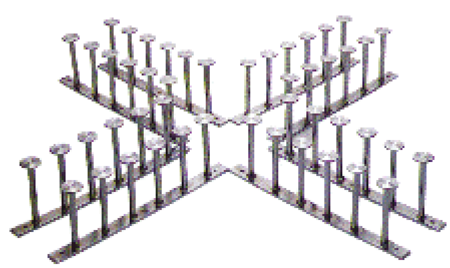
DECON® STUDRAIL® DESIGN MANUAL

INCLUDING A USER'S MANUAL FOR *STDESIGN V3.1*



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PART I: INTRODUCTION

Thank-you for your interest in Decon® Studrails® – an innovative and efficient solution to the problem of punching shear control in flat plate slab systems. Studrails® have become the standard method of increasing punching shear in many design firms across the USA, Canada, and around the world. Studrails® are also increasingly being used in another application: to reinforce post-tensioned anchorage zones against bursting forces.

This manual updates and replaces the previous Decon® Studrail® Design Manual dated August, 1996. Updates include new design information in the CSA A23.3-04 and ACI 318-05 design codes and a guide to the new Decon® STDESIGN V3.1 software.

The limiting criterion governing the design of most long span flat slabs is the punching shear strength of the concrete around the supporting column. At the connection of the flat slab and supporting columns, high shear can cause brittle punching failure. Until the advent of Studrails®, the shear resistance of flat slabs was usually increased by providing drop panels, column capitals, structural steel shearheads or stirrups.

With the exception of Studrails®, each method has its inherent disadvantages.

Drop panels and column capitals may be impractical for architectural reasons. They often necessitate the use of suspended ceilings, thereby increasing the floor to floor height. They are also costly to build because they do not take advantage of flying forms.

Shearheads are rarely used because their installation is very expensive. They also interfere with the placement of flexural reinforcing bars and post-tensioned tendons.

Increasing the strength of concrete slabs with conventional stirrups is becoming less common, as they too are cumbersome, costly and they impede the placement of flexural rebar. Post-tensioning tendons and longitudinal reinforcement must be threaded through and tied to the stirrup cages. The shear is resisted by the vertical legs of stirrups. However, because of bends, the lengths of the vertical legs of stirrups are too short to be effective, particularly in thin slabs. In Canada, Section 13.3.9.1 of CSA A23.3-04 restricts the use of stirrups to slabs not less than 300 mm (approximately 12 in.) thick. Section 11.12.3 of ACI 318-05 restricts the use of stirrups to slabs with a minimum effective depth of 6", but not less than 16 times the stirrup diameter. The accompanying commentary states that anchorage of stirrups "…according to the requirements of 12.13 is difficult in slabs thinner than 10 in."

An innovative, economical, quick, and easy solution is the Decon® Studrail® (originally patented under U.S. Patent #4406103 and Canadian Patent #1085642, and currently patented under U.S. Patent #5655349 and Canadian Patent #2165848). Originally introduced in 1988, a Studrail® SW consists of shear studs, with specially designed anchor heads, welded to a steel base rail. The new Studrail® CS contains double-headed studs that are crimped into a light gage steel channel. In order to develop the full yield

strength of the studs, the area of the anchor head must be a minimum of 10 times the cross sectional area of the stud stem. The steel base rail of the Studrail® SW serves the dual purpose of providing bottom anchorage of the studs and holding the studs in their correct position on the formwork. Since the studs on the Studrail® CS contain two anchor heads, the channel section simply ensures that the studs remain correctly positioned on the forms. Studrails® were initially designed using the same spacing and strength criteria as stirrups; in other words, a stud was considered equivalent to a vertical leg of a stirrup. However, Studrails® have been shown to provide a connection with superior strength and ductility as compared to slabs reinforced with stirrup cages. Therefore, spacing and connection design capacity limits have been increased for the studs, resulting in more efficient and lower cost designs.

Studrails® are referred to in the ACI 318-05 code commentary (Section R11.12.3) and are covered in detail in the Committee 421 report ACI 421.1R-99. ACI 318-08 incorporates most of the ACI 421.1R-99 provisions. The Canadian Standard, CSA A23.3-04, outlines the design of Studrails® in Section 13.4.8.

This manual outlines the design procedures for slab-column connections contained in ACI 318-05, ACI 421.1R-99, and CSA A23.3-04. A copy of the latest revision of the Decon® software for designing Studrails® is available for download at www.studrails.com. Part III of this manual provides help information for this software. Context sensitive help is also available in the software. Hand-worked and computer examples are given for further clarification of the design procedures. A reference list of journal articles is included to provide additional information on the research relevant to the use of Decon® Studrails®.

The Decon® design software also applies for the design of connections to raft foundations and footings. The software also contains subroutines to design Studrails® for ductility enhancement of flat plate systems in seismic regions.

Decon® Studrails® have been successfully used in thousands of structures in Canada, the USA, and around the world. This manual includes sample layout drawings and specifications, as well as giving an abbreviated list of some recently built structures in North America containing Studrails®.

Since the introduction of Decon® Studrails®, there have been other companies trying to supply various products purported to increase punching shear capacity. Some of these companies have introduced (and even sold) products that have not been adequately tested, and that violate the provisions of ACI 318. Marketing programs have exaggerated the performance and benefits of these systems.

In recent years, there have also been companies copying the Decon® Studrails® and claiming to be equal. This design manual and the STDESIGN software should only be used for authentic Decon® Studrails®. These design aids should not be used for any similar products. When specifying Studrails®, please be sure to specify Decon® by name and then enforce your specification. If you are presented with a

substitution request, please be sure to review the ICC ES report that is referenced in the request. There are currently two ICC ES reports on studs made to the same specifications as Decon® studs. However, many fabricators are implying that these reports cover the complete system that they are trying to substitute. This simply is not true. These two reports do not meet the requirements of ICC Evaluation Service's AC395, ASTM A1044, ACI 318-08, or IBC 2009. You should also check the section of the reports entitled "Evidence Submitted" to determine whether any relevant testing has been done using the proposed substitute product in slabs.

The next update of Decon®'s STDESIGN software will include provisions for designing using ACI 318-08. This recently published update to the design code incorporates the design of Decon® Studrails® in new Section 11.11.5. Many of the provisions of ACI 421.1R-99 have been included in ACI 318-08.

PART II: DESIGN OF STUDRAILS®

1. NOTATION

A_c	=	area of concrete of critical section (in^2 or mm^2)
A_v	=	cross-sectional area of the shear studs on one peripheral line parallel to the perimeter of the column section (in^2 or mm^2)
b_o	=	perimeter of critical section (inch or mm)
b_1	=	width of the critical section for shear measured in the direction of the span for which moments are determined (inch or mm) (CSA)
b_2	=	width of the critical section for shear measured in the direction perpendicular to b_1 (inch or mm) (CSA)
c_x,c_y	=	size of a rectangular column measured in two orthogonal span directions (inch or mm) (ACI)
c_1,c_2	=	size of a rectangular column measured in two orthogonal span directions (inch or mm) (CSA)
d	=	distance from the extreme compression fiber to the centroid of the flexural reinforcement running in the x and y directions. This is referred to as the effective depth of the slab. (inch or mm)
d_b	=	nominal diameter of flexural reinforcing bars (inch or mm)
d_c or d_{col}	=	diameter of a round column (inch or mm)
f'_c	=	specified compressive strength of concrete (psi or MPa)
f_{cp}	=	average value of compressive stress in concrete in two directions due to prestressing (ksi or MPa) (CSA)
f_{pc}	=	average value of compressive stress in concrete in two directions due to prestressing (ksi or MPa) (ACI)
f_{yv}	=	specified yield strength of studs in Studrails® (51 ksi or 350 MPa)
h	=	overall thickness of slab (inch or mm)
I_x,I_y	=	second moment of inertia of critical section about the x and y axes (in^4 or mm^4)
I_{xy}	=	product of inertia of the critical section about the x and y axes (in^4 or mm^4)
J_c	=	property of assumed critical section analogous to polar moment of inertia (in^4 or mm^4)
l	=	length of a segment of the critical section (inch or mm)
l_x,l_y	=	projections of critical section on x and y principal axes (inch or mm)
l_{x1},l_{y1}	=	length of sides of the critical section at d/2 from the column face (x and y directions) (inch or mm)
l_{x2},l_{y2}	=	length of sides of the critical section at d/2 from the outermost studs (x and y directions) (inch or mm)
M_{fx},M_{fy}	=	factored unbalanced moments transferred between the slab and the column about the column centroid (in-lb or N-mm) (CSA)
M_{ox},M_{oy}	=	factored unbalanced moments transferred between the slab and the column about the centroidal x and y axes of the critical section (in-lb or N-mm)

M_{ux}, M_{uy}	=	factored unbalanced moments transferred between the slab and the column about the column centroid (in-lb or N-mm) (ACI)
OAH	=	overall height of the Studrail® (inch or mm)
OAL	=	overall length of the Studrail® (inch or mm)
o_x or g_x	=	slab overhang dimension beyond the column in the x-direction (inch or mm)
o_y or g_y	=	slab overhang dimension beyond the column in the y-direction (inch or mm)
s	=	constant spacing between peripheral lines of studs. This is the same as the stud spacing along the Studrail® (inch or mm)
s_0	=	distance from the end of the Studrail® to the first stud (inch or mm)
v_c	=	design shear strength provided by concrete (ksi or MPa)
v_f	=	maximum shear stress due to the factored forces (ksi or MPa) (CSA)
v_n	=	design shear strength at the critical section, including the contributions of both the concrete and Studrails® (ksi or MPa) (ACI)
v_r	=	design shear strength at the critical section, including the contributions of both the concrete and Studrails® (ksi or MPa) (CSA)
v_s	=	design shear strength provided by the Studrails® per unit length of the critical section (ksi or MPa)
v_u	=	maximum shear stress due to the factored forces (ksi or MPa) (ACI)
V_f	=	applied shear force transferred at slab-column connection (lb or N) (CSA)
V_p	=	vertical component of all effective prestress forces crossing the critical section (lb or N)
V_u	=	applied shear force transferred at slab-column connection (lb or N) (ACI)
x,y	=	coordinates of any point on the critical section with respect to the centroidal principal axes x and y of the critical section (inch or mm)
α	=	factor times "d" giving the distance between the column face and each critical section
α_s	=	dimensionless coefficient used to calculate v_c and equal to 40, 30, and 20 for interior, edge, and corner columns respectively (ACI)
	=	dimensionless coefficient used to calculate v_c and equal to 4, 3, and 2 for interior, edge, and corner columns respectively (CSA)
β	=	ratio of long side to short side of column cross section (ACI)
β_c	=	ratio of long side to short side of column cross section (CSA)
β_p	=	constant used to compute v_c in prestressed slabs
γ_f	=	fraction of moment between slab and column that is considered transferred by flexure
γ_{vx}, γ_{vy}	=	fraction of moment between slab and column that is considered transferred by eccentricity of the shear about the principal centroidal x and y axes of the critical section
λ	=	factor to account for low-density concrete. The value is 1.00, 0.85, and 0.75 for normal weight, sand-lightweight or all-lightweight concrete respectively
ϕ	=	strength-reduction factor with a value of 0.75 (ACI)
ϕ_c	=	concrete resistance factor with a value of 0.65 (CSA)
ϕ_s	=	steel resistance factor with a value of 0.85 (CSA)

2. GENERAL DESIGN INFORMATION

Part II of this manual explains the design procedures of the ACI 318-05, and CSA A23.3-04 design codes, as well as the recommendations of ACI Committee 421 report ACI 421.1R-99. ACI 421.1R-99 is referenced as the Studrail® design guide in our ICC Evaluation Service Report #ESR-2494. Many of the provisions of ACI 421.1R-99 have also been adopted into ACI 318-08. An example is given in the following pages to show the application of each design procedure. The equations used in the following sections are referenced by either the equation number or section number in the corresponding design codes.

The design procedure for Decon® Studrails® to enhance the punching shear capacity of slab to column connections can be summarized as follows:

Step 1. Analyze the critical section at d/2 from the column face to check whether the section is adequate to resist the design loads. If there is not adequate capacity, Studrails® are required. In seismic zones, consideration must be given to ensuring adequate ductility depending on the design combination of gravity loads versus capacity and lateral interstorey drift.

Step 2. If Studrails® are required, calculate the required Studrail® capacity. Select the number of Studrails®, diameter of studs, and stud spacing to satisfy this criterion.

Step 3. Estimate the number of studs required per rail and calculate the concrete shear resistance at a critical section at d/2 outside this shear reinforced zone. If the resistance is too low, add another stud and repeat this step. If the resistance is too high, remove a stud and repeat this step until the optimum number of studs is determined.

Full scale testing of Decon® Studrails® began at the University of Calgary in the 1970's and continues today at universities around the world. During this ongoing experimental program, certain design rules were developed. These rules have been further modified by the design codes. The general rules are outlined below. Code specific rules, limits and examples are given in Sections 3 through 10 of this manual.

2.1 Effective Depth

The slab effective depth is the distance from the extreme compression fiber to the centroid of the tension face flexural reinforcement running in the x and y directions. When bars of the same diameters and spacing are used in the two directions, d is equal to the slab thickness minus top cover, minus one bar diameter of flexural reinforcement.

For post-tensioned slabs, both ACI 318-05 (Section 11.4.1) and CSA A23.3-04 (Section 2.3) state that the effective depth value can be assumed to be at least 0.8h.

2.2 Number of Studrails®

Figure 1 shows typical Studrail® layouts around interior, edge and corner columns with rectangular cross-sections, and interior round columns. Studrails® are placed perpendicular to the column faces. At each column corner, one Studrail® must be placed perpendicular to both column faces. This requirement is because of the concentration of shear stresses at these locations as well as to ensure that the design critical section is reflected in construction. Thus, the minimum number of Studrails is 8, 6, and 4 for interior, edge and corner columns, respectively.

One more requirement for the maximum spacing between Studrails® is stated in Clause 11.12.3.3 of ACI 318-05. This limit is given as 2d in the direction parallel to the column faces. This limit helps ensure confinement of the concrete in the shear reinforced zone.

Both the requirement for Studrails® at the corners of the column and the 2d lateral spacing limit can be disregarded if it is physically impossible to meet these requirements due to slab openings.

On round columns, there are two placement options. We are showing an “x-y” placement in Figure 1. It is also possible to place the Studrails® in a radial pattern. However, we recommend the “x-y” placement as the radial placement can cause interference with the placement of rebar and tendons. When positioning the Studrails in the “x-y” pattern, the distance between the outermost Studrails on each “face” should be at least 0.6 d_{col}. If the Studrails are closer together, the capacity will be reduced since the location of the outer critical section will change.

2.3 Spacing s_o and s

When specifying Studrails®, two spacing values are required: the distance from the column face to the first stud (s_o), and the constant spacing between studs (s).

The distance, s_o, between the column face and the first peripheral line of studs must be small enough so that no cracks are allowed to occur between the column face and the first stud. Also, this initial spacing must be large enough so that the first stud is not ineffective.

The spacing, s, of the studs must be small enough so that every potential shear crack is intercepted by at least one stud. The stud spacing should also be large enough that there is room to place flexural reinforcement or post-tensioning tendons between the stud heads. See DEC 1300 (Part IV) for head sizes. We recommend you consider the following information when determining stud spacing:

Notes:

- Stud spacing, S, must be constant along a Studrail.
- When more than two Studrails are to be placed on one column face, they should be evenly spaced.

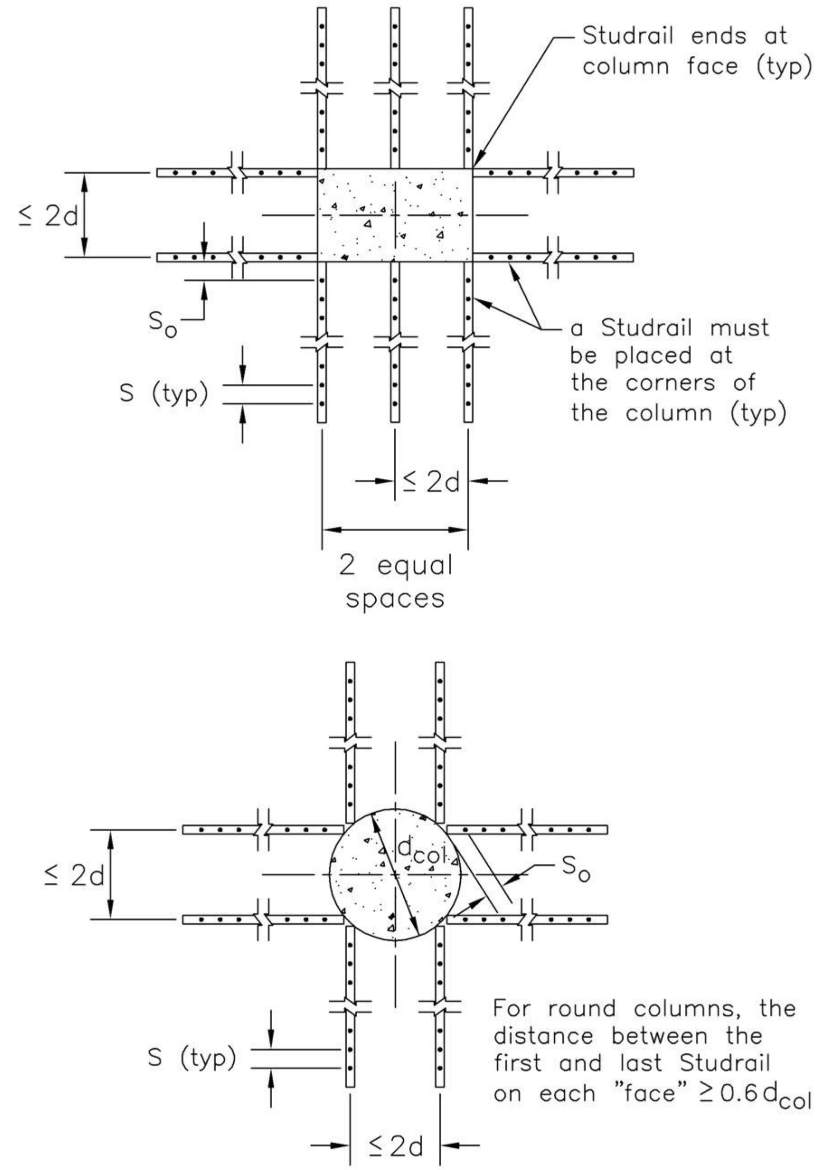


Figure 1: Typical arrangements of Studrails (plan views)

(continued on the next page)

Notes:

- Stud spacing, S, must be constant along a Studrail.
- If the slab edge is within 2 in. (50 mm) of a column face, the Studrail(s) beside that free edge should be moved so that they are located no closer than 2 in. (50 mm) from the edge.
- When more than two Studrails are to be placed on one column face, they should be evenly spaced.

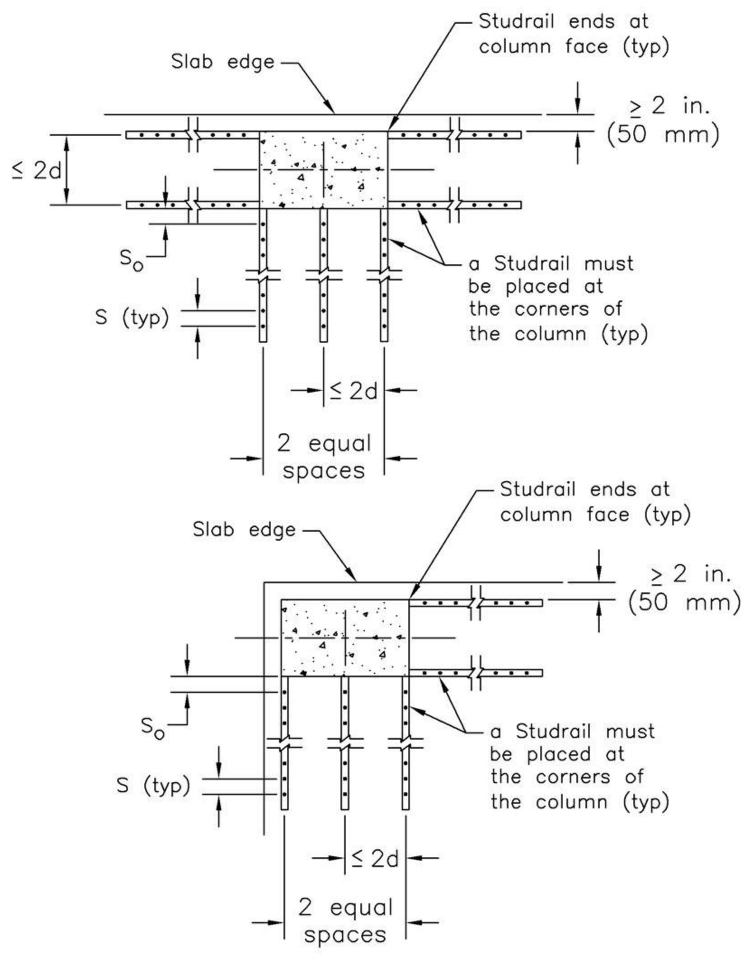


Figure 1: Typical arrangements of Studrails
(plan views)
(continued from previous page)

- Let the STDESIGN software calculate the spacing on the Studrails® required for your worst case connection and use this spacing throughout.
- The largest allowable spacing (meeting code limitations and loading conditions) will generally make placement of the other reinforcement simpler.
- Matching the stud spacing to the top rebar spacing could simplify installation of the rebar.
- Matching the stud spacing to the post-tension anchor spacing for edge and corner columns could simplify placement of the tendons.

