IN-LB	Inch-Pound Units
SI	International System of Units

Guide for Shear Reinforcement for Slabs

Reported by Joint ACI-ASCE Committee 421

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Tests have established that punching shear in slabs can be effectively resisted by reinforcement consisting of vertical rods mechanically anchored at top and bottom of slabs. ACI 318 sets out the principles of design for slab shear reinforcement and makes specific reference to stirrups and headed studs. This guide reviews available types and makes recommendations for their design. The application of these recommendations is illustrated through numerical examples.

Keywords: column-slab connection; concrete flat plate; headed shear studs; moment transfer; prestressed concrete; punching shear; shear heads; shear stresses; slabs; two-way slabs.

CONTENTS

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

In flat-plate floors, slab-column connections are subjected to high shear stresses produced by the transfer of the internal forces between the columns and the slabs. ACI 318-14 Section 8.7.6.1 allows the use of shear reinforcement for slabs and footings in the form of bars, as in the vertical legs of stirrups. ACI 318 emphasizes the importance of anchorage details and accurate placement of the shear reinforcement, especially in thin slabs. ACI 318-14 Section 8.7.7.1 permits headed shear stud reinforcement conforming to ASTM A1044/A1044M. A general procedure for evaluation of the punching shear strength of slab-column connections is given in ACI 318-14 Section 8.5.3.

Shear reinforcement consisting of vertical rods (studs) or the equivalent, mechanically anchored at each end, can be used. In this guide, all types of mechanically anchored shear reinforcement are referred to as shear stud or stud. To be fully effective, the anchorage should be capable of developing the specified yield strength of the studs. The mechanical anchorage can be obtained by heads or strips connected to the studs by welding. The heads can also be formed by forging the stud ends.

1.2—Scope

Recommendations in this guide are for the design of shear reinforcement in slabs. The design is in accordance with ACI 318. Numerical design examples are included.

1.3—Evolution of the practice

Extensive tests (Dilger and Ghali 1981; Andrä 1981a,b; Van der Voet et al. 1982; Mokhtar et al. 1985; Elgabry and Ghali 1987; Mortin and Ghali 1991; Dilger and Shatila 1989; Cao 1993; Brown and Dilger 1994; Megally 1998; Birkle 2004; Ritchie and Ghali 2005; Gayed and Ghali 2006) have confirmed the effectiveness of mechanically-anchored shear reinforcement, such as shown in Fig. 1.3a, in increasing the strength and ductility of slab-column connections subjected to concentric punching or punching combined with moment. Stud assemblies consisting of either a single-head stud attached to a steel base rail by welding (Fig. 1.3a(a)) or double-headed studs mechanically crimped into a nonstructural steel channel (Fig. 1.3a(b)) are specified in ASTM A1044/A1044M. Figure 1.3b is a top view of a slab that shows a typical arrangement of shear reinforcement (stirrup legs or studs) in the vicinity of an interior column. ACI 318 requires that the spacing g between adjacent stirrup legs or studs, measured on the first peripheral line of shear reinforcement, be equal to or less than $2d$. Recommendations for the distances s_o and s are given in Chapter 4.

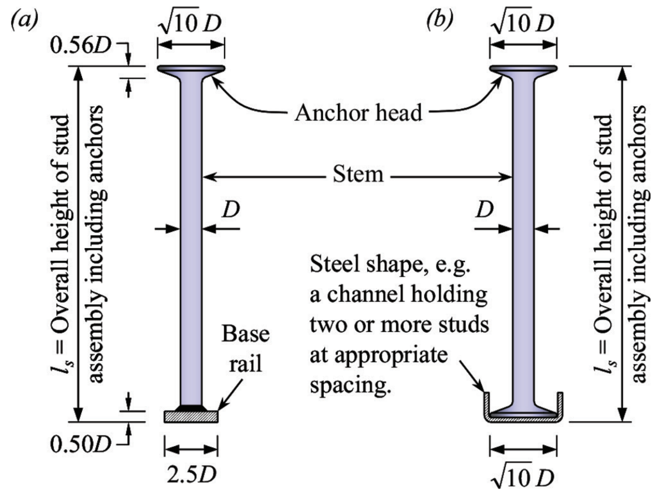

Fig. 1.3a—Stud assemblies conforming to ASTM A1044/A1044M: (a) single-headed studs welded to a base rail; and (b) double-headed studs crimped into a steel channel.

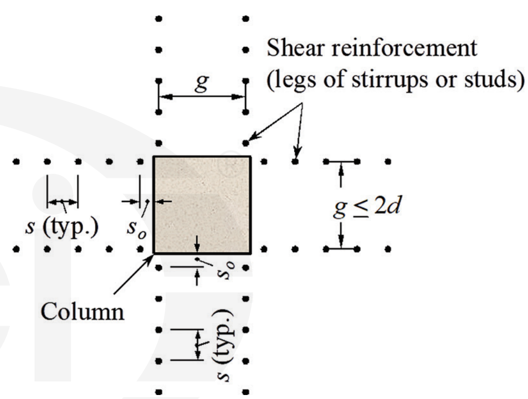

Fig. 1.3b—Top view of flat plate showing arrangement of shear reinforcement in vicinity of interior column.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_c = area of concrete of assumed critical section, in.^{2} (mm^2)

