Mustansyriah University
College of Engineering
Civil Engineering Department
4th Stage

Reinforced Concrete-II

Design of Two-Way Slabs

Shear Strength of RC Slabs

Prof. Dr. Ali Hameed Aziz

T.D Building and Construction (Bahsra Technical Institute) 1988
BSc. Civil Engineering (University of Baghdad) 1994
MSc. Civil Engineering-Structures (Jordan University) 2000
Ph.D. Civil Engineering-Structures (Al-Mustansiriyah University) 2006
Assist. Prof. 2010
Professor 2017

October 2021

1-Shear in RC Slabs

In engineering, shear strength is the strength of a material or component against the type of yield or structural failure when the material or component fails in shear. Shear failure occurs when the slab or beam has shear resistance lower than flexural strength and the shear force exceeds the shear capacity of different materials of the slab or beam. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force. In reinforced concrete members, a shear failure which is caused by the development of diagonal cracks predominates in higher reinforced concrete beams without transverse reinforcement. If a concrete member without properly designed shear requirement (reinforcement and thickness) is overloaded to failure, shear collapse is likely to occur suddenly, with no advance warning of distress. With no shear reinforcement provided, the member failed immediately upon formation of the critical crack in the high-shear region near support. To increase the shear strength, reinforcing bar (rebar) or adequate slab thickness are used.

2- Shear strength of Slab System with Interior Beams

Generally, the shear in slabs with interior beams may be considered *satisfactory*, but let's try it!!

The shear shall be checked at a distance **(d)** from the face of the support (beam), and the ***shear strength of concrete***, according to ACI318-14/CL (22.5.5.1) is:-

$V_c = 0.17\sqrt{f_c'} * b_w * d$

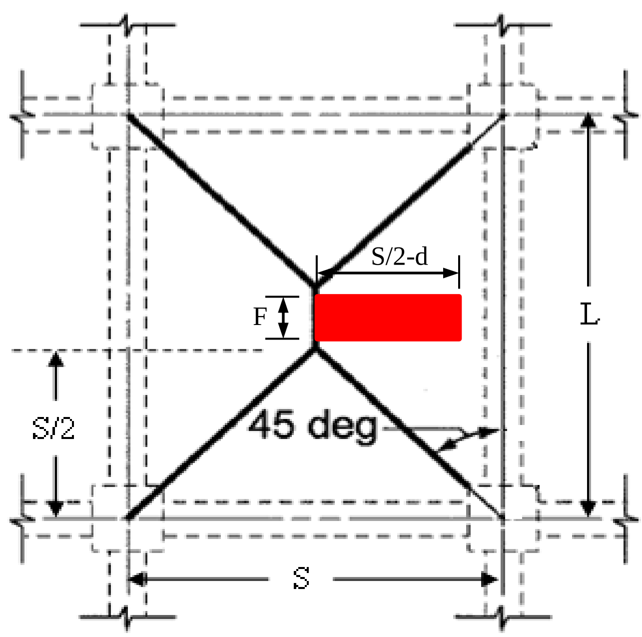
Shear Strength of Concrete $\rightarrow \phi V_c = \phi 0.17\sqrt{f_c'} * F * d$

The ***Applied shear stress (or force)*** can be calculated directly by taking a loaded strip of width (F) and length (S/2-d).

Shear stresses $\rightarrow$ $V_u = W_u * F * (S/2 - d)$.

Where

V_c= Shear strength of concrete.
V_u= Shear stresses.
b_w=Beam web width.
f_c'=Ultimate compressive strength of concrete.
d=Effective depth.
F= Loaded strip width.
W_u=Factored load.
S=Short span of the slab.
ϕ=Shear reduction factor=0.75.



Shear of Slab System with Interior Beams

3- Shear strength of Slab System without Interior Beams (Flat Plate & Flat Slabs)

There are two types of shear:-

3-1-Beam Action (One-way Shear)

The critical section extends across the entire width of a distance (d) from either of the following:-

i- The face of rectangular column (or column capital).

ii- The face of equivalent square column (or column capital).

iii- The face of drop panel (if any).

The ***applied shear force (or shear stress)*** can be calculated directly by using the following formula:-

$$V_u = W_u * A$$

The ***shear strength of concrete***, according to ACI318-14/CL (22.5.5.1) is:-

$$V_c = 0.17\sqrt{f_c'} * b_o * d$$

IF ($Vu/\phi \leq V_c$) → No shear reinforcement is permitted to resist flexural shear.

Where

V_u= Shear stresses.

W_u=Factored load.

A= Loaded area.

= $(S*(L/2-c_2/2-d))$ **or** $(L*(S/2-c_1/2-d))$

V_c= Shear strength of concrete.

f_c'=Ultimate compressive strength of concrete.

b_o=Perimeter along the critical section.

d=Effective depth=t-cover-d_b

ϕ=Shear reduction factor=0.75.

d_b= Bar diameter.

c_1= Column dimension in Longitudinal direction.