The maximum limits of s_o and s are given below for the three sets of design rules:

$$ACI318-05: \quad \left.\begin{matrix} s_0 \le 0.5d \\ s \le 0.5d \end{matrix}\right\} \qquad (11.12.3.3)$$

$$ACI421.1R-99: \quad \begin{matrix} \left.\begin{matrix} s_0 \ge 0.35d \\ s_0 \le 0.4d \\ s \le 0.5d \end{matrix}\right\} if \dfrac{v_u}{\emptyset} > 6\sqrt{f'_c(psi)} \\ \left.\begin{matrix} s_0 \ge 0.35d \\ s_0 \le 0.4d \\ s \le 0.75d \end{matrix}\right\} if \dfrac{v_u}{\emptyset} \le 6\sqrt{f'_c(psi)} \end{matrix} \qquad (3.3.2, 5.4)$$

$$CSA\ A23.3-04: \quad \begin{matrix} \left.\begin{matrix} s_0 = 0.4d \\ s \le 0.5d \end{matrix}\right\} if\ v_f > 0.56\lambda\phi_c\sqrt{f'_c(MPa)} \\ \left.\begin{matrix} s_0 = 0.4d \\ s \le 0.75d \end{matrix}\right\} if\ v_f \le 0.56\lambda\phi_c\sqrt{f'_c(MPa)} \end{matrix} \qquad (13.3.8.6)$$

2.4 Stud Sizes

The stud diameters and the dimensions of Decon® Studrails® are given in DEC 1300 (Part IV) of this manual. Economics should be considered when selecting stud sizes. Generally, designs using either 3/8" or 1/2" diameter studs are the most economical in standard slabs. When the slab thickness exceeds approximately 11", the larger diameter studs may become a better choice. It is generally a good idea to maintain the same stud diameter throughout a project unless there is a wide range of slab thicknesses.

The height of the Studrail® is determined by the slab thickness and the concrete cover requirements. Each Studrail® contains studs of a uniform height, so the minimum slab thickness in the shear reinforced zone is used. Generally, the concrete cover for the Studrails® will be the same as for rebar.

2.5 Slab Overhangs

Edge and corner columns have slab overhangs if the column is set away from the edge of the slab. The punching shear strength is increased by the presence of any overhang. The

treatment of the overhangs shown in Figure 2 is adapted from Figure N13.3.3.4 of the Explanatory Notes to CSA A23.3-04. This figure indicates that only a portion of the overhang should be used in the design calculation for punching shear capacity. However, this is an area that needs further research as it indicates that openings within 10h of the column face reduce the shear capacity, yet a free edge more than 5d away has no effect.

2.6 Openings

Openings are discussed in Section 11.12.5 of ACI 318-05 and Section 13.3.3.4 of CSA A23.3-04. In both codes, openings cause a reduction in the shear strength when the openings are located either within 10h from the column face, or within the column strip. The reduction is calculated as follows:

Two lines should be drawn from the column centroid and tangent to each opening in the slab. Any portion of the critical section contained within these two lines is ignored in the punching shear stress calculation. This will change the geometric properties of the critical section.

Clause 11.12.5.2 of ACI 318-05 states that "for slabs with shearheads, the ineffective portion of the perimeter shall be one-half of that defined…" Since shearheads are defined as structural steel shapes that are embedded in the slab, we have conservatively assumed this clause does not apply to stirrups or Studrails®. However, PCA has assumed that this clause applies to all types of slab shear reinforcement in their publication entitled "Notes on ACI 318-05 Building Code Requirements for Structural Concrete."

2.7 Designs Using Stirrups

Although the design procedures and the code models are similar for stirrups and Studrails®, there are several important distinctions.

2.7.1 ACI 318-05

This code assumes that one stud is equivalent to one stirrup leg and the design procedure is the same. However, Section 11.12.3 of ACI 318-05 restricts the use of stirrups to slabs with a minimum effective depth of 6", but not less than 16 times the stirrup diameter. The accompanying commentary states that anchorage of stirrups "…according to the requirements of 12.13 is difficult in slabs thinner than 10 in." This minimum limit does not apply to Studrails®.

2.7.2 ACI 421.1R-99

It is not possible to design stirrups using ACI 421.1R-99. The higher design capacities given in this document are specifically laid out to incorporate the superior performance of Studrails® versus stirrups. These provisions have been adopted into new Section 11.11.5 of ACI 318-08.

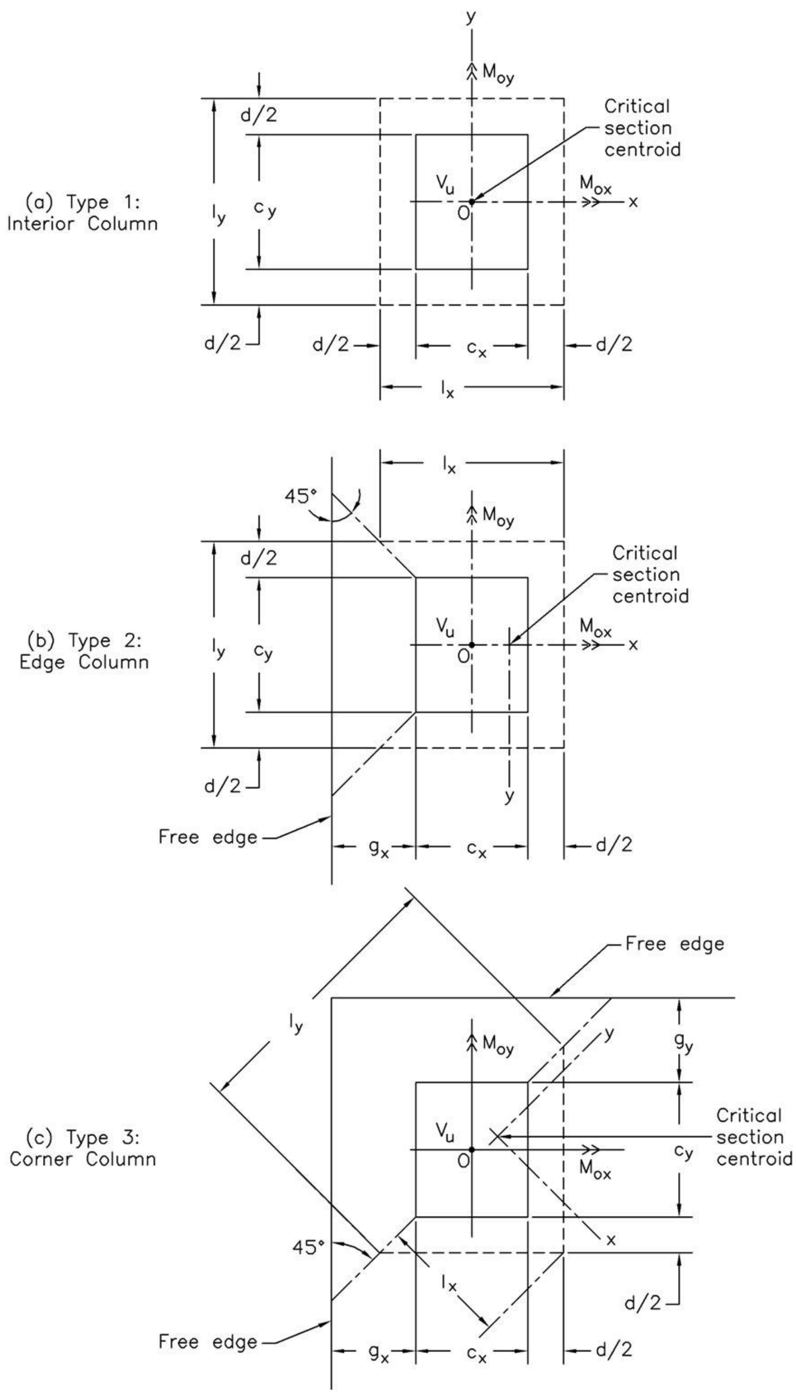


Figure 2: Definition of slab – column connection parameters and critical section at d/2 from column face

2.7.3 CSA A23.3-04

Designs using Studrails® and stirrups are outlined in Sections 13.3.8 and 13.3.9 respectively. CSA A23.3-04 gives higher allowable capacities and spacing for Studrails® relative to stirrups. Clause 13.3.9.1 of CSA A23.3-04 restricts the use of stirrups to slabs not less than 300 mm (approximately 12 in.) thick.

3. DESIGN BY ACI 318-05 CODE

3.1 Design Steps

With reference to the three steps given in Section 2 of this manual, the ACI 318-05 design code specifies the following (equations given in terms of stress rather than force so that they can be used for both concentric and eccentric punching calculations):

Step 1: Check to determine whether Studrails® are required.

Design for punching shear resistance of slabs at column connections is based on:

$$\emptyset v_n \geq v_u \qquad (Eq. 11-1)$$

Where v_u is the maximum factored shear stress on the critical section due to the design loads; Φ is a strength reduction factor with the value of 0.75; and v_n is the nominal shear strength at the critical section. It is important to ensure that the loading used to calculate v_u uses a load combination specified in Clause 9.2 of ACI 318-05. All input loads should be from the same load case; do not select the maximum vertical shear and unbalanced moments from separate load cases. For a slab without shear reinforcement,

$$v_n = v_c = Minimum \begin{Bmatrix} \left(2 + \frac{4}{\beta}\right)\sqrt{f'_c} \\ \left(\frac{\alpha_s d}{b_0} + 2\right)\sqrt{f'_c} \\ 4\sqrt{f'_c} \end{Bmatrix} \qquad (11.12.2.1)$$

For prestressed slabs, the design shear resistance is calculated by,

$$v_n = v_c = \left(\beta_p\sqrt{f'_c} + 0.3 f_{pc}\right) + \frac{V_p}{b_0 d} \qquad (11.12.2.2)$$

We recommend that the V_p term be set to zero since this relies on a precise installation of the tendon profile. The following restrictions on this equation are set in Clause 11.12.2.2:

- The column must be located at least *4h* from any slab edge
- The design value of $\sqrt{f'_c}$ cannot exceed 70 psi

- f_{pc} in each direction must be between 125 psi and 500 psi

ACI 318-05 requires that the shear stress caused by any unbalanced moment that is resisted by shear be linearly distributed over the critical section. Accordingly, the maximum shear stress is calculated by:

$$v_u = \frac{V_u}{A_c} - \frac{\gamma_{vx} M_{ux} y}{I_x} + \frac{\gamma_{vy} M_{uy} x}{I_y}$$

The point *(x,y)* relative to the principal centroidal axes should be selected such that v_u is a maximum. The negative sign in front of the second term is required due to the sign convention that we have adopted in our software. Figure 2 shows the positive convention for the orientation and location of the axes and forces. Decon® uses the moment of inertia, *I*, rather than the parameter J_c, which is “analogous to the polar moment of inertia”. Equations for the moment of inertia, *I*, for different critical sections can be found in Reference 12. γ_v, the fraction of the unbalanced moment that is resisted by shear, is calculated as follows (see Figures 2 and 3):

Interior connections:

$$\gamma_{vx} = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{l_y/l_x}}$$

$$\gamma_{vy} = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{l_x/l_y}}$$

Edge connections:

$$\gamma_{vx} = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{l_y/l_x}}$$

$$\gamma_{vy} = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{(l_x/l_y) - 0.2}}$$

Corner connections:

$$\gamma_{vx} = 0.4$$

$$\gamma_{vy} = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{(l_x/l_y) - 0.2}}$$

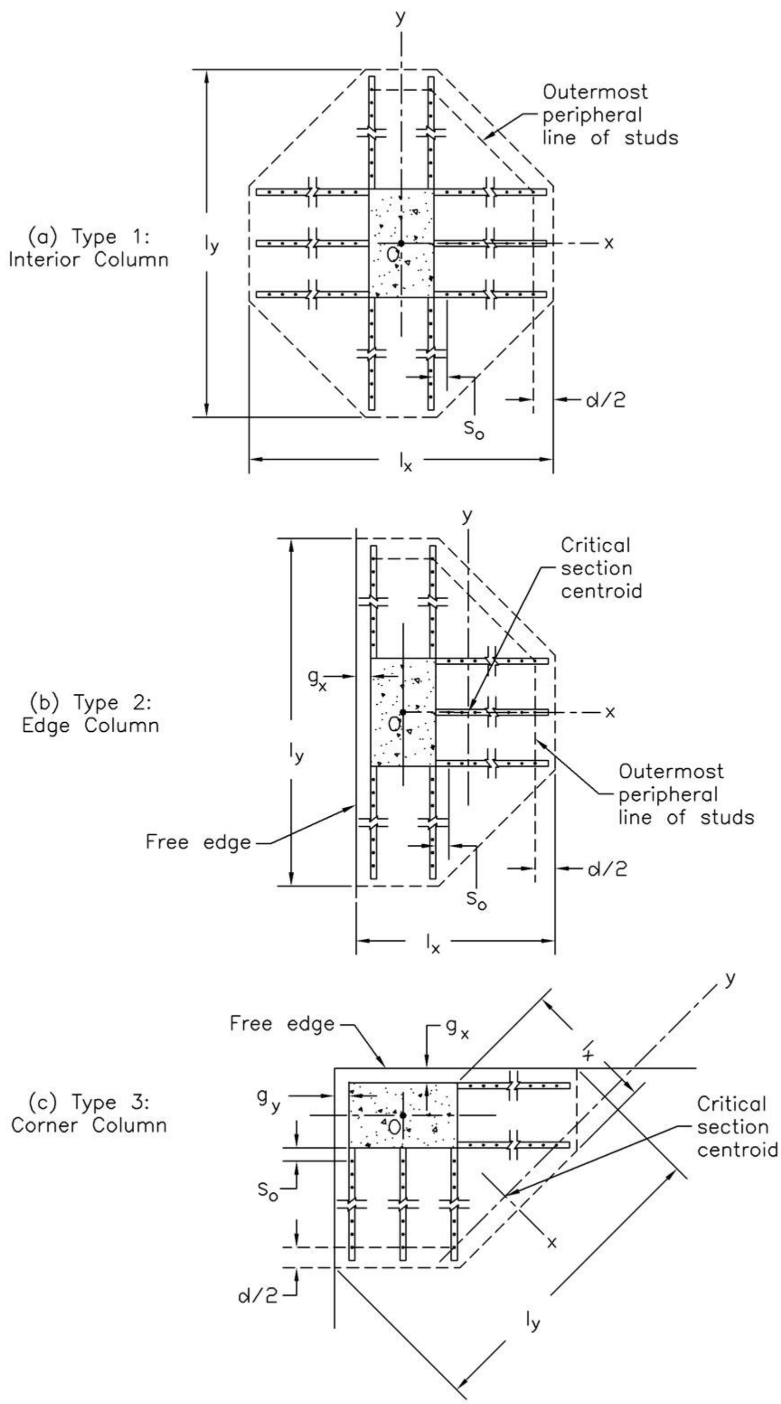


Figure 3: Typical arrangements of Studrails and location of critical section outside shear reinforced zone

For the edge and corner connections, γ_{vy} becomes zero when $(l_x/l_y) < 0.2$. These equations for γ_v are contained in Figure B2 of ACI 421.1R-99. We are using them for ACI 318-05 as well based on the reference at the end of commentary section R11.12.6.2.

If Eq. (11-1) is not satisfied, Studrails® are needed. If $v_n > 6\sqrt{f'_c}$, then Clause 11.12.3.2 of ACI 318-05 states that the slab is inadequate to resist the design loads. (Note that both ACI 421.1R-99 and CSA A23.3-04 allow higher resistance with Studrails®). Increasing f'_c, d, or the dimensions of the column cross-section may increase v_n such that Clause 11.12.3.2 can be satisfied.

Refer to Section 9 of this manual to decide whether Studrails® should be used to provide ductility to the slab column connection even if the strength calculation indicates that Studrails® are not required.

Step 2: Select Studrail® layout, stud diameter, and stud spacing.

Eq. 11-1 must be satisfied along the critical section located d/2 from the column face with:

$$v_n = v_c + v_s \leq 6\sqrt{f'_c} \qquad (11.1.1, 11.12.3.2)$$

where:

$$v_c = 2\sqrt{f'_c} \qquad (11.12.3.1)$$

$$v_s = \frac{A_v f_{yv}}{b_0 s}, f_{yv} = 50ksi \qquad (11.5.7.2)$$

$$A_v = (\#\ of\ rails)X(Area\ of\ one\ stud)$$

Step 3: Determine the extent of the required shear reinforced zone.

Figure 3 shows the critical section outside the shear reinforced zone. By trial and error, determine the number of studs required to satisfy Eq. 11-1 on this critical section with:

$$\emptyset v_n = \emptyset v_c = \emptyset\left(2\sqrt{f'_c}\right) \qquad (11.12.6.2)$$

3.2 General Comments

The equations in Section 3.1 of this manual are given for the U.S. Customary system of units with the concrete strength f'_c in pounds per square inch. For metric designs, the constant in front of each $\sqrt{f'_c}$ symbol should be divided by 12 and f'_c should be given in megapascals.

For the case of corner column connections, or when asymmetric openings exist, the principal axes of the critical section will not be oriented in the direction of the column lines. There are two ways to deal with this so that equilibrium of the design stresses is maintained. The first option is to determine the directions of the principal axes and then perform the design as described above. Alternatively, the maximum shear stress could be calculated by (see Appendix B of Reference 12):

$$v_u = \frac{V_u}{A_c} + y\frac{\gamma_{vx}M_{ux}I_y - \gamma_{vy}M_{uy}I_{xy}}{I_xI_y - I_{xy}^2} + x\frac{\gamma_{vy}M_{uy}I_x - \gamma_{vx}M_{ux}I_{xy}}{I_xI_y - I_{xy}^2}$$

ACI 318-05 includes section 13.5.3.3 (first introduced in the 1995 edition) which allows designers to modify the values of γ_v and γ_f in some instances. This provision has not been included in STDESIGN as it has been shown to be unsafe (References 10, 26, 30). If the user of STDESIGN wishes to use this clause, the input values of M_{ox} and M_{oy} can be appropriately adjusted. Also, any corresponding increase of γ_f must be considered in the design of the flexural reinforcement.

4. EXAMPLE 1: INTERIOR COLUMN DESIGN BY ACI 318-05

This example shows the design procedure of the ACI 318-05 code. An interior slab column connection with the following parameters is to be designed:

Slab thickness, h = 8”
Concrete cover = 3/4” (top & bottom)
#5 Flexural rebar = 5/8” diameter
Concrete strength, f’c = 4000 psi
Column size, $c_x = c_y$ = 20”
Loads: V_u = 160 kip
M_{ox} = 30 ft-kip = 360 in-kip
M_{oy} = 30 ft-kip = 360 in-kip

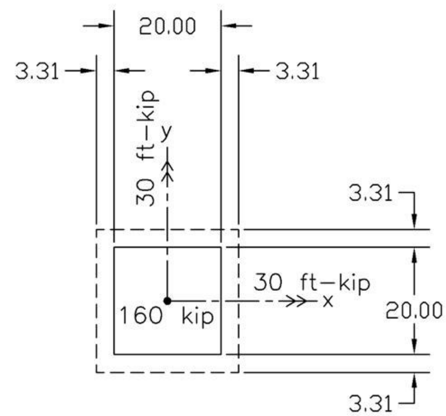
SOLUTION

Step 1: Check to determine whether Studrails® are required.

See Figure 4(a) for dimensions of critical section located d/2 from the column face.

$$\begin{aligned} d &= h - top\ cover - bar\ diameter \\ &= 8 - \frac{3}{4} - \frac{5}{8} \\ &= 6.625\ in \end{aligned}$$

(a) critical section at d/2 from column face



(b) critical section outside shear reinforced zone

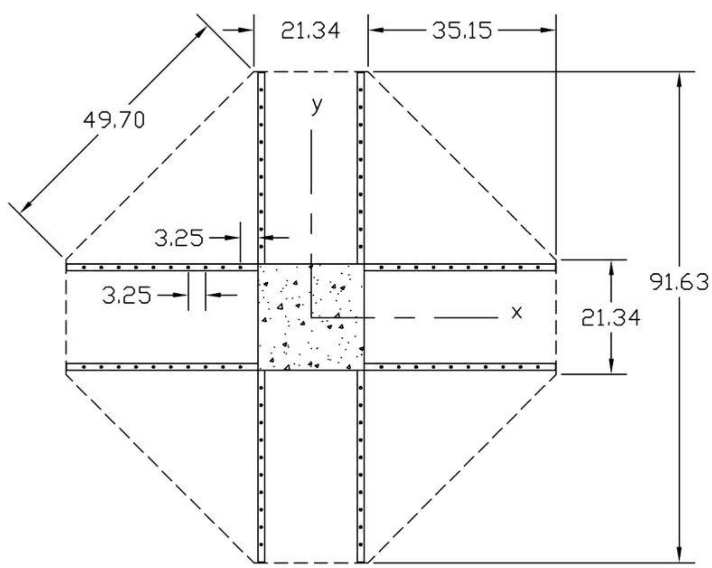


Figure 4: Interior slab−column connection of Example 1

$$\begin{aligned} l_x = l_y &= c_x + d \\ &= 20 + 6.625 \\ &= 26.625\ in \end{aligned}$$

$$\begin{aligned} b_0 &= 2l_x + 2l_y \\ &= 4(26.625) \\ &= 106.5\ in \end{aligned}$$

$$A_c = b_0 d = 106.5(6.625) = 705.6\ in^2$$

$$\begin{aligned} \gamma_{vx} = \gamma_{vy} &= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{l_y}{l_x}}} \\ &= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{20}{20}}} \\ &= 0.4 \end{aligned}$$

$$\begin{aligned} I_x = I_y &= d\left\{\frac{l_{x1}^3}{6} + \frac{l_{y1} l_{x1}^2}{2}\right\} \\ &= (6.625)\left\{\frac{26.625^3}{6} + \frac{26.625(26.625)^2}{2}\right\} \\ &= 8.336 \times 10^4\ in^4 \end{aligned}$$

For maximum stress,

$$x = \frac{20}{2} + \frac{6.625}{2} = 13.31\ in$$

$$y = -\frac{20}{2} - \frac{6.625}{2} = -13.31\ in$$

Therefore, the maximum shear stress is:

$$\begin{aligned} v_u &= \frac{V_u}{A_c} - \frac{\gamma_{vx} M_{ux} y}{I_x} + \frac{\gamma_{vy} M_{uy} x}{I_y} \\ &= \frac{160}{705.6} - \frac{0.4(360)(-13.31)}{8.336 \times 10^4} + \frac{0.4(360)(13.31)}{8.336 \times 10^4} \\ &= 0.273\ ksi \end{aligned}$$

Checking the stresses at the other corners of the critical section indicates the following stress levels:

- At (x,y) = (13.31, 13.31), vu = 0.227 ksi
- At (x,y) = (-13.31, 13.31), vu = 0.181 ksi
- At (x,y) = (-13.31, -13.31), vu = 0.227 ksi

The shear resistance is:

$$\begin{aligned} v_n &= Minimum \begin{Bmatrix} \left(2+\frac{4}{\beta}\right)\sqrt{f'_c} \\ \left(\frac{\alpha_s d}{b_0}+2\right)\sqrt{f'_c} \\ 4\sqrt{f'_c} \end{Bmatrix} \\ &= Minimum \begin{Bmatrix} \left(2+\frac{4}{1}\right)\sqrt{4000} \\ \left(\frac{40(6.625)}{106.5}+2\right)\sqrt{4000} \\ 4\sqrt{4000} \end{Bmatrix} \\ &= 0.253\ ksi \end{aligned}$$

Therefore,

$$v_u > \emptyset v_n \ and \ v_u = 4.0\sqrt{f'_c} < \emptyset 6\sqrt{f'_c}$$

Therefore, the punching shear capacity is adequate if Studrails® are provided.

