Architectural Structures: Form, Behavior, and Design

ARCH 331

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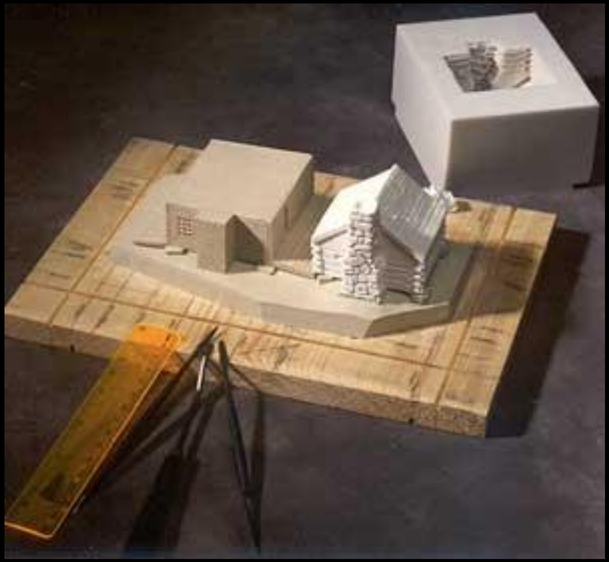
Fall 2013

lecture
thirteen



design loads & 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)

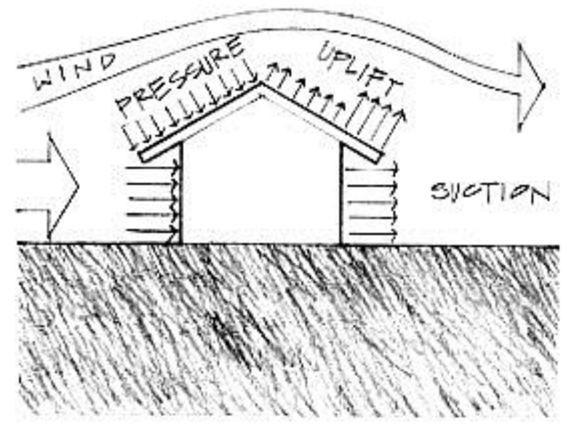
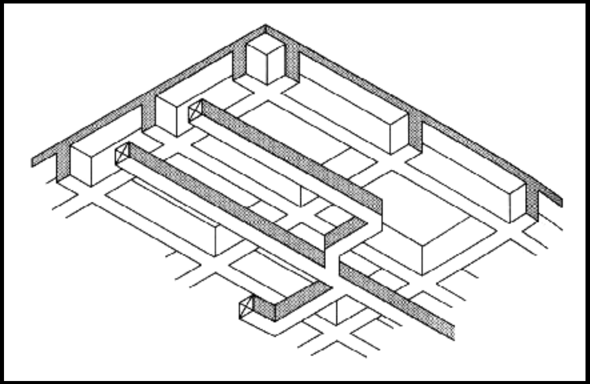


Figure 1.13 Wind loads on a structure.

Dead Loads

- *fixed elements*
  - *structure itself*
  - *internal partitions*
  - *hung ceilings*
  - *all internal and external finishes*
  - *HVAC ductwork and equipment*
  - *permanently mounted equipment*
- *F = mg (GRAVITY)*



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*

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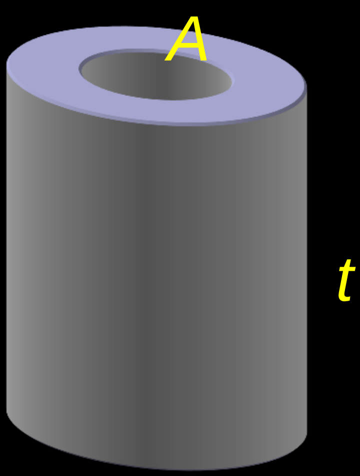
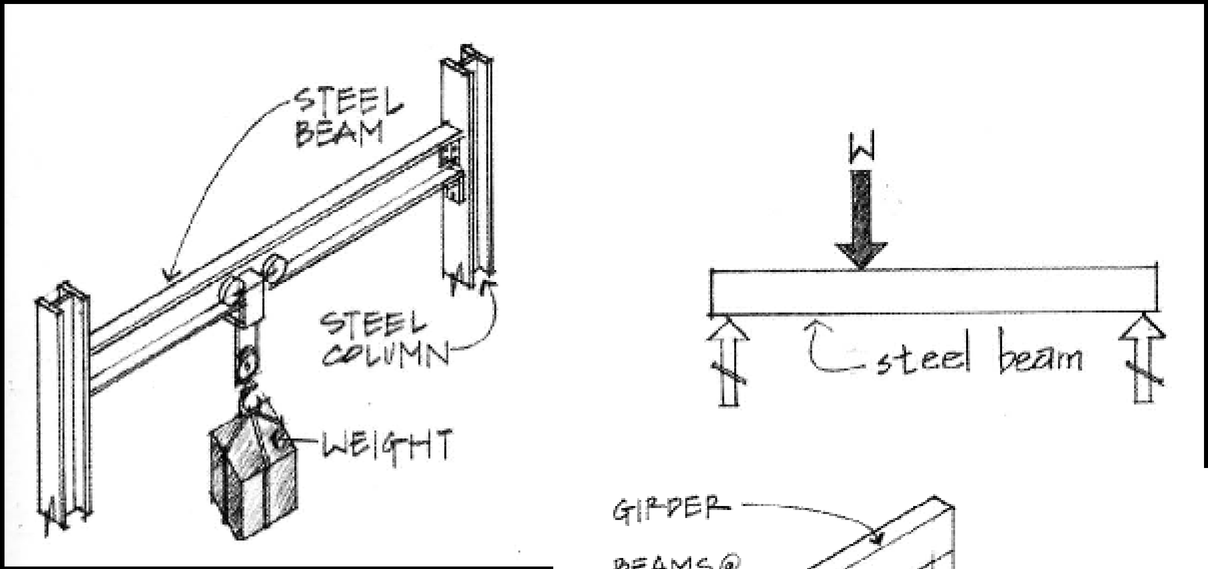
Table 5.1 Selected building material weights.