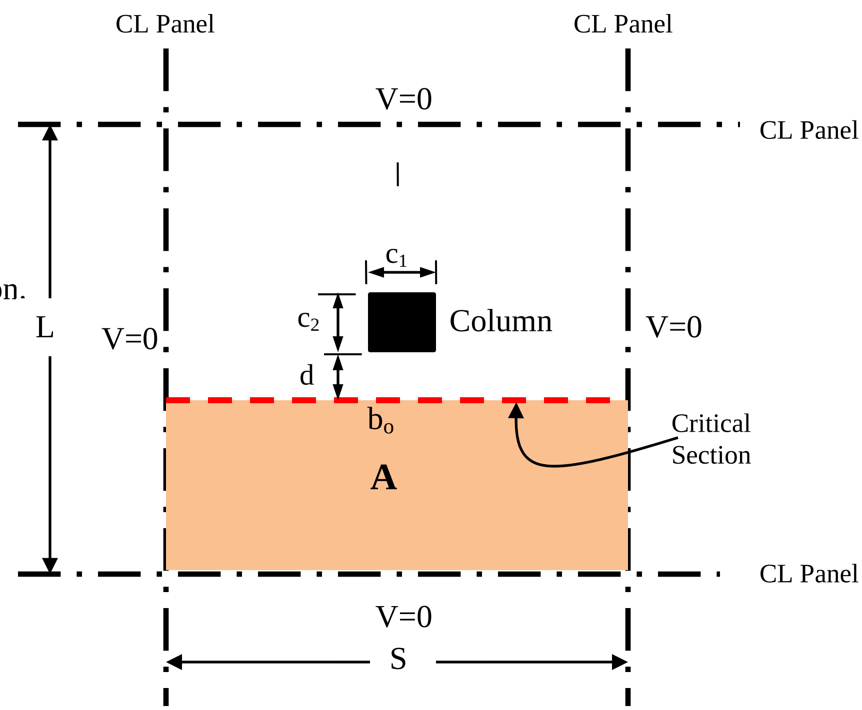
c_2= Column dimension in Transverse direction.

Note

Shorter critical section is controlling because it has shorter length of wider area.

$V_u = W_u*[S*(L/2-c_2/2-d)]$

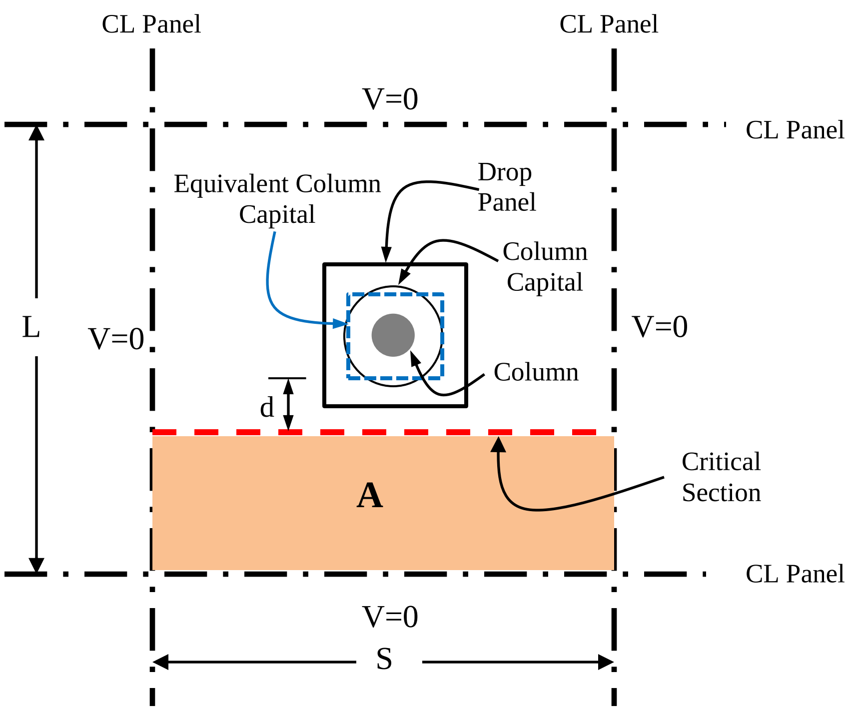
$v_n = V_n/b_o.d = V_n/S.d$



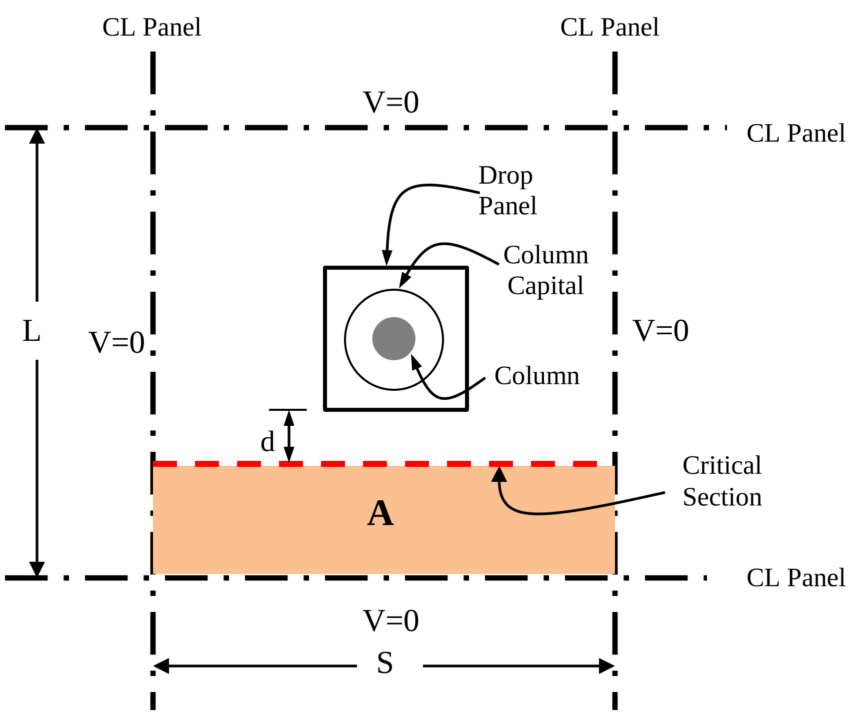
One-way shear in Flat Plate

One-way shear for flat slab, there are two possible cases:-

Case-I: Critical Section at distance (d) from the face of **Equivalent Column Capital**



