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Concrete - Innovation and Design

fib Symposium Proceedings

Editors: Henrik Stang and Mikael Braestrup

18 to 20 May 2015
Tivoli Congress Center
Copenhagen, Denmark

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This book contains the forefront papers in concrete research and the practical use of innovative solutions in new and existing structures presented in Copenhagen at the *fib* Symposium held from18 to 20 May 2015.

The *fib* (Fédération internationale du béton – International Federation for Structural Concrete) is a not-for-profit association committed to advancing the technical, economic, aesthetic and environmental performance of concrete structures worldwide.The *fib* plays an essential role in stimulating research and promoting the use and development of concrete.

The main symposium topics are:

• Civil works
• Conservation of structures
• Innovation in buildings
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PREFACE

In the world today concrete is the most important building material by far. Concrete is used in all areas of the globe, and in one way or another in almost every structure that is built. However, what we are asking concrete to do is not static. The industry is forever setting new and increasing demands for cheaper, faster and more efficient ways of using concrete.

Furthermore we see an ever increasing wish to make more daring and soaring structures. Again these wishes generates demands as to how we can calculate and design concrete structures which leans, twists, reaches or soars into the sky.

The fib symposia and congresses are important opportunities for people in the concrete industry around the globe to gain new ideas and knowledge and to discuss and debate the latest innovations, ideas and techniques.

In your hand you are holding the proceedings from the *fib* Symposium 2015 – Concrete Innovation and Design. We have strived to collect the latest state-of-the-art knowledge of concrete in almost all aspects of its use. More than 200 authors have presented their latest work, or their finest projects. It is an amazing collection of Innovation and Design, and we are very thankful that so many authors have wished to share their ideas and their work.

The book contains the abstracts of all the papers presented at the Symposium. The full papers or presentations have been published on the USB issued to all participants.

Putting all this together and reviewing all the work requires a gargantuan effort by the entire Scientific Committee. More than 40 reviewers around the globe have worked together to make these proceedings happen, and we thank you all for your hard work.

Enjoy

Kaare K.B. Dahl
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FIBRE REINFORCED CONCRETE

PUNCHING SHEAR STRENGTHENING OF FLAT SLABS: CFRP AND SHEAR REINFORCEMENT

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Abstract

Punching in slabs is usually associated to the application of concentrated loads or to the presence of columns. One of the main concerns related to flat slabs is its punching shear capacity at slab-column connection, which is subjected to a very complex three-dimensional stress state. Provided that bending capacity is installed, punching shear failure is hence characterized by the development of a truncated cone shaped surface at the slab-column connection. The experimental programme carried out by the authors includes four normal strength concrete slabs (1100×1100×100 mm^3), with and without shear reinforcement, submitted to punching under a concentrated load. One of the specimens included typical bent-down bars as shear reinforcement. Frequently, there is the need to strengthen existing flat slabs against punching shear failure. Current paper intends to further investigate the structural response of such reinforcement techniques. One of the strengthening practices, which have been tested within current experimental programme, consists on gluing carbon fibre reinforced polymers on concrete surface. Moreover, the near surface mounted technique has also been tested within current experimental work. Finally, a fourth specimen served as reference. The effects of shear reinforcement and of the carbon fibre reinforced polymers enhancing punching shear capacity are observed.

Keywords: Punching shear, CFRP, NSM, Building codes, Experimental tests

1 Introduction

Two strengthening techniques enhancing directly the bending capacity of slab-column connections are employed. The collateral increase in the ultimate punching shear capacity is analysed. The use of carbon fibre reinforced polymers (CFRP) on structural repair and strengthening has continuously increased during the last years due to the following main advantages of this composite material when compared to conventional materials like steel and concrete: low specific weight, easy installation, high durability and tensile strength, electromagnetic permeability, and practically unlimited availability regarding size, geometry and dimensions (ACI 2008). The most widely used technique aiming to increase load carrying capacity is to apply CFRP plates on the tension surface of the RC slab as externally bonded (EB) reinforcement. CFRP laminates and sheets are generally applied on the faces of the elements to be strengthened configuring which is commonly designated as the EB reinforcing technique. The research carried out up to now has revealed that this method cannot mobilize the full tensile strength of CFRP materials due to the occurrence of premature debonding phenomenon (Nigro, Ludovico & Bilotta 2008). Due to the fact that CFRP is often directly exposed to the weathering conditions the reinforcing performance of this technique should be accounted for. EB systems are also vulnerable regarding fire action and vandalism acts. Alternatively, the near surface mounted (NSM) technique, which consists of cut-in openings strengthened with CFRP materials, can be used. This technique was used is some practical applications (Barros & al. 2006) and several benefits were pointed out. In order to assess the efficacy of this strengthening system as regards structural elements failing in punching shear, flat slab specimens were tested. The carried out tests are described and the most significant outcomes are presented and analyzed. Experimental results are also compared with design code predictions regarding the punching shear strength.

2 Experimental results and conclusions

All the specimens failed in punching. Experimental failure loads as well as predicted failure modes are indicated in Table 1. Design code approaches accurately predicted the failure load of the non-strengthened reference specimen BC01. Accordingly, $P_{u,exp}/V_{Rm,ns}$ ratio was computed for the remaining specimens and obtained values are indicated in Table 1. Punching failure loads are consistently overestimated for shear-reinforced and CFRP strengthened specimens ($P_{u,exp}/V_{Rm}$ ratio). The NSM strengthening technique appears to be more effective than EB method.

Table 1
Experimental and predicted failure loads

Slab	Experimental failure load, $P_{u,exp}$ (kN)	Non-strengthened (predicted) failure load, $V_{Rm,ns}$ (kN)	Strengthened (predicted) failure load, V_{Rm} (kN)	$P_{u,exp}/V_{Rm,ns}$ (-)	$P_{u,exp}/V_{Rm}$ (-)
BC01	176.8	173.4	-	1.02	-
BCA1	209.8	162.9	243.5	1.29	0.86
BCN1	168.7	147.8	186.8	1.14	0.90
BCG1	155.0	149.0	194.4	1.04	0.80

Further to current investigation, following conclusions can be drawn: flat slab specimen reinforced with steel bent-down bars showed an enhanced punching shear strength of approximately 29% when compared with non-strengthened reference slab; the NSM specimen presented an enhanced punching shear capacity strength that can be estimated as 14%. This value should be considered relatively large when compared with results from other researchers; no evidence of debonding was observed in the NSM specimen. On the contrary, a pure punching shear failure was obtained; the NSM CFRP strips presented an enhanced performance compared to EB CFRP plates regarding punching shear failure. In the later, premature surface debonding of the laminates triggered the specimen's failure; on the EB CFRP specimen, no significant enhancement (4%) could be achieved to the overall shear stress using this strengthening scheme. A premature debonding of CFRP laminates was detected at the punching cone onset that preceded failure.

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