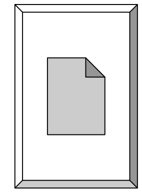
APPLIED ARCHITECTURAL STRUCTURES:
STRUCTURAL ANALYSIS AND SYSTEMS
ARCH 631
DR. ANNE NICHOLS
FALL 2013

lecture
eight

plates and grids


http://nisee.berkeley.edu/godden

Term Project

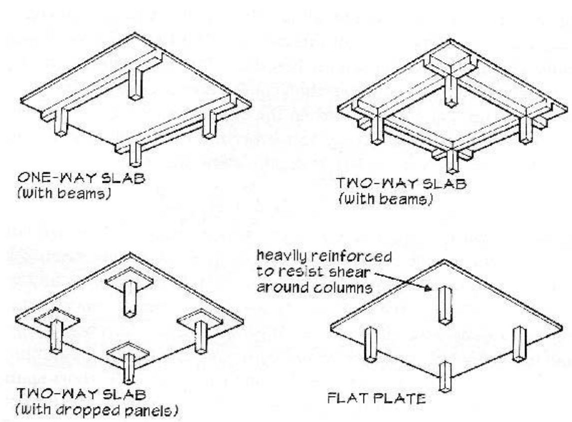


Plates, Slabs & Grids

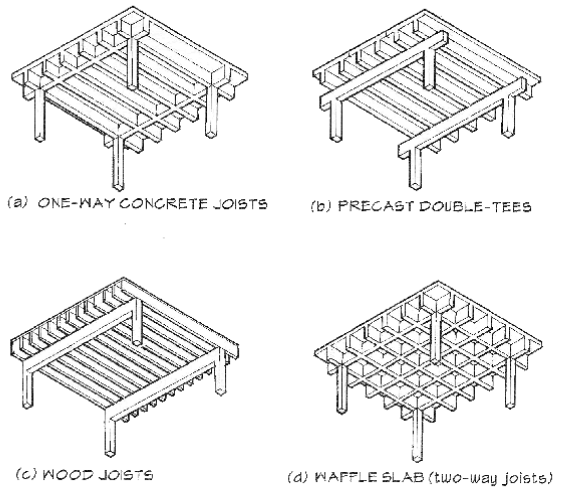
- plates – horizontal plane, rigid
- slabs – thin, flat, rigid
  - extremely common in concrete
- grids – crossed beams
- see
  - bending
  - shear

Plates, Slabs & Grids

- types & spanning direction



Plates, Slabs & Grids



Plates, Slabs & Grids

- *loads & behavior*
  - *comparison with beams*

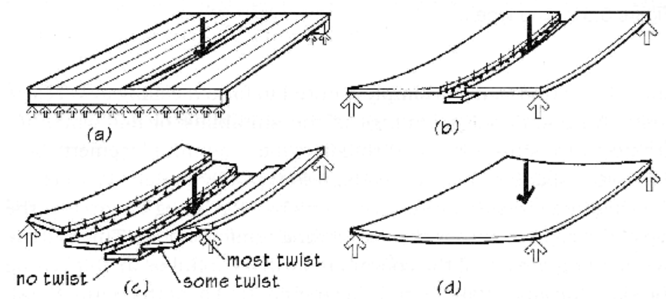


Plate Structures

- *waffles & grids*

http://www.bluffton.edu

http://nisee.berkeley.edu/godden

Plates, Slabs & Grids

- *compatibility*
  - *deflections same, even with stiffer side*
  - *stiffness* $\propto$ *to* $\dfrac{EI}{L}$
  - *twisting causes torsional stresses*
- *supports*
  - *at points*
  - *flexible*
  - *continuous*

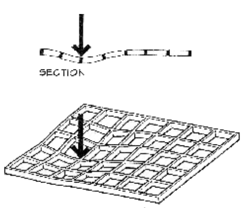
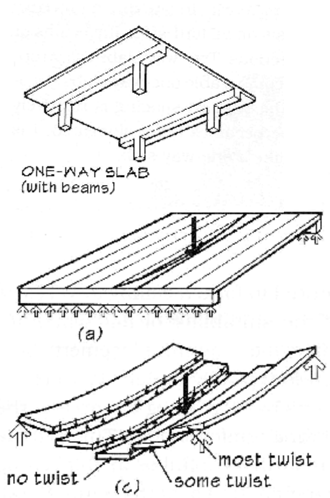


Figure 8.47: The deformation of a beam grid due to an applied point load.

