



Concrete - Innovation and Design

fib Symposium Proceedings

Editors: Henrik Stang and Mikael Braestrup

18 to 20 May 2015

Tivoli Congress Center
Copenhagen, Denmark

RAMBOLL

Technical University
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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 from 18 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
- New materials and structures
- Analysis and design
- Modelling of concrete
- Numerical modelling
- Life-cycle design
- Safety and reliability



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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

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LIST OF CONTENTS

Overview:

Keynotes	37
Keynote Lectures	39
Closing Lecture	44
Analysis and Design	45
Civil Works	155
New Materials and Structures	183
Life Cycle Design	285
Modelling of Concrete	315
Conservation of Structures	353
Numerical Modelling	405
Safety and Reliability	443
Innovation in Buildings	463
Index	483

ANALYSIS AND DESIGN

SHEAR I

INVESTIGATION OF SHEAR DESIGN ACCORDING TO FIB MODEL CODE 2010 AND UNDERLYING THEORIES

Page 47, by Norskov, Strørup, Hagsten

ON THE DEVELOPMENT OF A THEORY FOR FLEXURAL MEMBERS FAILED IN SHEAR

Page 49, by Tung, Tue

SHEAR DESIGN OF REINFORCED AND PRESTRESSED CONCRETE BEAMS BASED ON A MECHANICAL MODEL

Page 51, by Marí, Jesús Miguel, Cladera, Ribas

ANALYTICAL INVESTIGATION ON SHEAR FAILURE MECHANISM OF RC T-BEAMS WITH STIRRUPS

Page 53, by Nakamura, Sato

THE SHEAR RATIO AND TYPE OF APPLIED LOAD - EXPERIMENTAL ANALYSIS FOR THE CRITICAL CROSS-SECTION

Page 55, by Bodzak

SHEAR II

INVESTIGATIONS INTO THE SHEAR LOAD BEARING CAPACITY OF A PRESTRESSED TWO-SPAN CONCRETE BEAM - FINDINGS FROM A LARGE SCALE EXPERIMENT

Page 57, by Gleich

SHEAR BEHAVIOR OF EXISTING BRIDGES WITHOUT AND WITH A MINIMUM AMOUNT OF SHEAR REINFORCEMENT

Page 59, by Huber

EFFECT OF SHRINKAGE AND STRENGTH DEVELOPMENT HISTORIES ON HIGH STRENGTH CONCRETE BEAMS IN SHEAR

Page 61, by Matsumoto, Osakabe, Niwa

DEFORMABILITY OF REINFORCED CONCRETE MEMBERS
IN SHEAR

Page 63, by Hong

TEST AND ANALYSIS OF PARTLY PRECAST RC SHEAR WALL

Page 65, by Li, Lu, Xilin

SEISMIC BEHAVIOUR OF REINFORCED CONCRETE WALLS WITH
MINIMUM VERTICAL REINFORCEMENT

Page 67, by Lu, Henry

SHEAR III

EXPERIMENTAL INVESTIGATIONS ON THE SHEAR CAPACITY
OF RC SLABS UNDER CONCENTRATED LOADS – INFLUENCE OF
DEGREE OF RESTRAINT AND MOMENT-SHEAR RATIO