Case-II: Critical Section at distance (d) from the face of **Drop Panel**

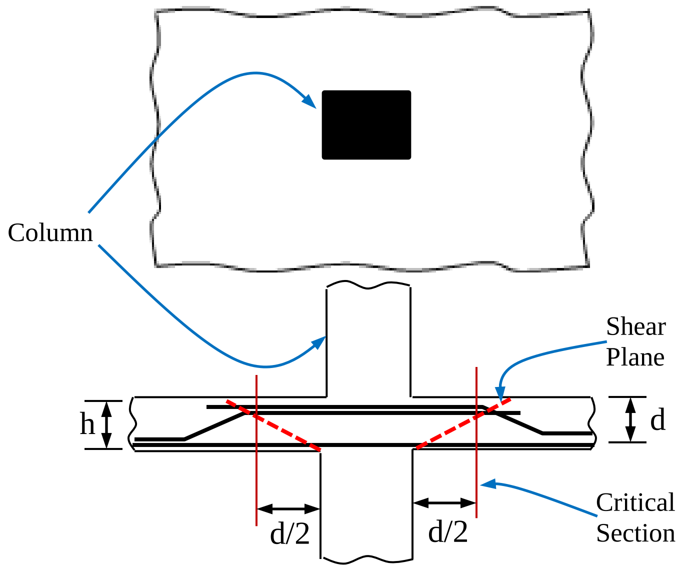


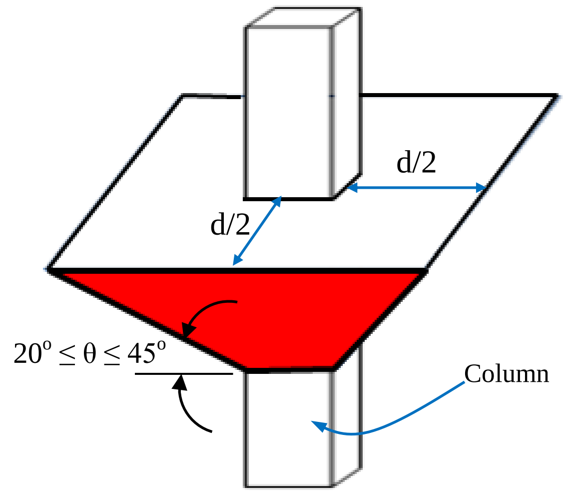
3-2-Two-way Shear Action (Punching Shear)

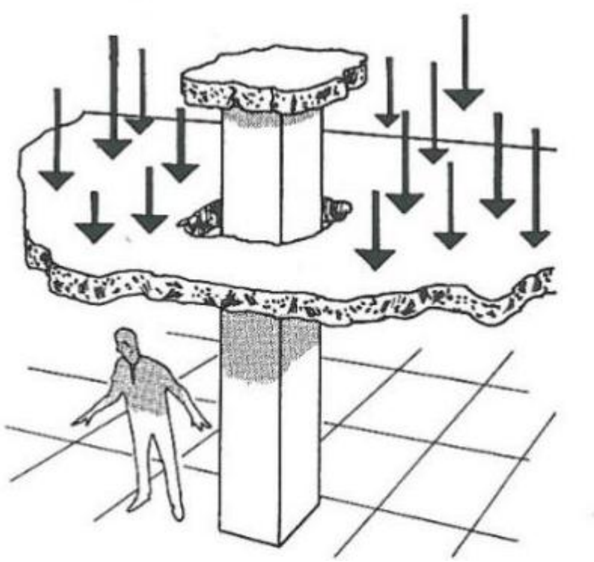
The critical section is located so that it periphery (b_o) is at distance equal to (d/2) from either of the following:-

i- The face of rectangular column (or column capital).

ii- The face of drop panel (if any).