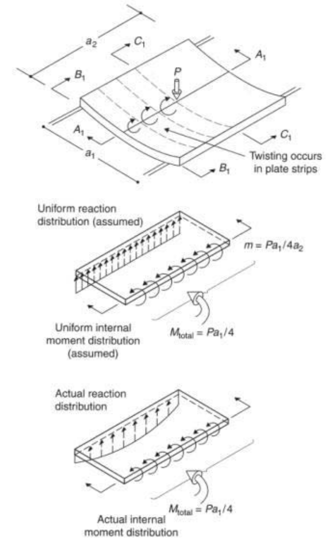
One-Way Plates

- *with uniform loads*
  - *like "wide" beams*
  - *moment / unit width*
  - *uniform curvature*
- *with point loads*
  - *resisted by stiffness of adjacent strips*
  - *more curvature in middle*



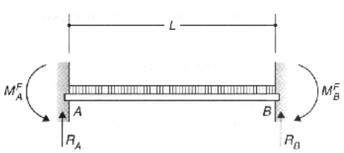
Moment Redistribution

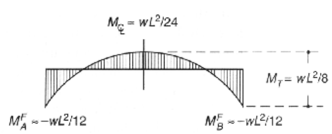
- *total moment for ½ plate*
  - *value from basic equilibrium*
  - *because of curvature, it isn't uniform at support*
  - *redistribution*
    - *bigger with big curvature*
    - *smaller with small curvature*



Moment Redistribution

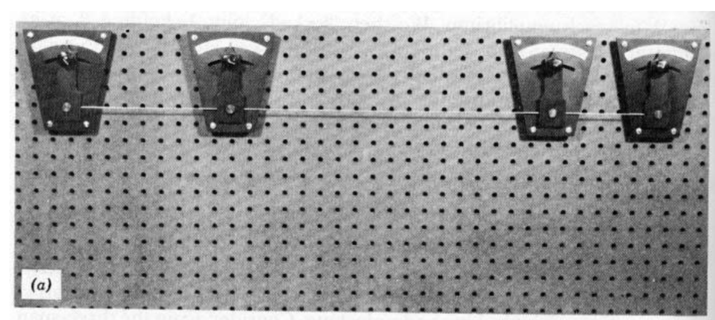
- *continuous slabs & beams with uniform loading*
  - *joints similar to fixed ends, but can rotate*
- *change in moment to center =* $\dfrac{wL^2}{8}$
  - *M_{max} for simply supported beam*





Moment Distribution Method (a)

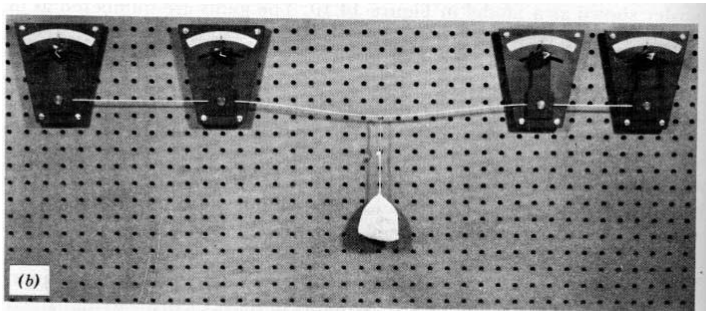
- *no load*



http://nisee.berkeley.edu/godden

Moment Distribution Method (b)

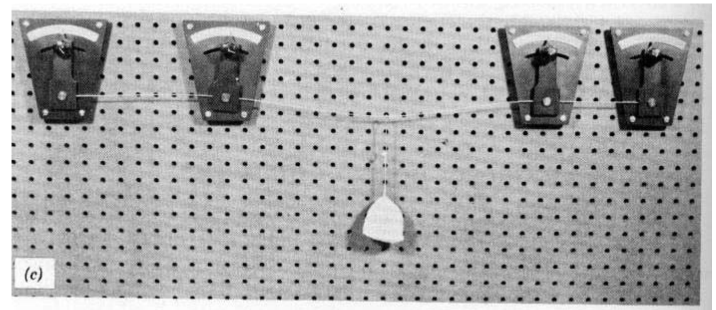
- *add load*



http://nisee.berkeley.edu/godden

Moment Distribution Method (c)