Step 2: Select Studrail® layout, stud diameter, and stud spacing.

$$v_u \leq \emptyset(v_c + v_s)$$

Thus,

$$\begin{aligned} v_s &\geq \frac{v_u}{\emptyset} - v_c \\ &\geq \frac{273}{.75} - 2\sqrt{4000} \\ &\geq 237\ psi = 0.237\ ksi \end{aligned}$$

Select 12 Studrails® with 1/2 in. diameter studs with 3 1/4 in. spacing. Therefore,

$$v_s = \frac{A_v f_{yv}}{b_0 s}$$
$$= \frac{12(0.196)(50)}{106.5(3.25)}$$
$$= 0.340\ ksi$$

Step 3: Determine the extent of the required shear reinforced zone.

Assume 10 studs are required per Studrail®. The dimensions of the critical section are shown in Figure 4(b) and calculated below:

$$l_{y1} = l_{x1} = c_x - b_{rail} + 2\left(\frac{d}{2}\tan(22.5°)\right)$$
$$= 20 - 1.25 + 2\left(\frac{6.625}{2}tan(22.5°)\right)$$
$$= 21.34\ in$$

$$l_{y2} = l_{x2} = c_x + 2\left(s_0 + 9s + \frac{d}{2}\right)$$
$$= 20 + 2\left(3.25 + 9(3.25) + \frac{6.625}{2}\right)$$
$$= 91.63\ in$$

$$l = \frac{1}{2}(l_{x2} - l_{x1})\sqrt{2}$$
$$= \frac{1}{2}(91.63 - 21.34)\sqrt{2}$$
$$= 49.70\ in$$

$$b_0 = 4(l_{x1} + l)$$
$$= 4(21.34 + 49.70)$$
$$= 284.16\ in$$

$$A_c = b_0 d$$
$$= 284.16(6.625)$$
$$= 1883\ in^2$$

$$I_x = I_y = d\left\{\frac{l_{x1}l_{y2}^2}{2} + \frac{l_{y1}^3}{6} + \frac{l}{4}\left[\left(l_{y2} + l_{y1}\right)^2 + \frac{1}{3}\left(l_{y2} - l_{y1}\right)^2\right]\right\}$$
$$= 6.625\left\{\frac{21.34(91.63)^2}{2} + \frac{21.34^3}{6} + \frac{49.7}{4}\left[(91.63 + 21.34)^2 + \frac{(91.63 - 21.34)^2}{3}\right]\right\}$$
$$= 1.794 \times 10^6\ in^4$$

The stress at each corner of the critical section is as follows:

- At (x,y) = (10.75,45.81), v_u= 0.082 ksi
- At (x,y) = (45.81,10.75), v_u= 0.088 ksi
- At (x,y) = (45.81,-10.75), v_u= 0.089 ksi
- At (x,y) = (10.75,-45.81), v_u= 0.089 ksi
- At (x,y) = (-10.75,-45.81), v_u= 0.088 ksi
- At (x,y) = (-45.81,-10.75), v_u= 0.082 ksi
- At (x,y) = (-45.81,10.75), v_u= 0.080 ksi
- At (x,y) = (-10.75,45.81), v_u= 0.080 ksi

Therefore, the maximum stress occurs at (x,y) = (45.81,-10.75) and was calculated by:

$$\begin{aligned} v_u &= \frac{V_u}{A_c} - \frac{\gamma_{vx} M_{ux} y}{I_x} + \frac{\gamma_{vy} M_{uy} x}{I_y} \\ &= \frac{160}{1893} - \frac{0.4(360)(-10.75)}{1.794 \times 10^6} + \frac{0.4(360)(45.81)}{1.794 \times 10^6} \\ &= 0.089\ ksi \end{aligned}$$

The shear resistance is:

$$\emptyset v_n = \emptyset v_c = 0.75(2)\sqrt{4000} = 0.095\ ksi$$

Therefore,

$$v_u < \emptyset v_n$$

Design summary:

- 12 Studrails® with 10, 1/2 inch diameter studs per rail
- spacing: s_o = s = 3.25 in
- Overall height of Studrail® (OAH) = 6.5 in
- Overall length of Studrail® (OAL) = 35.75 in

5. DESIGN USING ACI 421.1R-99

ACI 318-05 still treats each stud on a Studrail® in the same manner as a stirrup leg despite the fact that testing on Studrails® have shown them to be far superior to stirrups. ACI Committee 421 (Design of Slabs) reviewed the results of the tests on Studrails® and issued report ACI 421.1R-92 entitled “Shear Reinforcement for Slabs” to give designers the option of creating more efficient Studrail® designs than ACI 318-05. This report was subsequently updated to ACI 421.1R-99 and is contained in Volume 5 of the current edition of the ACI Manual of Concrete Practice (prior to 2002, it was contained in Volume 3 of the ACI Manual of Concrete Practice).

The design procedure in ACI 421.1R-99 is the same as outlined for ACI 318-05. The primary differences between the two documents are the values of v_c, v_n and the maximum spacing, s, between the studs. Another difference is that ACI 421.1R-99 allows a reduction in the calculated peak shear stress in certain situations.

There are new equations for γ_v given in Appendix B of ACI 421.1R-99. These equations have also been adopted for Decon® Studrail® designs using ACI 318-05 (based on reference 11.66 in ACI 318-05 commentary section R11.12.6.2). Compared to the old equations, these new equations predict a much more realistic drop in the shear stress away from the slab to column connections. These equations are given in Section 3.1 of this manual.

The ACI 318-05 procedures and equations outlined in Section 3 are used with the following exceptions:

The upper limit of the punching shear capacity of slab-column connections is calculated by:

$$v_n = v_c + v_s \leq 8\sqrt{f'_c} \qquad (5.3)$$

where:

$$v_c = 3\sqrt{f'_c} \qquad (5.2)$$

The upper limits for the spacing, s, between studs along the Studrail® is given in Section 2.2 of this manual. Using the same input data as Example 1, a stud spacing of 4.875" could be used (s_o = 2.625") and the number of studs per Studrail would be reduced from 10 to 7, thus giving a more economical design.

The design for punching shear involves ensuring that the shear resistance is higher than the peak shear stress that can occur anywhere along the critical section. Generally, the peak shear stress occurs along one side of the critical section. However, the peak shear occurs only at a single point on the critical section for corner columns, connections transferring unbalanced moments about both axes, and connections with asymmetrical openings. Exceeding the design capacity at a single point on the critical section will not govern the strength of the connection due to stress redistribution. In this case, ACI 421.1R-99 allows the designer to design for the shear stress that occurs at a distance of 0.4d from the peak shear stress. However, this reduction in shear stress cannot be more than 15% of the peak shear stress (Appendix B).

6. EXAMPLE 2: CORNER COLUMN DESIGN USING ACI 421.1R-99

This example shows the design procedure of ACI 421.1R-99. A corner slab column connection with the following parameters is to be designed:

Slab thickness, h = 8”
Concrete cover = 3/4” (top & bottom)
#5 Flexural rebar = 5/8” diameter
Concrete strength, f'_c = 4000 psi
Column size, c_x = 18”, c_y = 18”
No overhangs, $g_x = g_y = 0$
Loads: V_u = 70 kip
M_{ox} = 50 ft-kip = 600 in-kip
M_{oy} = 45 ft-kip = 540 in-kip

SOLUTION

Step 1: Check to determine whether Studrails® are required.

See Figure 5(a) for dimensions of the critical section located d/2 from the column face.

$$\begin{aligned} d &= h - top\ cover - bar\ diameter \\ &= 8 - \frac{3}{4} - \frac{5}{8} \\ &= 6.625'' \end{aligned}$$

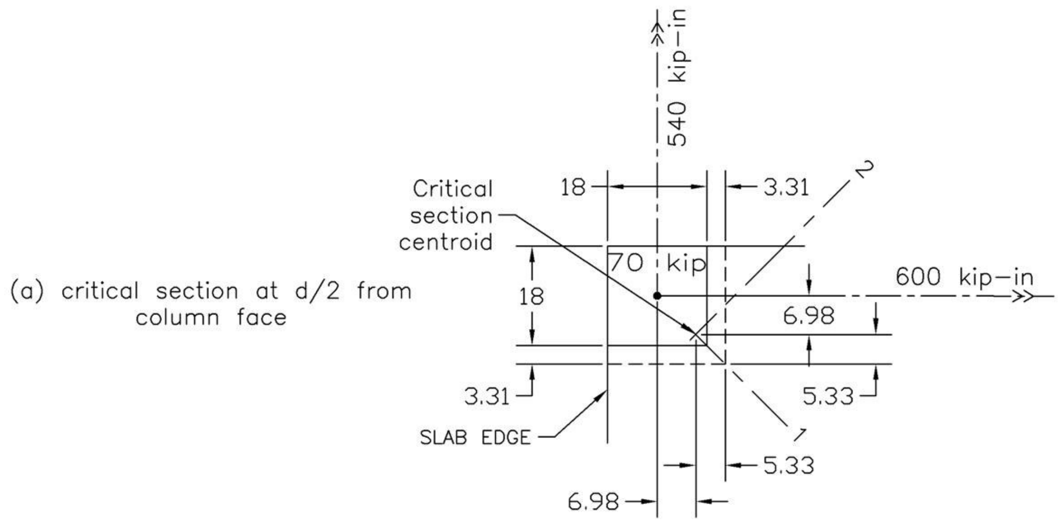
$$\begin{aligned} l_x &= c_x + d/2 \\ &= 18 + \frac{6.625}{2} \\ &= 21.313'' \end{aligned}$$

$$\begin{aligned} l_y &= c_y + d/2 \\ &= 18 + 6.625/2 \\ &= 21.313'' \end{aligned}$$

$$\begin{aligned} b_0 &= l_x + l_y \\ &= 21.313 + 21.313 \\ &= 42.625'' \end{aligned}$$

$$A_c = b_0 d = 42.625(6.625) = 282.4 in^2$$

The principal axes are rotated -45° as shown in Figure 5(a).



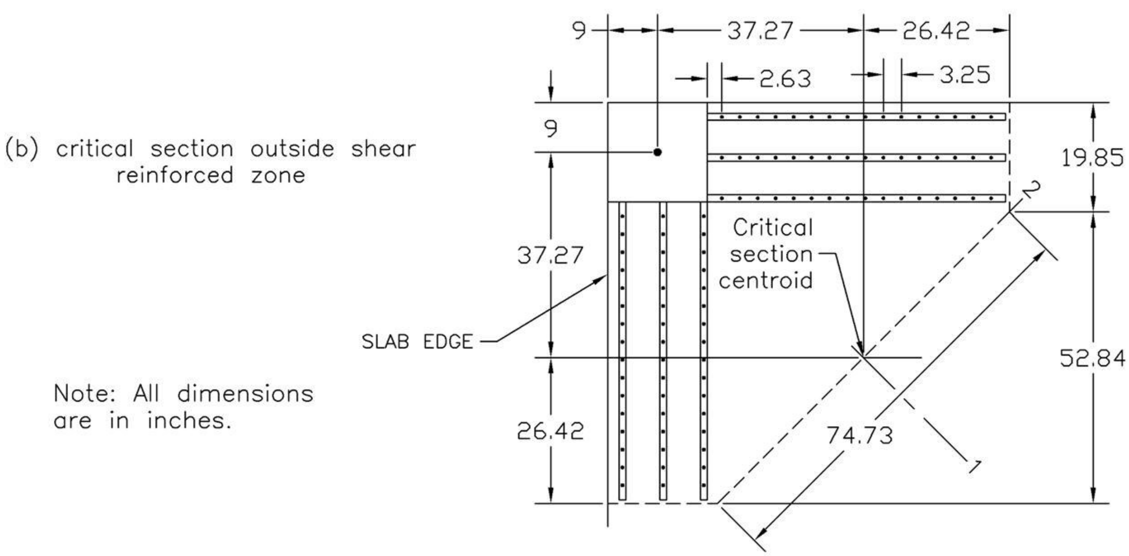


Figure 5: Corner slab–column connection of Example 2

$$\gamma_{v1} = 0.4$$

$$\begin{aligned}\gamma_{v2} &= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{l_x}{l_y} - 0.2}} \\ &= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{15.071}{30.141} - 0.2}} \\ &= 0.267\end{aligned}$$

$$\begin{aligned}I_1 &= 2d\left\{\frac{l_x}{3}\left(\frac{l_x}{\sqrt{2}}\right)^2\right\} \\ &= 2(6.625)\left\{\frac{21.313}{3}\left(\frac{21.313}{\sqrt{2}}\right)^2\right\} \\ &= 2.138 \times 10^4\ in^4\end{aligned}$$

$$\begin{aligned}I_2 &= 2d\left\{\frac{l_x}{3}\left(\frac{l_x}{2\sqrt{2}}\right)^2\right\} \\ &= 2(6.625)\left\{\frac{21.313}{3}\left(\frac{21.313}{2\sqrt{2}}\right)^2\right\} \\ &= 0.534 \times 10^4\ in^4\end{aligned}$$

For maximum stress (relative to the principal axes),

x = 7.54”, y = 0”, e_1 = 9.877”, e_2 = 0

$$\begin{aligned}M_2 &= \frac{M_{ox}}{\sqrt{2}} + \frac{M_{oy}}{\sqrt{2}} - V_u e_1 \\ &= \frac{600}{\sqrt{2}} + \frac{540}{\sqrt{2}} - 70(9.877) \\ &= 115\ in - kip\end{aligned}$$

Therefore, the maximum shear stress is:

$$\begin{aligned}v_u &= \frac{V_u}{A_c} - \frac{\gamma_{v1} M_{u1} y}{I_1} + \frac{\gamma_{v2} M_{u2} x}{I_2} \\ &= \frac{70}{282.4} + \frac{0.267(115)(7.54)}{0.534 \times 10^4} \\ &= 0.291\ ksi\end{aligned}$$

Checking the stresses at the other corners of the critical section indicates the following stress levels:

- At (x,y) = (-7.54, -7.54), vu = 0.211 ksi
- At (x,y) = (-7.54, 7.54), vu = 0.199 ksi

The shear resistance is:

$$
\begin{aligned}
v_n \quad &= Minimum \begin{Bmatrix} \left(2+\dfrac{4}{\beta}\right)\sqrt{f'_c} \\ \left(\dfrac{\alpha_s d}{b_0}+2\right)\sqrt{f'_c} \\ 4\sqrt{f'_c} \end{Bmatrix} \\
&= Minimum \begin{Bmatrix} \left(2+\dfrac{4}{1}\right)\sqrt{4000} \\ \left(\dfrac{20(6.625)}{42.625}+2\right)\sqrt{4000} \\ 4\sqrt{4000} \end{Bmatrix} \\
&= 0.253\ ksi
\end{aligned}
$$

Therefore,

$$v_u > \emptyset v_n\ and\ v_u = 4.6\sqrt{f'_c} < \emptyset 8\sqrt{f'_c}$$

Therefore, the punching shear capacity is adequate if Studrails® are provided.

Step 2: Select Studrail® layout, stud diameter, and stud spacing.

$$v_u \le \emptyset(v_c + v_s)$$

$$
\begin{aligned}
v_s \quad &\ge \frac{v_u}{\emptyset} - v_c \\
&\ge \frac{291}{.75} - 3\sqrt{4000} \\
&\ge 198\ psi
\end{aligned}
$$

Select 6 Studrails® with 3/8 in. diameter studs with 3 1/4 in. spacing. Therefore,

$$
\begin{aligned}
v_s &= \frac{A_v f_{yv}}{b_0 s} \\
&= \frac{6(0.110)(50000)}{42.625(3.25)} \\
&= 238\ psi
\end{aligned}
$$

Step 3: Determine the extent of the required shear reinforced zone.

Assume 16 studs are required per Studrail®. The dimensions of the critical section are shown in Figure 5(b) and calculated below:

$$
\begin{aligned}
l_{x1} &= c_x + \left(\frac{d}{2}\tan\,(22.5°)\right) \\
&= 18 + \left(\frac{6.625}{2}\,tan(22.5°)\right) \\
&= 19.85\ in
\end{aligned}
$$

$$
\begin{aligned}
l_{y1} &= c_y + \left(\frac{d}{2}\tan\,(22.5°)\right) \\
&= 18 + \left(\frac{6.625}{2}\,tan(22.5°)\right) \\
&= 19.85\ in
\end{aligned}
$$

$$
\begin{aligned}
l_{x2} &= c_x + \left(s_0 + 15s + \frac{d}{2}\right) \\
&= 18 + \left(2.625 + 15(3.25) + \frac{6.625}{2}\right) \\
&= 72.69\ in \\
l_{y2} &= c_x + \left(s_0 + 15s + \frac{d}{2}\right) \\
&= 18 + \left(2.625 + 15(3.25) + \frac{6.625}{2}\right) \\
&= 72.69\ in
\end{aligned}
$$

$$
\begin{aligned}
l &= (l_{x2} - l_{x1})\sqrt{2} \\
&= (72.69 - 19.85)\sqrt{2} \\
&= 74.73\ in
\end{aligned}
$$

$$
\begin{aligned}
b_0 &= l_{x1} + l_{y1} + l \\
&= 19.85 + 19.85 + 74.73 \\
&= 114.4\ in
\end{aligned}
$$

$$
\begin{aligned}
A_c &= b_0 d \\
&= 114.4(6.625) \\
&= 757.9\ in^2
\end{aligned}
$$

Again, the principal axes are rotated 45°. For maximum stress (relative to the principal axes),

x = -11.13”, y = -51.40”, e_1 = 49.80”, e_2 = 0

$$\gamma_{v1} = 0.4$$

$$\gamma_{v2} = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{l_x}{l_y} - 0.2}}$$
$$= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{14.04}{102.80} - 0.2}}$$
$$= 0$$

$$M_1 = \frac{M_{ox}}{\sqrt{2}} - \frac{M_{oy}}{\sqrt{2}}$$
$$= \frac{600}{\sqrt{2}} - \frac{540}{\sqrt{2}}$$
$$= 42\ in - kip$$

$$I_1 = d\sum\left[\frac{l}{3}\left(y_i^2 + y_i y_j + y_j^2\right)\right]$$
$$= 6.625\left\{\frac{2(19.85)}{3}(37.36^2 + 37.36(51.40) + 51.40^2) + \frac{74.73}{3}(37.36)^2\right\}$$
$$= 7.527 \times 10^5\ in^4$$

$$I_2 = d\sum\left[\frac{l}{3}\left(x_i^2 + x_i x + x_j^2\right)\right]$$
$$= 6.625\left\{\frac{2(19.85)}{3}(11.13^2 + 11.13(2.91) + 2.91^2) + \frac{74.73}{3}3(2.91)^2\right\}$$
$$= 1.295 \times 10^4\ in^4$$

The stress at each corner of the critical section is as follows:
- At (x,y) = (-11.13, 51.40), v_u = 0.092 ksi
- At (x,y) = (2.91, 37.36), v_u = 0.092 ksi
- At (x,y) = (2.91, -37.36), v_u = 0.094 ksi
- At (x,y) = (-11.13, -51.40), v_u = 0.094 ksi

Therefore, the maximum stress occurs at (x,y) = (-11.13, -51.40) and was calculated by:

$$\begin{aligned} v_u &= \frac{V_u}{A_c} - \frac{\gamma_{v1} M_{u1} y}{I_1} + \frac{\gamma_{v2} M_{u2} x}{I_2} \\ &= \frac{70}{754.3} - \frac{0.4(42)(-51.40)}{7.527 \times 10^5} \\ &= 0.094\ ksi \end{aligned}$$

The shear resistance is:

$$\emptyset v_n = \emptyset v_c = 0.75(2)\sqrt{4000} = 0.095\ ksi$$

Therefore,

$$v_u < \emptyset v_n$$

Design summary:

- 6 Studrails® with 16, 3/8 in diameter studs per rail
- spacing: s_o = 2.625 in; s = 3.25 in
- Overall height of Studrail® (OAH) = 6.5 in
- Overall length of Studrail® (OAL) = 54 in

7. DESIGN USING CSA A23.3-04

The design procedure using the Canadian Standard CSA A23.3-04 is identical to the procedure outlined in ACI 318-05. However, the design shear resistances are different. The following equations are used:

$$v_f \le v_r$$

$$v_r = v_c = Minimum \begin{Bmatrix} \left(1 + \frac{2}{\beta_c}\right) 0.19 \lambda \phi_c \sqrt{f'_c} \\ \left(\frac{\alpha_s d}{b_0} + 0.19\right) \lambda \phi_c \sqrt{f'_c} \\ 0.38 \lambda \phi_c \sqrt{f'_c} \end{Bmatrix} \qquad 13.3.4.1$$

where λ is a factor to account for low density concrete; φ_c = 0.6 is the resistance factor for concrete; φ_s = 0.85 is the resistance factor for steel; and αs is a constant with values of 2, 3 and 4 for corner, edge and interior slab column connections respectively.

$$v_f = \frac{V_f}{b_0 d} + \left[\frac{\gamma_v M_f e}{I}\right]_{x1} + \left[\frac{\gamma_v M_f e}{I}\right]_{y1} \qquad 13.3.5.5$$

$$\gamma_v = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{b_1}{b_2}}} \qquad 13.3.5.3$$

$$v_r = v_c + v_s \leq 0.75\lambda\emptyset_c\sqrt{f'_c} \qquad 13.3.8.2$$

$$v_c = 0.28\lambda\emptyset_c\sqrt{f'_c} \qquad 13.3.8.3$$

$$v_s = \frac{\emptyset_s A_v f_{yv}}{b_0 s}, f_{yv} = 345\ MPa \qquad 13.3.8.5$$

$$A_v = (\#\ of\ rails) \times (Area\ of\ one\ stud)$$

Per Clause 13.3.7.4, the Studrails® need to be extended a minimum of 2d from the column face and the peak stress on the critical section outside the shear-reinforced zone must be less than:

$$v_r = v_c = 0.19\lambda\emptyset_c\sqrt{f'_c} \qquad 13.3.7.4$$

For edge and corner connections with overhangs, N13.3.3.4 gives a guideline as to the contribution of the overhang to the shear capacity. Generally, the maximum overhang that can be used in the calculation is equal to the distance from the column face to the critical section.

