Elements of Architectural Structures: Form, Behavior, and Design

ARCH 614

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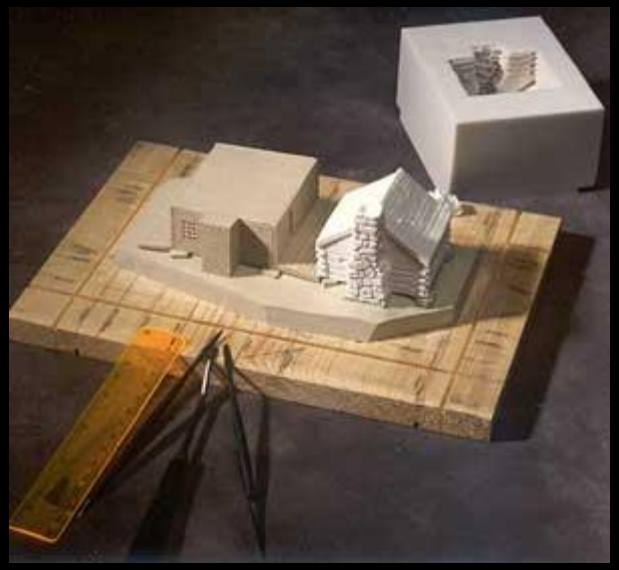
Spring 2014

lecture twelve



design methods, structural codes

Design

- *factors out of the designer's control*
  - *loads*
  - *occurrence*
- *factors within the designer's control*
  - *choice of material*
  - *"cost" of failure (F.S., probability, location)*
  - *economic design method*
  - *analysis method*

Design Methods

- *different approaches to meeting strength/safety requirements*
  - *allowable stress design (elastic)*
  - *ultimate strength design*
  - *limit state design*
  - *plastic design*
  - *load and resistance factor design*
- *assume a behavior at failure or other threshold and include a margin of safety*

Load Types

- *D = dead load*
- *L = live load*
- *L_r = live roof load*
- *W = wind load*
- *S = snow load*
- *E = earthquake load*
- *R = rainwater load or ice water load*
- *T = effect of material & temperature*
- *H = hydraulic loads from soil (F from fluids)*

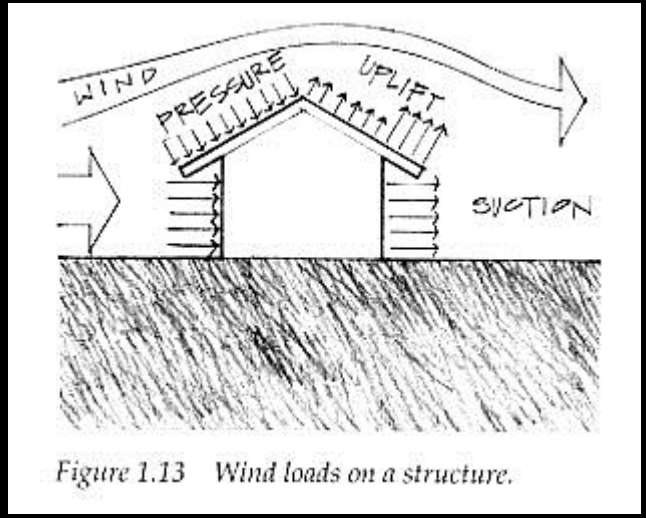


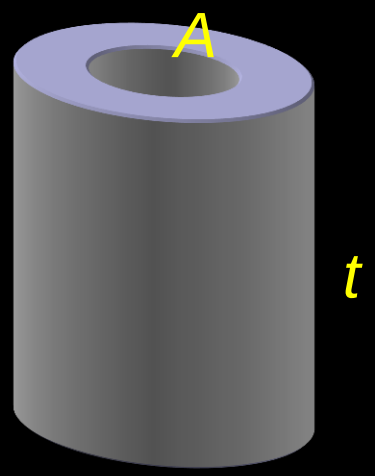
Figure 1.13 Wind loads on a structure.

