PUNCHING SHEAR (TWO-WAY FOOTINGS AND SLABS)

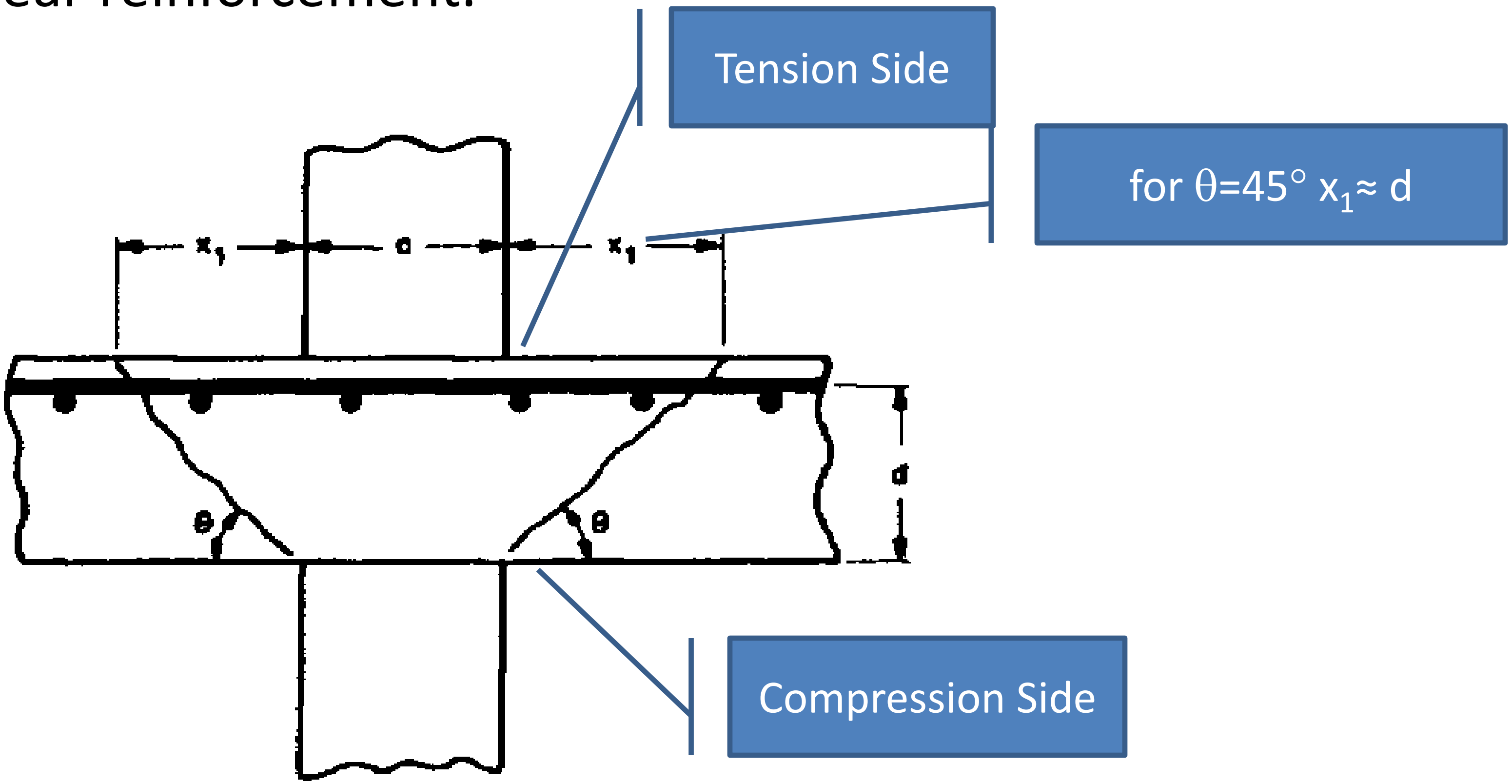
When the two-way slabs are supported directly by columns, as in the case of flat plates or flat slabs, principal stresses around the column can cause severe diagonal cracking, which can lead to very sudden and extremely brittle failure.

In two-way individual column footings, a similar problem exists.

When a loaded flat plate or a footing is supported by a column, the normal and shear stresses can create very high principal tensile stresses, which can exceed the tensile strength of concrete. Cracks forming orthogonal to the principal tensile stresses follow the surface of a truncated cone around the column.

The failure surface extends from the bottom of the slab (from the face of the column) diagonally upward to the top face.

The inclination of the crack depends on the reinforcement in the slab, varying from 25° to 45°, usually close to 45° for slabs without shear reinforcement.



Diagonal cracks usually develop as the extension of flexural cracks. Such cracks extend into the compression zone of the slab where resistance is encountered due to local compression from the column. The slab or footing continues to carry the load for a while and, finally fails suddenly, pushing out a pyramid or cone of concrete. The failure is similar to shear-compression failures in beams.

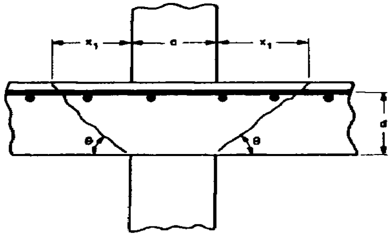
The punching failure is <u>very sudden and extremely brittle</u>. Structural failures, which were caused by punching shear, took place <u>in a few seconds</u> without any warning. Such failures, therefore, cause considerable casualties.