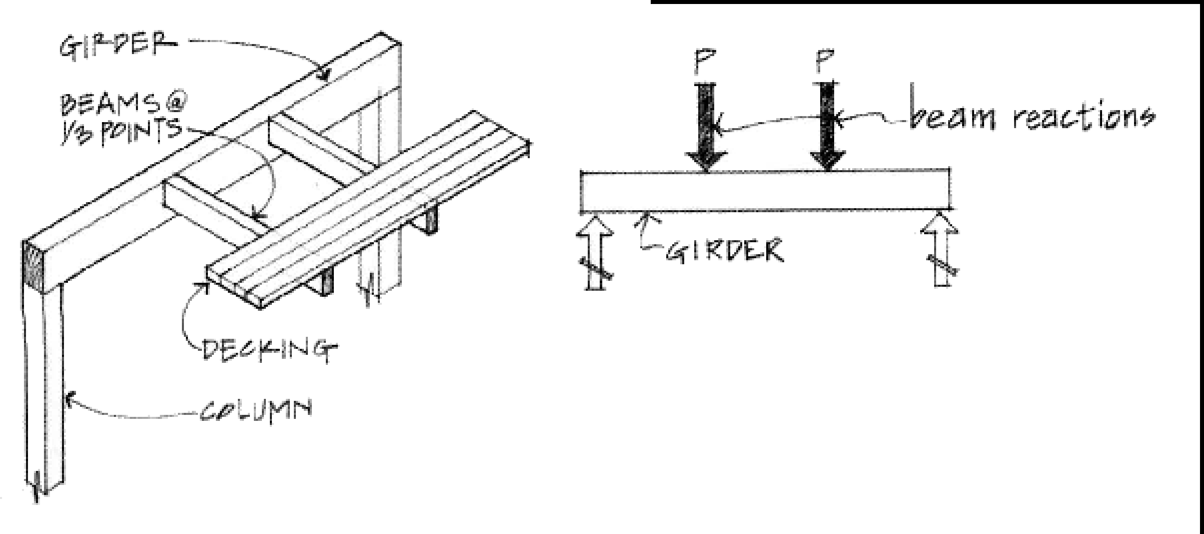
Assembly	lb./ft.²	kN/m²
Roofs:		
3-ply and gravel	5.5	0.26
5-ply and gravel	6.5	0.31
Wood shingles	2	0.10
Asphalt shingles	2	0.10
Corrugated metal	1–2.5	0.05–0.12
Plywood	3/inch	0.0057/mm
Insulation —fiberglass batt	0.5	0.0025
Insulation—rigid	1.5	0.075

Assembly	lb./ft.²	kN/m²
Floors:		
Concrete plank	6.5	0.31
Concrete slab	12.5/in.	0.59/mm
Steel decking w/concrete	35–45	1.68–2.16
Wood joists	2–3.5	0.10–0.17
Hardwood floors	4/in.	0.19/mm
Ceramic tile w/thin set	15	0.71
Lightweight concrete	8/in.	0.38/mm
Timber decking	2.5/in.	0.08/mm