These equations are based on the SI system of units, with the concrete strength f'_c in megapascals. To use these equations with f'_c in psi, simply multiply the factors in front of the $\sqrt{f'_c}$ term by 12 in each of the equations.

8. EXAMPLE 3: EDGE COLUMN DESIGN BY CSA A23.3-04

This example shows the design procedure of the CSA A23.3-04 code. An edge slab column connection with the following parameters is to be designed:

Slab thickness, h = 250 mm
Concrete cover = 20 mm (top & bottom)
15M Flexural rebar = 16 mm diameter
Concrete strength, f'c = 30 MPa
Column size, c_x = 300 mm, c_y = 500 mm
Slab overhang, g_x = 100 mm

Loads: $V_u = 450$ kN
$M_{ox} = 0$
$M_{oy} = 150$ kN-m

SOLUTION

Step 1: Check to determine whether Studrails® are required.

See Figure 6(a) for dimensions of critical section located d/2 from the column face.

$$
\begin{aligned}
d &= h - top\ cover - bar\ diameter \\
&= 250 - 20 - 16 \\
&= 214\ mm
\end{aligned}
$$

$$
\begin{aligned}
l_x &= c_x + \frac{d}{2} + g_x \\
&= 300 + \frac{214}{2} + 100 \\
&= 507\ mm
\end{aligned}
$$

$$
\begin{aligned}
l_y &= c_y + d \\
&= 500 + 214 \\
&= 714\ mm
\end{aligned}
$$

$$
\begin{aligned}
b_0 &= 2l_x + l_y \\
&= 2(507) + 714 \\
&= 1728\ mm
\end{aligned}
$$

$$A_c = b_0 d = 1728(214) = 3.698 \times 10^5\ mm^2$$

$$
\begin{aligned}
\gamma_{vx} &= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{l_y}{l_x}}} \\
&= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{714}{507}}} \\
&= 0.442
\end{aligned}
$$

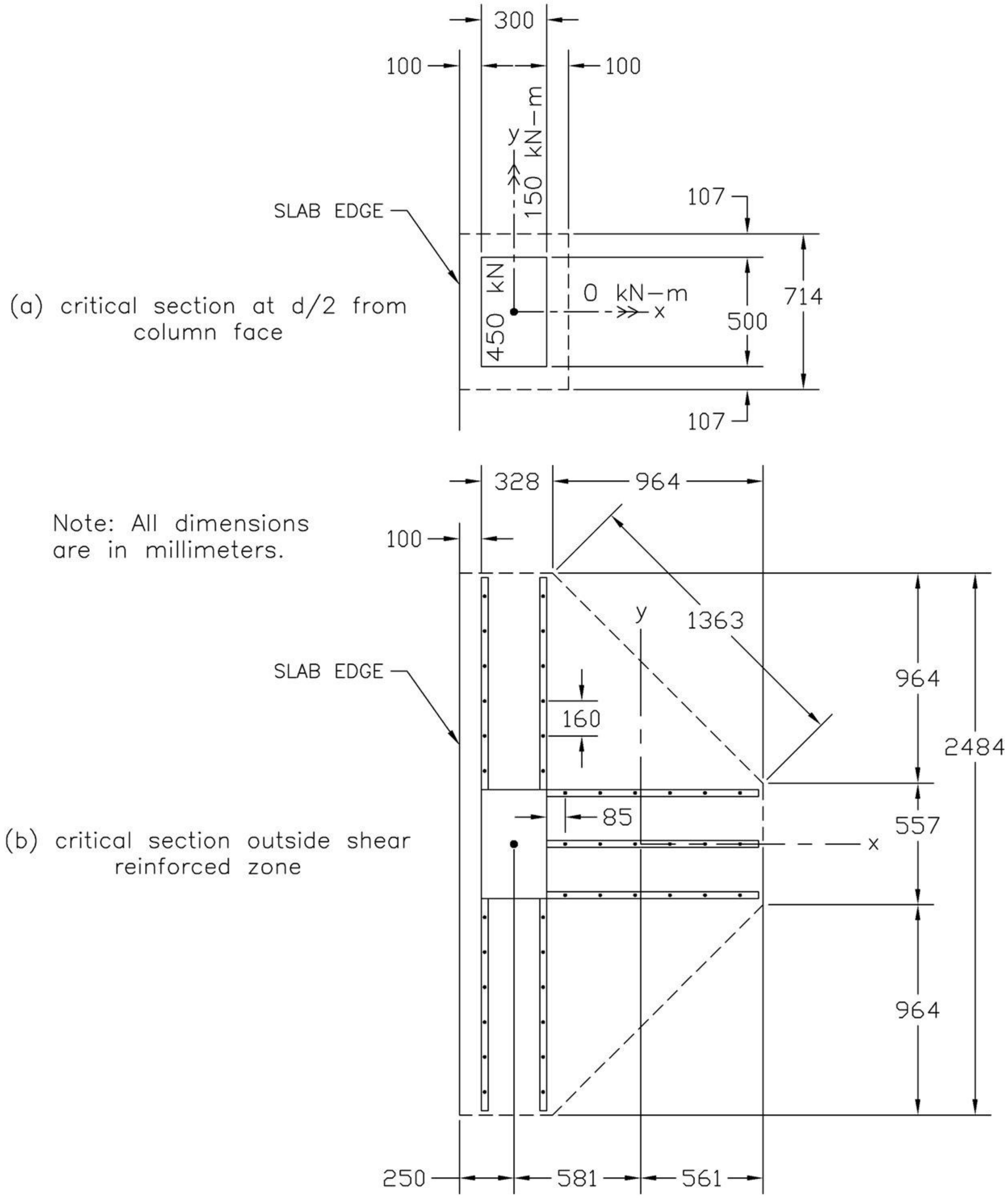


Figure 6: Edge slab-column connection of Example 3

$$\gamma_{vy} = 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{l_x}{l_y}}}$$

$$= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{507}{714}}}$$

$$= 0.323$$

$$I_x = d\left\{\frac{l_x l_y^2}{2} + \frac{l_y^3}{12}\right\}$$

$$= (214)\left\{\frac{507(714)^2}{2} + \frac{(714)^2}{12}\right\}$$

$$= 3.415 \times 10^{10}\ mm^4$$

$$x_0 = \frac{l_x^2}{2l_x + l_y} - \frac{d}{2} - \frac{c_x}{2}$$

$$= \frac{507^2}{2(507) + 714} - \frac{214}{2} - \frac{300}{2}$$

$$= -108.2\ mm$$

$$I_y = d\left\{l_y x_0^2 + \frac{l_x^3}{6} + 2l_x(0.5l_x - x_0)^2\right\}$$

$$= (214)\left\{714 * 108.2^2 + \frac{507^3}{6} + 2(507)\left(\frac{507}{2} - 108.2\right)^2\right\}$$

$$= 1.041 \times 10^{10}\ mm^4$$

$$M_{uy} = M_{oy} + V_u x_0$$

$$= 150 + 450(-.1082)$$

$$= 101.3\ kN - m$$

For maximum stress,

$$x = -108.2 + \frac{300}{2} + \frac{214}{2} = 148.8\ mm$$

Where x is relative to the centroid of the critical section. Therefore, the maximum shear stress is:

$$
\begin{aligned}
v_f &= \frac{V_u}{A_c} + \frac{\gamma_{vx} M_{ux} y}{I_x} + \frac{\gamma_{vy} M_{uy} x}{I_y} \\
&= \frac{450{,}000}{369{,}800} + 0 + \frac{0.323(101.3 \times 10^6)(148.8)}{1.041 \times 10^{10}} \\
&= 1.684\ MPa
\end{aligned}
$$

Checking the stresses at the other corners of the critical section indicates the following stress levels:

- At (x,y) = (x,y), vu = 0.094 MPa
- At (x,y) = (x,y), vu = 1.684 MPa
- At (x,y) = (x,y), vu = 0.094 MPa

The shear resistance is:

$$
\begin{aligned}
v_n &= Minimum \begin{Bmatrix} \left(1 + \frac{2}{\beta_c}\right) 0.19\lambda\phi_c\sqrt{f'_c} \\ \left(\frac{\alpha_s d}{b_0} + 0.19\right)\lambda\phi_c\sqrt{f'_c} \\ 0.38\lambda\phi_c\sqrt{f'_c} \end{Bmatrix} \\
&= Minimum \begin{Bmatrix} \left(1 + \frac{2}{500/300}\right)(0.19)(1)(0.65)\sqrt{30} \\ \left(\frac{4(214)}{1728} + 0.19\right)(1)(0.65)\sqrt{30} \\ 0.38(1)(0.65)\sqrt{30} \end{Bmatrix} \\
&= 1.353\ MPa
\end{aligned}
$$

Therefore,

$$
v_f > v_r \ and \ v_f = 0.47\lambda\emptyset_c\sqrt{f'_c} < 0.75\lambda\emptyset_c\sqrt{f'_c}
$$

Therefore, punching shear capacity is adequate if Studrails® are provided.

Step 2: Select Studrail® layout, stud diameter, and stud spacing.

$$
v_f \le v_c + v_s
$$

$$
\begin{aligned}
v_s &\ge v_f - v_c \\
&\ge \frac{1.684}{0.85} - 0.28\sqrt{30} \\
&\ge 0.75\ MPa
\end{aligned}
$$

Select 7 Studrails® with 12.7 mm diameter studs with 160 mm spacing. Therefore,

$$\begin{aligned} v_s &= \frac{A_v f_{yv}}{b_0 s} \\ &= \frac{7(127)(345000)}{1728(160)} \\ &= 1.106\ MPa \end{aligned}$$

Step 3: Determine the extent of the required shear reinforced zone.

Assume 6 studs are required per Studrail®. The dimensions of the critical section are shown in Figure 6(b) and calculated below:

$$\begin{aligned} l_{x1} &= c_x + \left(\frac{d}{2} tan(22.5°)\right) + g_x - \frac{b_{rail}}{2} \\ &= 500 + \left(\frac{214}{2} tan(22.5°)\right) + 100 - \frac{32}{2} \\ &= 428\ mm \end{aligned}$$

$$\begin{aligned} l_{y1} &= c_y + 2\left(\frac{d}{2} tan(22.5°)\right) - b_{rail} \\ &= 300 + 2\left(\frac{214}{2} tan(22.5°)\right) - 32 \\ &= 557\ mm \end{aligned}$$

$$\begin{aligned} l_{x2} &= c_x + \left(s_0 + 7s + \frac{d}{2}\right) + g_x \\ &= 300 + \left(85 + 7(160) + \frac{214}{2}\right) + 100 \\ &= 1392\ mm \end{aligned}$$

$$\begin{aligned} l_{y2} &= c_y + 2\left(s_0 + 7s + \frac{d}{2}\right) \\ &= 500 + 2\left(85 + 7(160) + \frac{214}{2}\right) \\ &= 2484\ mm \end{aligned}$$

$$\begin{aligned} l &= \sqrt{2}(l_{x2} - l_{x1}) \\ &= \sqrt{2}(1392 - 428) \\ &= 1363\ mm \end{aligned}$$

$$\begin{aligned} b_0 &= 2(l_{x1}) + l_{y1} + 2l \\ &= 2(428) + 557 + 2(1363) \\ &= 4139\ mm \end{aligned}$$

$$\begin{aligned} A_c &= b_0 d \\ &= 4139(214) \\ &= 885{,}800\ mm^2 \end{aligned}$$

$$\begin{aligned} \gamma_{vx} &= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{l_{y2}}{l_{x2}}}} \\ &= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{2484}{1392}}} \\ &= 0.471 \end{aligned}$$

$$\begin{aligned} \gamma_{vy} &= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{l_{x2}}{l_{y2}}}} \\ &= 1 - \frac{1}{1 + \frac{2}{3}\sqrt{\frac{1392}{2484}}} \\ &= 0.286 \end{aligned}$$

$$\begin{aligned} I_x &= d\left\{\frac{l_{x1}l_{y2}^2}{2} + \frac{l_{y1}^3}{12} + \frac{1}{8}\left[\left(l_{y2} + l_{y1}\right)^2 + \frac{1}{3}\left(l_{y2} - l_{y1}\right)^2\right]\right\} \\ &= (214)\left\{\frac{428(2484)^2}{2} + \frac{(557)^3}{12} + \frac{1}{8}\left[(2484 + 557)^2 + \frac{1}{3}(2484 - 557)^2\right]\right\} \\ &= 6.681 \times 10^{11}\ mm^4 \end{aligned}$$

$$\begin{aligned} x_0 &= \frac{2l_{x1}\left(l_{x2} - \frac{l_{x1}}{2}\right) + l(l_{x2} - l_{x1})}{b_0} - l_{x2} + g_x + \frac{c_x}{2} \\ &= \frac{2(428)\left(1392 - \frac{428}{2}\right) + 1363(1392 - 428)}{4139} - \frac{214}{2} - \frac{300}{2} \\ &= -581\ mm \end{aligned}$$

$$I_y = d\left\{l_{y1}x_{ab}^2 + \frac{l_{x1}^3}{6} + 2l_{x1}\left(l_{x2} - \frac{l_{x1}}{2} - x_{ab}\right)^2 + \frac{l(l_{x2} - l_{x1})^2}{6} + 2l\left[x_{ab} - \frac{l_{x2} - l_{x1}}{2}\right]^2\right\}$$

$$= (214)\left\{\begin{array}{c} 557(581)^2 + \dfrac{428^3}{6} + 2(428)\left(1392 - \dfrac{428}{2} - 581\right)^2 + \dfrac{1363(1392 - 428)^2}{6} \\ +2(428)\left[581 - \dfrac{1392 - 428}{2}\right]^2 \end{array}\right\}$$

$$= 1.589 \times 10^{11}\ mm^4$$

$$\begin{aligned} M_{uy} &= M_{oy} + V_u e_x \\ &= 150 + 450(-0.581) \\ &= -111.4\ kN - m \end{aligned}$$

The stress at each corner of the critical section is as follows:

- At (x,y) = (-831,1242), vu = 0.675 MPa
- At (x,y) = (-617,1242), vu = 0.632 MPa
- At (x,y) = (-135,278), vu = 0.535 MPa
- At (x,y) = (-135,-278), vu = 0.535 MPa
- At (x,y) = (-617,-1242), vu = 0.632 MPa
- At (x,y) = (-831,-1242), vu = 0.675 MPa

Therefore, the maximum stress occurs at (x,y) = (-831,1242) and was calculated by:

$$\begin{aligned} v_f &= \frac{V_u}{A_c} + \frac{\gamma_{vx}M_{ux}y}{I_x} + \frac{\gamma_{vy}M_{uy}x}{I_y} \\ &= \frac{450{,}000}{885{,}800} + 0 + \frac{0.286(-111.4 \times 10^6)(-831)}{1.589 \times 10^{11}} \\ &= 0.675\ MPa \end{aligned}$$

The shear resistance is:

$$\begin{aligned} v_n &= 0.19\lambda\phi_c\sqrt{f'_c} \\ &= 0.19(1)(0.65)\sqrt{30} \\ &= 0.675\ MPa \end{aligned}$$

Therefore,

$$v_f < v_n$$

Design summary:

- 7 Studrails® with 6, 12.7 mm diameter studs per rail
- spacing: s_o = 85 mm, s = 160 mm
- Overall height of Studrail® (OAH) = 210 mm
- Overall length of Studrail® (OAL) = 970 mm

9. DESIGNING STUDRAILS® FOR DUCTILITY

A complete design of a slab-column connection includes an analysis to ensure that there is both adequate strength and ductility. Although slab-column connections are not used as part of the lateral load resisting system in highly seismic regions, it is important to remember that these connections will be forced to move along with the building. Thus, there must be adequate ductility of the connection to ensure that it can move through the induced drift without collapsing.

It is a well-known fact that the drift capacity of a slab-column connection reduces as the applied gravity load increases. In the absence of slab shear reinforcement, the design drift capacity would be 1.5% and 2.5% respectively when the gravity load reaches 40% and 20% of the connection capacity. The addition of shear reinforcement enables the connection to move through higher drifts without distress.

Full-scale laboratory tests (References 3, 33, 36, 37, 38) indicate that the use of Studrails® will enable slab-column connections to move through drifts much higher than 2.5% regardless of the gravity load intensity.

Section 1908.1.6 of IBC 2003 contained design parameters for ductility punching shear reinforcement at slab-column connections that were not part of the lateral load resisting system. This design procedure follows:

Step 1. Determine whether slab shear reinforcement is required.

Shear reinforcement is required if:

$$design\ story\ drift > 0.035 - 0.05\left(\frac{V_u}{\emptyset V_c}\right)$$

where:
V_u = factored punching shear due to gravity load excluding unbalanced moment
φ = resistance factor (0.75 for ACI 318-02 and later)
V_c = nominal shear strength provided by the concrete

Shear reinforcement is not required if either $V_u/\emptyset V_c < 0.2$ or where the story drift ratio is less than 0.5%, except where Studrails® are required for strength.

Step 2: If slab shear reinforcement is required, provide a minimum of:

- Minimum capacity: $V_s \geq 3.5\sqrt{f'_c}$
- Minimum extent: *5h* from the face of the column

These parameters were modified slightly in ACI 318-05 and IBC 2006.

10. EXAMPLE DESIGN OF STUDRAILS® FOR DUCTILITY

This example shows the design of Studrails® for ductility. The interior column that was used in Example 1 is used again here with a lower loading. The lower loading would allow the connection to be constructed without shear reinforcement if the ductility requirement did not have to be met. However, due to IBC 2003, Studrails are required as follows:

Slab thickness, h = 8”
Concrete cover = 3/4” (top & bottom)
#5 Flexural rebar = 5/8” diameter
Concrete strength, f’c = 4000 psi
Column size, $c_x = c_y = 20$”
Loads: $V_u = 100$ kip

SOLUTION

Step 1: Check to determine whether Studrails® are required.

See Figure 4(a) for dimensions of critical section located d/2 from the column face. Parameters of the critical section at d/2 are given in Example 1. Since the loading is concentric, the stress level will be the same along the entire critical section.

Therefore, the maximum shear stress is:

$$\begin{aligned} v_u &= \frac{V_u}{A_c} \\ &= \frac{100}{705.6} \\ &= 0.142 ksi \end{aligned}$$

The shear resistance is:

$$
\begin{aligned}
v_n &= Minimum \begin{Bmatrix} \left(2+\dfrac{4}{\beta}\right)\sqrt{f'_c} \\ \left(\dfrac{\alpha_s d}{b_0}+2\right)\sqrt{f'_c} \\ 4\sqrt{f'_c} \end{Bmatrix} \\
&= Minimum \begin{Bmatrix} \left(2+\dfrac{4}{1}\right)\sqrt{4000} \\ \left(\dfrac{40(6.625)}{106.5}+2\right)\sqrt{4000} \\ 4\sqrt{4000} \end{Bmatrix} \\
&= 0.253\ ksi
\end{aligned}
$$

Therefore,

$$v_u < \emptyset v_n \ but\ Studrails\ are\ required\ due\ to\ IBC\ 2003$$

Step 2: Select Studrail® layout, stud diameter, and stud spacing.

$$v_s \geq 3.5\sqrt{f'_c} = 0.221\ ksi$$

Select 12 Studrails® with 3/8 in. diameter studs with 2 3/4 in. spacing. Therefore,

$$
\begin{aligned}
v_s &= \frac{A_v f_{yv}}{b_0 s} \\
&= \frac{12(0.110)(50)}{106.5(2.75)} \\
&= 0.225\ ksi
\end{aligned}
$$

Step 3: Determine the extent of the required shear reinforced zone.

The Studrails must extend a minimum 5h from the column face. Therefore, 15 studs are required so that the last stud is 41 1/4" from the column face and the Studrail length is 44".

PART III: DECON® STDESIGN V3.1 STUDRAIL® DESIGN SOFTWARE

Part III of this manual explains how to use the Decon® STDESIGN software to design Studrails® in accordance with ACI 318-05, ACI 421.1R-99, and CSA A23.3-04. The output designs can be confirmed using hand calculations as outlined in Part II of this manual.

This design software is provided as an engineering service and should be used exclusively for Decon® Studrails® and not any alternate products.

11. INSTALLATION OF SOFTWARE

The STDESIGN V3.1 software is a free download from the www.deconusa.com website. The downloaded file is named **Decon STDesign V3.1 Setup**. To install the software, double-click on this file and follow the instructions. You will need to agree to the disclaimer in order to install this software. This disclaimer must also be acknowledged every time you run this software.

The default directory for installation of the software is "C:\Program Files\Decon STDesign\". You may change this directory during the installation. You will also have the option of including shortcuts to this software on both the Start Menu and your Desktop.

12. USING STDESIGN V3.1

12.1 Introduction

To run STDESIGN V3.1, simply double-click on the program icon or select it from your Windows Start Menu.

An introduction window with a disclaimer will be opened. To continue running STDESIGN V3.1, the user must indicate that (s)he has read the disclaimer and accepts responsibility for verifying the accuracy of any design. The STDESIGN V3.1 window will then open. The layout of the window is a listing of connections on the left, input information in the center, and a real-time graphic display of the design on the right. There is context-sensitive help included in the software. Additional information about the various input fields is contained in Sections 12.6To 12.9 of this manual.

12.2 STDESIGN V3.1 Design Procedure

STDESIGN V3.1 carries out a Studrail design based on the requirements of the selected design code. The criteria for each code are given in Part II of this manual. The design is

real-time; in other words, the design is constantly being updated as the input fields are modified.

The input data is checked as it is typed. If any errors are discovered, those cells will be highlighted red. If you click on the error message at the bottom of the screen, you will get full details about the error. If it is still unclear, try the <F1> button for help.