During the tests, same types of sudden and brittle failures have been observed.

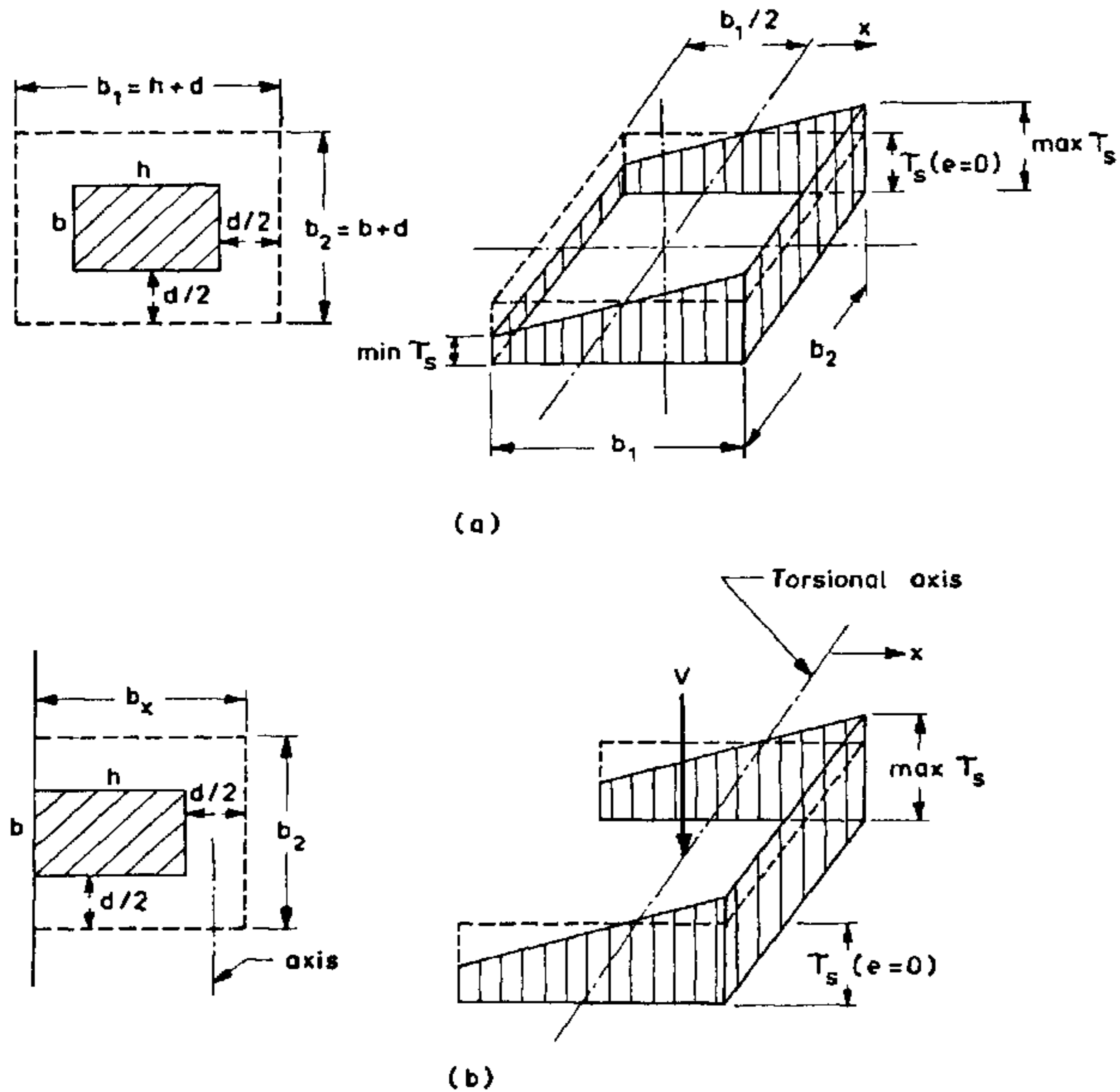
PUNCHING STRENGTH OF SLABS AND FOOTING WITHOUT SHEAR REINFORCEMENT

Punching shear stress can be calculated by dividing the shear force by the area, which resists the punching force. To define the shear resisting area, a critical perimeter has to be defined.

Although the crack perimeter is at the face of the column on the compression side and is approximately at a distance "d" from the face of the column or the loaded area on the tension side;



the design codes in general specify an equivalent critical perimeter to simplify the calculations. The equivalent perimeter is defined at a distance d/2 from the face of the column or the loaded area.



b1 = h + d
h
b
d/2
b2 = b + d
d/2
b1/2
x
max Ts
Ts (e=0)
min Ts
b2
b1
(a)
Torsional axis
x
V
bx
h
d/2
b
b2
d/2
max Ts
axis
Ts (e=0)
(b)

If the critical perimeter at a distance d/2 is denoted as u_p, the punching strength can be written as:

$$V_{pc} = \gamma f_{ctk} (u_p) d$$

In the design, f_{ctk} should be replaced by f_{ctd}.

“ γ” is a coefficient, which depends on the moment transfer in the two-way-slab.

In cases where the moment on the column is negligible, g can be taken as unity, γ = 1.0.