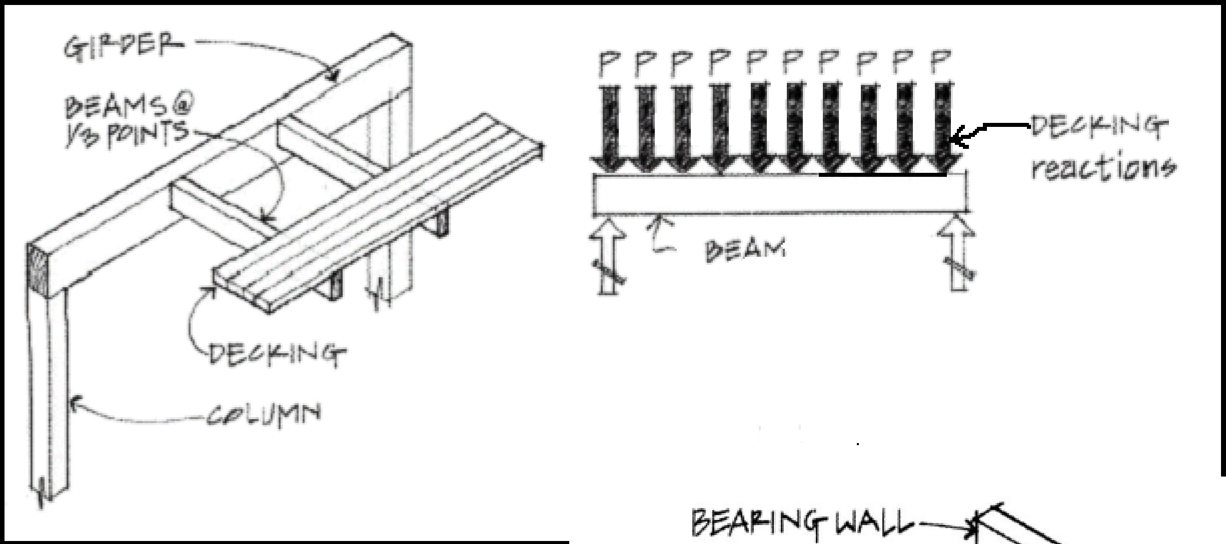


Concentrated Loads



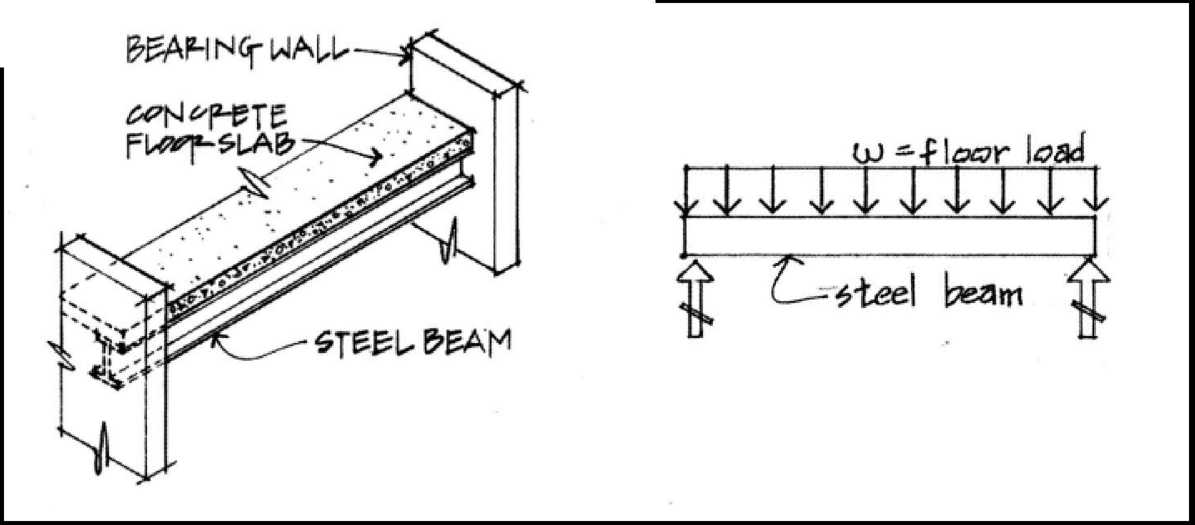


Distributed Loads



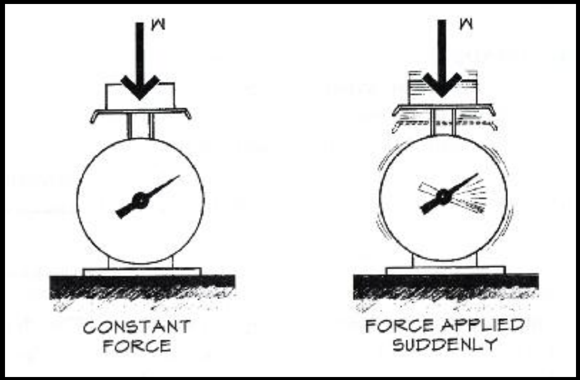
- *for an area*

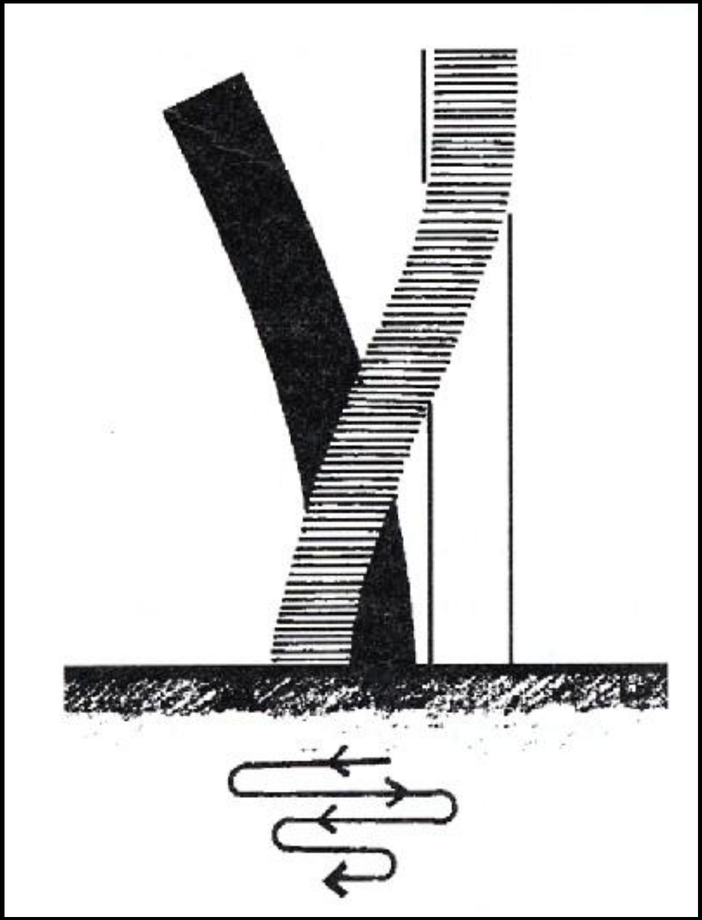
$$w = \gamma A$$



Dynamic Loads

- *time, velocity, acceleration*
- *kinetics*
  - *forces causing motion*
    $W = m \cdot g$
  - *work*
  - *conservation of energy*





Load Locations

- *centric*
- *eccentric*
- *bending or flexural load*
- *torsional load*
- *combined loading*

