# Design Guide for Twisting Moments in Slabs

Reported by Joint ACI-ASCE Committee 447

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*This guide assists practitioners in understanding: 1) twisting moments in two-way slabs, when twisting moments are an essential consideration; 2) methods that can be used to account for twisting moments in design; and 3) the options available for each method of the various system geometries. Descriptions of twisting moments are provided theoretically and visually in the guide, and the methods of accounting for twisting moments in design are discussed. Applicability of the various methods is evaluated through a comparison of designs resulting from each method for a variety of two-way slab types and geometries. The theories described in the guide also apply to the design of two-way wall and two-way dome systems.*

**Keywords:** finite element analysis; shell design; slab design; torsion; twist; twisting moments; wall design.



## CONTENTS



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# CHAPTER 1—INTRODUCTION AND SCOPE

## 1.1—Introduction

Section 8.2.1 of ACI 318-14 allows slabs to be designed by any procedure that satisfies equilibrium and geometric compatibility, and requires that, at each section, the design strength exceeds the required strength and serviceability requirements are fulfilled.

Traditional strip design methods for slabs are based on approximate analysis and provide neither a complete equilibrium load path or satisfy geometric compatibility. Nonetheless, these methods have been used successfully for many years to design slabs with supports arranged in a rectangular grid.

From 1995 to 2015, design engineers transitioned from predominantly using traditional slab analysis methods to using finite element analysis (FEA). More recently, engineers use FEA to assist in the structural design of two-way concrete members. Twisting moments in two-way slabs can require additional reinforcement from those proportioned for bending moments, yet they are often misunderstood and sometimes ignored, neglected, or both, by practitioners in design. This is most likely due to their lack of being discussed comprehensively in design codes and frequent exclusion from college concrete design course curricula.

Although FEA solutions provide a full equilibrium load path and satisfy geometric compatibility, they determine load paths that require twisting moments for equilibrium (Shin et al. 2009). Many designers using FEA have ignored these twisting moments—a possible unconservative assumption where twisting moments are high (Park and Gamble 2000). To provide designers with guidance related to this issue, methods for explicitly incorporating twisting moments determined from FEA in the design of slabs are discussed in this guide.

The purpose of this design guide is to provide advice to design engineers who analyze slab systems with finite element methods and who need to ensure their designs are satisfactory for the twisting moments predicted by the analysis. This guide provides background information regarding twisting moments and describes multiple approaches for consideration of twisting moments in design. It also provides advice for designers of walls and shells with twisting moment conditions similar to those in slabs.

## 1.2—Scope

This design guide applies to slabs of both uniform and nonuniform thicknesses, including drop caps and drop panels, except where noted in the text. This guide does not apply to waffle slabs, or the beams of beam-and-slab floor systems. Chapters 3 through 6 address slabs and walls in which the response is determined purely by bending. Chapter 7 addresses shells for which the response is determined by bending and membrane action. Chapter 6 and the theory sections of this guide are applicable to walls. Chapter 7 and the theory sections of this guide are applicable to shells, with the caveat that equations presented in Chapter 3 are not valid for curved shells.

# CHAPTER 2—NOTATION AND DEFINITIONS

## 2.1—Notation

$c_{i,j}$ = fraction for consideration of sections partially crossing element to apply to forces in local node $j$ in element $i$
$D$ = flexural rigidity of plate, in.-lb (N·mm)
$E$ = Young's modulus, psi (MPa)
$F$ = force vector, lb (N)
$f_{i,j}$ = nodal force vector for local node $j$ in element $i$
$h$ = thickness of slab or plate, in. (mm)
$L$ = width of design section, in. (mm)
$M$ = bending moment, or moment vector, in.-lb (N·mm)
$M_d$ = design bending moment, in.-lb (N·mm)
$M_i$ = bending moment from isotropic analysis, in.-lb (N·mm)
$M_{tf}$ = bending moment from twist-free analysis, in.-lb (N·mm)
$M_u$ = design moment for slab cross section, in.-lb (N·mm)
$m_{i,j}$ = nodal moment vector for local node $j$ in element $i$, in.-lb/in. (N·mm/mm)
$m_r$ = bending moment causing stresses parallel to $r$-axis, per unit length of slab or plate, in.-lb/in. (N·mm/mm)
$m_{rs}$ = twisting moment relative to $r$-$s$-axes per unit length of slab or plate, in.-lb/in. (N·mm/mm)
$m_s$ = bending moment causing stresses parallel to $s$-axis, per unit length of slab or plate, in.-lb/in. (N·mm/mm)