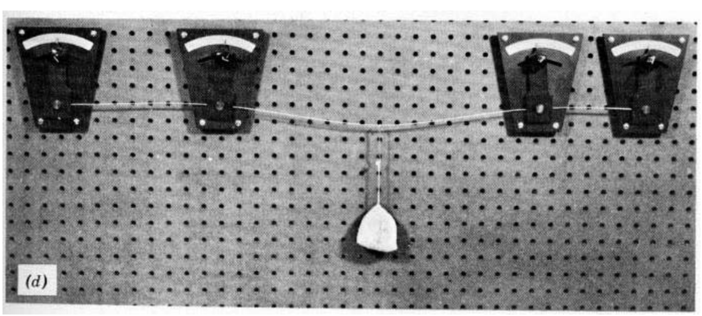
- *release joint 2*



http://nisee.berkeley.edu/godden

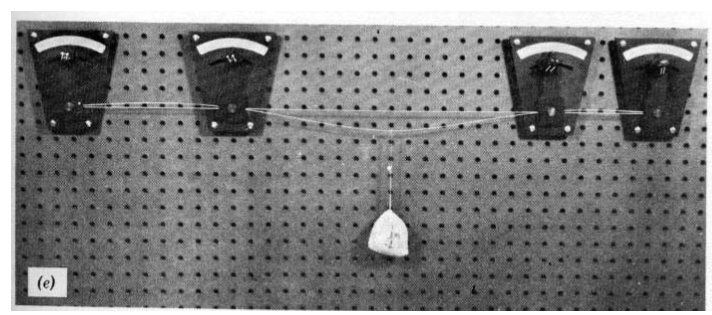
Moment Distribution Method (d)

- *release joint 3*



Moment Distribution Method (e)

- *exposure of final shape after cycles over initial shape*



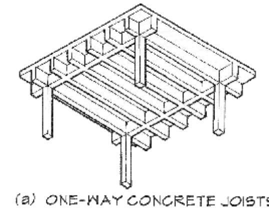
http://nisee.berkeley.edu/godden

Ribbed Plates

Walter P. Moore & Assoc.

Ribbed Plates

- typical in reinforced concrete
- pans can be standard or wide



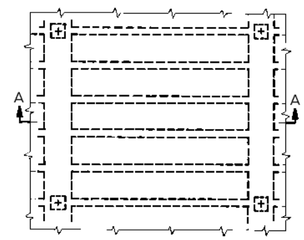
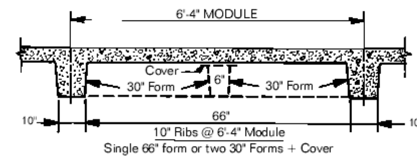
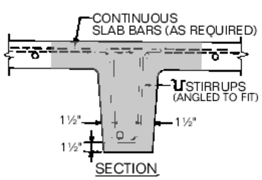


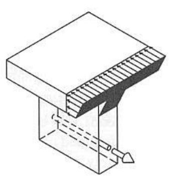
Figure 5 – Typical Wide-Module Joist Layout



Ribbed Plates

- design them as T-beams
  - flange compression
  - stem compression
- "effective" flange width





