

# Guide to Design of Reinforced Two-Way Slab Systems

Reported by Joint ACI-ASCE Committee 421

ACI 421.3R-15



American Concrete Institute  
*Always advancing*



## Guide to Design of Reinforced Two-Way Slab Systems

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 via the errata website at <http://concrete.org/Publications/DocumentErrata.aspx>. Proper use of this document includes periodically checking for errata 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.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

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**  
3880 Country Club Drive  
Farmington Hills, MI 48331  
Phone: +1.248.848.3700  
Fax: +1.248.848.3701

[www.concrete.org](http://www.concrete.org)

# Guide to Design of Reinforced Two-Way Slab Systems

Reported by Joint ACI-ASCE Committee 421

Mustafa A. Mahamid,\* Chair

Simon J. Brown  
Pinaki R. Chakrabarti  
William L. Gamble  
Ramez Botros Gayed  
Amin Ghali  
Hershell Gill  
Neil L. Hammill  
Mahmoud E. Kamara\*

Theodor Krauthammer  
James S. Lai\*  
Faris A. Malhas  
Mark D. Marvin  
Sami Hanna Megally  
Michael C. Mota  
Edward G. Nawy\*  
Daniel Reider

Aly Said  
Eugenio M. Santiago  
Myoungsu Shin\*  
Matthew Smith  
Ying Tian  
Amy M. Reineke Trygestad  
Stanley C. Woodson

Author and editorial team.

Consulting Members  
Eugene Paul Holland  
J. Leroy Hulsey  
Sidney H. Simmonds

*This guide presents analysis methods, design procedures, slab reinforcement and detailing practices, and strength and serviceability considerations, as well as information for the resistance to lateral forces for slab-column frames. It also covers the design for flexure and shear and torsion, as well as the effect of openings. Both two-way nonprestressed slabs and post-tensioned slabs are included.*

**Keywords:** analysis method; deflection; direct design; flat plates; flat slabs; post-tension; reinforcement; shear; shearhead; slab-column frame; two-way slabs.

## CONTENTS

### CHAPTER 1—INTRODUCTION AND SCOPE, p. 2

- 1.1—Introduction: history of two-way slab system, p. 2
- 1.2—Scope, p. 2

### CHAPTER 2—NOTATION AND DEFINITIONS, p. 2

- 2.1—Notation, p. 2
- 2.2—Definitions, p. 3

### CHAPTER 3—ANALYSIS METHODS, p. 4

- 3.1—General, p. 4
- 3.2—Analysis methods, p. 4
- 3.3—Finite element analysis, p. 10
- 3.4—Yield-line theory, p. 11
- 3.5—Strip method analysis, p. 11

### CHAPTER 4—DESIGN PROCEDURES, p. 11

- 4.1—General, p. 11
- 4.2—Gravity loading, p. 12
- 4.3—Flexural design, p. 12
- 4.4—Two-way action slab shear, p. 12
- 4.5—Critical section, p. 12
- 4.6—Openings in slab systems, p. 12
- 4.7—Unbalanced moments, p. 13
- 4.8—Shear strength, p. 14
- 4.9—Post-tensioned slabs, p. 14

### CHAPTER 5—SLAB REINFORCEMENT AND DETAILING, p. 14

- 5.1—General, p. 14
- 5.2—Slabs without beams, p. 15
- 5.3—Corner reinforcement, p. 15
- 5.4—Slab with drop panel, p. 16
- 5.5—Column strip reinforcement, p. 16
- 5.6—Middle strip reinforcement, p. 16
- 5.7—Bent bars, p. 16
- 5.8—Slab shear reinforcement, p. 17

ACI Committee Reports, Guides, and Commentaries are intended to provide 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 421.3R-15 was adopted and published October 2015.

Copyright © 2015, 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.