First, STDESIGN will check to determine whether the slab column connection is adequate without any shear reinforcement. If this is true, the graphic on the right side of the screen will show the column geometry but it will not show any Studrails. Otherwise, STDESIGN will then check to determine whether Studrails will be adequate based on the limitations of the selected design code. If Studrails are adequate, the graphic on the right side of the screen will show the Studrail detail. Otherwise, the connection name in the connection "tree" on the left of the screen will go red. You can click on the error message at the bottom of the screen to get full details of the error(s) and perhaps a suggestion for resolving the error.

If Studrails are required, and the user has not selected any automatic design parameters, STDESIGN will analyze the connection using the given input. If the design is adequate, the results will be displayed; otherwise a message will prompt the user to modify the input.

If Studrails are required and "Automatic" is selected for any of the input, STDESIGN will optimize the design of the connection as follows (only the automatic parameters will be adjusted):

STDESIGN first determines the minimum number of Studrails that are required based on the ratio of each column face to the slab effective depth. Projecting from each column face, there must be a minimum of two Studrails placed at the corners of the column. The distance between each Studrail must be no greater than twice the slab effective depth.

STDESIGN then begins the design of the Studrails. STDESIGN calculates the maximum stud spacing that is allowed based on the selected design code. If the required capacity is inadequate, STDESIGN will reduce the stud spacing and check the capacity again until a viable result is obtained. If necessary to achieve the required capacity, additional Studrails may be added. If the stud diameter is set to automatic, STDESIGN performs this subroutine for each of the four available sizes. The four designs are then compared and the most economical result is selected. Please note that this optimization is for the individual connection, not for the entire project. Using the same stud size and spacing throughout is generally the best option because unit pricing of the Studrails is reduced with larger quantities. Placement errors on the jobsite are also minimized by maintaining the same stud diameter and spacing at every location.

Finally, STDESIGN determines how far the Studrails must extend such that the concrete outside the shear reinforced zone is adequate to resist the punching shear stresses.

12.3 Drop-Down Menus and Connection Tree

There are drop-down menus at the top-left corner of the screen. Most of the items in these menus are the same as in many Windows programs and therefore don't need explanation. The following drop-down options are unique to this software:

1. **Properties:** This will take you to the "Current Project Settings Tab".
2. **New Connection:** This will add a new connection into the data file with all input fields blank.
3. **Copy Connection:** This will add a new connection in the data file containing all of the same input values as the current connection.
4. **Delete Connection:** This will delete the current connection from the data file.

There is always a "Connection Tree" present on the far left side of the screen. This tree shows the project name and a listing of all of the connections that are included in the current data file.

Clicking on the project name will result in giving the user the options outlined below for the "Current Project Settings" and "New Project Defaults" tabs. The project name can be changed by editing the name in the title box immediately to the right of the top of the tree.

Clicking on any of the connection names will result in that specific connection being displayed. The user will have the options outlined below for the following tabs: "Slab", "Connection", "Studrails", "Openings", and "Calculation". The connection name can be changed by editing the name in the title box immediately to the right of the top of the tree. A good method would be to include the level and grid mark(s) as the connection name.

12.4 Current Project Settings Tab

Initially, the cursor will be highlighting "Untitled Project" in the top left corner of the screen. This is the project name and can be modified in the box just to the right. The current project information appears to the right. There are two tabs in this area: **Current Project Settings** and **New Project Defaults**. **Current Project Settings** and **New Project Defaults** are accessible through the **Properties** command on the **File** pulldown menu or by clicking on the project title at the top of the tree diagram. The values in the **Current Project Settings** tab are the values actually used in the current project. These entries all appear in the output.

1. **Project Number:** This is an optional user-assigned project file number or billing identifier.
2. **Engineer:** Optionally, the designer's initials are recorded here.
3. **Design Code:** STDESIGN allows the user to choose one of the following three sets of design rules:

a) ACI 318-05 Building Code
b) ACI 421.1R-99 Committee report
c) Canadian Standard CSA A23.3-04

Sections 3, 5, and 7 of this manual respectively explain the design parameters of these three sources. Our ICC Evaluation Service Report #ESR-2494 indicates that ACI 421.1R-99 can be used as the design document.

ACI 318-05 treats each stud as being equivalent to the leg of a stirrup. However, extensive testing at The University of Calgary (and other Universities across North America and around the world) has shown that the studs are more effective than stirrups. In other words, Studrails result in greater strength and ductility than the "equivalent" stirrups. These benefits are summarized in the various publications listed in the References section at the end of this manual. ACI 421.1R-99 recognizes this superior performance and thereby allows higher design strengths and larger a stud spacing. ACI 318-08 has incorporated most of the provisions of ACI 421.1R-99. Depending on jurisdiction, use of ACI 421.1R-99 may require building official approval. Differences between these two standards are discussed in Part 2 of this manual. ACI 421.1R-99 is published annually in the ACI Manual of Concrete Practice and is available separately from ACI in either print or downloadable PDF versions for a nominal charge. An earlier edition of this document, ACI 421.1R-92 is the design document referenced in ICC Evaluation Service Report #ESR-2494. Design under ACI 421.1R-92 and ACI 318-95 may be accomplished using STDesign Version 1.x.

The CSA A23.3-04 code also recognizes the superior performance of Studrails over stirrups. In fact, stirrups are now only allowed in slabs with a minimum thickness of 300 mm. The contribution of the concrete to the shear strength is also higher using Studrails as compared to stirrups. Version 3.1 of STDESIGN has been amended to allow the use of imperial (inch, pound, etc) units for designs using the CSA A23.3-04 code.

4. **Meet 2003 IBC ductility requirement**: If this box is checked the design will be made to conform to Sections 21.11.5.1 and 21.11.5.2, added to ACI 318-02 as amendments under Section 1908.1.6 of the 2003 IBC. The interaction equation in Section 21.11.5 is not used as the drift ratio is not part of the input in this software. The user may decide to review the $V_u/\emptyset V_c$ load intensity and drift ratio of individual slab-column connections to determine whether Studrails® can be eliminated.
5. **Unit System:** Either customary US units or SI units may be used. The units will appear to the right of each applicable input field and output value. All Studrail production is done in imperial units; metric values are converted to the nearest 1/8" (stud diameter and spacing values) or 1/4" (stud height).
6. **Calculation Output Header:** The user may want to insert some lines of text here that will appear as a centered heading at the top of the first page of the calculation output.

12.5 New Project Defaults Tab

The categories of data recorded here are identical to the Current Project Settings tab. The entries under the **New Project Defaults** tab are retained in system memory long term and are used as the default entries for the **Current Project Settings** tab when you start this software.

12.6 Slab Tab

12.6.1 Slab Tab – Effective Depth

The value of effective depth should be the weighted average value considering the full perimeter of the slab-column connection. Typically, this value is calculated by subtracting the top cover requirement and one bar diameter of the top layer of flexural steel from the slab thickness. Clause 9.5.3.2 of ACI 318-05 specifies a minimum slab thickness of 5 inches. Assuming a minimum cover of 3/4 inch and a minimum flexural reinforcement diameter of 1/2 inch, a minimum practical effective depth of 3-¾ inch (95.25 mm) results. This minimum is enforced for designs under ACI 318-05 or ACI 421.1R. Clause 13.3.1 of CSA A23.3-04 specifies a minimum slab thickness of 120 mm. Assuming minimum cover of 20 mm and a minimum flexural reinforcement diameter of 10 mm, a minimum practical effective depth of 90 mm (3.54”) results. This minimum is enforced for designs under CSA A23.3-04.

12.6.2 Slab Tab – Prestress

Optionally, the user can input an effective in-plane compression due to post-tensioning of the slab.

The ACI and CSA codes allow a higher nominal shear strength at a critical section at d/2 from the column face when the slab is prestressed. See respectively code Equations 11-36 and 18-5. When ACI 421.1R-99 is selected, the ACI 318-05 code Equation 11-36 is used. The codes also allow a reduction of the shear stress due to the vertical components of all effective prestressing forces crossing the critical section. STDESIGN V3.1 accounts for the prestress f_{pc} (f_{pc} is the ACI notation and the CSA code refers to this variable as f_{cp}) but ignores the vertical component of the prestress forces. The reason for ignoring the vertical component is discussed below. f_{pc} is the average compressive stress in both directions in the concrete (after allowance for all prestress losses) at the middle of the slab thickness.

Use of equations 11-36 (ACI 318-05) or 18-5 (CSA A23.3-04) is allowed only when the entire column cross-section is at least 4 times the slab thickness from any discontinuous edge. If this condition is not satisfied, the slab must be treated as if it were non-prestressed and STDESIGN V3.1 will set this input field to zero.

Also, the slab must be treated as non-prestressed when f_{pc} in each direction is smaller than 125 psi or 0.8 MPa. If a smaller value is input, STDESIGN V3.1 will set it to zero.

The maximum allowable design values for f_{pc} are 500 psi and 3.5 MPa. If a larger value in input, STDESIGN V3.1 will assume one of these maximum values.

Due to limited test data, the design codes limit the design value of f'c to 4900 psi and 35 MPa respectively. If prestressing is specified with a higher strength concrete, STDESIGN V3.1 will carry out two designs. The first design will ignore the prestressing (all other input will be used) and the second design will consider the prestressing in conjunction with either 5000 psi or 35 MPa concrete. The design result will be the one giving higher allowable nominal shear strength at a critical section at d/2 from the column face.

When the maximum stress due to factored forces exceeds the allowable nominal shear strength, Studrails are provided and the prestressing is ignored when designing the Studrails.

As mentioned above, both the ACI and CSA codes allow an increase equal to V_p in the nominal shear strength resisted by concrete; where V_p is the vertical component of the effective prestress forces crossing the critical section at d/2 from the column face. STDESIGN V3.1 does not have an input field for V_p since the design could be unsafe if the tendon profiles assumed in the calculations are not carefully followed during construction. This can occur when the tendons above the column start sloping down at points closer to the column center than assumed. The ACI 318-05 code commentary contains a similar statement in R11.12.2.2: "In a prestressed slab with distributed tendons, the V_p term in Eq. (11-36) contributes only a small amount to the shear strength; therefore, it may be conservatively taken as zero. If V_p is to be included, the tendon profile assumed in the calculations should be noted."

12.6.3 Slab Tab – Concrete Density

The user can select a concrete density of either Normal Weight, Sand-Lightweight, or All-Lightweight. This parameter will usually be set to "Normal Weight." The codes (ACI 318-05 Clause 11.2.1.2 and CSA A23.3-04 Clause 8.6.5) reduce the shear capacity by inserting factors of 0.85 and 0.75 for sand-lightweight and all-lightweight concrete respectively.

The following definitions are taken from ACI 213R-03 (Guide for Structural Lightweight-Aggregate Concrete):

Sand lightweight concrete – concrete with coarse lightweight aggregate and normalweight fine aggregate
All lightweight concrete – concrete in which both the coarse- and fine-aggregate components are lightweight aggregates

12.6.4 Slab Tab – Concrete Strength

For designs by ACI, the minimum concrete strength is 2,500 psi (ACI 318-05 Clause 5.1.1) and the maximum concrete strengths for design are 10,000 psi for RC slabs (ACI 318-05 Clause 11.1.2) and 4,900 psi for PT slabs (ACI 318-05 Clause 11.12.2.2). For designs by CSA, the minimum concrete strength is 20 MPa (CSA A23.3-04 Clause 8.6.1.1) and the maximum concrete strengths for design are 80 MPa for RC slabs (CSA A23.3-04 Clause 8.6.1.1) and 35 MPa for PT slabs (CSA A23.3-04 Clause 18.12.3.3). STDESIGN V3.1 will provide error messages if the input value does not fall within these limits.

Although the benefits of post-tensioning cannot be used in the punching shear calculation for slab strengths higher than the limits given above, the software will still analyze the connections and design any required Studrails®. The software will create two designs and use the higher resistance. The first design will ignore the post-tensioning and use the design concrete strength and the second design will consider the post-tensioning in conjunction with the maximum allowable concrete strength (4900 psi or 35 Mpa).

12.6.5 Slab Tab – Slab Thickness

Although this information is not required for shear design, it is required for the calculation of the required height of the Studrails®.

Clause 9.5.3.2 of ACI 318-05 specifies a minimum slab thickness of 5 inches. This minimum is enforced for designs under ACI 318-05 or ACI 421.1R. Clause 13.3.1 of CSA A23.3-04 specifies a minimum slab thickness of 120 mm. This minimum is enforced for designs under CSA A23.3-04.

12.6.6 Slab Tab – Top Cover

The specified top concrete cover for Studrails is typically the same as for the rebar. Location, fire rating and exposure conditions generally dictate this dimension. Both Section 7.7 of ACI 318-05 and Clause 7.9 of CSA A23.3-04 specify an absolute minimum cover of ¾” (20 mm). Where there are steps or slopes in the slab, we assume that the specified top concrete cover applies at the thinnest slab area in which the Studrails extend. Each Studrail maintains the same stud height along its entire length.

12.6.7 Slab Tab – Bottom Cover

The specified bottom concrete cover for Studrails is typically the same as for the rebar. Location, fire rating and exposure conditions generally dictate this dimension. Decon can provide standard support chairs in heights of ¾”, 1”, 1 ¼” and 1 ½”. Taller chairs can be created by stacking standard chairs. Both Section 7.7 of ACI 318-05 and Clause 7.9 of CSA A23.3-04 specify an absolute minimum cover of ¾” (20 mm). Where there are steps or slopes in the slab, we assume that the specified bottom concrete cover applies at the

thinnest slab area in which the Studrails extend. Each Studrail maintains the same stud height along its entire length.

12.7 Connection Tab

12.7.1 Connection Tab – Column Shape

The user can select a column shape of either rectangular or round. Any other shapes can be approximated with an "equivalent" rectangular or round column. The shape of the critical section at d/2 from the column face will match the column (i.e. it will also be either rectangular or round).

The graphic on the right side of the screen will show the column shape, as well as the shape of the assumed critical section.

12.7.2 Connection Tab – Connection Location

The user can select from any of the following:

- Interior
- Edge – West
- Edge – East
- Edge – North
- Edge – South
- Corner – Northwest
- Corner – Northeast
- Corner – Southwest
- Corner – Southeast

The graphic on the right side of the screen will show the column along with the location of any slab edge. Please refer to the information relating to our "Sign Convention for Forces" in Section 12.11 as the correct sign of any applied unbalanced moment will be affected by the location of any slab edge.

12.7.3 Connection Tab – c_x

This is the dimension of the rectangular column below the slab in the x-direction. In CSA A23.3-04, this parameter is referred to as c_1.

12.7.4 Connection Tab – c_y

This is the dimension of the rectangular column below the slab in the y-direction. In CSA A23.3-04, this parameter is referred to as c_2.

12.7.5 Connection Tab – d_c

This is the diameter of the round column below the slab.

12.7.6 Connection Tab – o_x

Edge and corner columns have slab overhangs if the column is set away from the edge of the slab. The punching shear strength is usually increased by the presence of an overhang. The input value can be any positive dimension. o_x is the overhang in the x-direction.

If an overhang extends beyond the column a distance more than ten times the effective depth, the slab edge can be ignored.

For edge and corner connections with overhangs, N13.3.3.4 of the Explanatory Notes to CSA A23.3-04 gives a guideline as to the contribution of the overhang to the shear capacity. Generally, the maximum overhang that can be used in the calculation is equal to the distance from the column face to the critical section. STDESIGN V3.1 adopts this limit.

12.7.7 Connection Tab – o_y

See section 12.7.6. o_y is the overhang in the y-direction.

12.7.8 Connection Tab – V_u

An elastic frame, finite element analysis, or other analysis of the slab can be used to determine the magnitude of the loads that must be transferred between the slab and column. Vu is the factored vertical load that is being transferred.

12.7.9 Connection Tab – M_{ux}

M_{ux} is the total factored unbalanced moment that is being transferred between the column and the slab about the x-axis. This moment could be the result of unequal column spacing, lateral loads, a load case consisting of a reduced live load in a bay, or a slab edge. Please refer to the information relating to our "Sign Convention for Forces" in Section 12.11 as the correct sign of any applied unbalanced moment will be affected by the location of any slab edge.

12.7.10 Connection Tab – M_{uy}

See section 12.7.9. M_{uy} is the total factored unbalanced moment that is being transferred between the column and the slab about the y-axis.

12.8 Studrails Tab

There are four standard diameters for the studs on Decon® Studrails®. For most elevated slabs, either 3/8" or 1/2" diameter Studrails® provide the most economical design. 5/8" and 3/4" diameter Studrails® are generally not required unless the slab is more than 10" or 11" thick. Minimizing the number of different Studrail® sizes will generally result in the most economical design.

12.8.1 Studrails Tab – Number of Studrails

This field indicates the number of Studrails that will be positioned around the current slab-column connection. Normally, the user will set this to automatic, but a number can be typed into this input field. The minimum and maximum number of Studrails is generally shown beside this input box.

Figure 1 shows typical Studrail layouts around interior, edge and corner columns with rectangular cross-sections and interior round columns. Studrails are placed perpendicular to the column faces. At each column corner, one Studrail must be placed perpendicular to both column faces; this is because of the concentration of shear stresses at these locations. This requirement is not clearly mentioned in ACI 318-08 but it is stated in section A.2 of ACI 421.1R-99.

There are high shear stresses near slab edges and in the area adjacent to openings. Thus, Studrails should be placed at these locations. However, if the Studrails are placed too close to a slab discontinuity, cracking will result on the face of the opening. Generally, Studrails should be placed parallel to and 2 inches (50 mm) away from slab edges and openings.

Rather than selecting a number, this field is usually set to automatic. If a number is input, STDESIGN performs the following two checks on the data. There must be a minimum of two Studrails on each column face and the maximum spacing between Studrails is 2d (ACI 318-05 Clause 11.12.3.3). This maximum lateral spacing provides a fairly uniform resistance along the critical section as is assumed in design. It also helps provide confinement of the concrete, which increases its resistance to the applied loading.

12.8.2 Studrails Tab – Minimum Gap Between Stud Heads

The minimum spacing of the studs is governed by field placement considerations. It is good practice to ensure that there is adequate space between the stud heads to insert rebar, post-tension tendons and any conduit that is being placed around the slab-column connection. Studrails® running alongside post-tension anchors should have the stud spacing set the same as the spacing of the anchors. Please keep in mind that the head diameters are more than three times the stem diameter; actual head dimensions can be found in DEC1300 in Part IV of this manual.

12.8.3 Studrails Tab – Stud Diameter

This field can either be set to automatic, or a specific stud diameter can be selected from the pull-down input box.

There are four standard diameters for the studs on Decon® Studrails®. For most elevated slabs, either 3/8" or 1/2" diameter Studrails® provide the most economical design. 5/8" and 3/4" diameter Studrails® are generally not required unless the slab is more than 10" or 11" thick. We recommend that this field be set to "Automatic" for the most heavily loaded column connection and then revised to match this design for the other columns in the project. Minimizing the number of different Studrail® sizes will generally result in the most economical design.

12.8.4 Studrails Tab – End Stud Spacing (s_o)

This is the distance from either end of the Studrail to the centerline of the first stud. This input field is usually set to automatic, but it is possible to type a value. The code limits are given in Section 2.3 of this manual.

12.8.5 Studrails Tab – Typical Stud Spacing (s)

This input field is usually set to automatic, but it is possible to type a value. The stud spacing is constant along each Studrail. Maintaining the same stud diameter and spacing throughout a structure is recommended to minimize the chance of Studrail placement errors, and this will generally result in the most economical design.

The stud spacing maximum limits are different for each of the design documents. Using ACI 318-05, the maximum spacing is d/2. For both ACI 421.1R-99 and CSA A23.3-04, the maximum spacing is 3d/4 and d/2 for stress levels below and above $6\sqrt{f'_c}$ respectively. The minimum spacing of the studs is governed by field placement considerations. It is good practice to ensure that there is adequate space between the stud heads to insert rebar, post-tension tendons and any conduit that is being placed around the slab-column connection. Studrails® running alongside post-tension anchors should have the stud spacing set the same as the spacing of the anchors. Please keep in mind that the head diameters are more than three times the stem diameter; actual head dimensions can be found in DEC1300 in Part IV of this manual.

12.9 Openings Tab

The ACI and CSA codes state that part of the critical section is ineffective when openings are either located at a distance less than 10 times the slab thickness from the column face, or within the column strips. The critical section for shear at d/2 from the column face must be reduced as follows: *"…that part of the perimeter of the critical section that is enclosed by straight lines projecting from the centroid of the column, concentrated load,*

or reaction area and tangent to the boundaries of the openings shall be considered ineffective."

The software accounts for the effect of openings as defined in the ACI and CSA design codes. The graphic on the right side of the screen will draw two lines that intersect at the centroid of the column and are tangent to the opening. The portion of the critical section between these lines will be ignored for the design.

The box in the top left area of the screen will list the openings as they are input. To make modifications to any opening detail, click on the desired opening in this list and then modify the details that appear below the window.

12.9.1 Openings Tab – Add Opening

You may input any reasonable number of openings at each connection. When you click on the "Add Opening" button, a graphic will appear below with input fields to define the size and/or location of the opening. The bottom left corner of the graphic (the origin of the graph) is the centroid of the column. After all of the opening detail is filled in, the opening will appear in the graphic on the right side of the screen.

12.9.2 Openings Tab – Remove Opening

When you click on this button, the current opening will be removed.

12.9.3 Openings Tab – Opening Type

STDESIGN V3.1 gives the user three options on how to input the information defining each opening:

- Input the precise size and location of a rectangular opening
- Input the precise size and location of a round opening
- Input the angles of the lines running from the column centroid and tangent to the opening

When you select the opening type that you wish to input, the graphic and available input fields will change to reflect your choice.

12.9.4 Openings Tab – x1, x2 (Rectangular Opening)

These fields define the distance to the right of the column centroid for the start and end of the rectangular opening. To input an opening to the left of the column centroid, you should use negative numbers in these fields.

12.9.5 Openings Tab – y1, y2 (Rectangular Opening)

These fields define the distance above the column centroid for the start and end of the rectangular opening. To input an opening below the column centroid, you should use negative numbers in these fields.

12.9.6 Openings Tab – x (Round Opening)

This field defines the distance to the right of the column centroid for the center of the round opening. To input an opening to the left of the column centroid, you should use a negative number in this field.

12.9.7 Openings Tab – y (Round Opening)

This field defines the distance above the column centroid for the center of the round opening. To input an opening below the column centroid, you should use a negative number in this field.

12.9.8 Openings Tab – d (Round Opening)

This field defines the diameter of the round opening.

