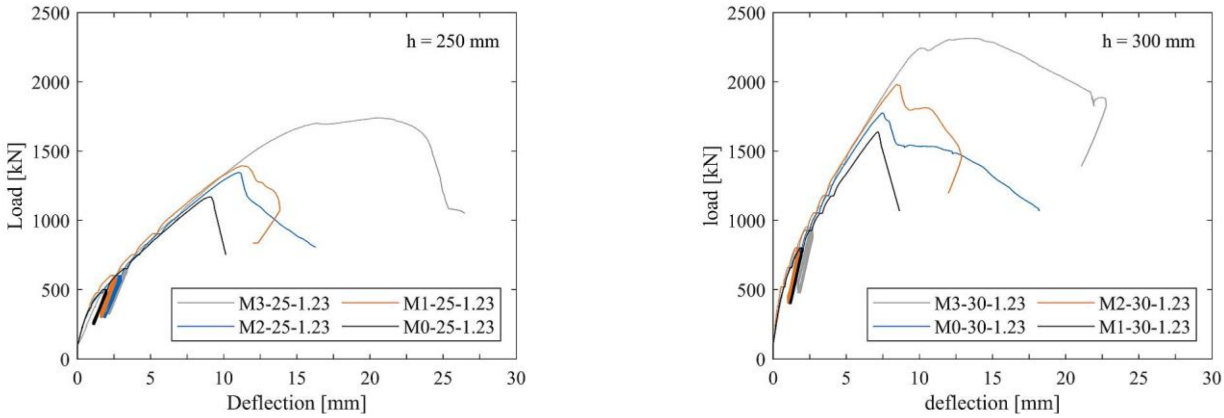


Figure 3: Load-deflection curve for slabs with a constant degree of longitudinal reinforcement of 1.23 % and a thickness of h = 250 mm (left) respectively h = 300 mm (right)

Parallel to the experimental investigations, in-depth numerical analyses of the punching tests were carried out with the non-linear finite element software solution ABAQUS UNIFIED FEA. Both the ultimate load and the cracking behaviour observed in the numerical calculations matched the experimental results quite well.

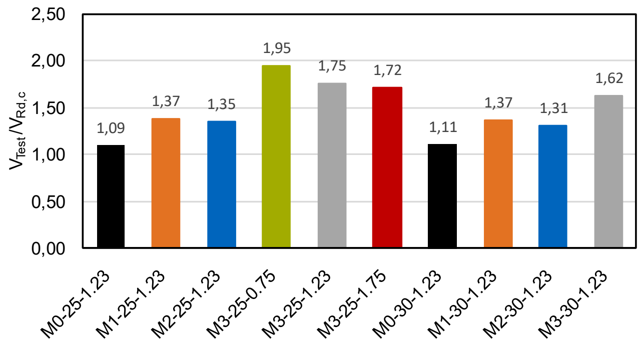


Figure 4: Comparison of the experimental test loads V_{Test} with the punching resistance $V_{Rd,c}$ according to DIN EN 1992-1-1

To check and evaluate the design approaches according to fib Model Code 2010 and the DAfStb guideline "Steel Fibre Reinforced Concrete", the experimental tests were also evaluated using these approaches. The calculated resistance (maximum load) showed a very good agreement with the test results, so that both approaches can also be proven as suitable for slab thicknesses mainly used in engineering practice and for modern steel fibre generations. The results obtained serve as a basis for the development and enhancement of future generations of standards and will be incorporated directly.

[1] Birkhäuser Verlag, „Building Types Online," Walter de Gruyter GmbH, 2018.
Online available: https://buildingtypesonline.com. [20.09.2017].
[2] Soroushian, P.; Lee, C.-D.: "Distribution and Orientation of Fibers in Steel Fiber Reinforced Concrete". in ACI Materials Journal 87 (1990), Nr. 5, pp. 433-439

Fazit

Beschreibung der geplanten Ziele und der erreichten Ergebnisse

Within the research project extensive investigations on the punching resistance of steel fibre reinforced flat slabs with high-performance fibres and practically relevant slab thicknesses were carried out. The data base gained from the literature with mostly very thin test specimens could be extended in a purposeful way. It could be confirmed that steel fibres are an alternative to conventional punching shear reinforcement and that existing design concepts also provide appropriate results for practice-relevant slab thicknesses. The avoidance of punching shear reinforcement reduces constraint points in the reinforcement installation and improves the component quality, resulting in a promising further development of the concrete construction method.

Eckdaten

Kurztitel: Innovative high-performance fibre reinforced concrete for flat slabs

Forscher / Projektleitung: Lehrstuhl für Massivbau
Ingenieurfakultät Bau Geo Umwelt
Technische Universität München
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Gesamtkosten: 247.630,80 € €

Anteil Bundeszuschuss: 172.730,80 €

Projektlaufzeit: 26 Monate

BILDER/ ABBILDUNGEN:

5 - 7 Druckbare Bilddaten als **eigene Datei** (*.tif, *.bmp, ...) mit der Auflösung von mind. 300 dpi in der Abbildungsgröße (z.B. Breite 10 - 20cm). Bilder frei von Rechten Dritter.
Bildnachweis jeweils:

Figure 1: Bewehrungsfühurng_DSC06123.jpg
Bild_1_rechts_oben_Dramix_4D.jpg
Bild_1_rechts_unten_Dramix_5D.jpg
Reinforcement with formwork (left) and steel fibres used (right)

Figure 2: Bild_2_links_Versuchsaufbau
Bild_2_rechts_schematischer_Versuchsaufbau.png
Used test setup

Figure 3: Bild_3_links_h=250mm_engl.jpg
Bild_3_rechts_h=300mm_engl.jpg
Load-deflection curve for slabs with a constant degree of longitudinal reinforcement of 1.23 % and a thickness of h = 250 mm (left) respectively h = 300 mm (right)

Figure 4: Bild_4_Vergleich_bezogene_Versuchslasten.png
Comparison of the experimental test loads V_{Test} with the punching resistance $V_{Rd,c}$ according to DIN EN 1992-1-1