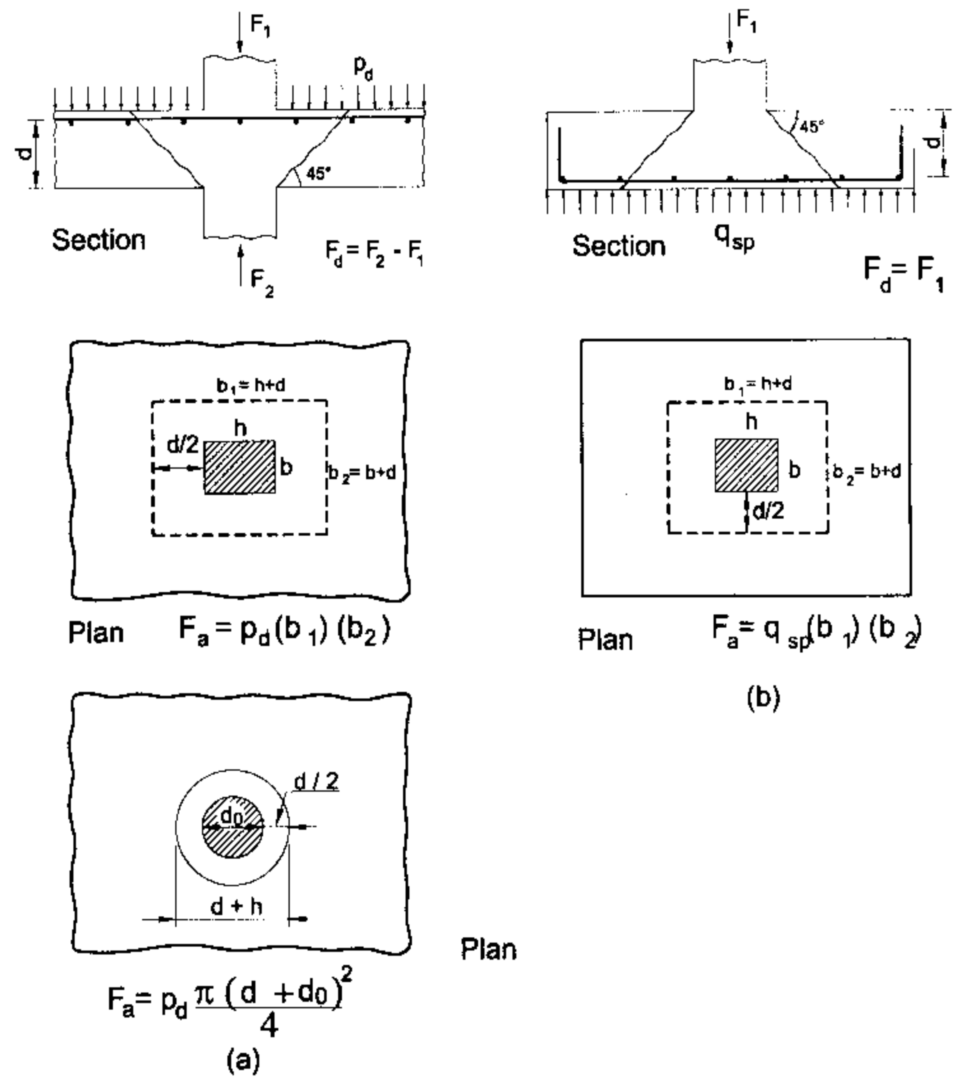
Design requirements for punching shear will be satisfied when:

$$V_{pc} > V_d$$

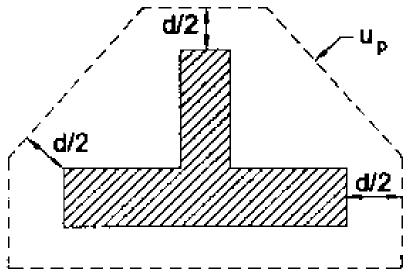
Where:

$$V_d = F_d - F_a$$

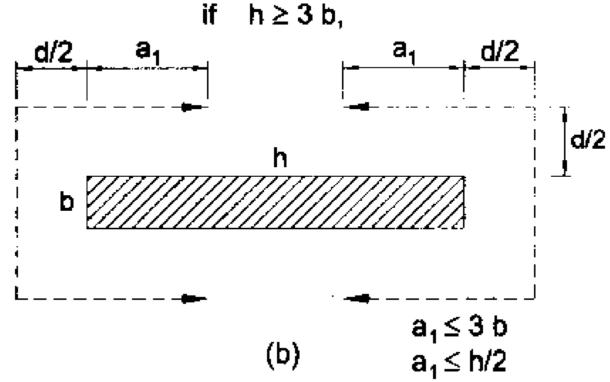
$$F_d = F_2 - F_1$$



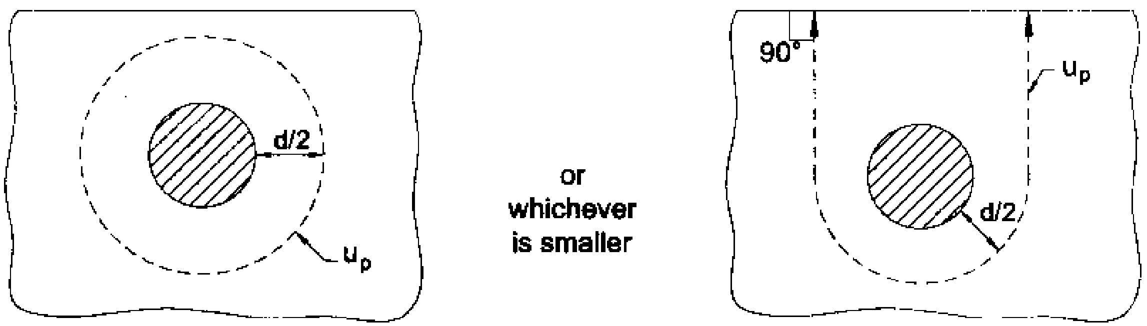
CRITICAL PERIMETERS FOR SOME TYPICAL CASES