12.9.9 Openings Tab – T1, T2 (Angular Opening)

These fields define the angles of the two lines that project from the column centroid and are tangent to the opening.

12.10 Calculation Tab

This shows a summary of the design input and results.

12.11 Sign Convention For Forces

The sign convention for forces used in STDESIGN 3.1 is shown in Figure 2 of this manual. This is summarized as follows:

- The X axis is positive toward the east.
- The Y axis is positive toward the north.
- V_u is normally positive; only an unusual uplift condition would result in a negative value of V_u.
- Moments are thought of as imparted by the slab to the column.
- Moments obey the right-hand rule. Therefore,
- A positive value of M_{ux} will result in shear stresses on the south, or negative Y, side of the column that are additive with those caused by V_u when V_u is positive.

- A positive value of M_{uy} will result in shear stresses on the right (east, positive X) side of the column that are additive with those caused by V_u when V_u is positive.

13. EXAMPLES USING STDESIGN

The next 12 pages are output from the STDESIGN V3.1 software recreating the examples from Sections 4, 6, 8, and 10 of Part II of this manual.

STDesign 3.1 Decon® Studrail® Design
Interior Connection by ACI 318-05, Page 1

PROJECT DATA

Project name: Example 1: Interior Column Design by ACI 318-05
Project number:
Engineer:
Date: 28 January 2009
File path: C:\Users\Neil Hammill\Documents\Citrix My Documents\Studrail design software\Higgins updates\beta 4 June 2007 \STDesign manual examples.srp

INPUT DATA

Connection name: Interior Connection by ACI 318-05

General:
Design code: ACI 318-05
System of units: US (in, k, k-ft, psi)

Connection:
Connection location: Interior
Column dimension, c_x: 20.00 in
Column dimension, c_y: 20.00 in

Loads:
V_u: 160.0 k
M_{ux}: 30.00 k-ft
M_{uy}: 30.00 k-ft

Slab:
Effective depth, d: 6.625 in
Slab thickness: 8.000 in
Top cover: 0.750 in
Bottom cover: 0.750 in
Concrete compressive strength, f'_c: 4000 psi
Concrete density: Normal weight
Prestress, f_{pc}: 0.000 psi

Studrails:
2003/2006 IBC ductility requirement: No
Stud yield strength, f_{yv}: 5.000×10^4 psi
Stud diameter: Automatic
Typical stud spacing, S: Automatic
End stud spacing, S_0: Automatic
Number of studrails: Automatic

Openings:
None.

STDesign 3.1 Decon® Studrail® Design

Interior Connection by ACI 318-05, Page 2

STUDRAIL SUMMARY

Number of studrails per column: 12
Number of studs per studrail: 10
Stud diameter: 0.5 in

Typical stud spacing, S: 3.250 in
End stud spacing, S_0: 3.250 in
Overall height of studrail: 6.500 in

OUTPUT DATA

Inner Critical Section (d/2 outside of column face):

Common Properties

Area, A_c: 705.6 in^2
Critical Section Perimeter, b_0: 106.5 in

Natural Axis Properties

Centroid coordinate, e_x: 0.0 in
Centroid coordinate, e_y: 0.0 in
Section moment of inertia, I_x: 8.336×10^4 in^4
Section moment of inertia, I_y: 8.336×10^4 in^4
Section product of inertia, I_{xy}: 0.0 in^4

Principal Axis Properties

Centroid coordinate, e_1: 0.0 in
Centroid coordinate, e_2: 0.0 in
Section moment of inertia, I_1: 8.336×10^4 in^4
Section moment of inertia, I_2: 8.336×10^4 in^4
Principal axis rotation, (theta): 0.0 degrees
Moment fraction, γ_{v1}: 0.400
Moment fraction, γ_{v2}: 0.400

Natural Axis Loads

V_u: 160.0 k
M_{ux}: 30.00 k-ft
M_{uy}: 30.00 k-ft

Principal Axis Loads

V_u: 160.0 k
M_{u1}: 30.00 k-ft
M_{u2}: 30.00 k-ft

Stresses

Maximum shear stress, v_u: 272.8 psi
at x = 13.31 in, y = -13.31 in

Shear resistance, ϕv_n (concrete only):
189.7 psi
Shear resistance, ϕv_n (with Studrails):
350.1 psi
Shear resistance, ϕv_n (upper limit):
284.6 psi

Outer Critical Section (d/2 outside of reinforced zone):

Common Properties

Area, A_c: 1884 in^2
Critical Section Perimeter, b_0: 284.3 in

Natural Axis Properties

Centroid coordinate, e_x: 0.0 in
Centroid coordinate, e_y: 0.0 in
Section moment of inertia, I_x: 1.794×10^6 in^4
Section moment of inertia, I_y: 1.794×10^6 in^4
Section product of inertia, I_{xy}: 0.0 in^4

Principal Axis Properties

Centroid coordinate, e_1: 0.0 in
Centroid coordinate, e_2: 0.0 in
Section moment of inertia, I_1: 1.794×10^6 in^4
Section moment of inertia, I_2: 1.794×10^6 in^4
Principal axis rotation, (theta): 0.0 degrees
Moment fraction, γ_{v1}: 0.400
Moment fraction, γ_{v2}: 0.400

Natural Axis Loads

V_u: 160.0 k
M_{ux}: 30.00 k-ft
M_{uy}: 30.00 k-ft

Principal Axis Loads

V_u: 160.0 k
M_{u1}: 30.00 k-ft
M_{u2}: 30.00 k-ft

Stresses

Maximum shear stress, v_u: 89.48 psi
at x = 45.81 in, y = -10.75 in

Shear resistance, ϕv_n: 94.87 psi

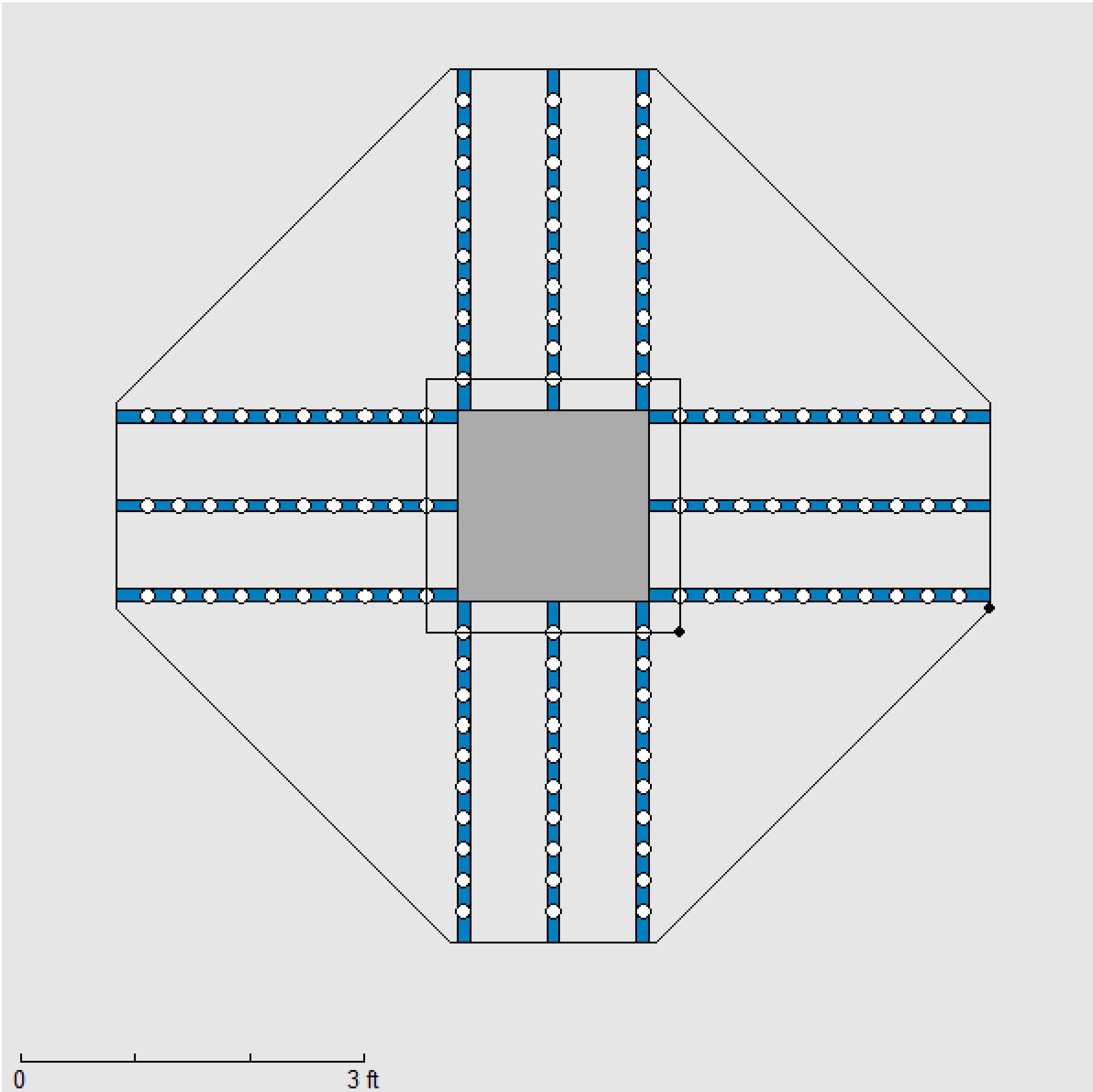
Design Comments:

None.

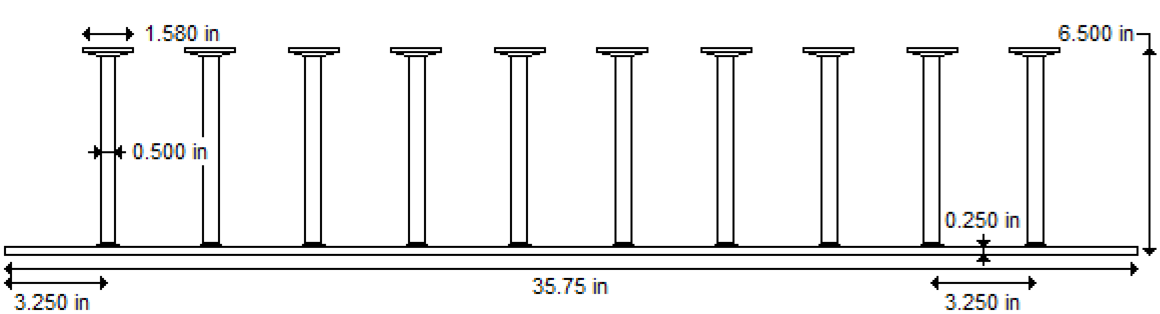
STDesign 3.1 Decon® Studrail® Design

Interior Connection by ACI 318-05, Page 3

PLAN VIEW



ELEVATION VIEW



STDesign 3.1 Decon® Studrail® Design
Corner Connection by ACI 421.1R-99, Page 1

PROJECT DATA

Project name: Example 2: Corner Column Design by ACI 421.1R-99
Project number:
Engineer:
Date: 28 January 2009
File path: C:\Users\Neil Hammill\Documents\Citrix My Documents\Studrail design software\Higgins updates\beta 4 June 2007 \STDesign manual examples.srp

INPUT DATA

Connection name: Corner Connection by ACI 421.1R-99

General:
Design code: ACI 421.1R-99
System of units: US (in, k, k-ft, psi)

Connection:
Connection location: Corner - Northwest
Column dimension, c_x: 18.00 in
Column dimension, c_y: 18.00 in
Overhang dimension, o_x: 0.000 in
Overhang dimension, o_y: 0.000 in

Loads:
V_u: 70.00 k
M_{ux}: 50.00 k-ft
M_{uy}: 45.00 k-ft

Openings:
None.

Slab:
Effective depth, d: 6.625 in
Slab thickness: 8.000 in
Top cover: 0.750 in
Bottom cover: 0.750 in
Concrete compressive strength, f'_c: 4000 psi
Concrete density: Normal weight
Prestress, f_{pc}: 0.000 psi

Studrails:
2003/2006 IBC ductility requirement: No
Stud yield strength, f_{yv}: 5.000×10^4 psi
Stud diameter: Automatic
Typical stud spacing, S: Automatic
End stud spacing, S_0: Automatic
Number of studrails: Automatic

STDesign 3.1 Decon® Studrail® Design
Corner Connection by ACI 421.1R-99, Page 2

STUDRAIL SUMMARY

Number of studrails per column: 6
Number of studs per studrail: 16
Stud diameter: 0.375 in

Typical stud spacing, S: 3.250 in
End stud spacing, S_0: 2.625 in
Overall height of studrail: 6.500 in

OUTPUT DATA

Inner Critical Section (d/2 outside of column face):

Common Properties

Area, A_c: 282.4 in^2
Critical Section Perimeter, b_0: 42.63 in

Natural Axis Properties

Centroid coordinate, e_x: 6.984 in
Centroid coordinate, e_y: -6.984 in
Section moment of inertia, I_x: 1.336×10^4 in^4
Section moment of inertia, I_y: 1.336×10^4 in^4
Section product of inertia, I_{xy}: 8017 in^4

Principal Axis Properties

Centroid coordinate, e_1: 9.877 in
Centroid coordinate, e_2: 0.0 in
Section moment of inertia, I_1: 2.138×10^4 in^4
Section moment of inertia, I_2: 5345 in^4
Principal axis rotation, (theta): -45.00 degrees
Moment fraction, γ_{v1}: 0.400
Moment fraction, γ_{v2}: 0.2675

Natural Axis Loads

V_u: 70.00 k
M_{ux}: 50.00 k-ft
M_{uy}: 45.00 k-ft

Principal Axis Loads

V_u: 70.00 k
M_{u1}: 3.536 k-ft
M_{u2}: 67.18 k-ft

Stresses

Maximum shear stress, v_u: 291.1 psi
at x = 12.31 in, y = -12.31 in

Shear resistance, ϕv_n (concrete only):
189.7 psi
Shear resistance, ϕv_n (with Studrails):
321.7 psi
Shear resistance, ϕv_n (upper limit):
379.5 psi

Outer Critical Section (d/2 outside of reinforced zone):

Common Properties

Area, A_c: 754.3 in^2
Critical Section Perimeter, b_0: 113.9 in

Natural Axis Properties

Centroid coordinate, e_x: 35.22 in
Centroid coordinate, e_y: -35.22 in
Section moment of inertia, I_x: 3.792×10^5 in^4
Section moment of inertia, I_y: 3.792×10^5 in^4
Section product of inertia, I_{xy}: 3.681×10^5 in^4

Principal Axis Properties

Centroid coordinate, e_1: 49.80 in
Centroid coordinate, e_2: 0.0 in
Section moment of inertia, I_1: 7.473×10^5 in^4
Section moment of inertia, I_2: 1.115×10^4 in^4
Principal axis rotation, (theta): -45.00 degrees
Moment fraction, γ_{v1}: 0.400
Moment fraction, γ_{v2}: 0.0

Natural Axis Loads

V_u: 70.00 k
M_{ux}: 50.00 k-ft
M_{uy}: 45.00 k-ft

Principal Axis Loads

V_u: 70.00 k
M_{u1}: 3.536 k-ft
M_{u2}: 67.18 k-ft

Stresses

Maximum shear stress, v_u: 93.97 psi
at x = -9.000 in, y = -63.69 in

Shear resistance, ϕv_n: 94.87 psi

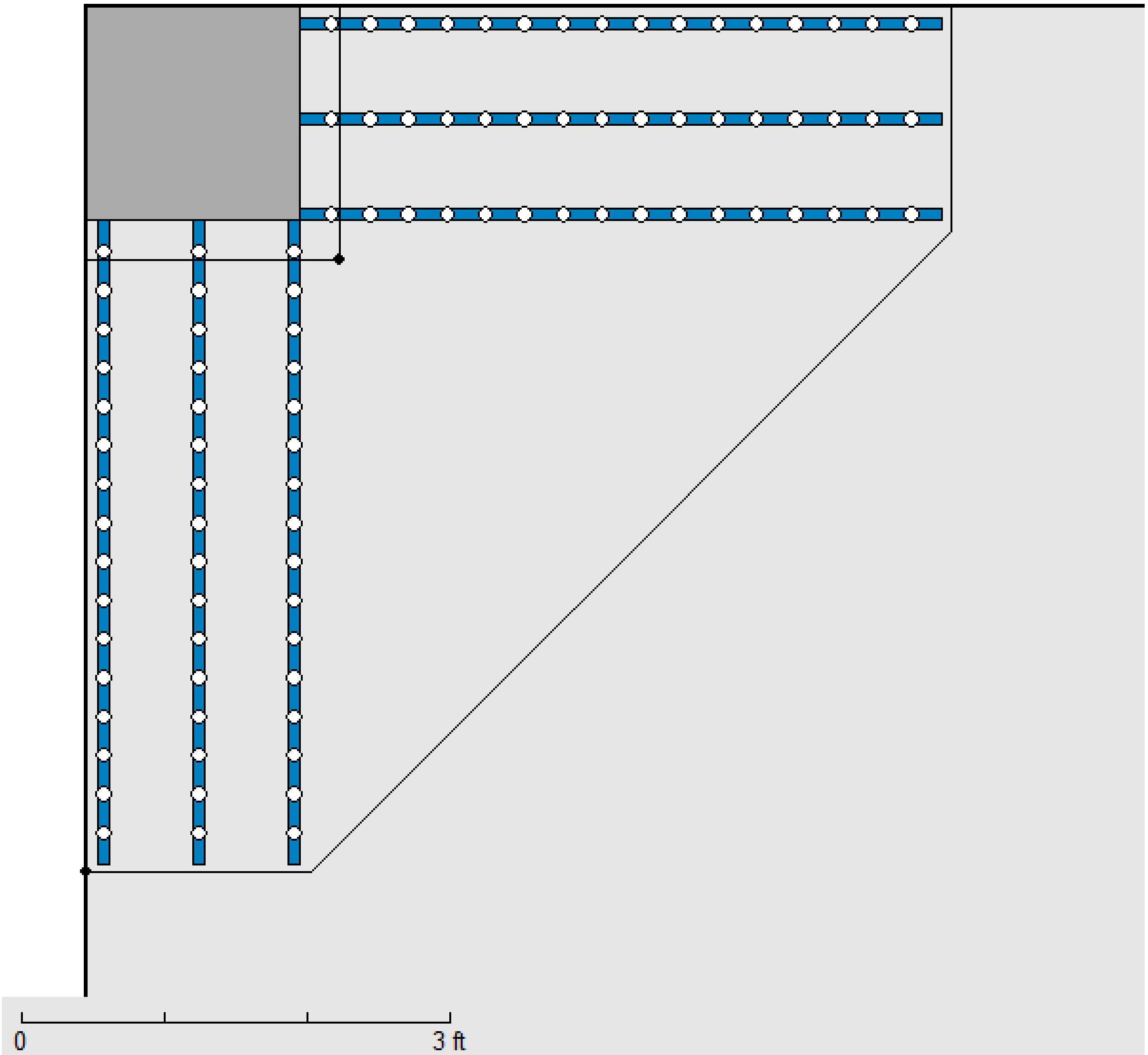
Design Comments:

None.

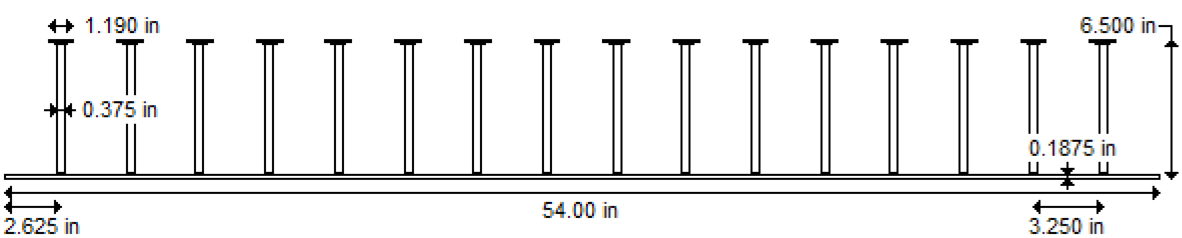
STDesign 3.1 Decon® Studrail® Design

Corner Connection by ACI 421.1R-99, Page 3

PLAN VIEW



ELEVATION VIEW



STDesign 3.1 Decon® Studrail® Design
Edge Connection by CSA A23.3-04, Page 1

PROJECT DATA

Project name: Example 3: Edge Column Design by CSA A23.3-04
Project number:
Engineer:
Date: 28 January 2009
File path: C:\Users\Neil Hammill\Documents\Citrix My Documents\Studrail design software\Higgins updates\beta 4 June 2007 \STDesign manual examples.srp

INPUT DATA

Connection name: Edge Connection by CSA A23.3-04

General:
Design code: CSA A23.3-04
System of units: SI (mm, kN, kN-m, MPa)

Connection:
Connection location: Edge - West
Column dimension, c_x: 300.0 mm
Column dimension, c_y: 500.0 mm
Overhang dimension, o_x: 100.0 mm

Loads:
V_u: 450.0 kN
M_{ux}: 0.000 kN-m
M_{uy}: 150.0 kN-m

Slab:
Effective depth, d: 214.0 mm
Slab thickness: 250.0 mm
Top cover: 20.00 mm
Bottom cover: 20.00 mm
Concrete compressive strength, f'_c: 30.00 MPa
Concrete density: Normal weight
Prestress, f_{pc}: 0.000 MPa

Studrails:
2003/2006 IBC ductility requirement: No
Stud yield strength, f_{yv}: 344.7 MPa
Stud diameter: Automatic
Typical stud spacing, S: Automatic
End stud spacing, S_0: 85.60 mm
Number of studrails: Automatic

Openings:
None.