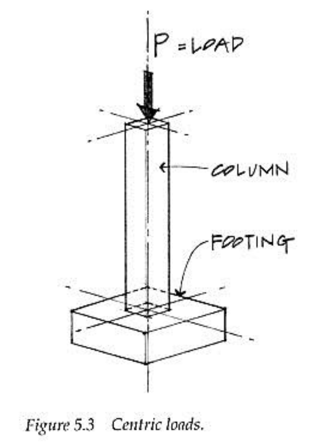
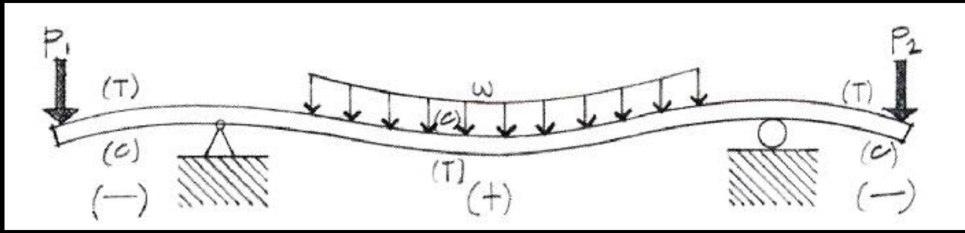
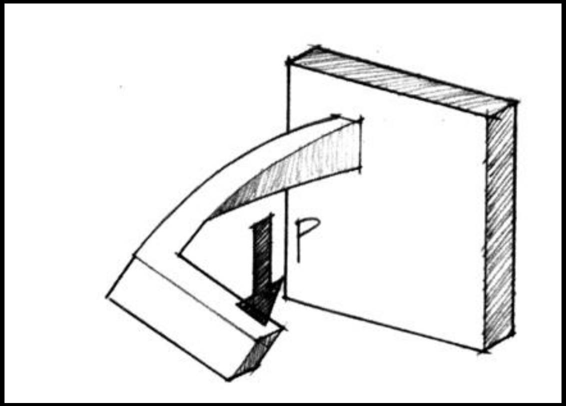


Figure 5.3 Centric loads.





Load Paths

- *tributary areas*
- *transfer*

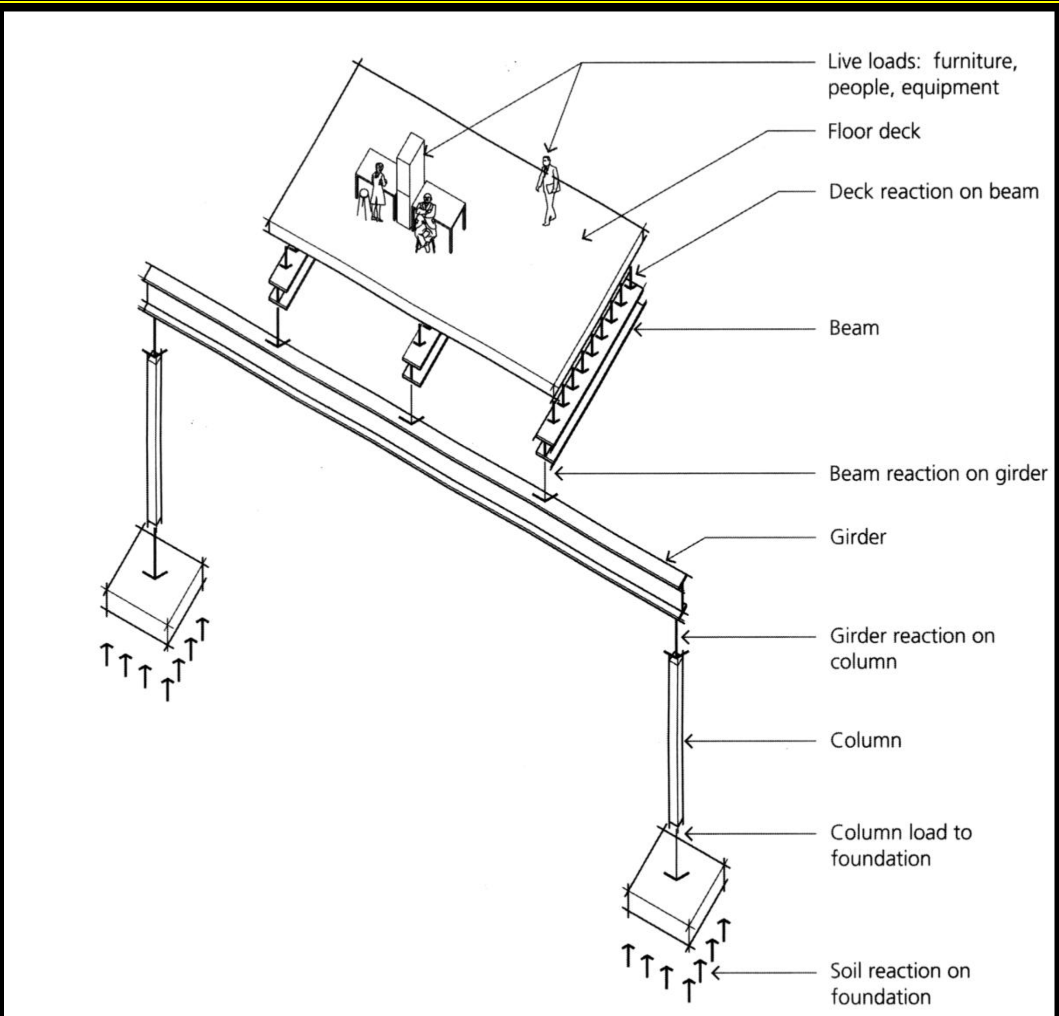
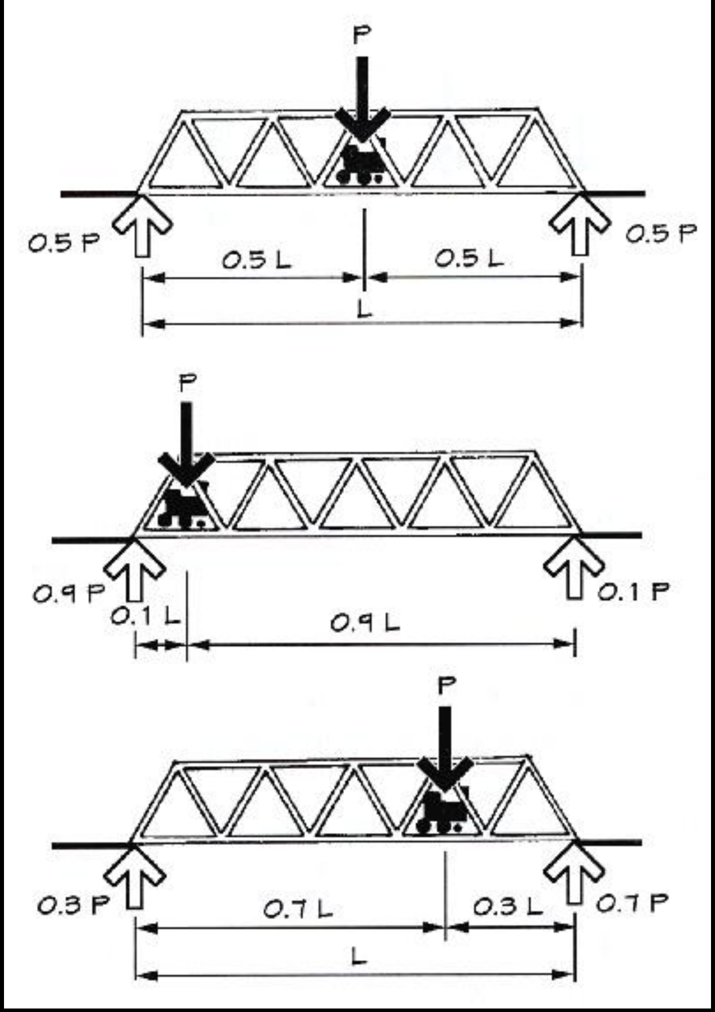