(a)

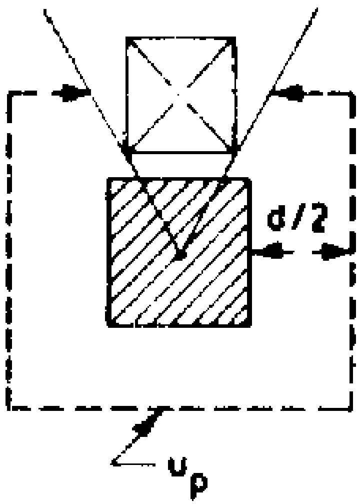


(b)

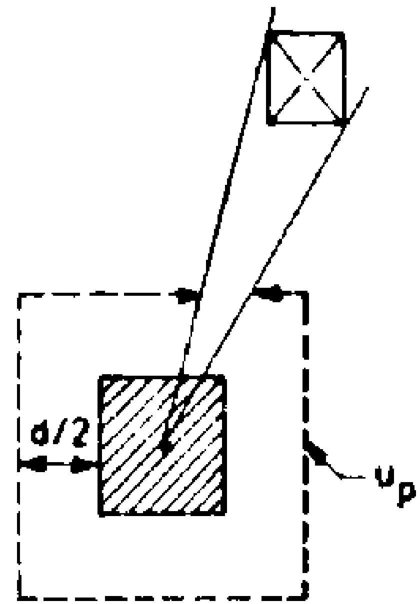


(c)

OPENINGS IN SLABS



(a)



(b)

If the opening in the slab is closer than five times the thickness of the slab (to the column face), that part of "u_p" included within radial lines projecting from the opening to the centroid of the column should be considered to be ineffective.

Special Features

The punching strength is directly proportional to the tensile strength of concrete. Therefore, in flat plates or related type of floors, concrete quality is extremely important. Many of the punching shear failures have been caused by low quality of concrete.

Openings in flat plates, especially the ones close to the column, reduce the shear strength. Therefore, the designer should be fully aware of such openings and should be informed if, for some reason, the contractor is asked to make openings which are not shown on the design drawings.

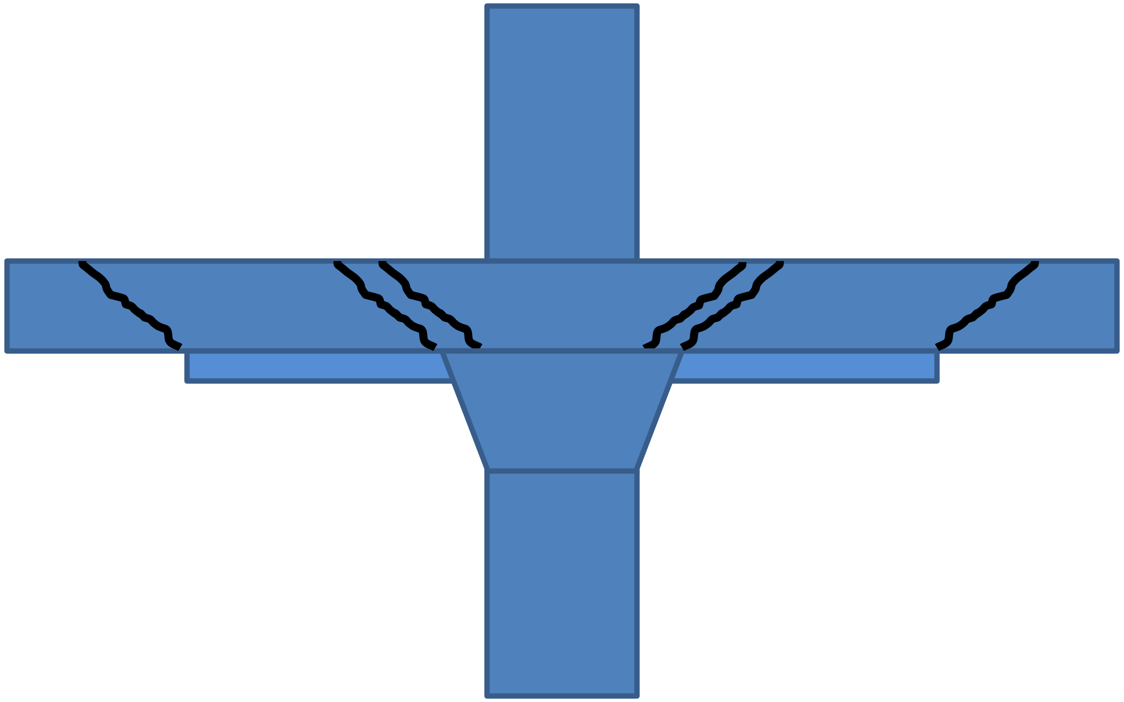
Special Features

In flat plates, self-weight of the slab usually exceeds the floor live load. During casting of concrete, if the floor below is not properly reshored, loading on this floor may exceed the design load. Punching failures have occurred because the floor below the one where concrete was being placed was not reshored. Therefore, the design engineer and inspecting engineer should consider the construction loads and should take the necessary precautions.