STDesign 3.1 Decon® Studrail® Design

Edge Connection by CSA A23.3-04, Page 2

STUDRAIL SUMMARY

Number of studrails per column: 7
Number of studs per studrail: 6
Stud diameter: 12.7 mm

Typical stud spacing, S: 160.0 mm
End stud spacing, S_0: 85.00 mm
Overall height of studrail: 210.0 mm

OUTPUT DATA

Inner Critical Section (d/2 outside of column face):

Common Properties

Area, A_c: 3.698×10^5 mm^2

Critical Section Perimeter, b_0: 1728 mm

Natural Axis Properties

Centroid coordinate, e_x: 108.2 mm
Centroid coordinate, e_y: 0.0 mm
Section moment of inertia, I_x: 3.415×10^{10} mm^4
Section moment of inertia, I_y: 1.041×10^{10} mm^4
Section product of inertia, I_{xy}: 0.0 mm^4

Principal Axis Properties

Centroid coordinate, e_1: 108.2 mm
Centroid coordinate, e_2: 0.0 mm
Section moment of inertia, I_1: 3.415×10^{10} mm^4
Section moment of inertia, I_2: 1.041×10^{10} mm^4
Principal axis rotation, (theta): 0.0 degrees
Moment fraction, γ_{v1}: 0.4417
Moment fraction, γ_{v2}: 0.3226

Natural Axis Loads

V_u: 450.0 kN
M_{ux}: 0.0 kN-m
M_{uy}: 150.0 kN-m

Principal Axis Loads

V_u: 450.0 kN
M_{u1}: 0.0 kN-m
M_{u2}: 150.0 kN-m

Stresses

Maximum shear stress, v_u: 1.684 MPa
at x = 257.0 mm, y = 357.0 mm

Shear resistance, ϕv_n (concrete only):
1.353 MPa
Shear resistance, ϕv_n (with Studrails):
1.937 MPa
Shear resistance, ϕv_n (upper limit):
2.670 MPa

Outer Critical Section (d/2 outside of reinforced zone):

Common Properties

Area, A_c: 8.858×10^5 mm^2

Critical Section Perimeter, b_0: 4139 mm

Natural Axis Properties

Centroid coordinate, e_x: 581.0 mm
Centroid coordinate, e_y: 0.0 mm
Section moment of inertia, I_x: 6.681×10^{11} mm^4
Section moment of inertia, I_y: 1.589×10^{11} mm^4
Section product of inertia, I_{xy}: 3.937×10^{-5} mm^4

Principal Axis Properties

Centroid coordinate, e_1: 581.0 mm
Centroid coordinate, e_2: 0.0 mm
Section moment of inertia, I_1: 6.681×10^{11} mm^4
Section moment of inertia, I_2: 1.589×10^{11} mm^4
Principal axis rotation, (theta): 0.0 degrees
Moment fraction, γ_{v1}: 0.4711
Moment fraction, γ_{v2}: 0.2858

Natural Axis Loads

V_u: 450.0 kN
M_{ux}: 0.0 kN-m
M_{uy}: 150.0 kN-m

Principal Axis Loads

V_u: 450.0 kN
M_{u1}: 0.0 kN-m
M_{u2}: 150.0 kN-m

Stresses

Maximum shear stress, v_u: 0.6746 MPa
at x = -250.0 mm, y = 1242 mm

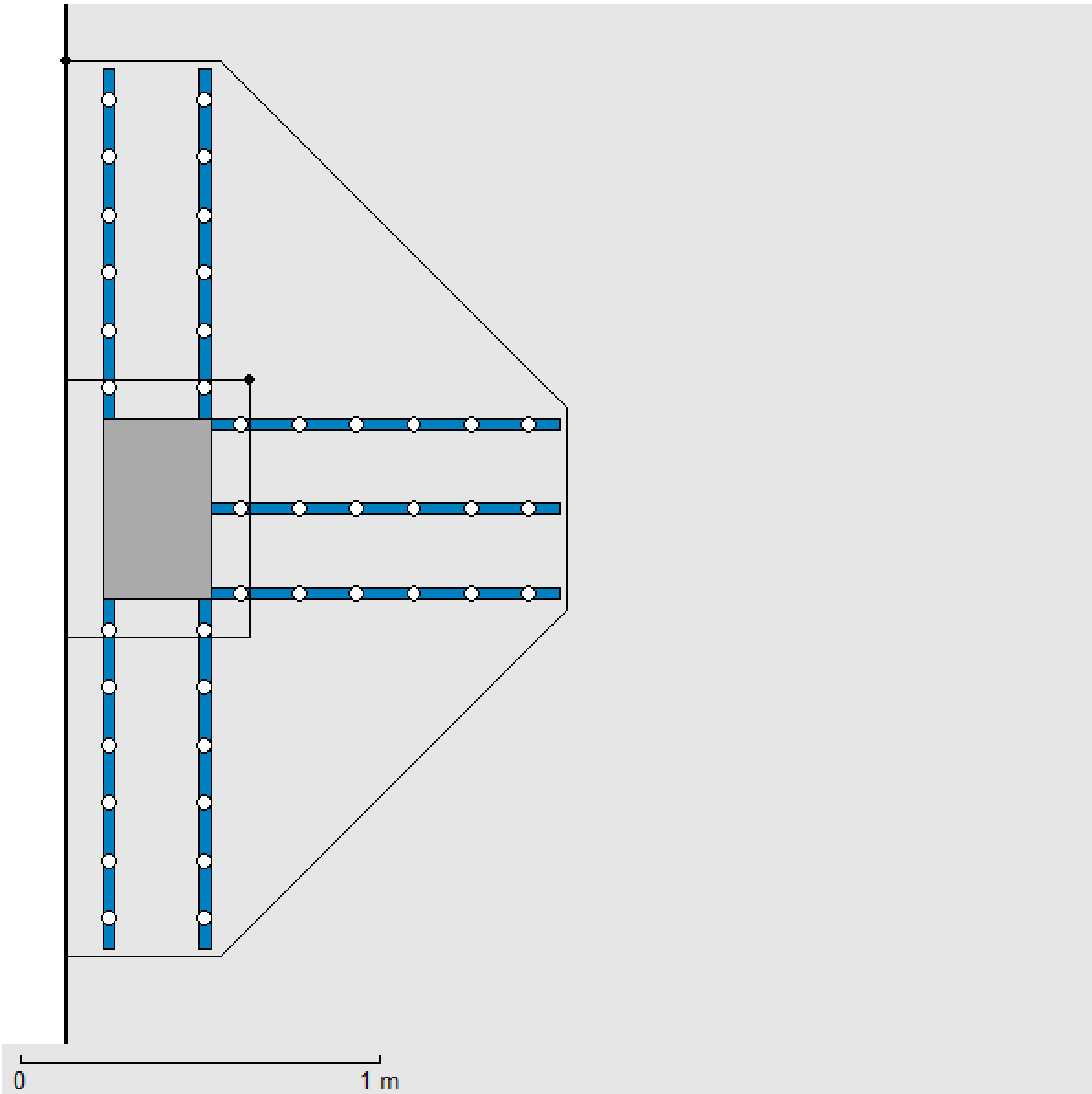
Shear resistance, ϕv_n: 0.6764 MPa

Design Comments:

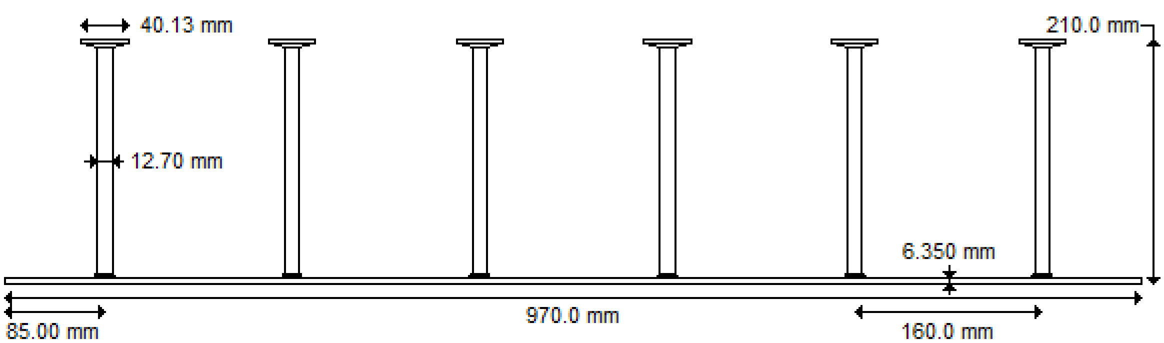
None.

STDesign 3.1 Decon® Studrail® Design
Edge Connection by CSA A23.3-04, Page 3

PLAN VIEW



ELEVATION VIEW



STDesign 3.1 Decon® Studrail® Design
Interior Connection by IBC 2003 ductility, Page 1

PROJECT DATA

Project name: Example 4: Interior Column Design by IBC 2003
Project number:
Engineer:
Date: 30 January 2009
File path: C:\Users\Neil Hammill\Documents\Citrix My Documents\Studrail design software\Higgins updates\beta 4 June 2007 \STDesign manual examples.srp

INPUT DATA

Connection name: Interior Connection by IBC 2003 ductility

General:
Design code: ACI 318-05
System of units: US (in, k, k-ft, psi)

Connection:
Connection location: Interior
Column dimension, c_x: 20.00 in
Column dimension, c_y: 20.00 in

Loads:
V_u: 100.0 k
M_{ux}: 0.000 k-ft
M_{uy}: 0.000 k-ft

Slab:
Effective depth, d: 6.625 in
Slab thickness: 8.000 in
Top cover: 0.750 in
Bottom cover: 0.750 in
Concrete compressive strength, f'_c: 4000 psi
Concrete density: Normal weight
Prestress, f_{pc}: 0.000 psi

Studrails:
2003/2006 IBC ductility requirement: Yes
Stud yield strength, f_{yv}: 5.000×10^4 psi
Stud diameter: Automatic
Typical stud spacing, S: Automatic
End stud spacing, S_0: Automatic
Number of studrails: Automatic

Openings:
None.

STDesign 3.1 Decon® Studrail® Design

Interior Connection by IBC 2003 ductility, Page 2

STUDRAIL SUMMARY

Number of studrails per column: 12
Number of studs per studrail: 15
Stud diameter: 0.375 in
Typical stud spacing, S: 2.750 in
End stud spacing, S_0: 2.750 in
Overall height of studrail: 6.500 in

OUTPUT DATA

Inner Critical Section (d/2 outside of column face):

Common Properties

Area, A_c: 705.6 in^2
Critical Section Perimeter, b_0: 106.5 in

Natural Axis Properties

Centroid coordinate, e_x: 0.0 in
Centroid coordinate, e_y: 0.0 in
Section moment of inertia, I_x: 8.336×10^4 in^4
Section moment of inertia, I_y: 8.336×10^4 in^4
Section product of inertia, I_{xy}: 0.0 in^4

Principal Axis Properties

Centroid coordinate, e_1: 0.0 in
Centroid coordinate, e_2: 0.0 in
Section moment of inertia, I_1: 8.336×10^4 in^4
Section moment of inertia, I_2: 8.336×10^4 in^4
Principal axis rotation, (theta): 0.0 degrees
Moment fraction, γ_{v1}: 0.400
Moment fraction, γ_{v2}: 0.400

Natural Axis Loads

V_u: 100.0 k
M_{ux}: 0.0 k-ft
M_{uy}: 0.0 k-ft

Principal Axis Loads

V_u: 100.0 k
M_{u1}: 0.0 k-ft
M_{u2}: 0.0 k-ft

Stresses

Maximum shear stress, v_u: 141.7 psi
at x = 13.31 in, y = 13.31 in

Shear resistance, ϕv_n (concrete only):
189.7 psi
Shear resistance, ϕv_n (with Studrails):
264.6 psi
Shear resistance, ϕv_n (upper limit):
284.6 psi

Outer Critical Section (d/2 outside of reinforced zone):

Common Properties

Area, A_c: 2214 in^2
Critical Section Perimeter, b_0: 334.1 in

Natural Axis Properties

Centroid coordinate, e_x: 0.0 in
Centroid coordinate, e_y: 0.0 in
Section moment of inertia, I_x: 2.882×10^6 in^4
Section moment of inertia, I_y: 2.882×10^6 in^4
Section product of inertia, I_{xy}: 0.0 in^4

Principal Axis Properties

Centroid coordinate, e_1: 0.0 in
Centroid coordinate, e_2: 0.0 in
Section moment of inertia, I_1: 2.882×10^6 in^4
Section moment of inertia, I_2: 2.882×10^6 in^4
Principal axis rotation, (theta): 0.0 degrees
Moment fraction, γ_{v1}: 0.400
Moment fraction, γ_{v2}: 0.400

Natural Axis Loads

V_u: 100.0 k
M_{ux}: 0.0 k-ft
M_{uy}: 0.0 k-ft

Principal Axis Loads

V_u: 100.0 k
M_{u1}: 0.0 k-ft
M_{u2}: 0.0 k-ft

Stresses

Maximum shear stress, v_u: 45.18 psi
at x = 54.56 in, y = 10.87 in

Shear resistance, ϕv_n: 94.87 psi

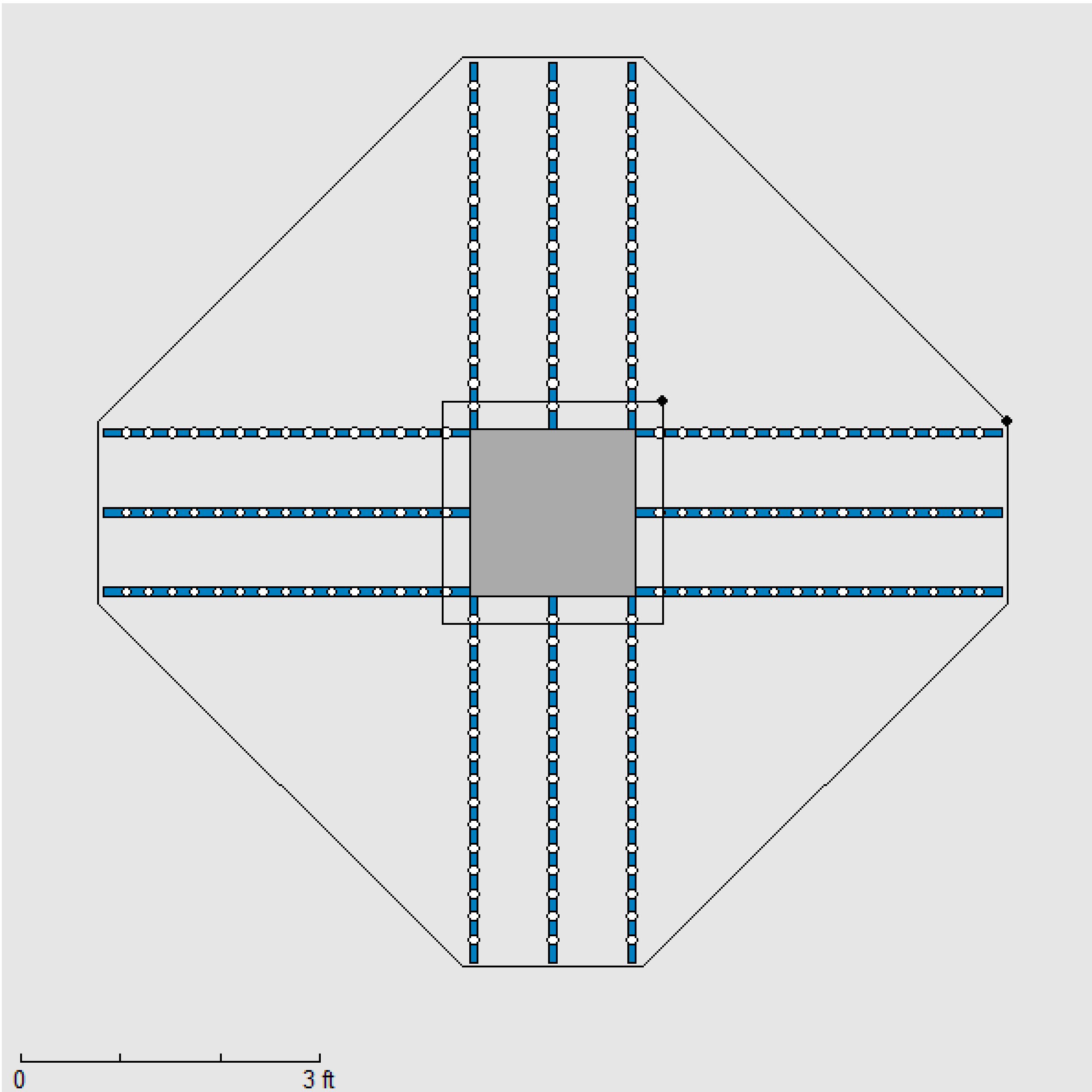
Design Comments:

None.

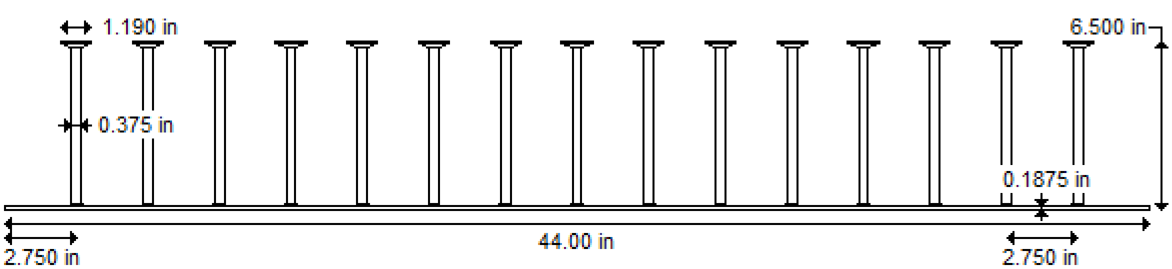
STDesign 3.1 Decon® Studrail® Design

Interior Connection by IBC 2003 ductility, Page 3

PLAN VIEW



ELEVATION VIEW



14. ABBREVIATED RECENT PROJECT LIST

Decon Studrails have been specified on blueprints for new building construction since 1988. We have supplied thousands of projects across the USA, Canada, the Caribbean, and overseas. Some of our recent projects have included:

PROJECT	CUSTOMER	ENGINEER OF RECORD
10 Rittenhouse Square Philadelphia, PA	Pietrini Contracting	Thornton-Tomasetti Engineers
400 5th Avenue New York, NY	Navillus Contracting	DeSimone Engineers
Ala Wai Garden Plaza Honolulu, HI	RLP	Allison – IDE Structural Engineers LLC
Aqua Building P Chicago, IL	RKD Construction Supply	Magnusson Klemencic Associates
Asbury Green Denver, CO	Kiewit Building Group	KL & A, Inc.
Avalon Towers Bellevue, WA	Albrecht Birkenbuel Inc.	Cary Kopczynski & Company
Broadstone Town Square Phoenix, AZ	PT of Nevada	Caruso, Turley, Scott, Inc.
Centerpoint West Parking Anchorage, AK	PTC, Inc.	BBFM Engineers Inc.
Centro National City, CA	Morley Builders	KPFF Consulting Engineers
Charter Square Parking Raleigh, NC	National Reinforcing	SCA Consulting Engineers
Disney Grand Hotel Anaheim, CA	Largo Concrete	Gregory P. Luth & Assoc
Edgemont Building A Steamboat, CO	KLG Corporation	Monroe & Newell Engineers, Inc.
Elysian Hotel Chicago, IL	McHugh Construction	Halvorson & Partners Structural Engineers
Embassy Suites Palmdale, CA	Lakeview Builders	Seneca Structural Engineering Inc.
ETMC Tyler North Tower Tyler, TX	Baker Concrete	Hammel, Green and Abrahamson, Inc.
John Gray Campus Grand Cayman Island	Tom Jones International	APEC Consulting Engineers Ltd.
JW Marriott Indianapolis, IN	FA Wilhelm	Magnusson Klemencic Associates
Lake City Court Seattle, WA	Walsh Construction	Peter A Opsahl Structural Engineering

Madarin (City Center) Las Vegas, NV	Pacific Coast Steel	Halcrow Yolles
Marquette University Eckstein Hall Milwaukee, WI	KBS Construction	Opus Architects and Engineers, Inc.
Marriott Residence Inn Gaslamp San Diego, CA	JT Wimsatt Contracting	D'Amato Conversano Inc.
Microsoft Buildings 94/95 Redmond, WA	GLY Construction	Coughlin Porter Lundeen
Moran Asian Gardens Parking Westminster, CA	Covi Concrete	Seneca Structural Engineering Inc.
Myriad Genetics Salt Lake City, UT	AdVanced Reinforcement	Dunn Associates Inc.
Ritz Carlton Truckee, CA	McClone Construction	Jessen-Wright Structural Engineers
Roberts Tower St. Louis, MO	Rebar Specialists	KPFF Consulting Engineers
Roosevelt Collection Chicago, IL	Walsh Construction	Halvorson & Partners, Inc.
Russia Wharf Boston, MA	S&F Concrete	McNamara/Salvia Inc.
The Bow Calgary, AB	Harris Rebar	Halcrow Yolles
Trump Tower Honolulu, HI	Albert Kobayashi	Baldridge & Assoc.
Two Metropolitan Park McLean, VA	Miller & Long	Cagley & Associates
U.S. Institute of Peace Washington, DC	Clark Construction	Buro Happold
Veer Towers (City Center) Las Vegas, NV	Steel Engineers	Halcrow Yolles
View 14 Apartments Washington, DC	CCL USA, Inc.	Tadjer-Cohen-Edelson Inc.
W Hotel/Hollywood & Vine Apartments Webcor Builders	Hollywood, CA	D'Amato Conversano Inc.

15. REFERENCES

Studrails® were developed and extensively tested at the University of Calgary, Alberta, Canada. They have been the subject of numerous conference presentations and theses. The following is a partial list of articles published in North American journals. In these articles, Studrails® are usually referred to as either "shear studs" or "stud shear reinforcement (SSR®)".

1. ACI Committee 421, "Shear Reinforcement for Slabs," *Report ACI 421.1R-99*, American Concrete Institute, Farmington Hills, July 1999, 15 pp. (also contained in Part 5 of the 2005 edition of the ACI Manual of Concrete Practice).
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PART IV: ADDITIONAL INFORMATION

16. SPECIFICATION OF DECON® STUDRAILS®

The shear studs used in the fabrication of Studrails® are Low Carbon Steel, C1015 to C1018 in accordance with ASTM-A108. The strength and ductility requirements are:

Yield strength:	51,000 psi minimum (350 MPa)
Tensile strength:	65,000 psi minimum (450 MPa)
Elongation in 2 in.:	20% minimum
Reduction of Area:	50% minimum

The rails used in Studrails® are Low Carbon Steel Type 44W with the following strength and ductility requirements:

Yield strength:	44,000 psi minimum (300 MPa)
Tensile strength:	65,000 psi minimum (450 MPa)
Elongation in 8 in.:	20% minimum

The studs are welded in accordance with American Welding Society (AWS) D1.1 and CSA Standard W59 as certified by the Canadian Welding Bureau.

