

# Bulletin 81



## Punching shear of structural concrete slabs:

Honoring Neil M. Hawkins

*ACI-fib* International Symposium



ACI SP-315

*ACI-fib* symposium proceedings



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CEB-FIP  
Bulletin 81

**Punching shear of  
structural concrete slabs:  
Honoring Neil M. Hawkins**



American Concrete Institute  
*Always advancing*

**Technical report**

Proceedings of a symposium held in Philadelphia, PA, USA,  
on 25 October 2016

Edited by Carlos E. Ospina, Denis Mitchell and Aurelio Muttoni

April 2017

## Approval of this bulletin

Subject to priorities defined by the technical council and the presidium, the results of the *fib*'s work in commissions and task groups are published in a continuously numbered series of technical publications called *bulletins*. The following categories are used.

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Technical report	Task group and the chairpersons of the Commission
State-of-the-art report	Commission
Manual/Guide to good practice/Recommendation	Technical council
Model code	General assembly

Any publication that has not met the above requirements will be clearly identified as preliminary draft.

*fib* Bulletin 81 is published as a technical report and is a collection of contributions to a symposium that was co-sponsored by the *fib* and the American Concrete Institute (ACI). The authors have presented their individual views. Although these contributions have not been discussed in any of the *fib*'s working bodies, the subject matter is highly topical and believed to be of general interest to members of the *fib*.

This bulletin is also published as an ACI Symposium Publication, ACI SP-315.

**Cover images:** Saw-cuts of inner slab-column connections failed in punching.  
Photographs courtesy of A. Herzog, EPFL

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## Foreword

*fib* Bulletin 81 deals with punching of slabs, which is a relevant issue in the design of reinforced concrete. Punching is one of the most frequent reasons for failure of concrete structures, which underlines the importance of this problem. Flat slabs are used in buildings, bridges and other structures. Punching may result in brittle failure, which requires that special attention be paid to the design of new structures and the assessment of existing ones. Punching and shear capacity of structures is often evaluated using empirical methods, which does not always provide a sufficient level of safety. This bulletin is a result of an international symposium where experts from *fib* and ACI met and exchanged their experience. The papers included in this bulletin provide new experimental evidence and a comprehensive review of analytical and numerical methods that are used to evaluate the structural performance of slab-column connections.

This bulletin provides a review of the performance of slabs under static, dynamic and seismic loading. The individual papers generally show the studied phenomena using experiments and analytical evaluation, which makes it possible to compare results obtained according to the European code (EC2), the ACI code and the international code, the *fib* Model Code for Concrete Structures (MC2010). Particular attention is paid to the so-called size effect (i.e. the nominal load carrying capacity of thicker slabs is lower than that of thin slabs). The arrangement of reinforcement is important for the residual strength after a local failure and robustness, which are instrumental to avoid the progressive collapse of the entire structure after a local failure. It is confirmed that the bottom reinforcement crossing the column is very beneficial to ensure sufficient residual strength and avoid progressive collapse. A paper dealing with the shear capacity of bridge slabs illustrates an extended strip model, which may be used for efficient assessment of bridge slabs under concentrated loads. This bulletin also presents new types of shear reinforcements and shows efficiency of distribution of classical shear reinforcing elements like headed studs. Some papers deal with retrofitting and strengthening of existing slabs. Post-installed shear reinforcing elements may be used for strengthening of existing structures.

This bulletin summarizes several phenomena that influence the performance of slabs sensitive to punching. It is a valuable summary of the state-of-the art knowledge for practicing engineers, academics and also for students. It is also important to appreciate that the opinions and experiences of American and European experts are summarised in one publication.

Finally, it is necessary to thank all authors, as well as the main organizers of the symposium (A. Muttoni convener of *fib* WP 2.2.3, and C. E. Ospina and D. Mitchell representing ACI committee 445) for their editing of this extraordinary document. Last but not least, many thanks to Laura Vidale for the preparation of the bulletin for publication.

Jan L. Vitek

Chairman of *fib* Commission 2, *Analysis and design*

## Preface

*fib* Bulletin 81 reports the latest information available to researchers and practitioners on the analysis, design and experimental evidence of punching shear of structural concrete slabs. It follows previous efforts by the International Federation for Structural Concrete (*fib*) and its predecessor the Euro-International Committee for Concrete (CEB), through CEB Bulletin 168, *Punching Shear in Reinforced Concrete* (1985) and *fib* Bulletin 12, *Punching of structural concrete slabs* (2001), and an international symposium sponsored by the punching shear sub-committee of ACI Committee 445 (Shear and Torsion) and held in Kansas City, Mo., USA, in 2005.



*Prof. Emeritus Neil M. Hawkins*

This bulletin contains 18 papers that were presented in three sessions as part of an international symposium held in Philadelphia, Pa., USA, on October 25, 2016. The symposium was co-organized by the punching shear sub-committee of ACI 445 and by *fib* Working Party 2.2.3 (Punching and Shear in Slabs) with the objectives of not only disseminating information on this important design subject but also promoting harmonization among the various design theories and treatment of key aspects of punching shear design. The papers are organized in the same order they were presented in the symposium. The symposium honored Professor Emeritus Neil M. Hawkins (University of Illinois at Urbana-Champaign, USA), whose contributions through the years in the field of punching shear of structural concrete slabs have been paramount.

The papers cover key aspects related to punching shear of structural concrete slabs under different loading conditions, the study of size effect on punching capacity of slabs, the effect of slab reinforcement ratio on the response and failure mode of slabs, without and with shear reinforcement, and its implications for the design and formulation in codes of practice, an examination of different analytical tools to predict the punching shear response of slabs, the study of the post-punching response of concrete slabs, the evaluation of design provisions in modern codes based on recent experimental evidence and new punching shear theories, and an overview of the combined efforts undertaken jointly by ACI 445 and *fib* WP 2.2.3 to generate test result databanks for the evaluation and calibration of punching shear design recommendations in North American and international codes of practice.

Sincere acknowledgments are extended to all authors, speakers, reviewers, as well as to *fib* and ACI staff for making the symposium a success and for their efforts to produce this long-awaited bulletin. Special thanks are due to Laura Vidale for preparing the bulletin for publication.

*The editors of fib Bulletin 81:*

Carlos E. Ospina (chair of ACI 445 Punching Shear Sub-committee)

Denis Mitchell (ACI 445)

Aurelio Muttoni (chair of *fib* Working Party 2.2.3)



*Participants in the 2016 ACI-*fib* symposium on punching shear of structural concrete slabs.*

*Standing, L to R: Sagaseta (Surrey, UK), Vollum (Imperial College, UK), Ramos (Nova, Portugal), Fernández Ruiz (EPFL, Switzerland), Kueres (Aachen, Germany), Genikomsou (Queen's, Canada), Walkner (Innsbruck, Austria), Topuzi (Toronto, Canada). Seated, L to R: Lantsoght (Delft, The Netherlands, and Quito, Ecuador), Polak (Waterloo, Canada), Ospina (Houston, USA), Hawkins (U. of Illinois, USA), Muttoni (EPFL, Switzerland), Mitchell (McGill, Canada), Criswell (Colorado State, USA), Alexander (Edmonton, Canada). Not shown: Bažant (Northwestern, USA), Dam (U. of Michigan, USA), Gayed (Calgary, Canada), Hueste (Texas A&M, USA). Photo by ACI staff.*

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