Weight of Materials

- *for a volume*
  - $W = \gamma V$ *where* γ *is weight/volume*
  - $W = \gamma t A$ *for an extruded area with height of t*

TABLE 4.1 Weight of Building Construction

	psf[a]	kPa[a]
Roofs		
3-ply ready roofing (roll, composition)	1	0.05
3-ply felt and gravel	5.5	0.26
5-ply felt and gravel	6.5	0.31
Shingles: Wood	2	0.10
Asphalt	2–3	0.10–0.15
Clay tile	9–12	0.43–0.58
Concrete tile	6–10	0.29–0.48
Slate, 3 in.	10	0.48



Building Codes

- *documentation*
  - *laws that deal with planning, design, construction, and use of buildings*
  - *regulate building construction for*
    - *fire, structural and health safety*
  - *cover all aspect of building design*
  - *references standards*
    - *acceptable minimum criteria*
    - *material & structural codes*

Building Codes

- occupancy
- construction types
- structural chapters
  - loads, tests, foundations
- structural materials, assemblies
  - roofs
  - concrete
  - masonry
  - steel

OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (lbs.)
1. Apartments (see residential)	—	—
2. Access floor systems		
Office use	50	2,000
Computer use	100	2,000
3. Armories and drill rooms	150	—
4. Assembly areas and theaters		
Fixed seats (fastened to floor)	60	
Lobbies	100	
Movable seats	100	—
Stages and platforms	125	
Follow spot, projections and control rooms	50	
Catwalks	40	

Prescribed Loads

- *ASCE-7*
  - *live load (not roof) reductions allowed*
- *International Building Code*
  - *occupancy*
  - *wind: pressure to static load*
  - *seismic: shear load function of mass and response to acceleration*
  - *fire resistance*

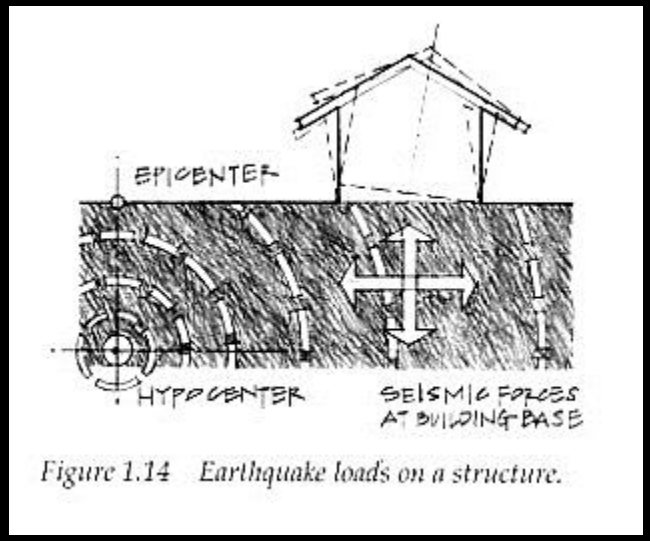


Figure 1.14 Earthquake loads on a structure.

Code Reduction of Live Loads

- for (ordinary) live loads
  - factored area supported ≥ 400 ft^2
  - reduction can't exceed
    - $0.5L_o$ (one floor) or $0.4L_o$ (more)

$$L = L_o\left(0.25 + \frac{15}{\sqrt{K_{LL}A_T}}\right)$$

TABLE 1607.10.1
LIVE LOAD ELEMENT FACTOR, K_{LL}

ELEMENT	K_{LL}
Interior columns	4
Exterior columns without cantilever slabs	4
Edge columns with cantilever slabs	3
Corner columns with cantilever slabs	2
Edge beams without cantilever slabs	2
Interior beams	2
All other members not identified above including: Edge beams with cantilever slabs; Cantilever beams; One-way slabs; Two-way slabs; Members without provisions for continuous shear transfer normal to their span	1

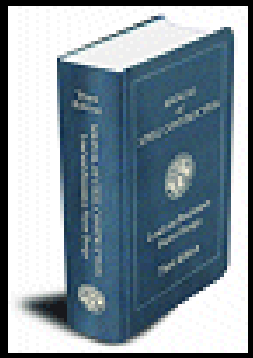
- for live loads > 100 lb/ft^2
  - live load reduction of 20% on columns
- for (ordinary) roofs: $L_r = L_o R_1 R_2$
  - 12 lb/ft^2 $\leq L_r \leq$ 20 lb/ft^2

Structural Codes

- *prescribe loads and combinations*
- *prescribe design method*
- *prescribe stress and deflection limits*
- *backed by the profession*
- *may require design to meet performance standards*
- *related to material or function*

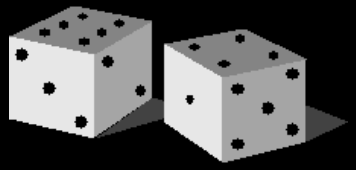
Structural Codes

- Design Codes
  - Wood
    - NDS
  - Steel
    - AISC
  - Concrete
    - ACI
    - AASHTO
  - Masonry
    - MSJC



Design Methods

- probability of loads and resistance
- material variability



- overload, fracture, fatigue, failure
- allowable stress design

$$f_{actual} = \frac{P}{A} \leq f_{allowed} = \frac{f_{capacity}}{F.S.}$$

- limit state design
  - design loads & capacities

Allowable Stress Design

- *historical method*
- *a.k.a. working stress, strength design*
- *stresses stay in ELASTIC range*