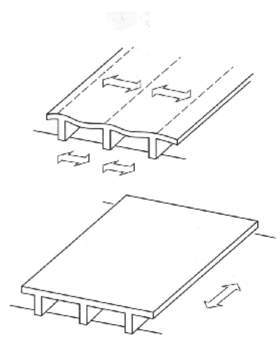


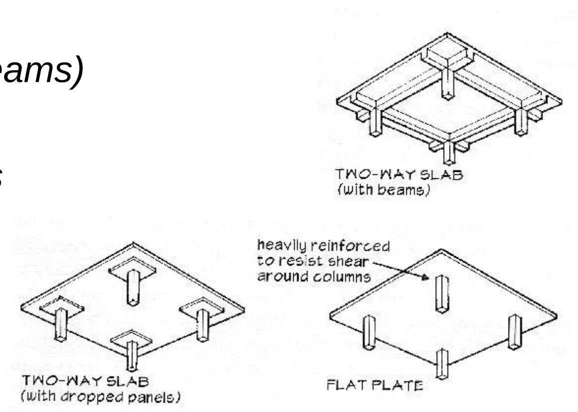
Plate Structures

- slabs & columns

http://nisee.berkeley.edu/godden

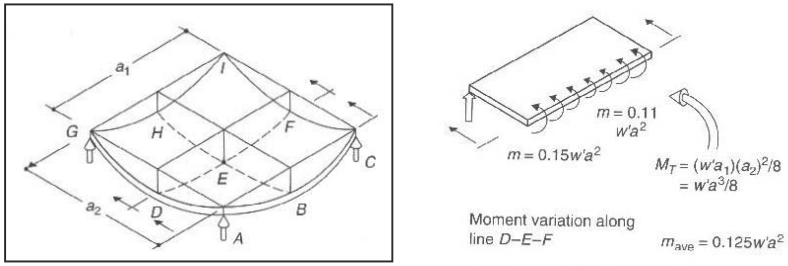
Two-Way Plates

- *support conditions*
  - *columns*
  - *flexible (beams)*
  - *simple*
  - *continuous*



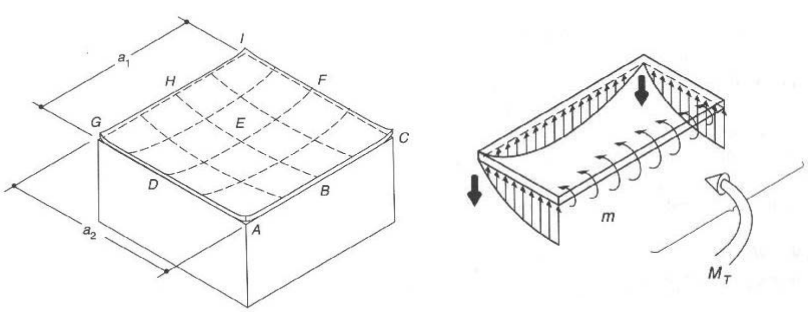
Two-Way Plates

- *supported by columns*
  - M_{max} *at midspan of edges*



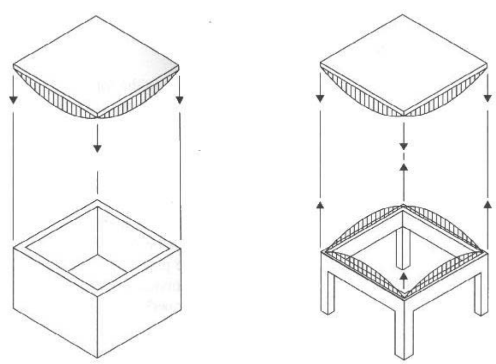
Two-Way Plates

- *simply supported*
  - *maximum curvature at midpoint of plate*



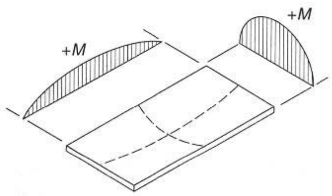
Two-Way Plates

- *beam vs. wall supports*
  - *stiffer supports, thinner slab*



Two-Way Plates

- *bay proportions*
  - *shorter side has bigger* $\frac{EI}{L}$
  - *ratio of longer side to shorter side > 1.5*
    - *acts like one-way plate*



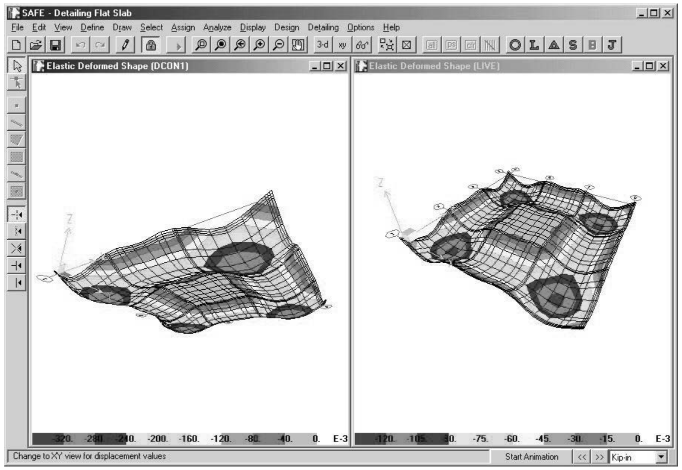
Two-Way Plates

- *moments found from tables or handbook solutions*
  - *depend on support conditions*