Corner and edge columns are always trouble spots for punching. Therefore, it is advisable to provide spandrel beams or extend the slab beyond the external faces of columns.

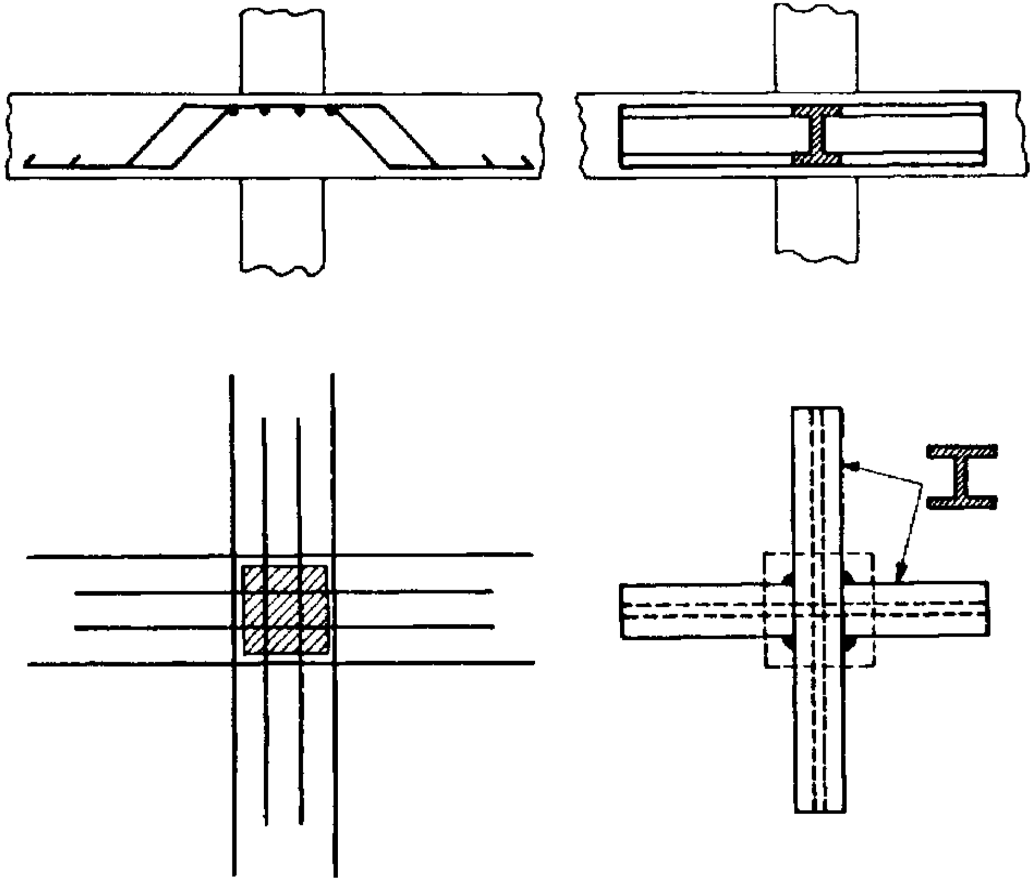
SPECIAL FEATURES

If it turns out to be $V_{pc} < V_d$, then the punching resistance can be increased by increasing either the slab thickness or the column dimensions or both. Increasing the slab thickness is generally more effective.



SPECIAL FEATURES

In some cases due to architectural or economical reasons dimensions cannot be increased beyond a certain limit. In such cases special shear reinforcement is used at the supports.



(a) (b)