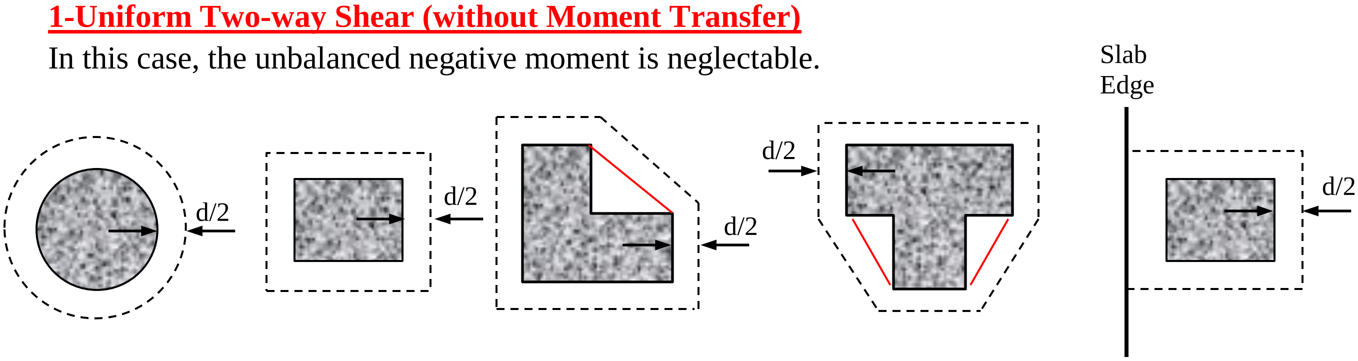


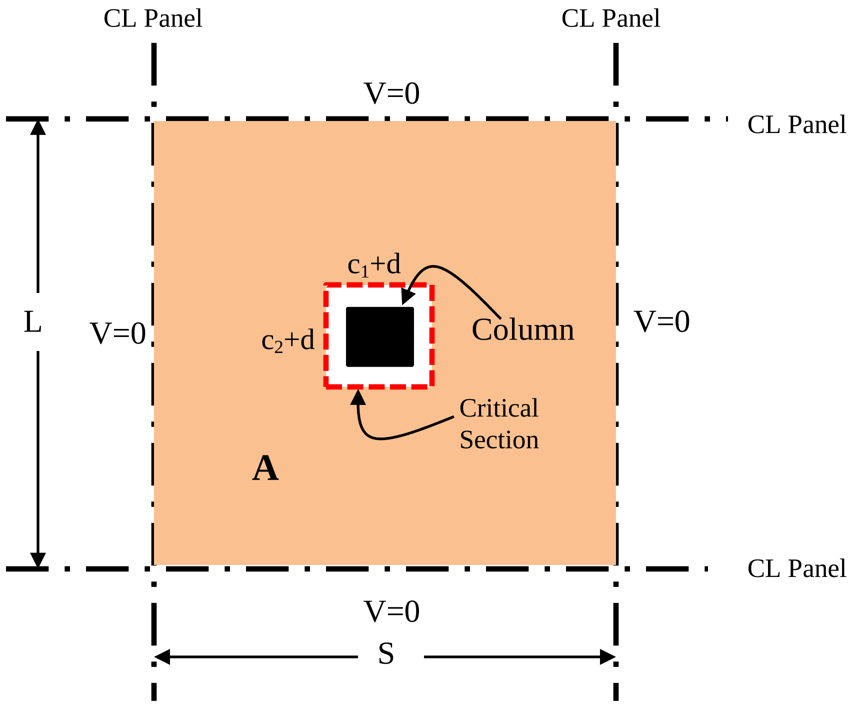


The Two-way Shear Action (Punching Shear) is divided into two types:-

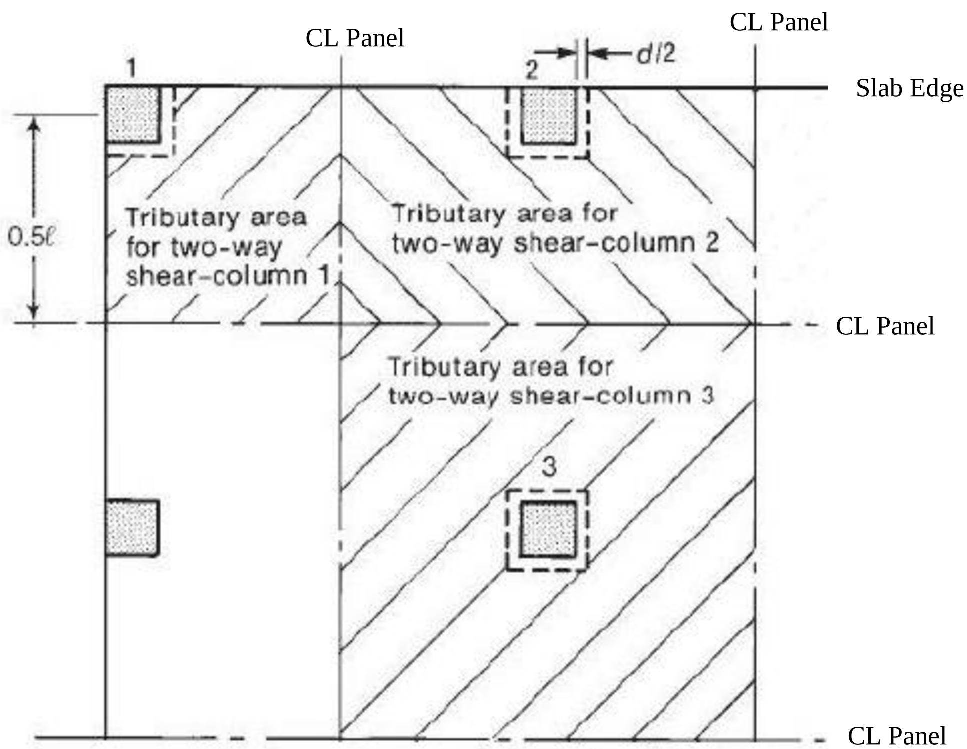
1-Uniform Two-way Shear (without Moment Transfer)

In this case, the unbalanced negative moment is neglectable.





Loaded area for interior panel



Loaded area for interior, exterior and corner panel

The ***applied shear force (V_u)*** can be calculated directly by using the following formula:-

$$V_u = W_u * A$$

Where
V_u= Applied Shear force.
W_u=Factored load.
A= Loaded area= Total area-Critical area.

The ***shear strength of concrete (V_c)*** is calculated according to Table (22.6.5.2) of ACI318-14/CL (22.6.5.2).

Table (22.6.5.2) Calculation (V_c) for two-way Shear

v_c		
Least of (a), (b), and (c):	$0.33\lambda\sqrt{f_c'}$	(a)
	$0.17\left(1+\frac{2}{\beta}\right)\lambda\sqrt{f_c'}$	(b)
	$0.083\left(2+\frac{\alpha_s d}{b_o}\right)\lambda\sqrt{f_c'}$	(c)

Where
λ=1.0
f_c'=Ultimate compressive strength of concrete
β=(Long Side/Short Side) of column or support.
α_s= Parameter Considering the effect of the location of column.
α_s=40 For interior column; α_s=30 For exterior (edge) column; α_s=20 For corner.
b_o=Perimeter along the critical section.
d=Average effective depth=t-cover-d_b

Effective depth (d)
For calculation of V_c and V_s for two-way shear, (d) shall be the average of the effective depths in the two orthogonal directions.

According to ACI318-14, ultimate design strength, a reduction factor (ϕ=0.75) shall be provided for shear; therefore the shear ***strength of concrete*** becomes (ϕV_c).