Fig. 1.3 Load paths through structures

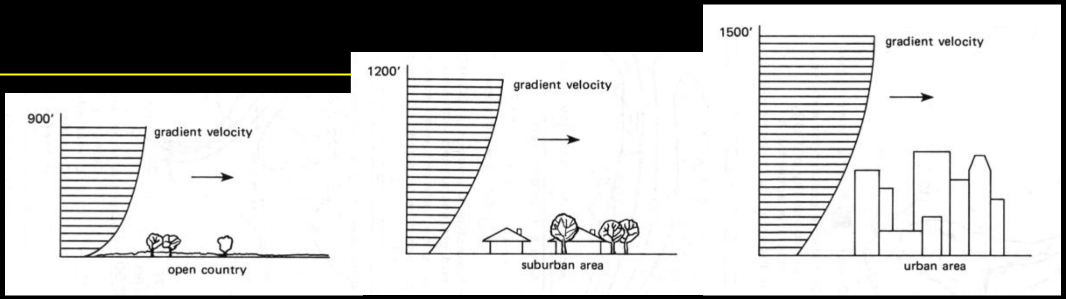
Live Loads

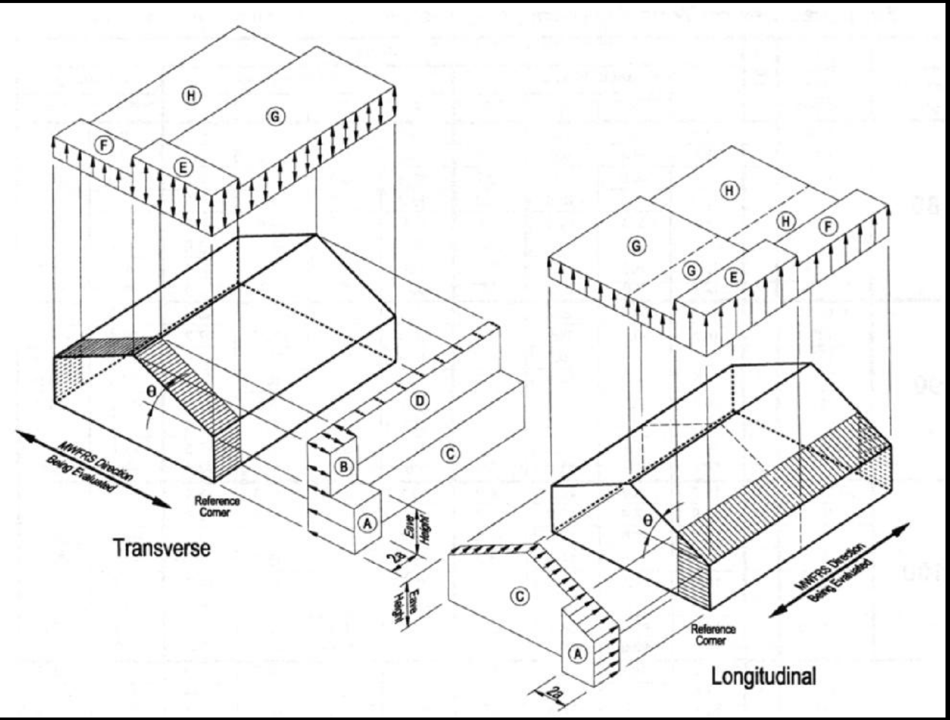
- occupancy
- movable furniture and equipment
- construction / roof traffic – L_r
- minimum values
- reduction allowed as area increases



Wind Load

- *wind speed*
- *gusting*
- *terrain*
- *windward, leeward, up and down!*
- *drag*
- *rocking*
- *harmonic*
- *torsion*