	Side Ratio a/b	Bending Moments $M_a = C_a\,wa^2$ C_a	$M_b = C_b\,wb^2$ C_b
Simply supported on all four sides	1.0	+0.0479	+0.0479
	2.0	+0.0116	+0.1017
Fixed edges on all four sides	1.0	+0.0231 −0.0513	+0.0231 −0.0513
	2.0	+0.0039 −0.0143	+0.0412 −0.0829
Free corner (corner balcony)	1.0	+0.027 −0.050	+0.027 −0.050

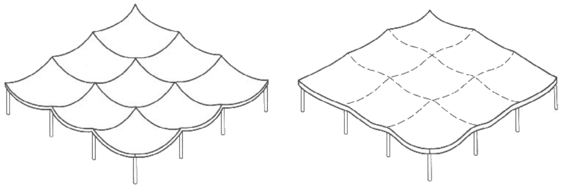
Two-Way Plates

- *other constraint conditions*



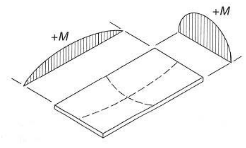
Design Considerations

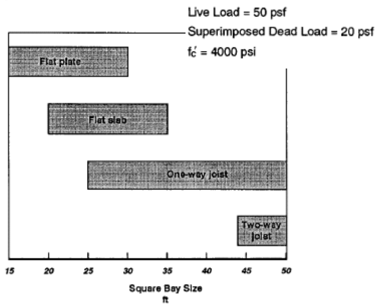
- *minimize bending (& depth)*
- *support conditions effective*
  - *continuous edge support preferred*
  - *fixed more than simple*
- *continuous surface*



Design Considerations (cont'd)

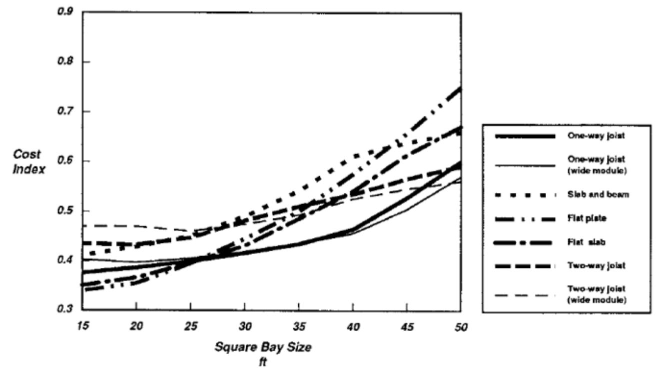
- *overhangs reverse curvature*
- *bay proportions*
  - *< 1:1.5*
- *load type*
  - *surface or point*
- *span range*
  - *rigid plates: 15'-60'*





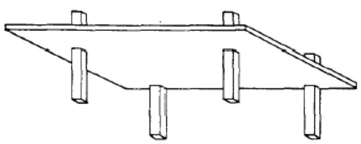
Reinforced Concrete Design

- *economical & common*
- *resist lateral loads*

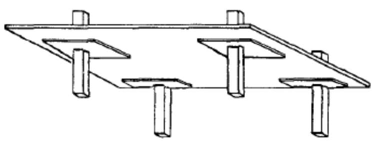


Reinforced Concrete Design

- *flat plate*
  - *5"-10" thick*
  - *simple formwork*
  - *lower story heights*

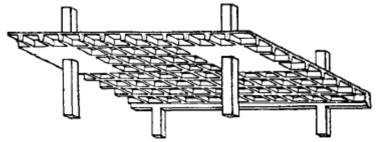


- *flat slab*
  - *same as plate*
  - *2 ¼" – 8" drop panels*

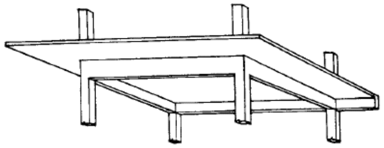


Reinforced Concrete Design

- *two-way joist*
  - *"waffle slab"*
  - *3"-5" slab*
  - *8"-24" stems*
  - *6"-8" webs*

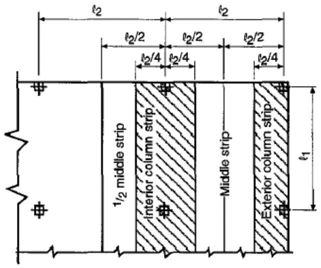


- *beam supported slab*
  - *5"-10" slabs*
  - *taller story heights*

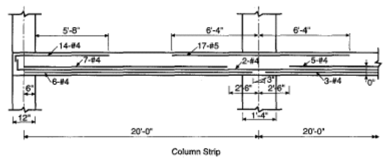


Reinforced Concrete Design

- *simplified frame analysis*
  - *strips, like continuous beams*
- *moments require flexural reinforcement*
  - *top & bottom*
  - *both directions of slab*
  - *continuous, bent or discontinuous*