If $\frac{V_u}{\phi} \leq V_c \rightarrow$ No Shear Reinforcement is required (i. e slab thickness ok)

If $V_c < \frac{V_u}{\phi} \leq \frac{1}{2}\sqrt{f_c'}\ b_o d \rightarrow$ Provide (use) Shear Reinforcement

If $\frac{V_u}{\phi} > \frac{1}{2}\sqrt{f_c'}\ b_o d \rightarrow$ Increase Slab thickness

i.e the max. permissible shear force in two-way shear action is $V_{u_{max.}} = \frac{\phi}{2}\sqrt{f_c'}\ b_o d$

بعد هذه القيمة يجب زيادة السمك

Note

If the steel reinforcement is used as shear reinforcement;

$$V_s = \frac{V_u}{\emptyset} - V_c$$

$$V_s = \frac{V_u}{\emptyset} - \frac{1}{6}\sqrt{f_c'}\, b_o\, d$$

$$V_s = \frac{A_v\, f_y\, d}{S}$$

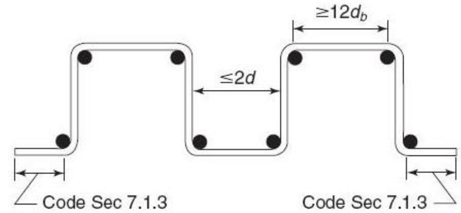
Shear Reinforcement

i-For Concrete columns

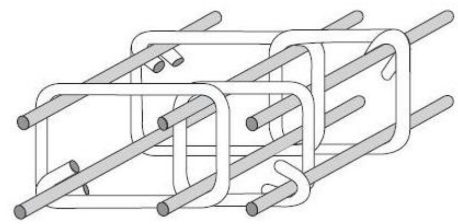
a- Stirrups (Multi-leg stirrups or Closed stirrups).

b- Hidden welded section (I-beam) or Shear head.

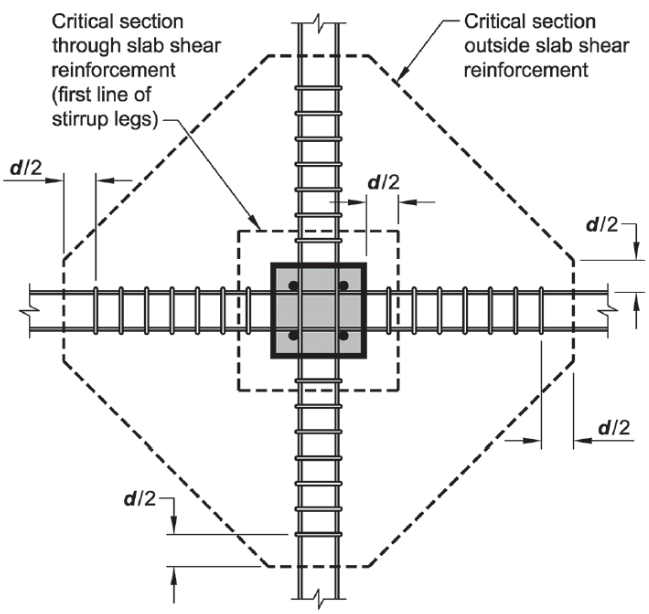
c- Steel reinforcement (Double-U or Bent bars).



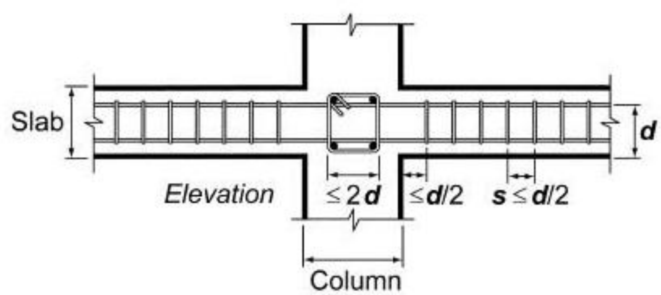
Multiple-leg stirrup.

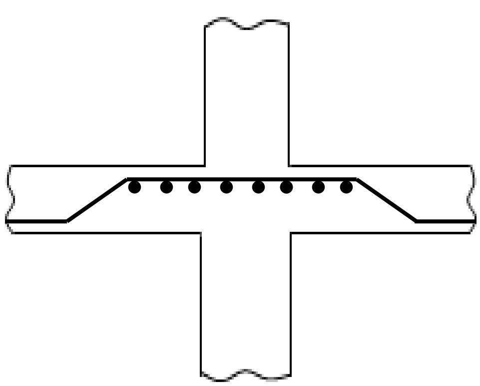


Closed stirrups.