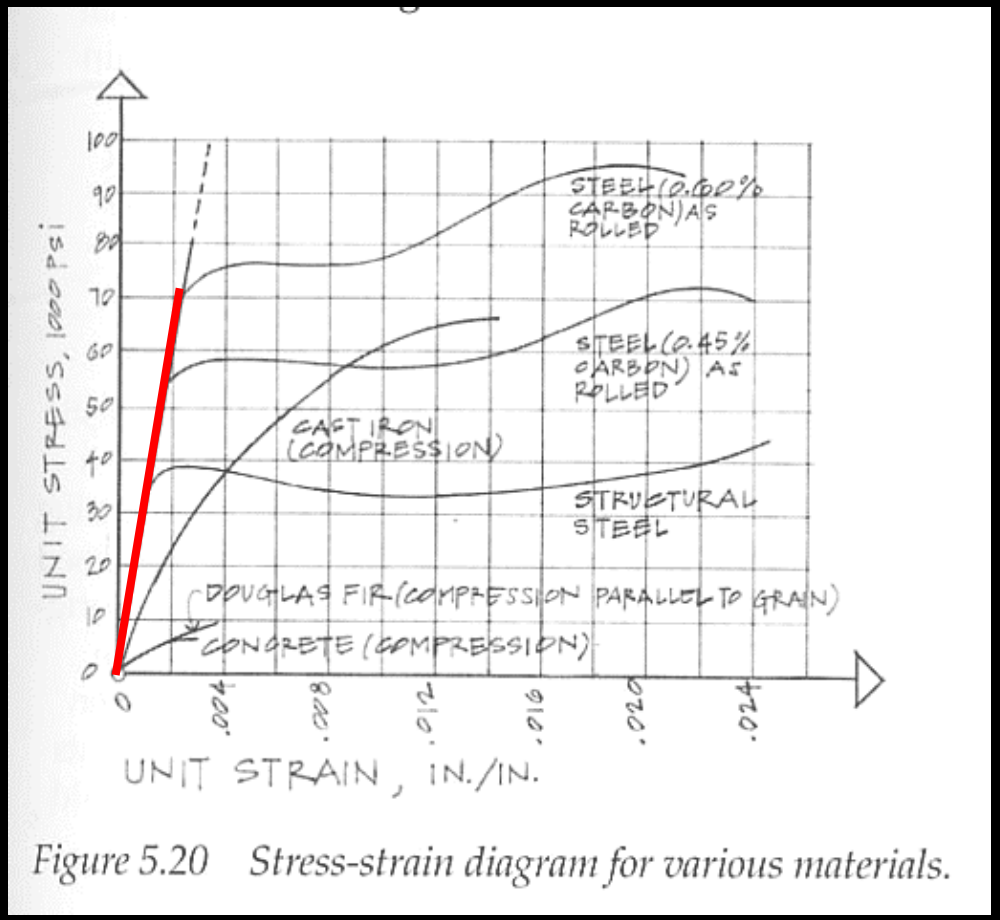


Figure 5.20 Stress-strain diagram for various materials.

ASD Load Combinations

ASCE-7 (2010)

- D
- D + L
- D + (L_r or S or R)
- D + 0.75L + 0.75(L_r or S or R)
- D + (0.6W or 0.7E)
- D + 0.75L + 0.75(0.6W or 0.7E) + (0.75L_r or S or R)
- 0.6D + (0.6W or 0.7E)

Limit State Design

- *a.k.a. strength design*
- *stresses go to limit (strain outside elastic range)*
- *loads may be factored*
- *resistance or capacity reduced by a factor*
- *based on material behavior*
- *“state of the art”*

Limit State Design

- load and resistance factor design (LRFD)
  - loads:
    - not constant,
    - possibly more influential on failure
    - happen more or less often
  - UNCERTAINTY