(a) Column strip for $\ell_2 \le \ell_1$



Reinforced Concrete Design

- *one-way slabs (wide beam design)*
  - *approximate analysis for moment & shear coefficients*
  - *two or more spans*
  - *~ same lengths*
  - *w_u from combos*
  - *uniform loads with L/D $\le$ 3*
  - *ℓ_n is clear span (+M) or average of adjacent clear spans (-M)*

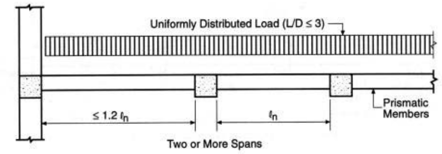


Figure 2-2 Conditions for Analysis by Coefficients (ACI 8.3.3)

Reinforced Concrete Design

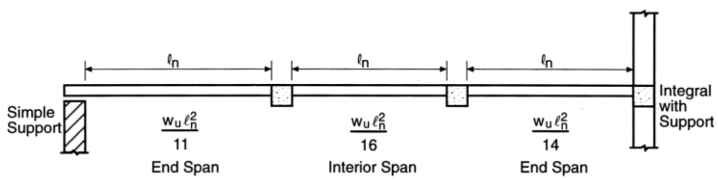


Figure 2-3 Positive Moments—All Cases

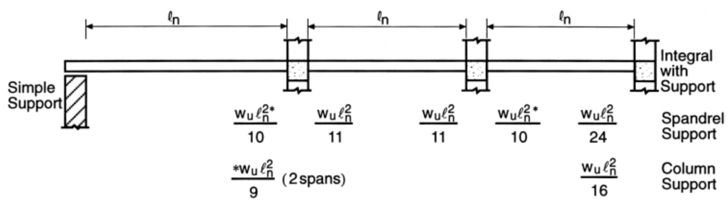
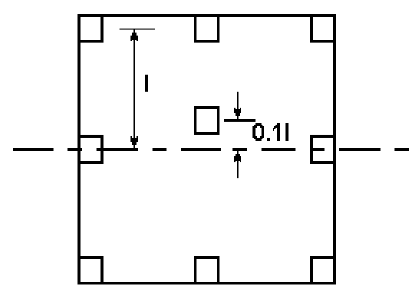


Figure 2-4 Negative Moments—Beams and Slabs

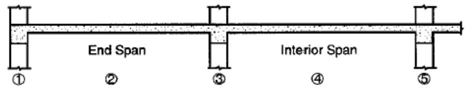
Reinforced Concrete Design

- *two-way slabs - Direct Design Method*
  - *3 or more spans each way*
  - *uniform loads with L/D $\le$ 3*
  - *rectangular panels with long/short span $\le$ 2*
  - *successive spans can't differ > longer/3*
  - *column offset no more than 10% span*