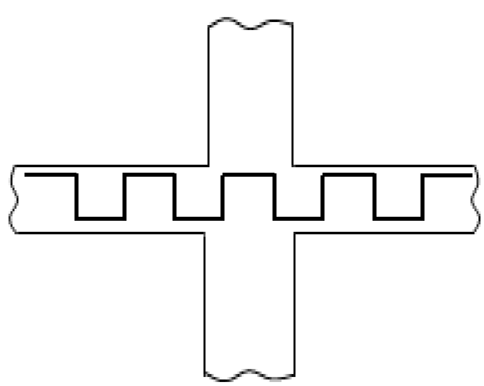


Plan

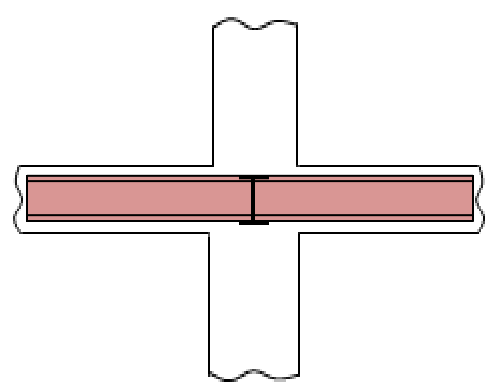




Bent bars

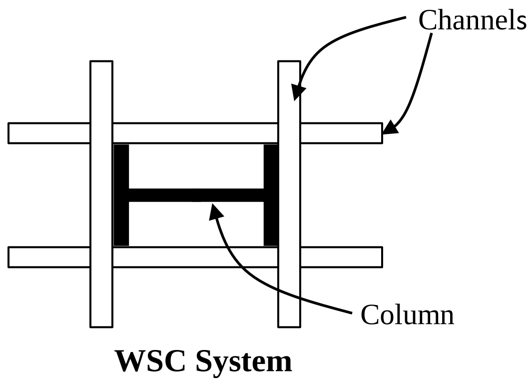


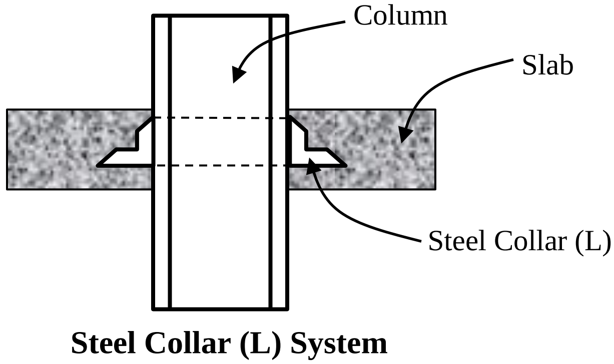
Double-U



Shear Head

ii-For Steel Columns
a-Welded Steel Channels (WSC)
b- Welded Steel Collar





2-Two-way Shear Considering the Transfer of Unbalanced Moment)

Usually, this case is most critical at exterior columns in flat plate floors. The unbalanced moment has to be transfer to column by both ***flexure*** and ***Eccentric shear***.

Let (M_u) be the unbalanced moment to be transferred to column.

$\gamma_f M_u$=Fraction of (M_u) transferred by flexure.

$\gamma_v M_u$=Fraction of (M_u) transferred by Eccentric shear.

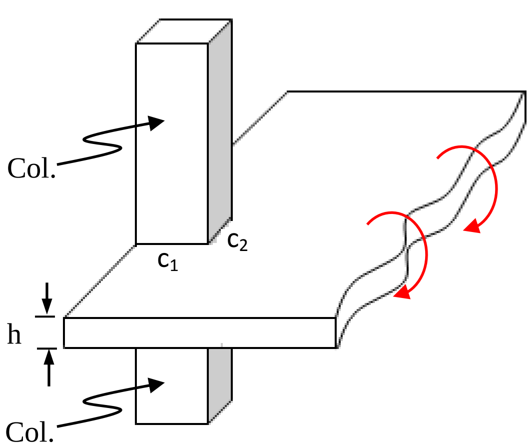
Where

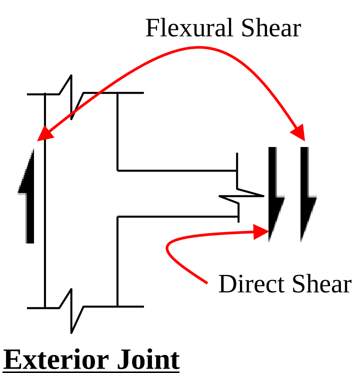
$$\gamma_f = \frac{1}{1+\left(\frac{2}{3}\right) * \sqrt{\frac{b_1}{b_2}}}$$