$$\gamma_D R_D + \gamma_L R_L \leq \phi R_n$$

ϕ - Resistance factor

γ - Load factor for (D)ead & (L)ive load

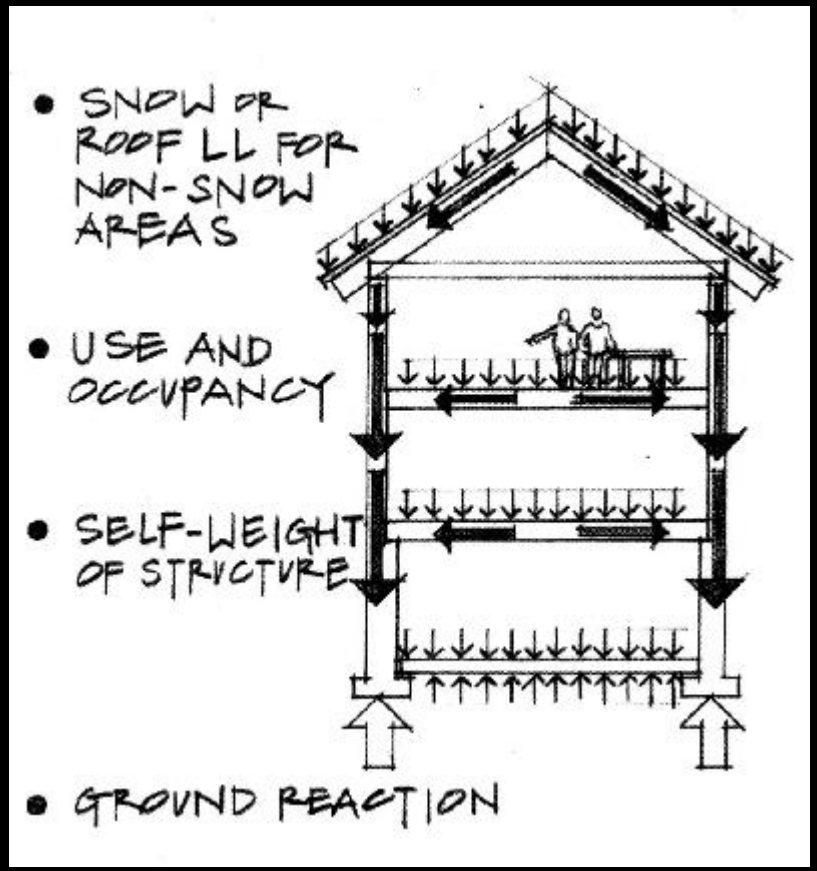
LRFD Load Combinations

ASCE-7 (2010)

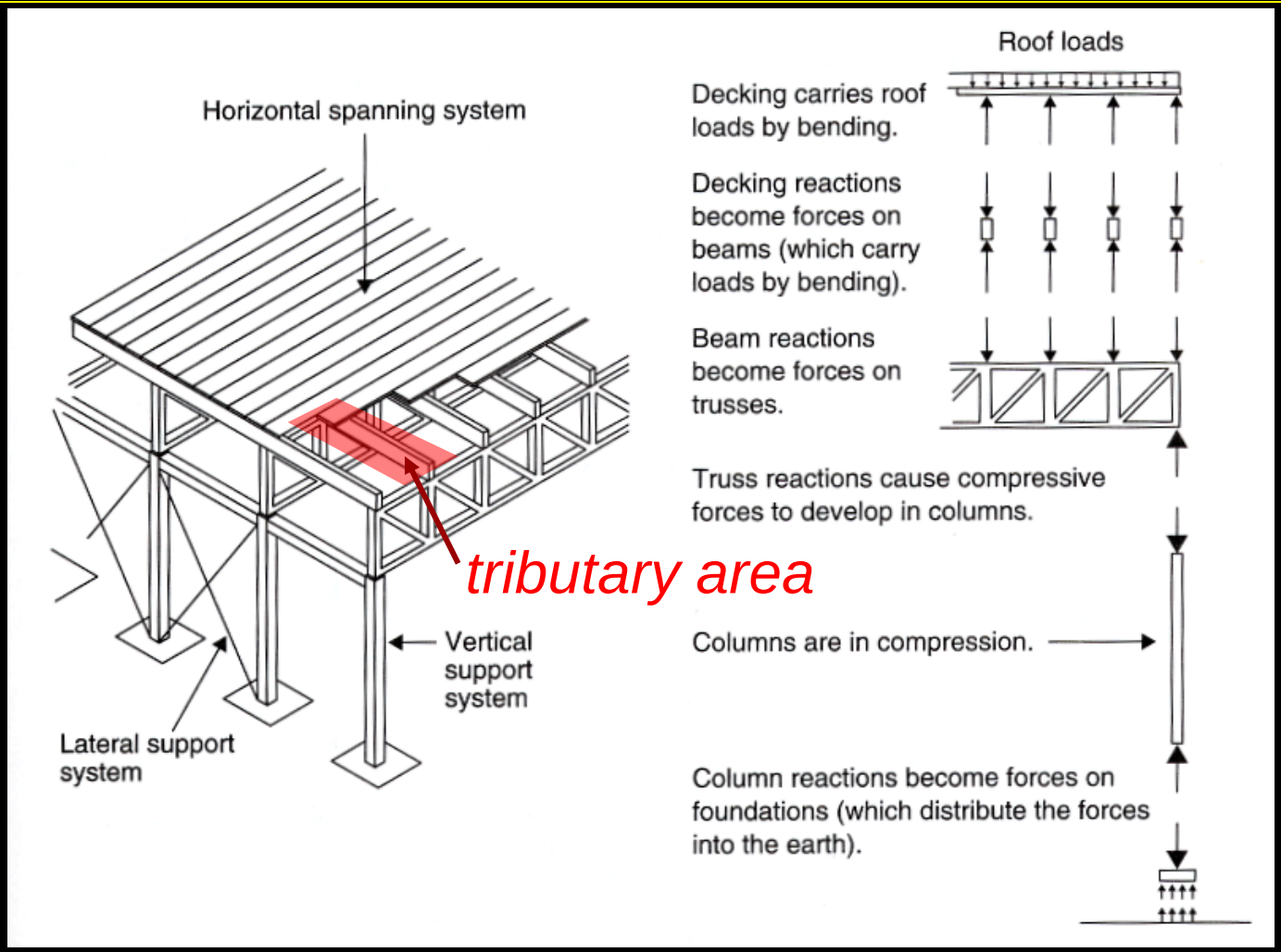
- 1.4D
- 1.2D + 1.6L + 0.5(L_r or S or R)
- 1.2D + 1.6(L_r or S or R) + (L or 0.5W)
- 1.2D + 1.0W + L + 0.5(L_r or S or R)
- 1.2D + 1.0E + L + 0.2S
- 0.9D + 1.0W
- 0.9D + 1.0E
  - F has same factor as D in 1-5 and 7
  - H adds with 1.6 and resists with 0.9 (permanent)