Punching Reinforcement

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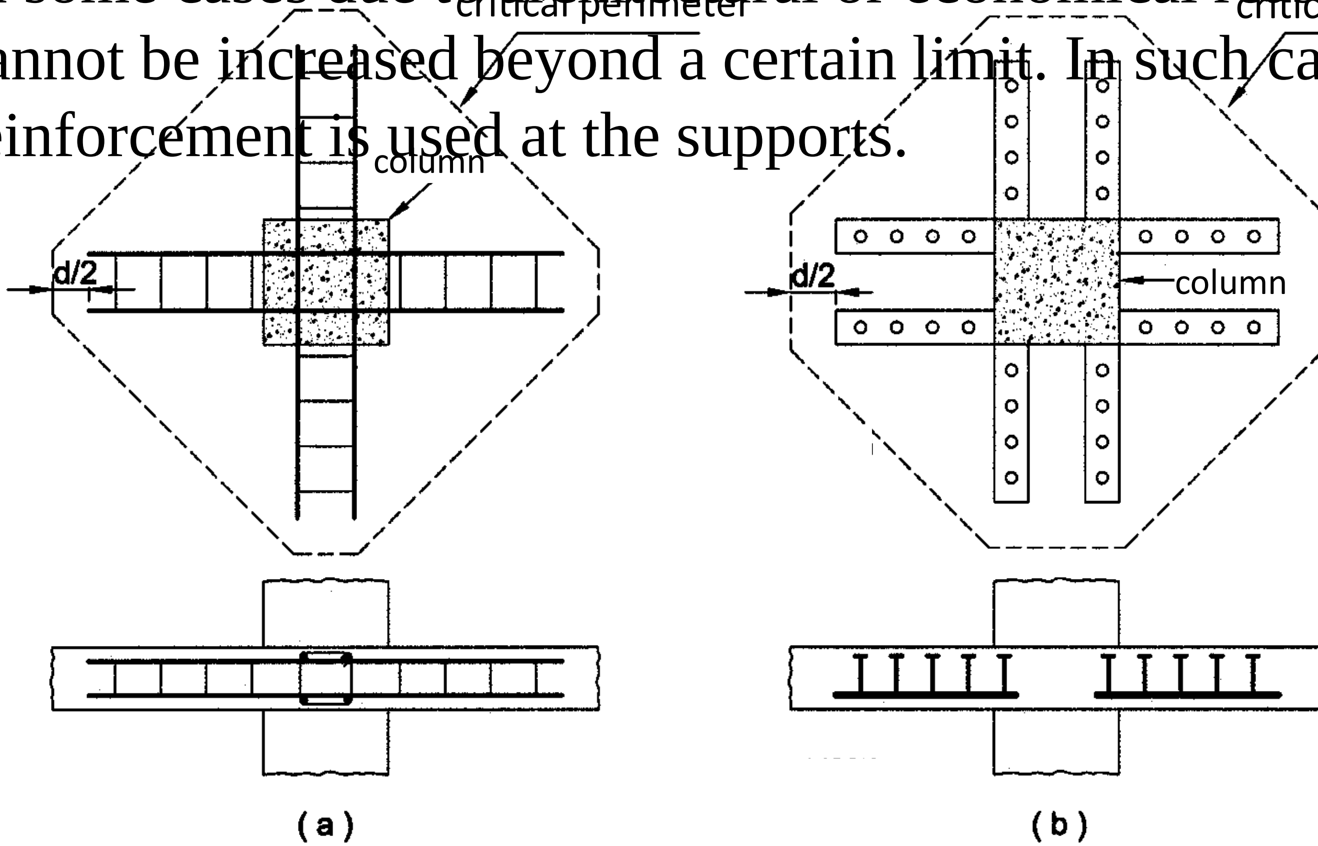
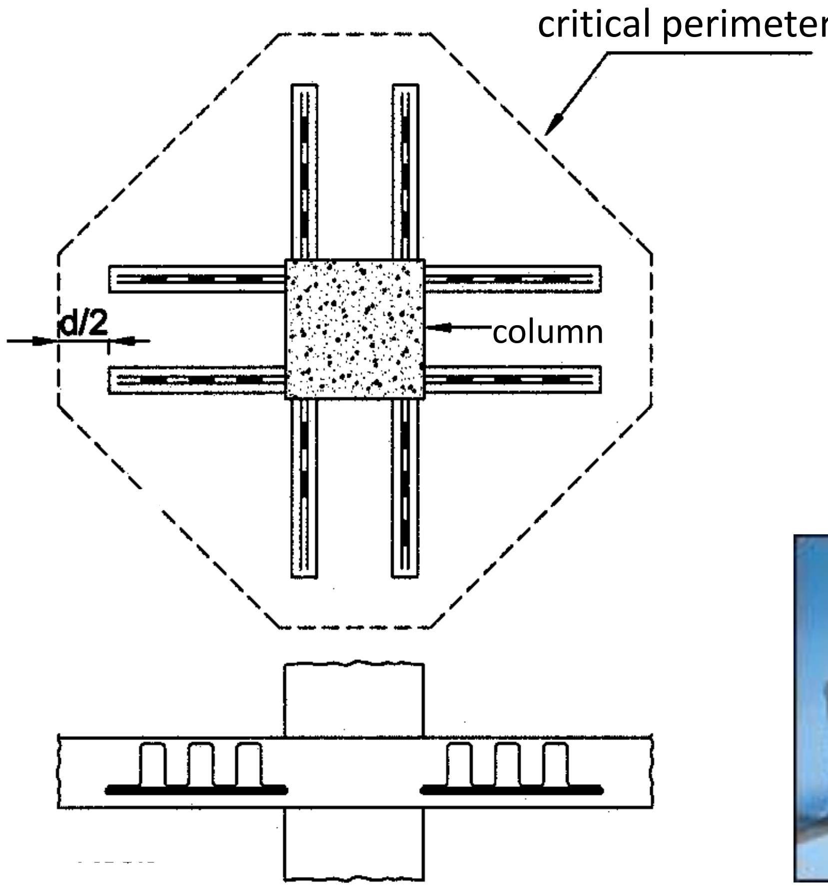