A_v = cross-sectional area of shear reinforcement on one peripheral line parallel to perimeter of column section, in.^{2} (mm^2)
b_o = length of perimeter of critical section, in. (mm)
c_b, c_t = clear concrete cover of reinforcement to bottom and top slab surfaces, respectively, in. (mm)
c_x, c_y = size of rectangular column measured in two orthogonal span directions, x and y, respectively, in. (mm)
D = stud diameter, in. (mm)
d = effective depth of slab; average of distances from extreme compression fiber to centroids of tension reinforcements running in two orthogonal directions, in. (mm)
d_b = nominal diameter of flexural reinforcing bars, in. (mm)
f_c' = specified compressive strength of concrete, psi (MPa)
f_{ct} = average splitting tensile strength of lightweight aggregate concrete, psi (MPa)
f_{pc} = average value of compressive stress in concrete in two directions (after allowance for all prestress losses) at centroid of cross section, psi (MPa)
f_{yt} = specified yield strength of shear reinforcement, psi (MPa)
g = distance between adjacent stirrup legs or studs, measured in a direction parallel to a column face, in. (mm)
h = overall thickness of slab, in. (mm)
J_c = property of assumed critical section, defined by ACI 318 as analogous to polar moment of inertia, in.^{4} (mm^4)
J_{cx}, J_{cy} = property of assumed critical section of any shape, equal to d multiplied by second moment of perimeter about x or y axis, respectively (Appendix B), in.^{4} (mm^4)
$J_{c\bar{x}\bar{y}}$ = d times product of inertia of assumed shear critical section about nonprincipal axes $\bar{x}$ and $\bar{y}$, in.^{4} (mm^4)
L = length of segment of assumed critical section, in. (mm)
l_s = overall specified height of headed stud assembly including anchors, in. (mm)
l_x, l_y = projections of assumed critical section on principal axes x and y, in. (mm)
l_{x1}, l_{y1} = length of sides in x- and y-directions of critical section at d/2 from column face, in. (mm)
l_{x2}, l_{y2} = length of sides in x- and y-directions of critical section at d/2 outside outermost legs of shear reinforcement, in. (mm)
$M_{sc\text{-}x}$, $M_{sc\text{-}y}$ = factored slab moments resisted by supporting column about centroidal principal axes x and y of assumed critical section, lb-in. (N-m)
$M_{sc-\bar{x}}$, $M_{sc-\bar{y}}$ = factored slab moments resisted by column about the centroidal nonprincipal $\bar{x}$ or $\bar{y}$ axis, lb-in. (N-m)
M_{scOx}, M_{scOy} = factored slab moment resisted by column about x or y axis through the column's centroid O, lb-in. (N-m)
n = number of studs or stirrup legs per line running in x- or y-direction
s = spacing between peripheral lines of shear reinforcement, in. (mm)
s_o = spacing between first peripheral line of shear reinforcement and column face, in. (mm)
V_p = vertical component of all effective prestress forces crossing the critical section, lb (N)
V_u = factored shear force, lb (N)
v_c = nominal shear strength provided by concrete in presence of shear reinforcement, psi (MPa)
v_n = nominal shear strength at critical section, psi (MPa)
v_s = nominal shear strength provided by shear reinforcement, psi (MPa)
v_u = maximum shear stress due to factored forces, psi (MPa)
w_{sd} = super-imposed dead load per unit area, lb/ft^2 (kN/m^2)
x, y = coordinates of point on perimeter of shear critical section with respect to centroidal principal axes x and y, in. (mm)
$\bar{x}$, $\bar{y}$ = coordinates of point on perimeter of shear critical section with respect to centroidal nonprincipal axes $\bar{x}$ and $\bar{y}$, in. (mm)
α_s = dimensionless coefficient equal to 40, 30, and 20 for interior, edge, and corner columns, respectively
β = ratio of long side to short side of column cross section
γ_{conc} = density of concrete, lb/ft^3 (kN/m^3)
γ_{vx}, γ_{vy}= factor used to determine moment about the axes x and y between slab and column that is transferred by shear stress at assumed critical section
λ = modification factor reflecting the reduced mechanical properties of lightweight concrete, all relative to normalweight concrete of the same compressive strength
ϕ = strength reduction factor = 0.75
κ = fraction of service dead load to be balanced by effective prestressing

2.2—Definitions

Please refer to the latest version of "ACI Concrete Terminology" for a comprehensive list of definitions. Definitions provided herein complement that resource.

headed shear stud reinforcement—reinforcement conforming to ASTM A1044/A1044M and composed of vertical rods anchored mechanically near the bottom and top surfaces of the slab.

shear cap—thickened portion of the slab around the column with plan dimensions not conforming with the ACI 318 requirements for drop panels.

shear critical section—cross section, having depth d and perpendicular to the plane of the slab, where shear stresses should be evaluated; two shear critical sections should be considered: (1) at d/2 from column periphery, and (2) at d/2 from the outermost peripheral line of shear reinforcement (if provided).

slab moment resisted by supporting column—sum of moments at the ends of the column above and below a slab-column joint.