Reinforced Concrete Design

Table 4-6 Two-Way Beam-Supported Slab

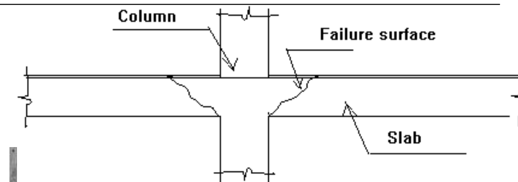


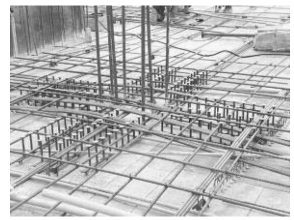
Span ratio	Slab Moments	End Span: 1 Exterior Negative	End Span: 2 Positive	End Span: 3 First Interior Negative	Interior Span: 4 Positive	Interior Span: 5 Interior Negative
ℓ_2/ℓ_1	Total Moment	$0.16\ M_o$	$0.57\ M_o$	$0.70\ M_o$	$0.35\ M_o$	$0.65\ M_o$
0.5	Column Strip Beam	$0.12\ M_o$	$0.43\ M_o$	$0.54\ M_o$	$0.27\ M_o$	$0.50\ M_o$
	Slab	$0.02\ M_o$	$0.08\ M_o$	$0.09\ M_o$	$0.05\ M_o$	$0.09\ M_o$
	Middle Strip	$0.02\ M_o$	$0.06\ M_o$	$0.07\ M_o$	$0.03\ M_o$	$0.06\ M_o$
1.0	Column Strip Beam	$0.10\ M_o$	$0.37\ M_o$	$0.45\ M_o$	$0.22\ M_o$	$0.42\ M_o$
	Slab	$0.02\ M_o$	$0.06\ M_o$	$0.08\ M_o$	$0.04\ M_o$	$0.07\ M_o$
	Middle Strip	$0.04\ M_o$	$0.14\ M_o$	$0.17\ M_o$	$0.09\ M_o$	$0.16\ M_o$
2.0	Column Strip Beam	$0.06\ M_o$	$0.22\ M_o$	$0.27\ M_o$	$0.14\ M_o$	$0.25\ M_o$
	Slab	$0.01\ M_o$	$0.04\ M_o$	$0.05\ M_o$	$0.02\ M_o$	$0.04\ M_o$
	Middle Strip	$0.09\ M_o$	$0.31\ M_o$	$0.38\ M_o$	$0.19\ M_o$	$0.36\ M_o$

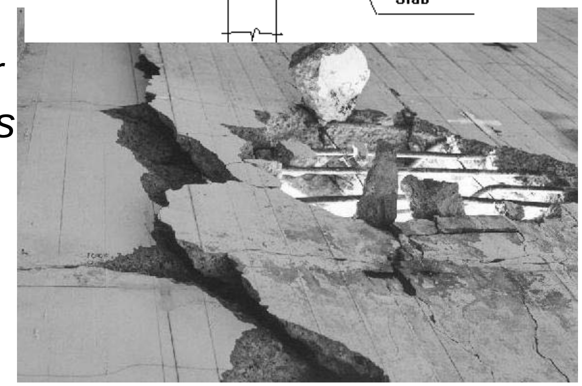
Notes: (1) Beams and slab satisfy stiffness criteria: $\alpha_1\ell_2/\ell_1 \ge 1.0$ and $\beta_t \ge 2.5$.
(2) Interpolate between values shown for different ℓ_2/ℓ_1 ratios.
(3) All negative moments are at face of support.
(4) Concentrated loads applied directly to beams must be accounted for separately.

Shear in Concrete

- *at columns*
- *want to avoid stirrups*
- *can use shear studs or heads*

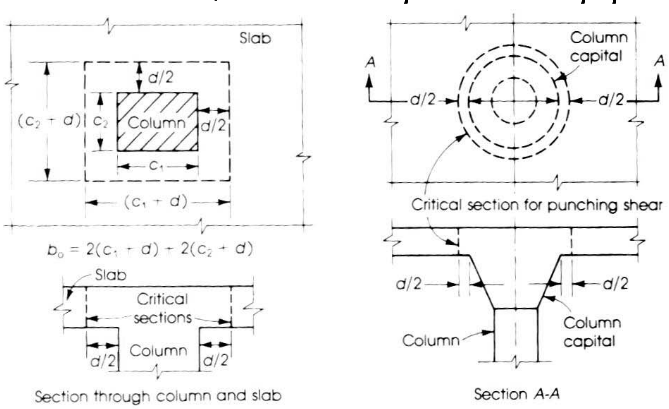






Shear in Concrete

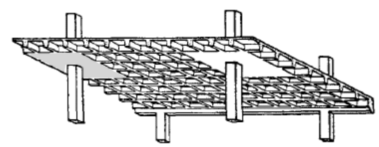
- *critical section at d/2 from*
  - *column face, column capital or drop panel*

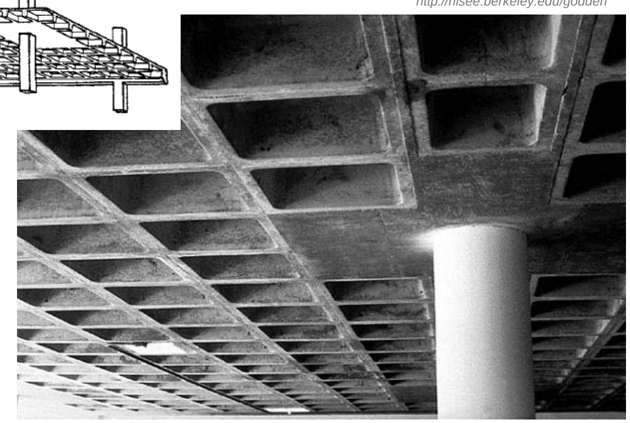


Shear in Concrete

- *at columns with waffle slabs*

http://nisee.berkeley.edu/godden





Openings in Slabs

- careful placement of holes
- shear strength reduced
- bending & deflection can increase