Snow Load

- *latitude*
- *solar exposure*
- *wind speed*
- *roof slope*

Moscow 2006 (BBC News)

Seismic Load

- *earthquake acceleration*
  - *F = ma*
  - *movement of ground (3D)*
  - *building mass responds*
  - *static models often used, V is static shear*
  - *building period, T ≈ 0.1N, determines C*
  - *building resistance – R_W*
  - *Z (zone), I (importance factor)*

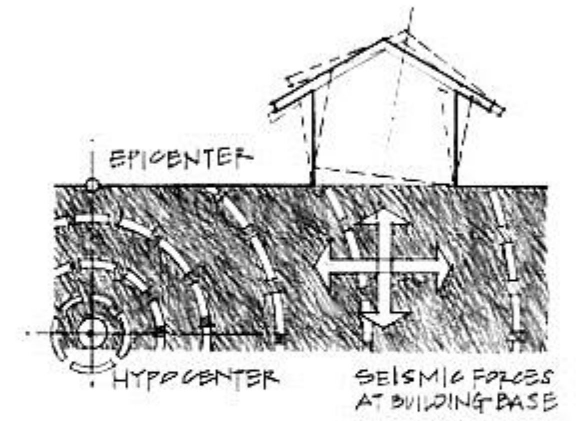
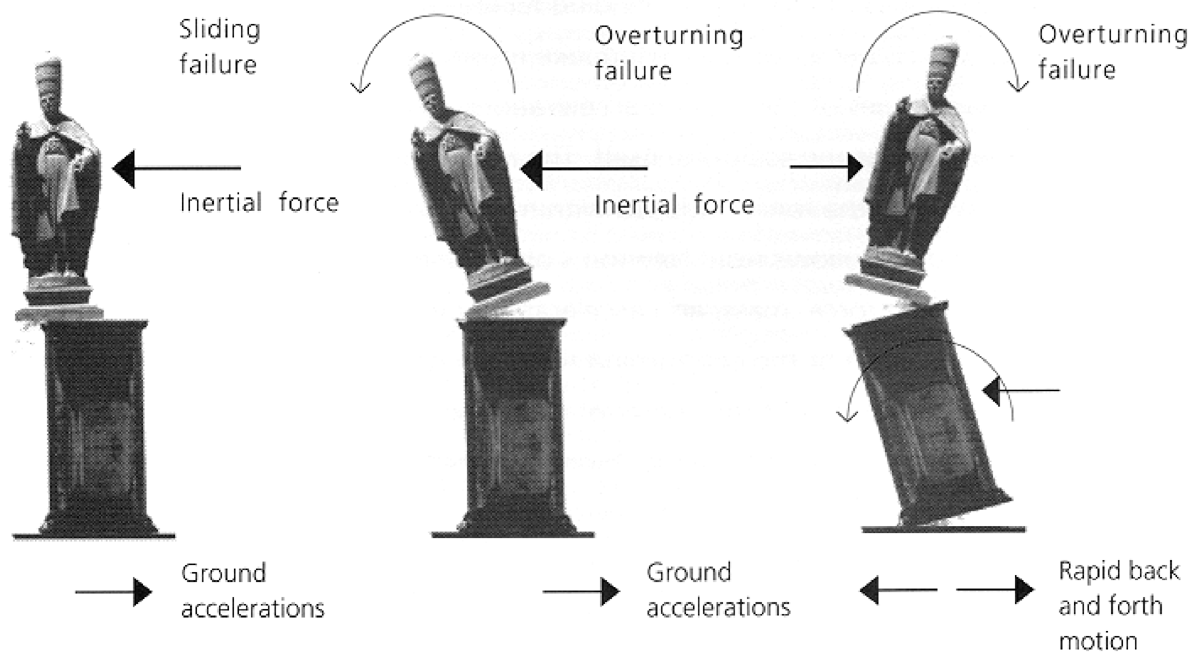


Figure 1.14 Earthquake loads on a structure.

$$V = \frac{ZICW}{R_W}$$

Dynamic Response

Statue in front of the cathedral of Palermo, Sicily



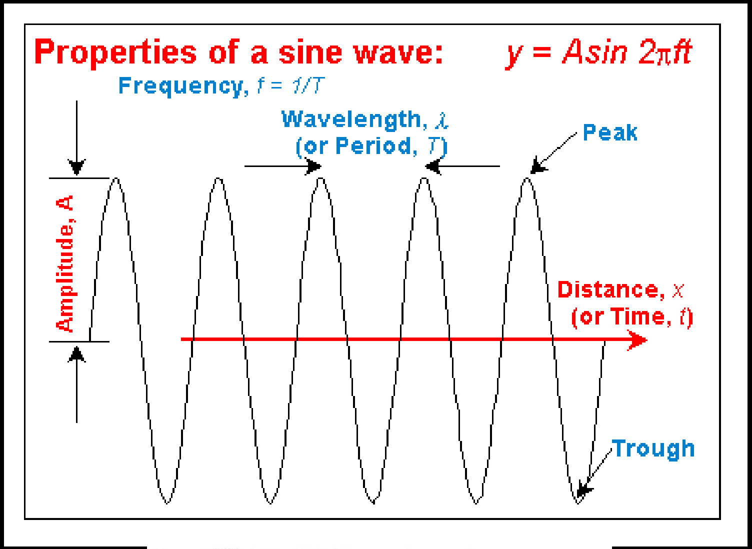
Lateral ground motions associated with earthquakes cause inertial forces to develop that are dependent on the weight of the structure. Sliding failures can occur.