Load Tracing

- *how loads are transferred*
  - *usually starts at top*
  - *distributed by supports as <u>actions</u>*
  - *distributed by <u>tributary areas</u>*



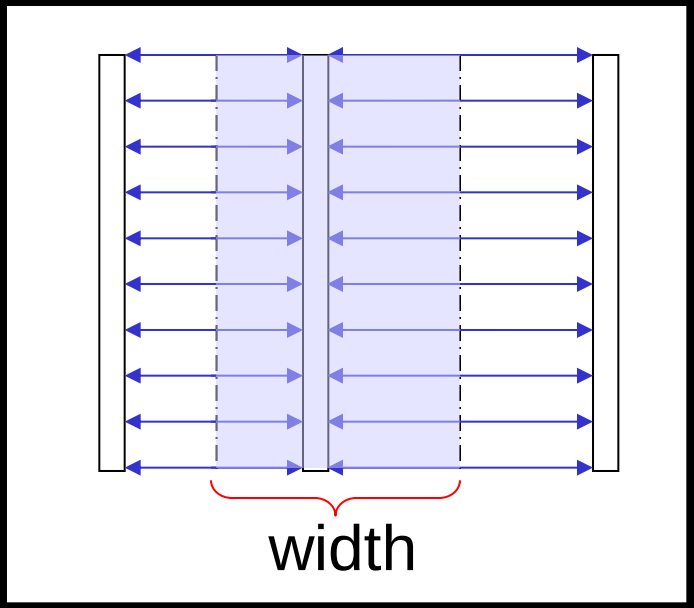
Load Tracing



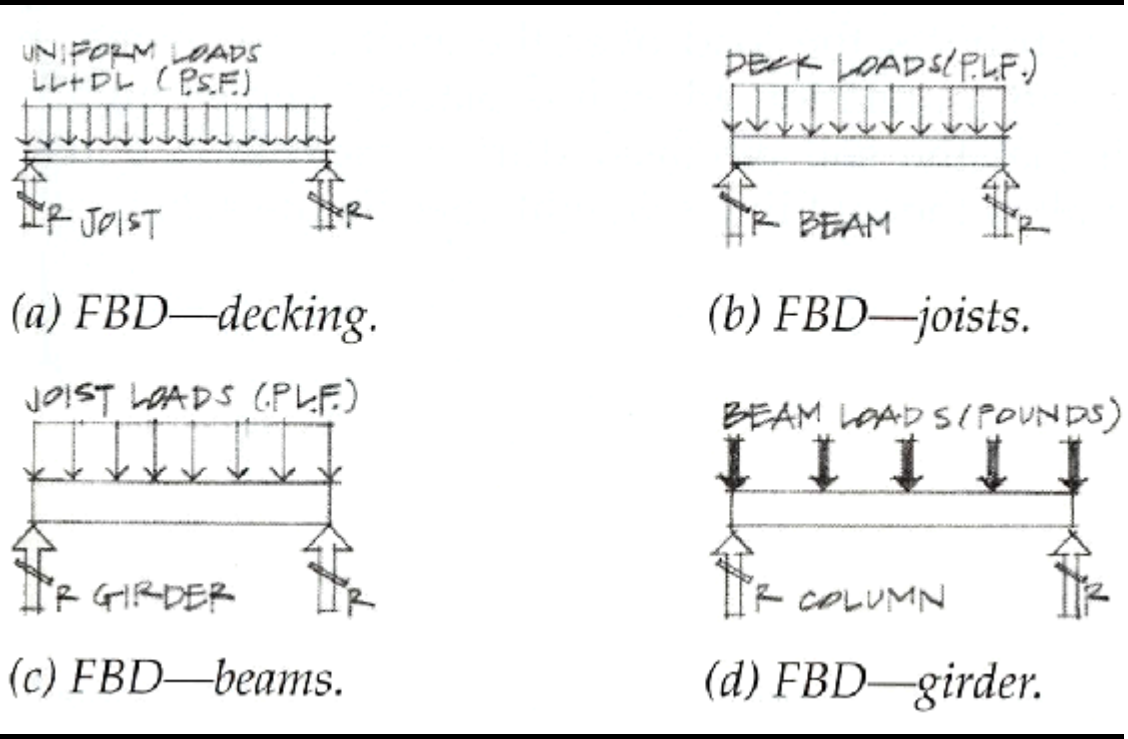
Load Tracing

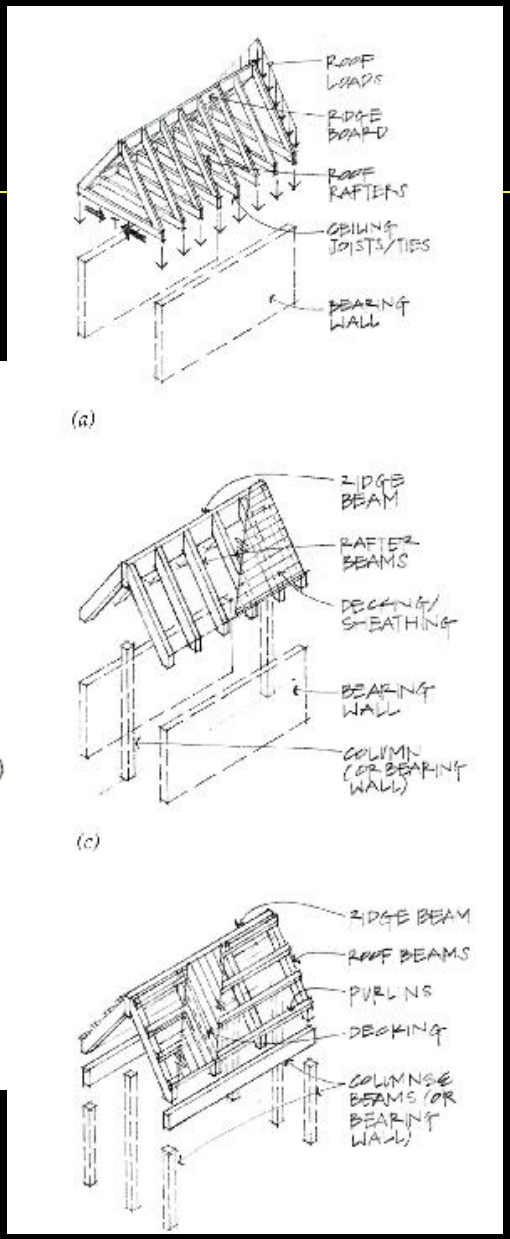
- *tributary load*
  - *think of water flow*
  - *"concentrates" load of area into center*

$$w = \left(\frac{load}{area} \right) \times (tributary\ width)$$



Load Paths


UNIFORM LOADS
LL+DL (PSF)
R JOIST R
(a) FBD—decking.
DECK LOADS (PLF)
R BEAM R
(b) FBD—joists.
JOIST LOADS (PLF)
R GIRDER R
(c) FBD—beams.
BEAM LOADS (POUNDS)
R COLUMN R
(d) FBD—girder.