5.9—Post-tensioned slabs, p. 18

5.10—Bonded reinforcement in post-tensioned slabs, p. 18

## CHAPTER 6—SERVICEABILITY

### CONSIDERATIONS, p. 19

6.1—Minimum slab thickness, p. 19

6.2—Deflection analysis, p. 20

6.3—Crack control in reinforced two-way action structural slabs and plates, p. 21

## CHAPTER 7—DESIGN OF SLAB-COLUMN FRAMES UNDER LATERAL FORCES, p. 21

7.1—General, p. 21

7.2—Analysis of slab-column frames under lateral forces, p. 22

7.3—Arrangement of reinforcement in slabs for intermediate moment frames, p. 22

7.4—Slab-column frames not designated as part of the seismic-force-resisting system, p. 23

7.5—Transfer of moments to column, p. 24

## CHAPTER 8—REFERENCES, p. 24

Authored documents, p. 24

## APPENDIX A—EXCERPT BUILDING CODE PROVISIONS, p. 25

A.1—Direct design method (ACI 318-14, Section 8.10), p. 25

A.2—Equivalent frame method (ACI 318-14, Section 8.11), p. 27

## CHAPTER 1—INTRODUCTION AND SCOPE

### 1.1—Introduction: history of two-way slab systems

Two-way flat slab construction in the United States evolved, and was invented and patented, in the early 1900s (Cohen and Heun 1979). Early two-way flat slab construction was built and subjected to load tests in place and scaled models were later tested in laboratories. While the amount of reinforcement in slab construction varied dramatically, flat slab systems were found to be economical for heavy live load occupancy. As the number of flat slab projects increased steadily worldwide, design rules were established and formalized (Sozen and Seiss 1963).

Prior to the 1950s, two-way waffle slabs and two-way flat slabs were designed and constructed with column capitals and some with drop panels. The hollow tile and concrete slab is a form of waffle slab that dates back to at least 1918 (Gamble et al. 1964). Column capitals were used to increase slab clear strength and drop panels to reduce the flexural reinforcement over columns, which allowed for thinner slabs. In the post-1970s era, field labor to construct formwork for column capitals and drop panels became costly; the introduction of reusable forms led to construction of flat plates, which are two-way flat slabs without column capitals or drop panels.

The lift-slab system for multistory construction was popular in the 1960s and 70s, but is no longer commonly

used. The slabs were cast in a stack at ground level, post-tensioned, and then lifted to their final elevations using jacks lifting on steel collars embedded in the slabs.

Draped post-tensioning can be designed to balance part of the gravity loads. Combining unbonded post-tensioned tendons and nonprestressed reinforcement results in reduced slab thickness. In addition, the use of nonprestressed reinforcement supplements prestressed tendons to meet the required nominal strength and control slab cracking.

### 1.2—Scope

The performance record of various two-way slab systems is well established based on results of extensive tests and practical construction improvements in the twentieth century. The ACI Building Code permits design of slab systems, both nonprestressed and post-tensioned, based directly on fundamental principles of structural mechanics that satisfy equilibrium and compatibility. This guide provides classic solutions based on linearly elastic continuum, as well as prescriptive procedures used in common practice for analysis and design of slab systems. The fundamental principles in this guide are applicable to all planar structural slab systems subjected to gravity loads and, in certain conditions, those combined with lateral forces.

This guide addresses recommended practice in the selection and distribution of flexural reinforcement, and guidelines to transmit loads from slabs to columns by flexure, torsion, and shear. Detailing practices for post-tensioned two-way slabs are found in ACI 423.3R-05. This guide also discusses aspects and parameters where two-way slabs without beams are incorporated in ordinary or intermediate moment frames with ductile detailing and toughness.

While two-way slab systems have more than 100 years of service history, various practical refinements and research programs continue to develop new materials and technologies that support sustainable construction of two-way slabs.

## CHAPTER 2—NOTATION AND DEFINITIONS

### 2.1—Notation

- $A_{cf}$  = larger gross cross-sectional area of the slab-column strips in the two orthogonal equivalent frames intersecting at a column in a two-way slab, ft<sup>2</sup> (m<sup>2</sup>)
- $A_{sb}$  = area of reinforcement through the column core used as integrity reinforcement
- $b_1$  = dimension of the critical section  $b_o$  measured in the direction of the span for which moments are determined, in. (mm)
- $b_2$  = dimension of the critical section  $b_o$  measured in the direction perpendicular to  $b_1$ , in. (mm)
- $b_e$  = effective slab width, in. (mm)
- $b_o$  = perimeter of critical section at  $d/2$  from face of support, in. (mm)
- $C$  = cross-sectional constant to define torsional properties of slab and beam
- $c_1$  = dimension of rectangular or equivalent rectangular column, capital, or bracket measured in the direc-