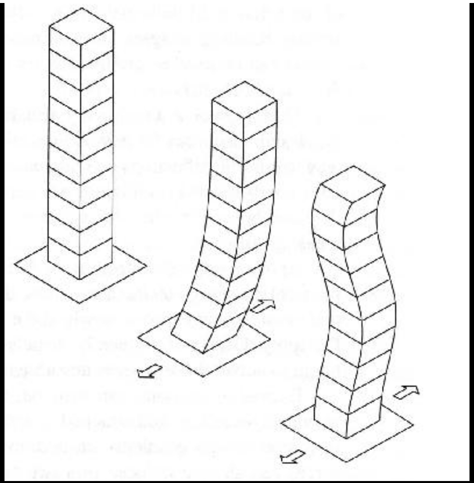
The lateral ground motions can also cause a sculpture to overturn. The magnitude of the overturning effect depends on the weight of the sculpture and its height above the ground.

Back and forth ground motions can cause different parts of the sculpture to move in different directions. Overturning or cracking of elements can consequently occur.

Dynamic Response

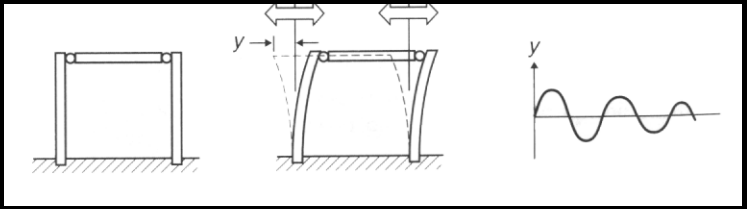
- period of vibration or frequency
  - wave
  - sway/time period
- damping
  - reduction in sway
- resonance
  - amplification of sway



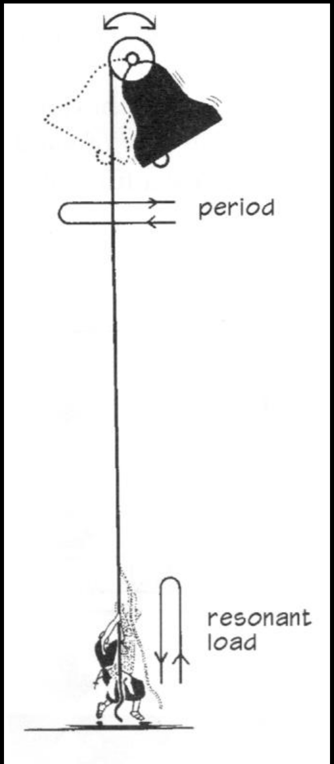


Frequency and Period

- *natural period of vibration*



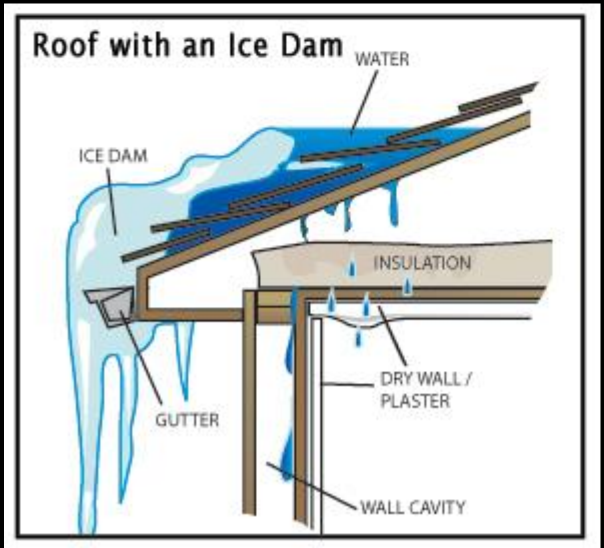
  - *avoid resonance*
  - *hard to predict seismic period*
  - *affected by soil*
  - *short period*
    - *high stiffness*
  - *long period*
    - *low stiffness*



"To ring the bell, the sexton must pull on the downswing of the bell in time with the natural frequency of the bell."

Water Load

- *rainwater – clogged drains*
- *ponding*
- *ice formation*



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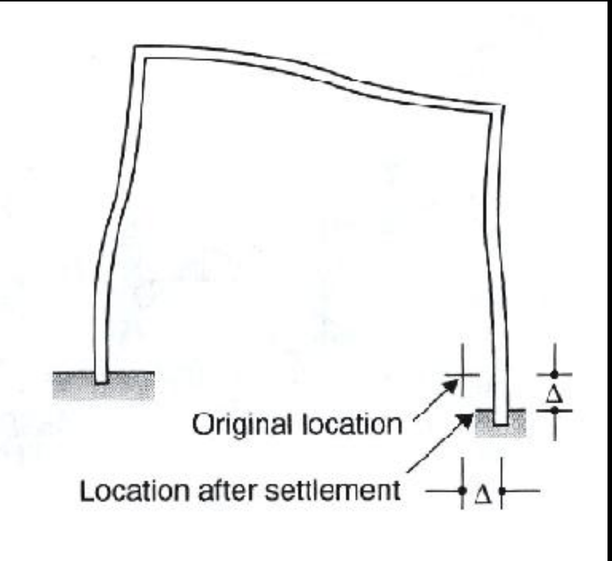
Thermal Load

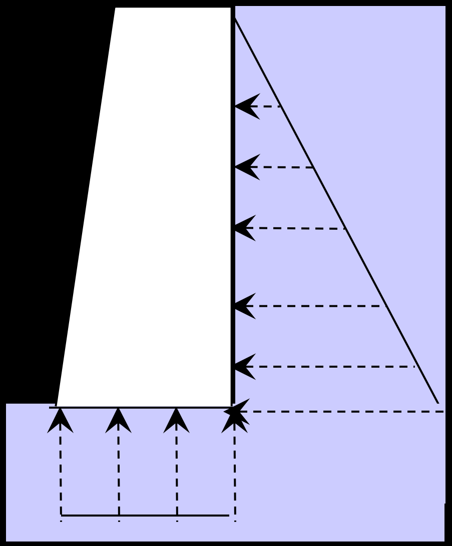
- *stress due to strain*
- *restrained expansion or contraction*
- *temperature gradients*
- *composite construction*



(a) Single-bay frame.