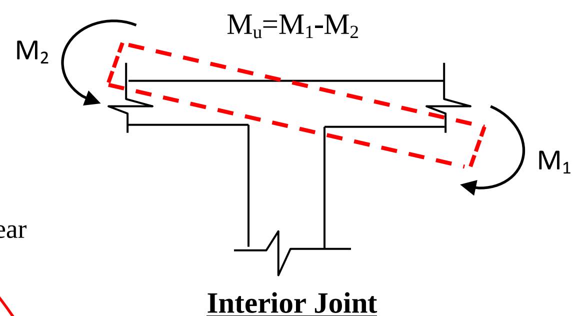
$\gamma_v = 1 - \gamma_f$

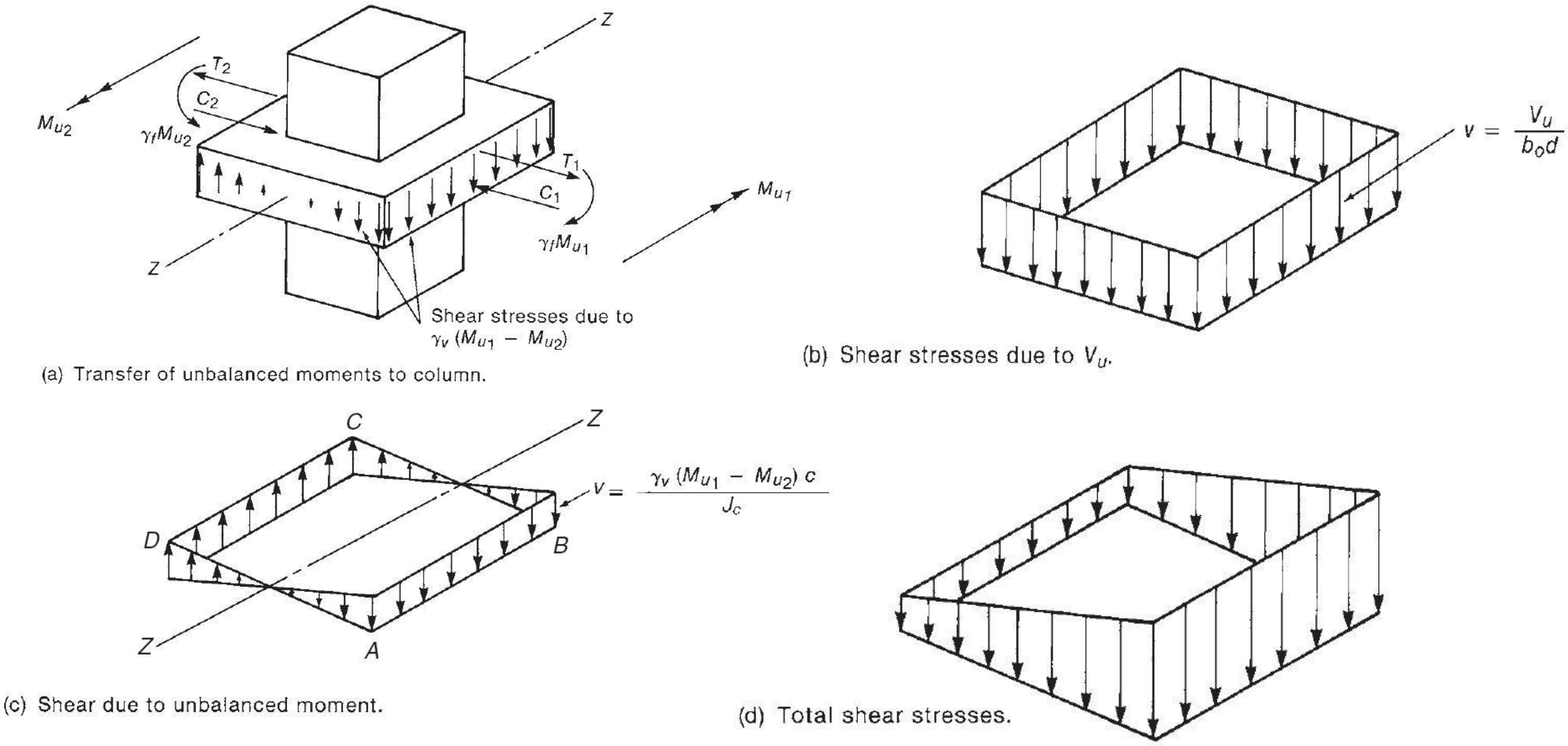
b_1= Width of critical section in longitudinal direction.

b_2= Width of critical section in transverse direction.

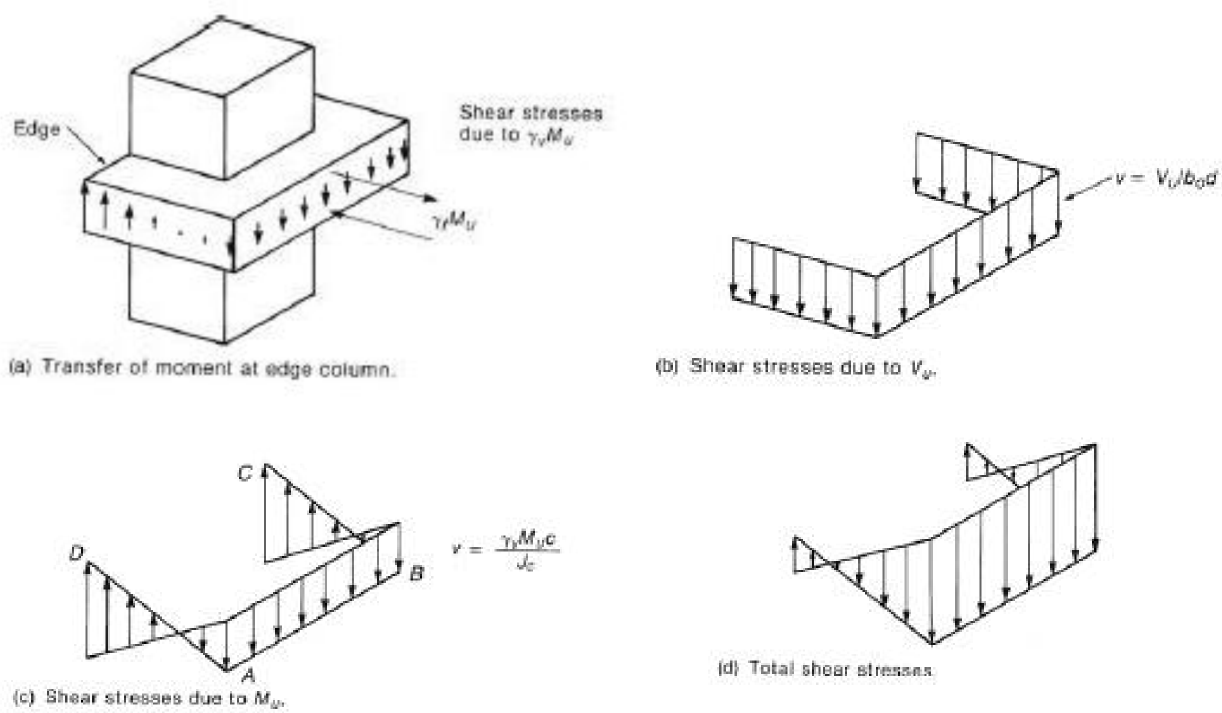








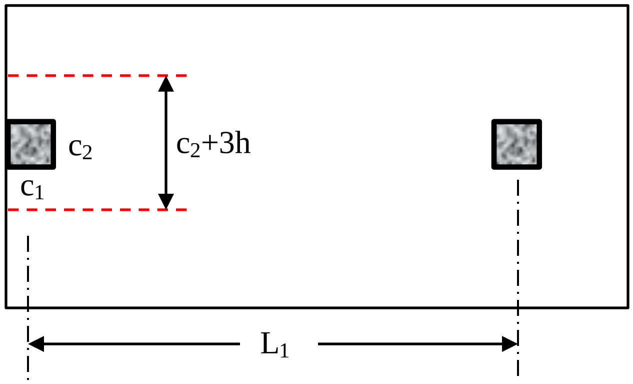
Shear stresses due to shear and moment transfer at an interior column.