ROOF LOADS
RIDGE BOARD
ROOF RAFTERS
CEILING JOISTS/TIES
BEARING WALL
(a)
RIDGE BEAM
RAFTER BEAMS
DECKING/ SHEATHING
BEARING WALL
COLUMN (OR BEARING WALL)
(c)
RIDGE BEAM
ROOF BEAMS
PURLINS
DECKING
COLUMNS/ BEAMS (OR BEARING WALL)

Load Paths

- *wall systems*

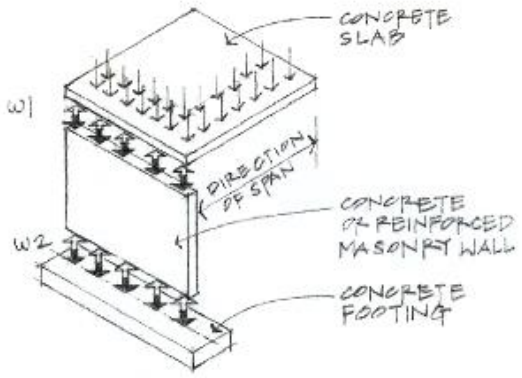


Figure 4.12 Uniform wall load from a slab.

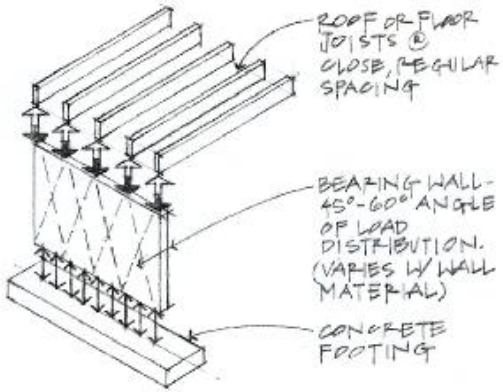


Figure 4.13 Uniform wall load from rafters and joists.

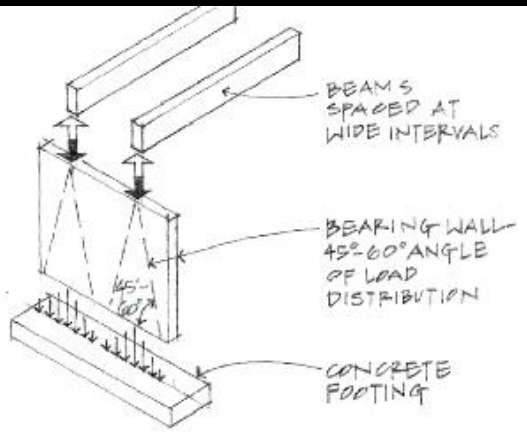


Figure 4.14 Concentrated loads from widely spaced beams.

Load Paths

- *openings & pilasters*

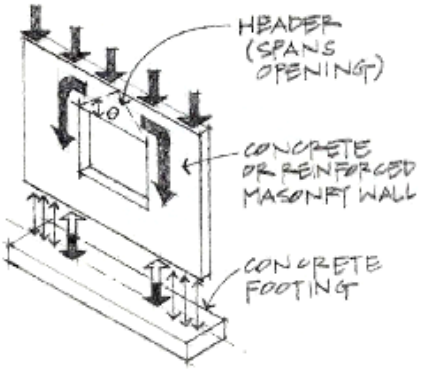


Figure 4.15 Arching over wall openings.

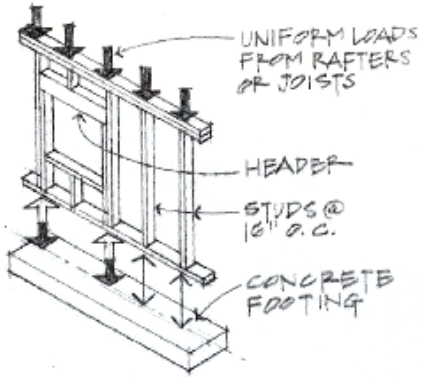


Figure 4.16 Stud wall with a window opening.

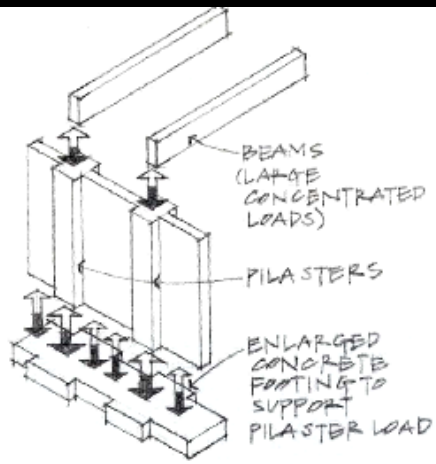


Figure 4.17 Pilasters supporting concentrated beam loads.