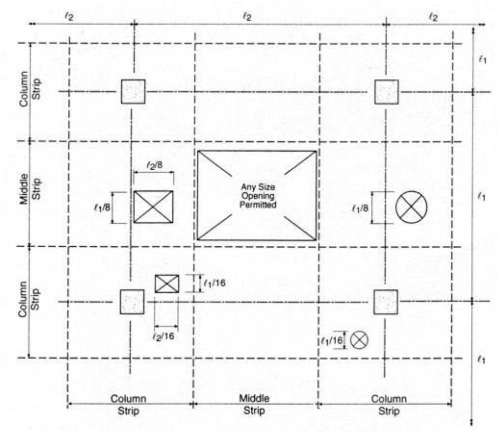
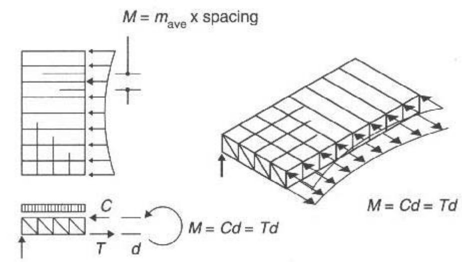


Figure 18-11 Openings in Slab Systems without Beams

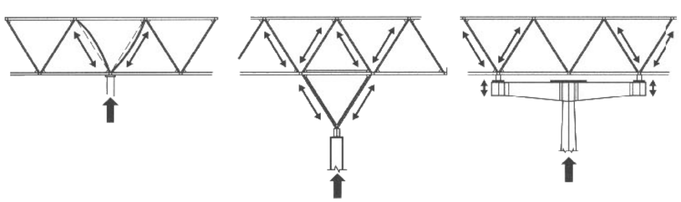
Space "Frame" Behavior

- handle uniformly distributed loads well
- bending moment
  - tension & compression "couple" with depth
  - member sizes can vary, but difficult



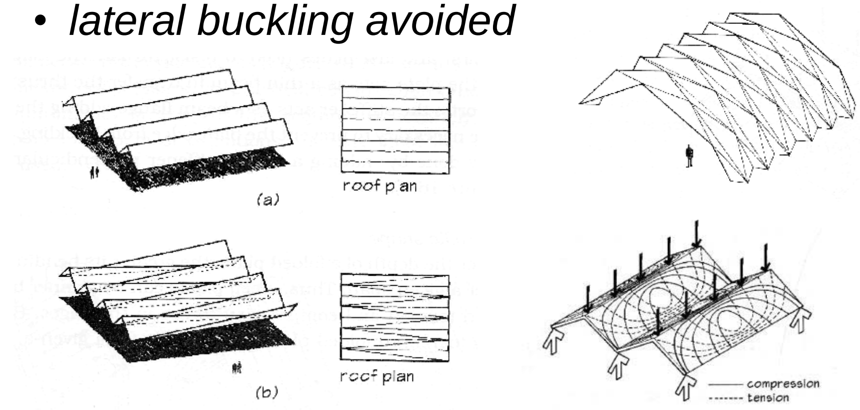
Space "Frame" Behavior

- shear at columns
- support conditions still important
  - point supports not optimal
- fabrication/construction can dominate design



Folded Plates

- increased bending stiffness with folding
- lateral buckling avoided



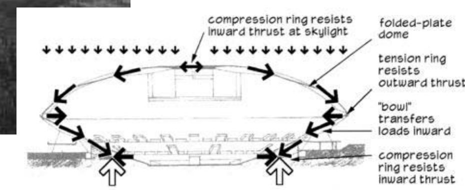
Folded Plates

- common for roofs
- edges need stiffening

http://nisee.berkeley.edu/godden

Folded Plates

www.library.illinois.edu



- State Farm Center, (Assembly Hall) University of Illinois
- Harrison & Abramovitz 1963
- Edge-supported dome spanning 400 feet wound with 614 miles of one-fifth inch steel wire