Shear stresses due to shear and moment transfer at an edge column

i- Moment ($\gamma_f M_u$)

It is transferred through slab width $=c_2+3h$



ii- Moment ($\gamma_v M_u$)

It is transferred by eccentric shear about the centroid of a critical section perpendicular to plane of slab located along a perimeter at a distance (d/2) from the perimeter of column.

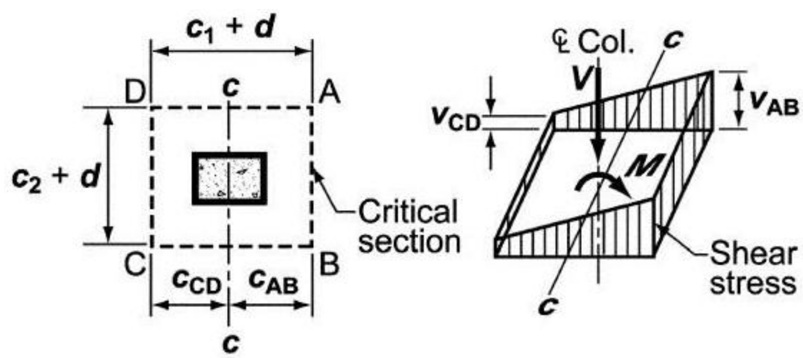
$$V_{u(AB)} = \frac{V_u}{A_c} \pm \frac{(\gamma_v.M_u).C_{AB}}{J_c}$$

$$V_{u(CD)} = \frac{V_u}{A_c} \pm \frac{(\gamma_v.M_u).C_{CD}}{J_c}$$

a- Interior Column

$A_c=2d * (b_1+b_2)$

$$J_c = \frac{d.b_1^3}{6} + \frac{b_1 d^3}{6} + \frac{d.b_2 b_1^2}{2}$$

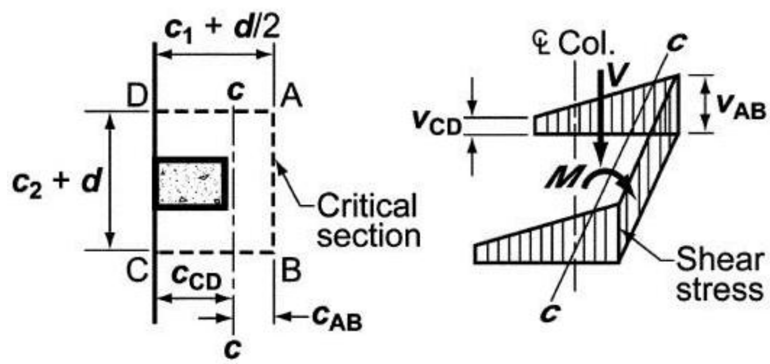


b- Edge Column

$A_c=d * (2b_1+b_2)$

$$J_c = d.\left[\frac{2}{3} b_1^3 - (2b_1 + b_2) C_{AB}^2\right] + \frac{b_1.d^3}{6}$$

$$C_{AB} = \frac{d.b_1^2}{A_c}$$



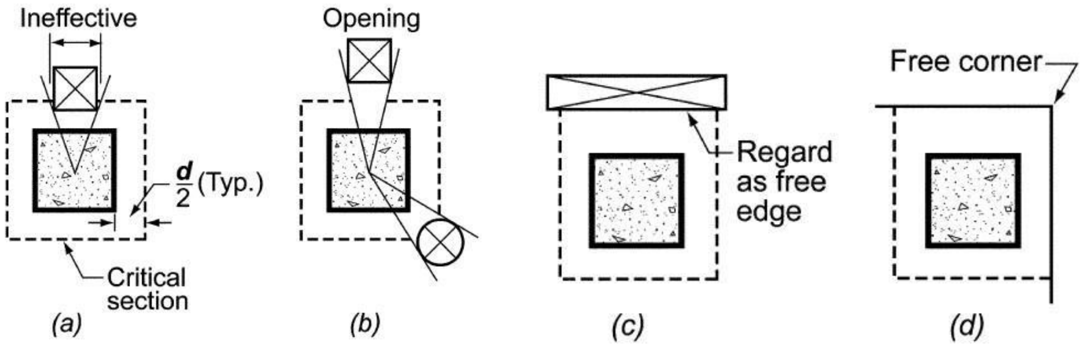
Where

A_c=Area of critical section around column.

J_c=Polar moment of inertia.

Effect of Openings

The effect of opening and free edges in slab shall be considered in calculating (Vn).



The effect of openings and free edges are:-
1-Reduce the effective perimeter as shown in dashed lines.
2-Reduce the loaded area.

References

1- Design of Concrete Structure, Arthur Nilson; David Darwin; Charles Dolan Nilson 15th Edition.

2-Reinforced Concrete Design, Wang C.K. and Salmon C.G.,4th Edition 1985

3- Building Code Requirements for Reinforced Concrete ACI 318M-14

4- Reinforced Concrete Fundamentals, Ferguson Phil M., 4th Editions 1981.

5- Design of Reinforced Concrete, McCormac, J. and Nelson, K., 7th Edition, (2006).

6- Reinforced Concrete Design, Leet, K. and Bernal, D., 3rd Edition, (1997).

7- Reinforced Concrete, Nawy, E., 6th Edition, (2009).

8- تصميم المنشاءات الخرسانية المسلحة وفقا لمتطلبات الكود ACI 318-02 جمال عبد الواحد

9-محاضرات تصاميم الخرسانة المسلحة- (ا.د.هشام الحسني)-المرحلة الرابعة-1993-قسم الهندسة المدنية-جامعة بغداد.