Load Paths

- *foundations*

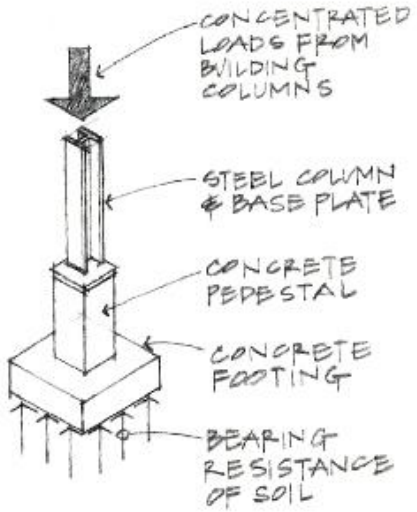


Figure 4.24 Spread footing.

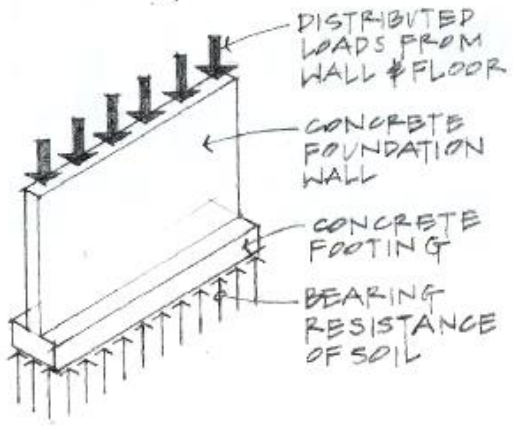


Figure 4.25 Wall footing.

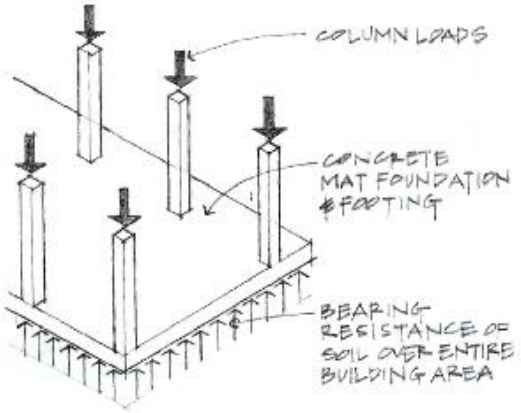


Figure 4.26 Mat or raft foundation.

Load Paths

- *deep foundations*

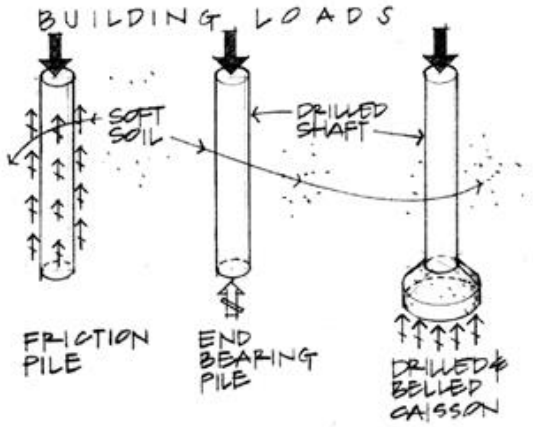


Figure 4.27 Pile foundations.

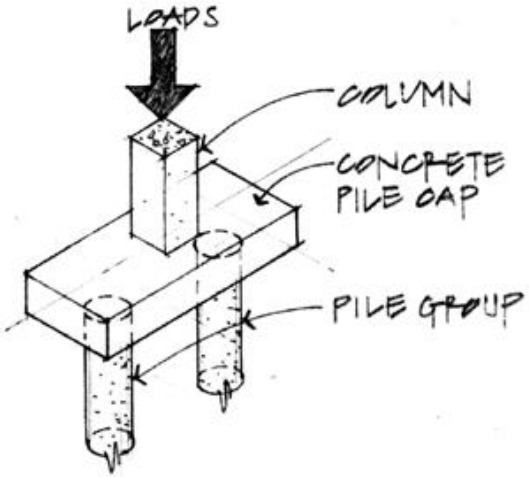


Figure 4.28 Pile cap on one pile group.

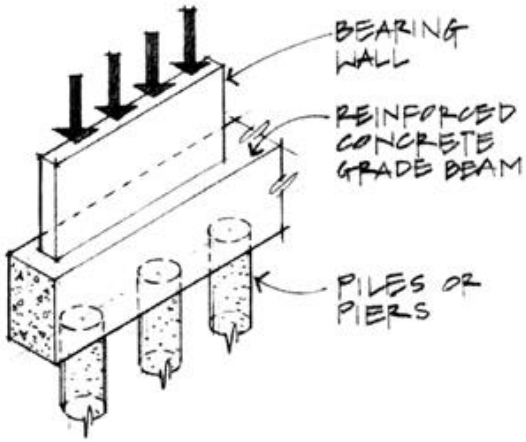


Figure 4.29 Grade beam supporting a bearing wall.