Guide to Seismic Design of Punching Shear Reinforcement in Flat Plates

Reported by Joint ACI-ASCE Committee 421
Guide to Seismic Design of Punching Shear Reinforcement in Flat Plates

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI. Proper use of this document includes periodically checking for errata at www.concrete.org/committees/errata.asp for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

Guide to Seismic Design of Punching Shear Reinforcement in Flat Plates

Reported by Joint ACI-ASCE Committee 421

Mahmoud E. Kamara
Chair

Simon J. Brown Amin Ghali* James S. Lai Edward G. Nawy
Pinaki R. Chakrabarti Hershell Gill Mark D. Marvin Eugenio M. Santiago
William L. Gamble* Neil L. Hammill Sami Hanna Megally* Thomas C. Schaeffer
Ramez Botros Gayed* Theodor Krauthammer Michael C. Mota Stanley C. Woodson

*Member of the subcommittee that prepared this guide.
The committee would like to thank Frieder Seible for his contribution to this guide.

During an earthquake, the unbalanced moments transferred at flat plate-column connections can produce significant shear stresses that increase the vulnerability of these connections to brittle punching shear failure. This guide provides recommendations for designing flat plate-column connections with sufficient ductility to withstand lateral drift without punching shear failure or loss of moment transfer capacity. This guide treats reinforced concrete flat plates with or without post-tensioning.

Keywords: ductility; flat plate; post-tensioning; punching shear; seismic design; shear reinforcement; stud shear reinforcement.

CONTENTS
Chapter 1—Introduction, p. 421.2R-2
1.1—General
1.2—Scope
1.3—Objective
1.4—Remarks

Chapter 2—Notation and definitions, p. 421.2R-3
2.1—Notation
2.2—Definitions

Chapter 3—Lateral story drift, p. 421.2R-5
3.1—Lateral-force-resisting systems
3.2—Limits on story drift ratio
3.3—Effects of gravity loads on story drift capacity
3.4—Design recommendations for flat plates with and without shear reinforcement

Chapter 4—Minimum shear and integrity reinforcements in flat plates, p. 421.2R-7

ACI Committee Reports, Guides, Manuals, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

ACI 421.2R-10 supersedes ACI 421.2R-07 and was adopted and published April 2010. Copyright © 2010, American Concrete Institute.
All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.
CHAPTER 1—INTRODUCTION

1.1—General
Brittle punching failure can occur due to the transfer of shear forces combined with unbalanced moments between slabs and columns. During an earthquake, significant horizontal displacement of a flat plate-column connection may occur, resulting in unbalanced moments that induce additional slab shear stresses. As a result, some flat plate structures have collapsed by punching shear in past earthquakes (Berg and Stratta 1964; Yanev et al. 1991; Mitchell et al. 1990, 1995). During the 1985 Mexico earthquake (Yanev et al. 1991), 91 waffle-slab and solid-slab buildings collapsed, and another 44 buildings suffered severe damage. Hueste and Wight (1999) studied a building with a post-tensioned flat plate that experienced punching shear failures during the 1994 Northridge, CA, earthquake. Their study provided a relationship between the level of gravity load and the maximum story drift ratio that a flat plate-column connection can undergo without punching shear failure. The displacement-induced unbalanced moments and resulting shear forces at flat plate-column connections, although unintended, should be designed to prevent brittle punching shear failure. Even when an independent lateral-force-resisting system is provided, flat plate-column connections should be designed to accommodate the moments and shear forces associated with the displacements during earthquakes.

1.2—Scope
In seismic design, the displacement-induced unbalanced moment and the accompanying shear forces at flat plate-column connections should be accounted for. This demand may be effectively addressed by changes in dimensions of certain members, or their material strengths (for example, shear walls and column sizes), or provision of shear reinforcement or a combination thereof. This guide does not address changes in dimensions and materials of such members, but focuses solely on the punching shear design of flat plates with or without shear reinforcement.

This guide, supplemental to ACI 421.1R, focuses on the design of flat plate-column connections with or without shear reinforcement that are subject to earthquake-induced displacement; reinforced concrete flat plates with or without post-tensioning are treated in the guide. Slab shear reinforcement can be structural steel sections, known as shearheads, or vertical rods. Although permitted in ACI 318, shearheads are not commonly used in flat plates. Stirrups and shear stud reinforcement (SSR), satisfying ASTM A1044/A1044M, are the most common types of shear reinforcement for flat plates. Shear stud reinforcement is composed of vertical rods anchored mechanically near the bottom and top surfaces of the slab. Forged heads or welded plates can be used as the anchorage of SSR; the area of the head or the plate is sufficient to develop the yield strength of the stud, with negligible slip at the anchorage. The design procedure recommended in this guide was developed based on numerical studies (finite element method) and experimental research on reinforced concrete slabs subjected to cyclic drift reversals that simulate seismic effects. The finite element analyses, supplemental to