Punching Reinforcement



METU Test for Strengthening the Flat Plates

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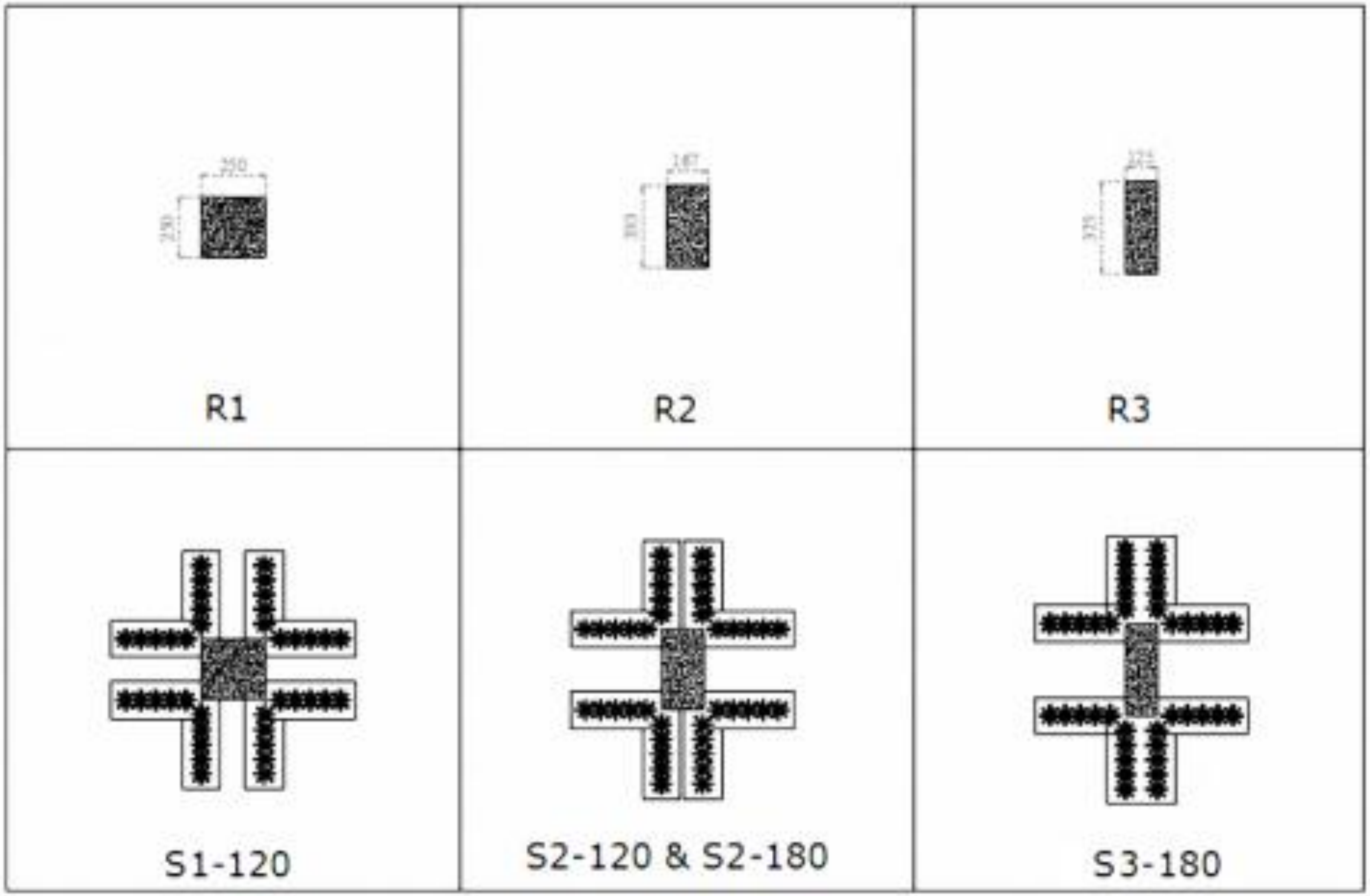