Drawing DEC1300 shows the size of studs that are available. The overall height of the stud is dependent on the slab thickness and the required concrete cover.

Studrails® should be specified in the project documents under "Section 3200 – Concrete Reinforcement" The engineer should use wording similar to the following:

Shear Reinforcement at the slab column connection as shown on the drawings and details, shall be Studrails® as manufactured by Decon® and detailed in ICC ESR-2494. The complete and finished Studrail® shall be ICC ES evaluated and welding shall take place in an ICC ES audited facility. Studrails® shall conform to the latest update of ASTM A1044.

Decon® USA Inc.
Sonoma, CA
866-DECON-US

Decon® USA Inc
Medford, NJ
800-527-RAIL

Decon® USA Inc.
Palm Harbor, FL
866-783-RAIL

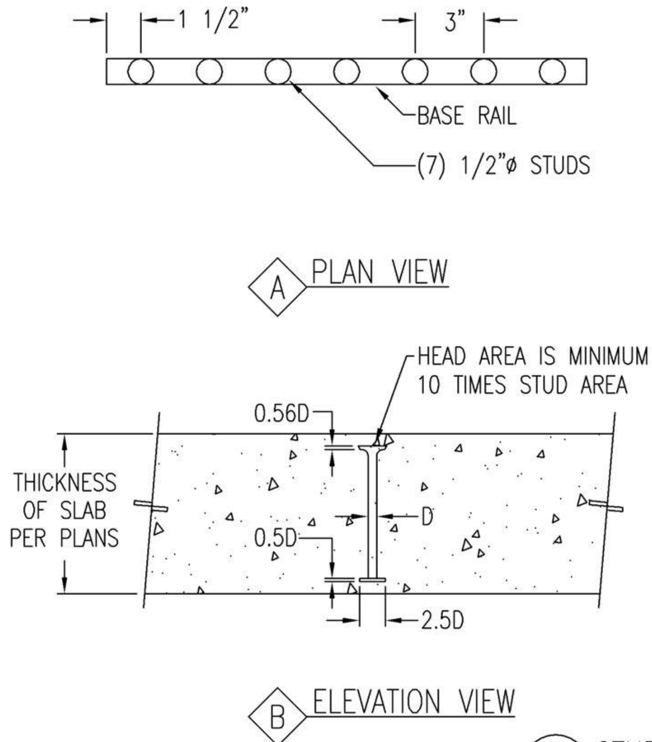
Decon® USA Inc.
Beaufort, SC
800-975-6990

Decon® Canada.
Brampton, ON
800-36-DECON

Please include our phone number on the drawings and in the specification manual so that bidders know how to locate our offices for price quotations.

Decon® requires at least the following information to issue quotations. This information must be available for extraction, or calculation, from the project drawings for each different design configuration.

Quantity of Rails:	____________________
Quantity of Studs/Rail:	____________________
Stud diameter (D):	____________________
Spacing s (between studs):	____________________
Spacing s_o (from column face to center line of first stud)	____________________
Slab Thickness:	____________________
Top & Bottom Cover:	____________________



NOTES:

1. SHEAR REINFORCEMENT AT THE SLAB COLUMN CONNECTION, AS SHOWN ON THE DRAWINGS AND DETAILS, SHALL BE STUDRAILS AS MANUFACTURED BY DECON (800-975-6990).

2. THE SHEAR STUDS USED IN THE FABRICATION OF STUDRAILS SHALL BE LOW CARBON STEEL, GRADE 1010 TO 1020 , IN ACCORDANCE WITH ASTM-A108. THE STRENGTH AND DUCTILITY REQUIREMENTS ARE:

   YIELD STRENGTH:............51,000 PSI MINIMUM
   TENSILE STRENGTH:........65,000 PSI MINIMUM
   ELONGATION IN 2":.........20% MINIMUM
   REDUCTION OF AREA:.....50% MINIMUM

3. THE RAILS USED IN STUDRAILS SHALL BE LOW CARBON STEEL TYPE 44W. THE STUDS SHALL BE WELDED IN ACCORDANCE WITH AWS D1.1 AND CSA W59 AS CERTIFIED BY THE CANADIAN WELDING BUREAU.

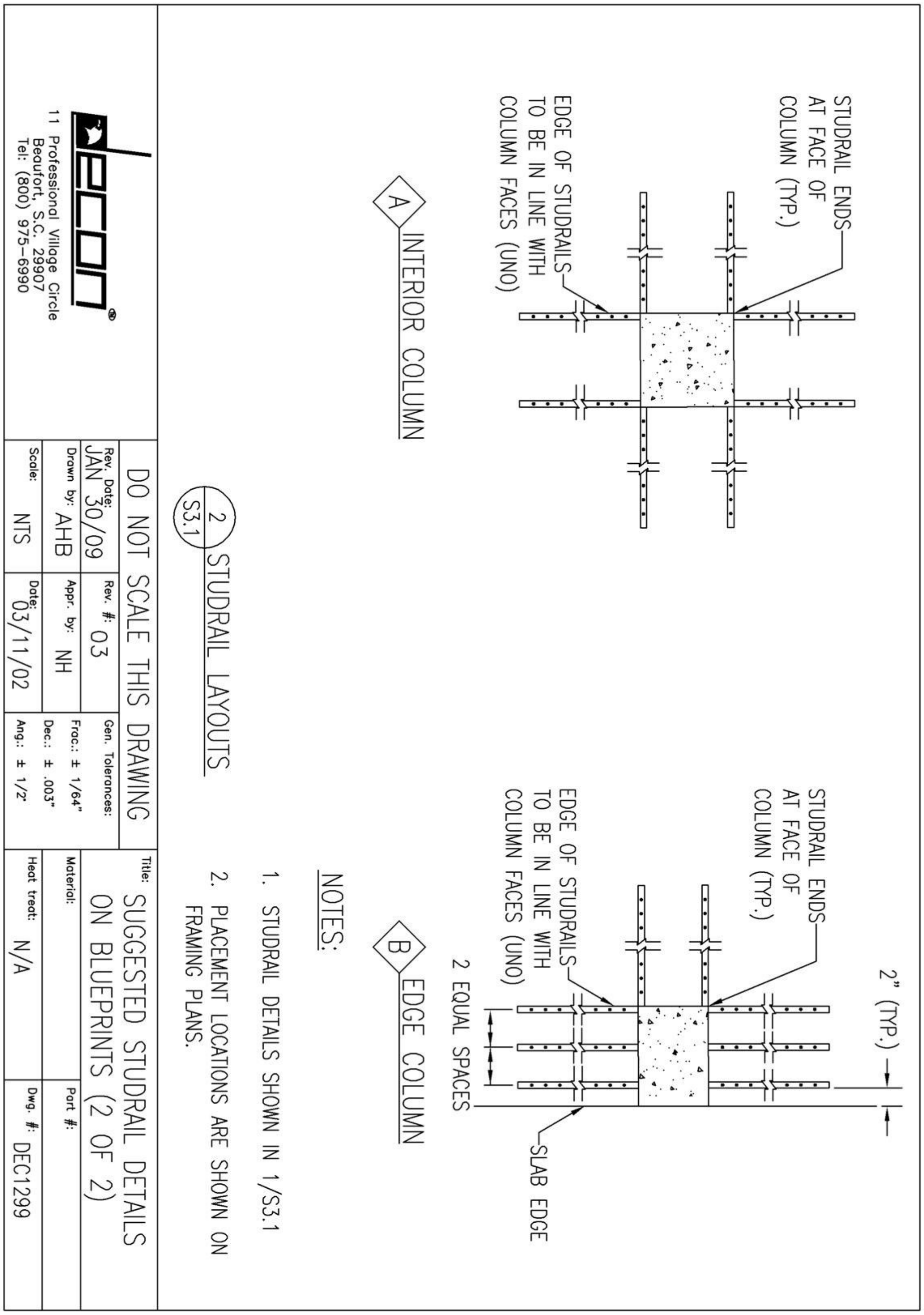
4. THE COMPLETE AND FINISHED STUDRAIL SHALL BE ICC ES EVALUATED AND WELDING SHALL TAKE PLACE IN AN ICC ES APPROVED AND AUDITED FACILITY.

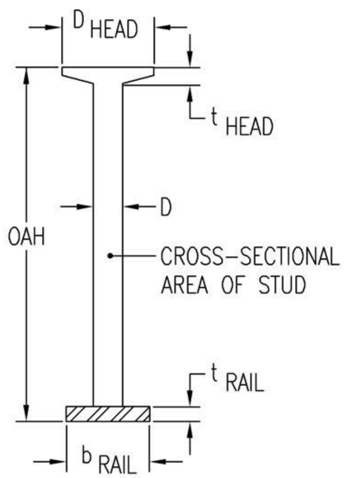
5. STUDRAILS SHALL CONFORM TO THE LATEST EDITION OF ASTM A1044.

6. PLACEMENT LOCATIONS ARE SHOWN ON FRAMING PLANS.

1 / S3.1 STUDRAIL DETAIL

DECON® 11 Professional Village Circle, Beaufort, S.C. 29907, Tel: (800) 975-6990	DO NOT SCALE THIS DRAWING			Title: SUGGESTED STUDRAIL DETAILS ON BLUEPRINTS (1 OF 2)	
	Rev. Date: JAN 30/09	Rev. #: 05	Gen. Tolerances:		
	Drawn by: AHB	Appr. by: NH	Frac.: ± 1/64" Dec.: ± .003"	Material:	Part #:
	Scale: NTS	Date: 03/11/02	Ang.: ± 1/2°	Heat treat: N/A	Dwg. #: DEC1298


STUDRAIL ENDS AT FACE OF COLUMN (TYP.)
EDGE OF STUDRAILS TO BE IN LINE WITH COLUMN FACES (UNO)
A INTERIOR COLUMN
2" (TYP.)
SLAB EDGE
2 EQUAL SPACES
STUDRAIL ENDS AT FACE OF COLUMN (TYP.)
EDGE OF STUDRAILS TO BE IN LINE WITH COLUMN FACES (UNO)
B EDGE COLUMN
NOTES:
1. STUDRAIL DETAILS SHOWN IN 1/S3.1
2. PLACEMENT LOCATIONS ARE SHOWN ON FRAMING PLANS.
2 S3.1 STUDRAIL LAYOUTS
DECON
11 Professional Village Circle
Beaufort, S.C. 29907
Tel: (800) 975-6990
DO NOT SCALE THIS DRAWING
Rev. Date: JAN 30/09
Rev. #: 03
Gen. Tolerances:
Drawn by: AHB
Appr. by: NH
Frac.: ± 1/64"
Dec.: ± .003"
Ang.: ± 1/2°
Scale: NTS
Date: 03/11/02
Title: SUGGESTED STUDRAIL DETAILS ON BLUEPRINTS (2 OF 2)
Material:
Part #:
Heat treat: N/A
Dwg. #: DEC1299



D IN. (mm)	X-SECT AREA $IN.^2$ (mm^2)	D_{HEAD} IN. (mm)	t_{HEAD} IN. (mm)	b_{RAIL} IN. (mm)	t_{RAIL} IN. (mm)	MIN. OAH IN. (mm)
3/8 (9.5)	0.110 (71)	1.19 (30.1)	0.21 (5.3)	1 (25.4)	3/16 (4.8)	3-1/2 (90)
1/2 (12.7)	0.196 (127)	1.58 (40.2)	0.28 (7.1)	1-1/4 (31.8)	1/4 (6.5)	3-1/2 (90)
5/8 (15.9)	0.307 (199)	1.98 (50.2)	0.35 (8.9)	1-3/4 (44.5)	5/16 (7.9)	4 (100)
3/4 (19.1)	0.442 (287)	2.37 (60.2)	0.42 (10.7)	2 (50.8)	3/8 (9.5)	4-1/2 (115)

NOTE:

1. OVERALL HEIGHT (OAH) OF THE STUD IS DETERMINED BY THE SLAB THICKNESS AND THE REQUIRED CONCRETE COVER.

decon®

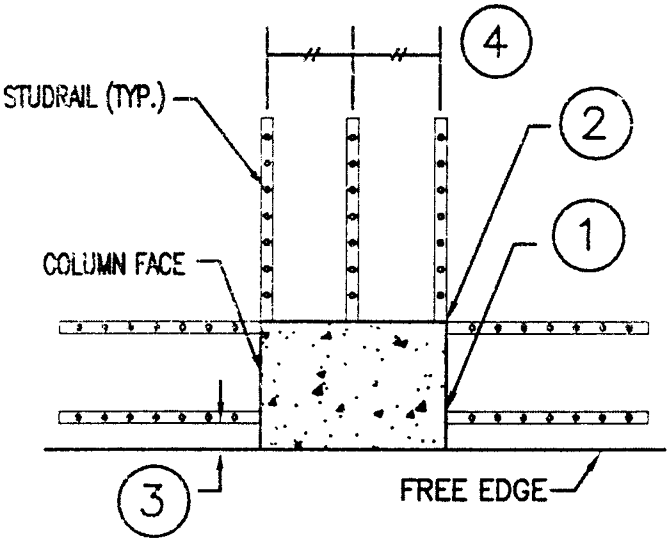
11 Professional Village Circle
Beaufort, S.C. 29907
Tel: (800) 975-6990

DO NOT SCALE THIS DRAWING

Title: DIMENSIONS OF DECON® STUDRAILS®

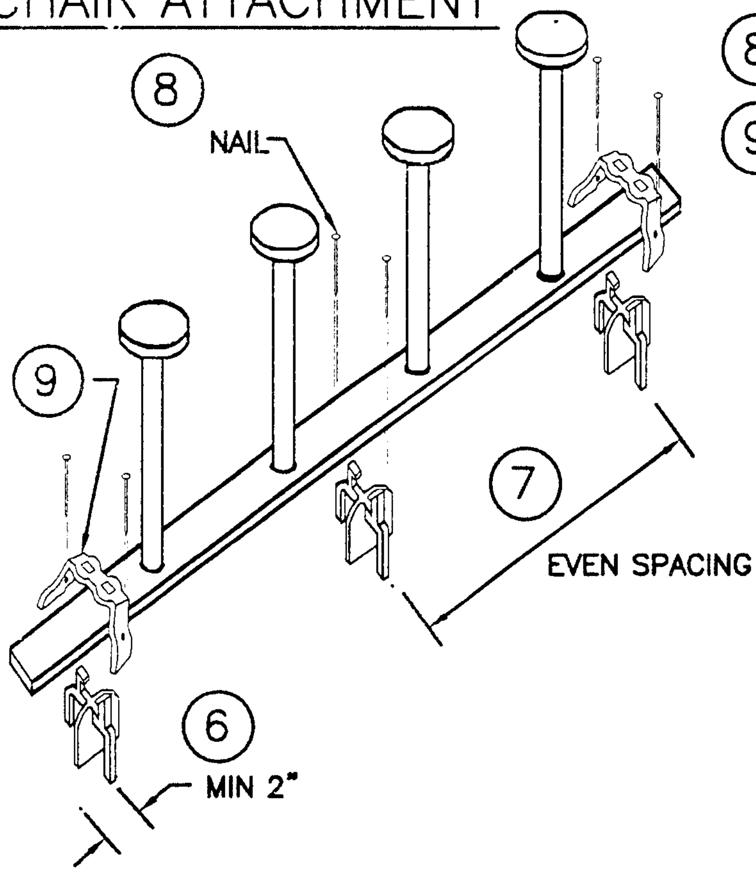
Rev. Date: JAN 30/09	Rev. #: 02	Gen. Tolerances:	Material:	Part #:
Drawn by: AHB	Appr. by: NH	Frac.: ± 1/64" Dec.: ± .003"		
Scale: NTS	Date: 03/11/02	Ang.: ± 1/2°	Heat treat: N/A	Dwg. #: DEC1300

IMPORTANT INSTALLATION INSTRUCTIONS FOR STUDRAILS



1. STUDRAIL ENDS AT COLUMN FACE.
2. STUDRAIL SHOULD BE PLACED AT COLUMN CORNERS UNO.
3. STUDRAILS ARE MIN 2" FROM OPENINGS AND EDGES.
4. STUDRAILS EQUALLY SPACED ALONG COLUMN FACE.
5. STUDRAILS MUST BE VERTICAL.
6. POSITION CHAIRS 2" MIN. FROM RAIL ENDS.
7. SLIDE ADDITIONAL CHAIRS ON RAIL EVENLY SPACED (SEE TABLE).
8. NAIL ADDITIONAL CHAIRS TIGHTLY TO FORM USE 4d–6d COMMON NAIL.
9. USE ONE CHAIR TOP AT EACH END OF STUDRAIL. INSERT NAIL THROUGH HOLE IN CHAIR TOP. POSITION CHAIR TOP OVER BASE RAIL. NAIL THROUGH CHAIR TO FORM.

CHAIR ATTACHMENT



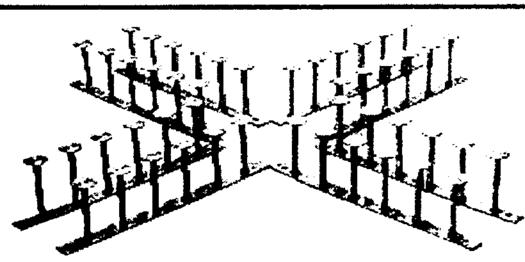
WARNING!
STUDRAILS MUST BE INSTALLED WITH THE STUDS VERTICAL.

OF CHAIRS PER RAIL

L	#
0–19 3/4"	2
20–39 3/4"	3
40–59 3/4"	4
60–79 3/4"	5
80" +	6

NOTE: CHAIRS SHIPPED REFLECTS REQUIRED QUANTITIES AS PER TABLE

DECON®
DECON USA, P.O BOX 1575
MEDFORD, NEW JERSEY, 08055–6575
TELEPHONE: 1–800–527–RAIL
(609)–953–5979
FAX: (609)–953–5980



DECON®
DECON CANADA, 35 DEVON RD.
BRAMPTON, ONTARIO, L6T 5B6
TELEPHONE : 1–800–36–DECON
(905)–458–5855
FAX: (905)–792–3711

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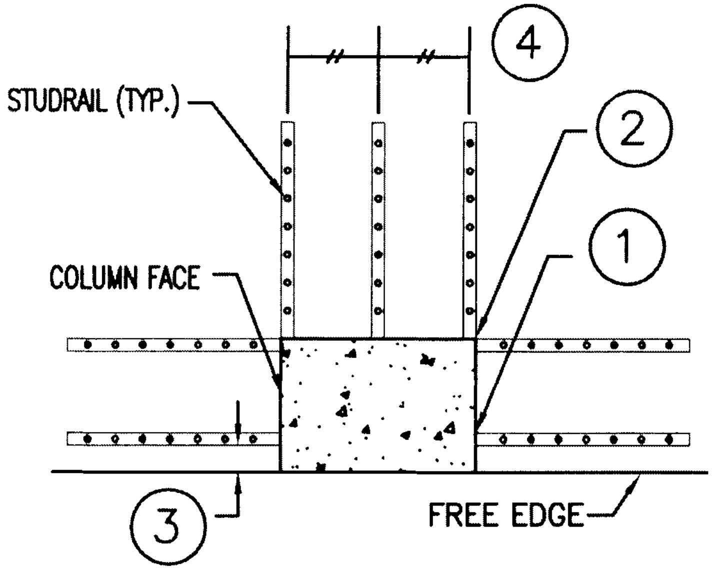

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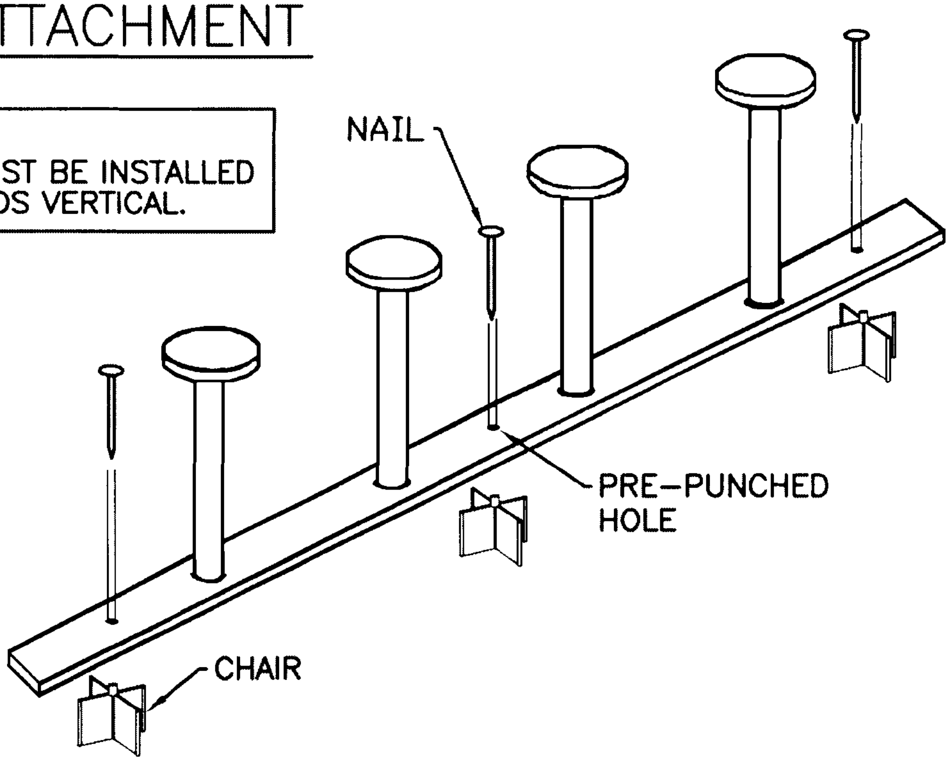

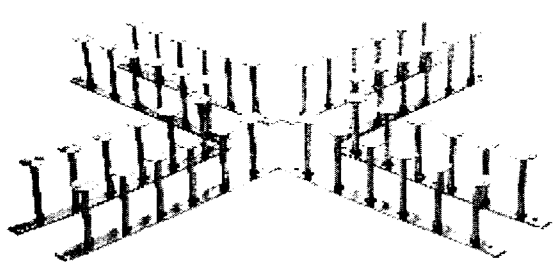

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