Page 68, by Reissen, Hegger

LIMIT ANALYSIS FOR PUNCHING SHEAR DESIGN OF COMPACT
SLABS AND FOOTINGS

Page 70, by Fernández Ruiz, Simões, Muttoni, Viúla Faria

MODIFIED BOND MODEL FOR SHEAR IN SLABS UNDER
CONCENTRATED LOADS

Page 72, by Lantsoght, Van der Veen, De Boer

PUNCHING OF RC THICK PLATES – EXPERIMENTAL TESTS
AND ANALYSIS

Page 74, by Krakowski, Swiniarski, Urban

PUNCHING IN POST-TENSIONED CONCRETE FLAT SLABS WITH
EDGE COLUMNS

Page 76, by Melo, Barban

FLAT SLAB PUNCHING BEHAVIOUR UNDER CYCLIC
HORIZONTAL LOADING

Page 77, by Almeida, Inácio, Lúcio, Ramos

SHEAR IV

EXPERIMENTAL INVESTIGATIONS OF PUNCHING SHEAR
CONCRETE SLABS WITH DIFFERENT TYPES TRANSVERSE
REINFORCEMENT

Page 79, by Krawczyk, Urban

PUNCHING SHEAR STRENGTHENING OF FLAT SLABS:
CFRP AND SHEAR REINFORCEMENT

Page 81, by Moreno

LOAD CARRYING CAPACITY OF KEYED JOINTS REINFORCED
WITH HIGH STRENGTH WIRE ROPE LOOPS

Page 83, by Joergensen, Hoang

ONE-WAY SHEAR BEHAVIOUR OF INDIRECTLY LOADED
LARGE FOOTINGS

Page 85, by Uzel, Bentz, Collins

ON THE RESISTANCE OF FASTENING PLATES WITH
SUPPLEMENTARY REINFORCEMENT

Page 87, by Bujňák, Farbak, Bahleda, Leinonen

THE INCREASING BEARING CAPACITY WHILE REMOVING
CONCRETE FROM REINFORCED BEAMS

Page 89, by Hoogen, Vergoossen, Blom

FIBRE REINFORCED CONCRETE

NEW SWEDISH DESIGN GUIDE FOR FIBRE CONCRETE
STRUCTURES

Page 91, by Silfwerbrand, Hedebratt

CRACK WIDTHS IN CONCRETE WITH FIBERS AND MAIN
REINFORCEMENT

Page 93, by Christensen, Ulfkjær

SHEAR CAPACITY OF FIBER-REINFORCED CONCRETE

Page 94, by Toubia, Ishtewi

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 ($1100 \times 1100 \times 100 \text{ mm}^3$), 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 in 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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Main author	Paper title	Page
Mino, Tomohiro	CHLORIDE-INDUCED DELAYED FRACTURE OF PRESTRESSING WIRES AND STRUCTURAL RELIABILITY OF PC BRIDGES	452
Miyamoto, Ayaho	PERFORMANCE EVALUATION AND REMAINING LIFE PREDICTION OF AN EXISTING BRIDGE BY J-BMS	297
Miyachi, Katsuyuki	MECHANICAL BEHAVIOUR OF RC BEAMS STRENGTHENED WITH LAMINATED PLATES OF CARBON FIBRE GRID AND POLYMER CEMENT MORTAR	263
Mizuno, Katsuhiko	DESIGN AND CONSTRUCTION OF THE MUKOGAWA BRIDGE	166
Mizuta, Maki	DAMAGE ASSESSMENT OF A RC STRUCTURE AFFECTED BY FROST AND SALT ACTIONS	369
Moreno, Carlos	PUNCHING SHEAR STRENGTHENING OF FLAT SLABS: CFRP AND SHEAR REINFORCEMENT	81
Mugnier, Patrick	DESIGN OF A MIXED FOUNDATION FOR THE HIGH SPEED RAILWAY STATION OF LODZ FABRYCZNA, POLAND	410
Munch-Petersen, Christian	LARGE DANISH INFRASTRUCTURE PROJECTS – A MATTER OF POLITICAL AND CONCRETE STRENGTH	
Munch-Petersen, Gitte Normann	EVALUATION OF MECHANICAL PROPERTIES OF CONCRETE	321
Mutou, Yoshiko	STUDY ON THE EFFECTIVE PROTECTION METHODS AGAINST CHLORIDE ATTACK IN SUBWAY TUNNELS	381
Nakamura, Takuro	ANALYTICAL INVESTIGATION ON SHEAR FAILURE MECHANISM OF RC T-BEAMS WITH STIRRUPS	53
Navarro-Gregori, Juan	EXPERIMENTAL AND NUMERICAL STUDY ON THE BEHAVIOUR OF RC AND SFRC PUSH-OFF SPECIMENS	436
Niederwald, Michael	CARBON REINFORCED CONCRETE UNDER CYCLIC TENSION LOADING	251
Nieminen, Jyri	PRECAST CONCRETE FOR SUSTAINABLE BUILDINGS	313
Norskov, Stine	INVESTIGATION OF SHEAR DESIGN ACCORDING TO FIB MODEL CODE 2010 AND UNDERLYING THEORIES	47
Nushi, Violeta	APPLIANCE OF NEW MATERIALS AND TECHNIQUES FOR RESTORATION OF STRUCTURES	403
Nyhus, Bente Skovseth	SHELLDESIGN – EFFICIENT AND INNOVATIVE DESIGN TOOL FOR CONCRETE STRUCTURES	407
Oettel, Vincent	CONCRETE ELEMENTS REINFORCED WITH LARGE DIAMETERS, PART 3: COLUMNS	114
Oshima, Katsuhito	RECENT DEVELOPMENT OF ULTRA-HIGH STRENGTH PRESTRESSING 19-WIRE STRAND 29.0 MM	245