ARE Structural Presentation Part 1

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DCI ENGINEERS

“When engineers and quantity surveyors discuss aesthetics and architects' study what cranes do we are on the right road.”

- OVE ARUP

Codes and Information

Design Codes

IBC: Chapters 16 – 21

ASCE 7 – Building Loads

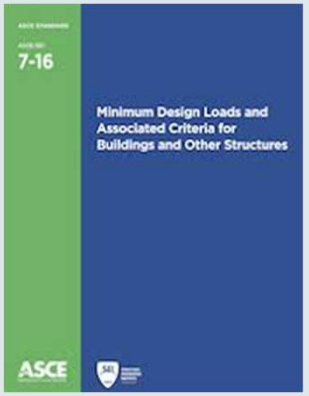
ACI 318 – Structural Concrete

MSJC – Structural Masonry

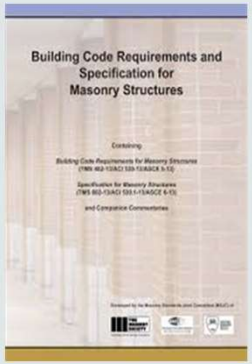
AISC Manual – Structural Steel

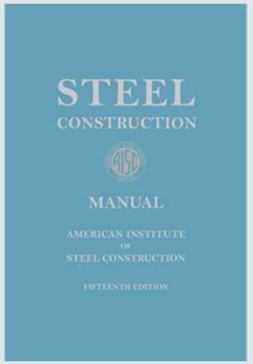
NDS – Structural Wood

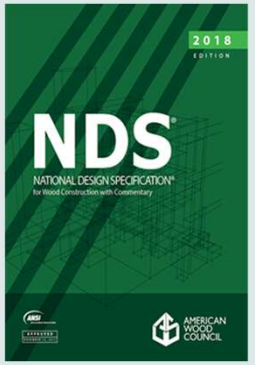
PRIMARY



DESIGN LOADS







MATERIAL DESIGN CODES

Prescriptive vs Analytic

Prescriptive

Using pre-defined processes, limits or standards to establish code compliance

Analytic

Using analysis pathways in accordance with defined criterion to establish code compliance

IBC Risk Category

Has impact to the minimum loading and design criteria required by the code.

- Category I – Low Hazard
- Category II – Typical Buildings
- Category III – Large & Special Occupancy Buildings
- Category IV – Essential Facilities