Hydraulic Loads

- pressure by water in soil, H
- fluid pressure, F
  - normal to surface
- flood



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

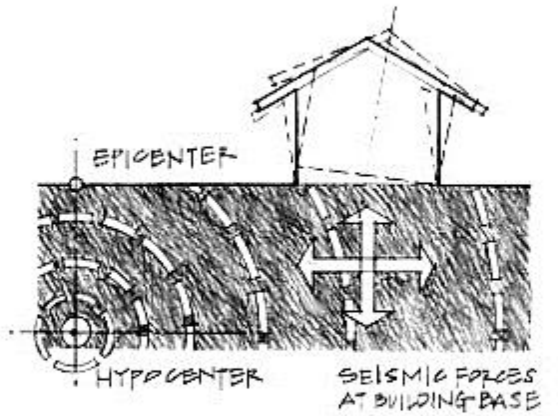


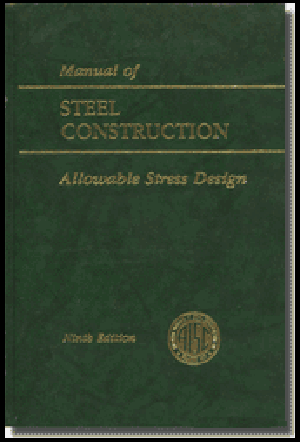
Figure 1.14 Earthquake loads on a structure.

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*

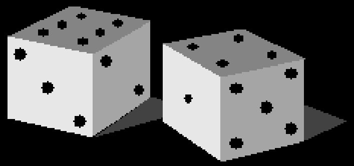
Structural Codes

- 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*

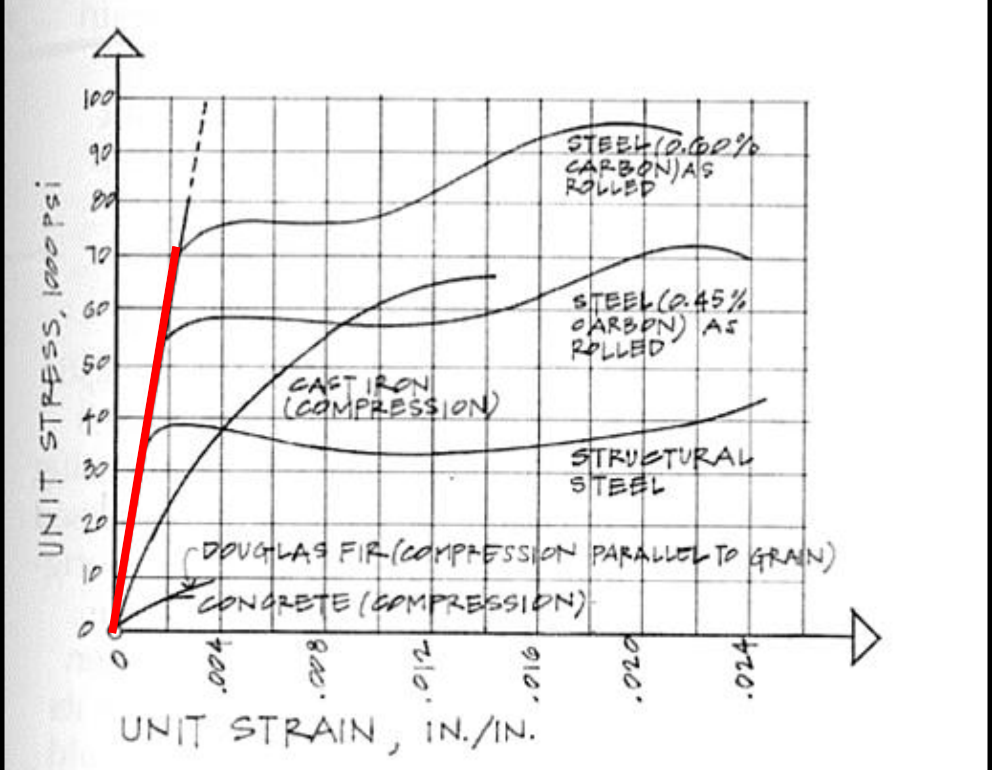


Figure 5.20 Stress-strain diagram for various materials.

ASD Load Combinations

ASCE-7 (2010)

- D
- $D + L$
- $D + 0.75(L_r \text{ or } S \text{ or } R)$
- $D + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$
- $D + (0.6W \text{ or } 0.7E)$
  - $D + 0.75L + 0.75(0.6W) + 0.75(L_r \text{ or } S \text{ or } R)$
  - $D + 0.75L + 0.75(0.7E) + 0.75S$
- $0.6D + 0.6W$
- $0.6D + 0.7E$

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)

Deflection Limits

- *based on service condition, severity*

Use	LL only	DL+LL
Roof beams:		
Industrial	L/180	L/120
Commercial		
plaster ceiling	L/240	L/180
no plaster	L/360	L/240
Floor beams:		
Ordinary Usage	L/360	L/240
Roof or floor (damageable elements)		L/480

Load Conditions

- loads, patterns & combinations
  - usually uniformly distributed gravity loads
  - worst case for largest moments...
  - wind direction can increase moments