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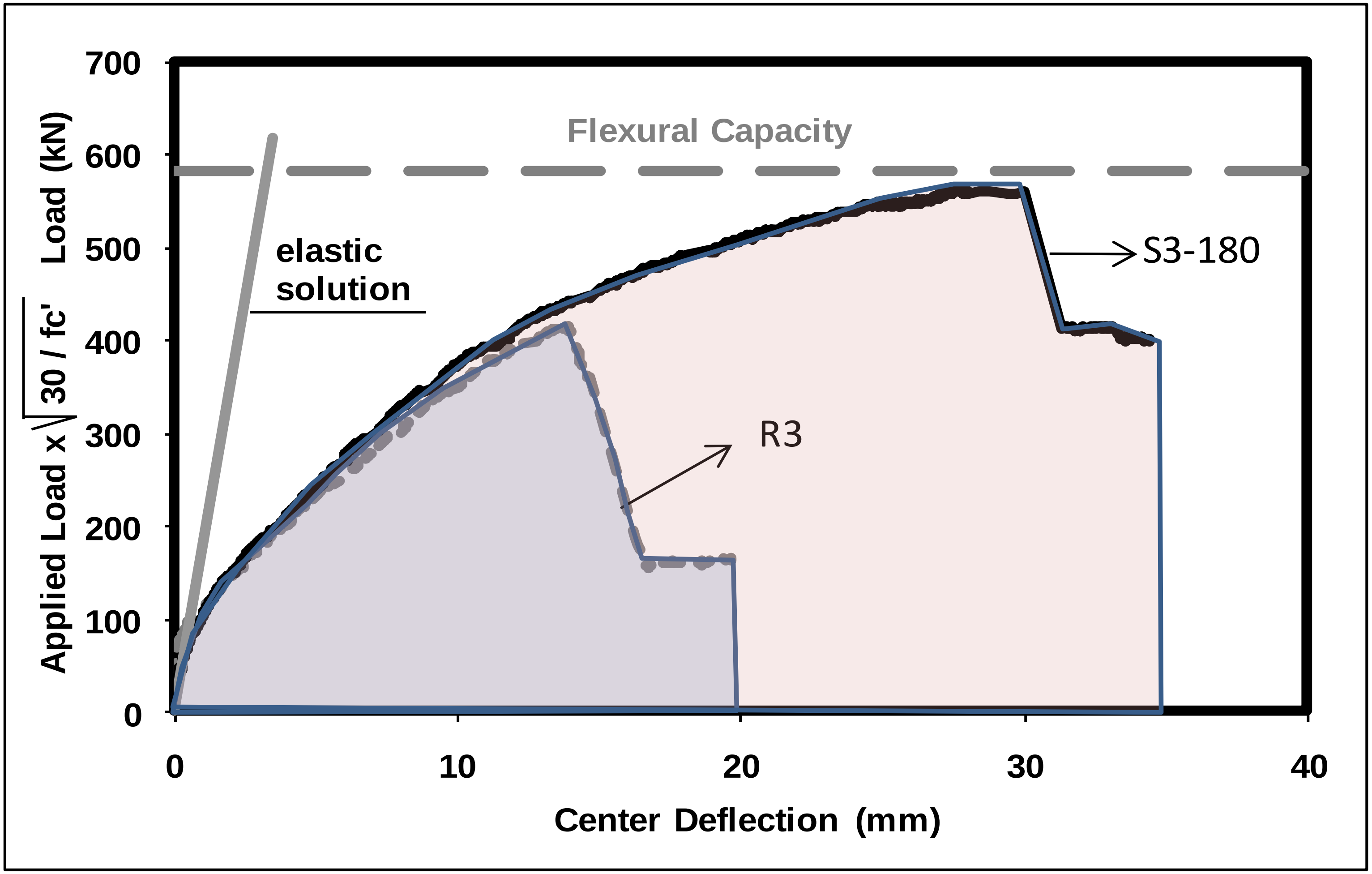
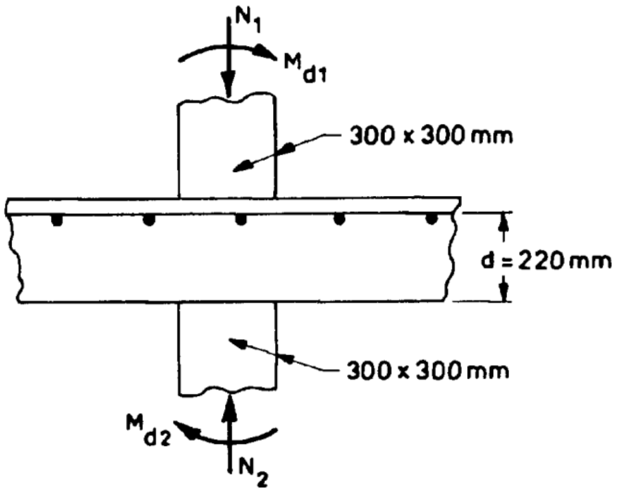


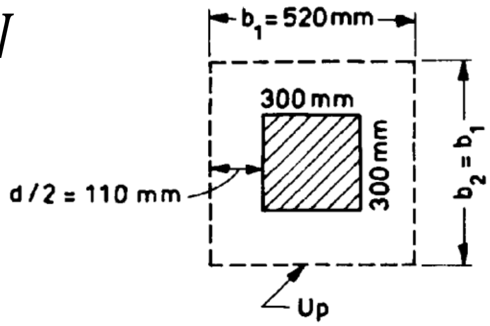
Catches of Punching Shear Design

- Tensile strength of concrete is directly proportional to punching strength → concrete quality is extremely important
- Punching shear reinforcement may remain inside the punch pyramid → ineffective
- Openings especially close to columns are very important
- Self weight of slab is generally higher than live load → during casting of concrete, the floor below should be properly reshored.
- Corner and edge columns are trouble spots for punching → provide spandrel beam or extend the slab beyond the column

Example 3

- Column 300×300 mm
- C20
  - $f_{cd} = 13\ MPa$ & $f_{ctd} = 1.0\ MPa$
- S420 ($f_{yd} = 365\ MPa$)
- $t = 250\ mm$ & $d = 220\ mm$
- $p_d = 10\ kN/m^2$
- $N_{d1} = 880\ kN$ & $N_{d2} = 1300\ kN$
- $M_{d1} = M_{d2} = 0$





- $u_p = (300 + 220)4 = 2080\ mm$

Example 3

- $F_d = N_{d2} - N_{d1} = 1300 - 880 = 420\ kN$
- $F_a = b_1 b_2 p_d = 0.52 \times 0.52 \times 10 = 2.7\ kN$
- $V_d = F_d - F_a = 420 - 2.7 = 417.3\ kN$
- in flat plate F_a is small, but in footings its value is high
- $V_{pc} = \gamma f_{ctd} u_p d = 1.0 \times 1.0 \times 2080 \times 220 = 457.6\ kN$
- $V_{pc} > V_d$ OK ✓ slab is safe in punching