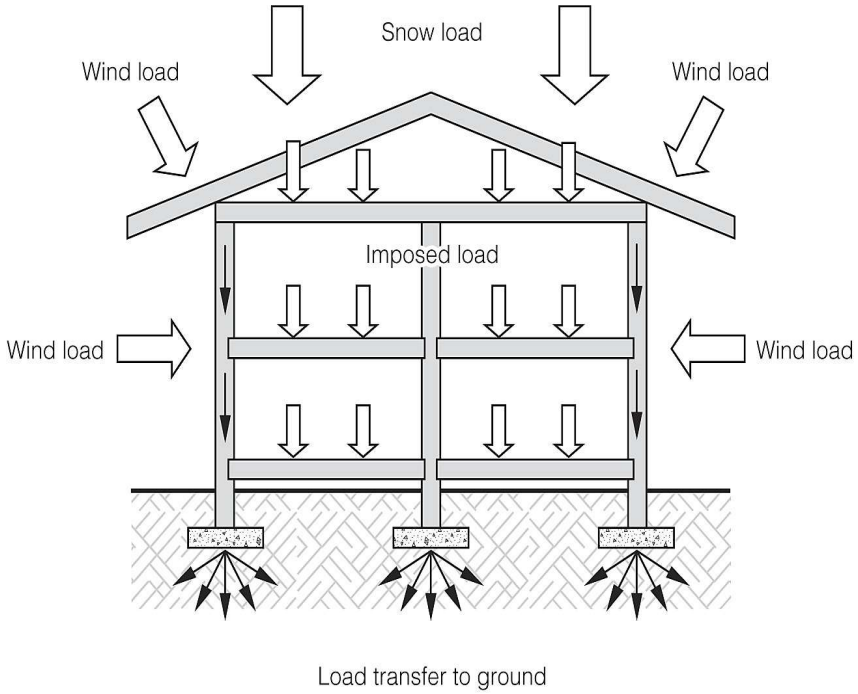
Table 1604.5

TABLE 1604.5
RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES

RISK CATEGORY	NATURE OF OCCUPANCY
I	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to: • Agricultural facilities. • Certain temporary facilities. • Minor storage facilities.
II	Buildings and other structures except those listed in Risk Categories I, III and IV.
III	Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: • Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures containing Group E occupancies with an occupant load greater than 250. • Buildings and other structures containing educational occupancies for students above the 12th grade with an occupant load greater than 500. • Group I-2, Condition 1 occupancies with 50 or more care recipients. • Group I-2, Condition 2 occupancies not having emergency surgery or emergency treatment facilities. • Group I-3 occupancies. • Any other occupancy with an occupant load greater than 5,000.[a] • Power-generating stations, water treatment facilities for potable water, wastewater treatment facilities and other public utility facilities not included in Risk Category IV. • Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and Are sufficient to pose a threat to the public if released.[b]
IV	Buildings and other structures designated as essential facilities, including but not limited to: • Group I-2, Condition 2 occupancies having emergency surgery or emergency treatment facilities. • Ambulatory care facilities having emergency surgery or emergency treatment facilities. • Fire, rescue, ambulance and police stations and emergency vehicle garages. • Designated earthquake, hurricane or other emergency shelters. • Designated emergency preparedness, communications and operations centers and other facilities required for emergency response. • Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures. • Buildings and other structures containing quantities of highly toxic materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and Are sufficient to pose a threat to the public if released.[b] • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.

Loads and Load Path

Load Path – The path a load or forces takes through the structural elements

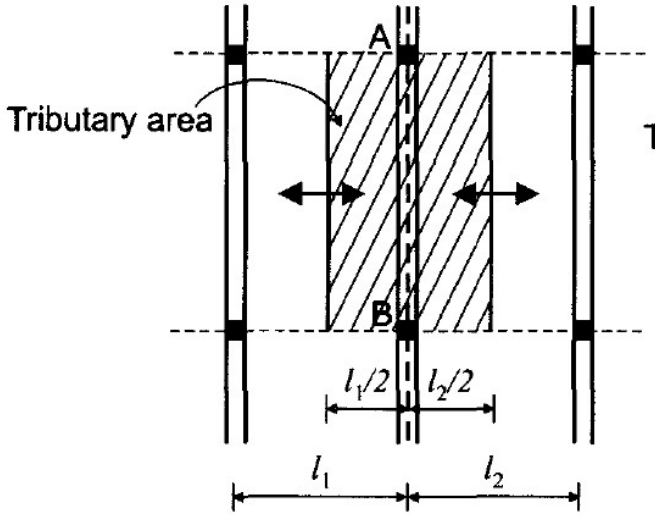


Load transfer to ground

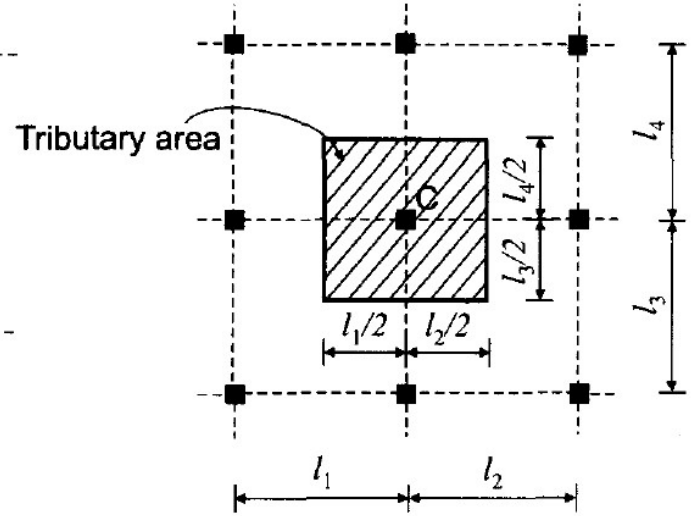
Load Distribution

One Way vs Two Way

Tributary Area



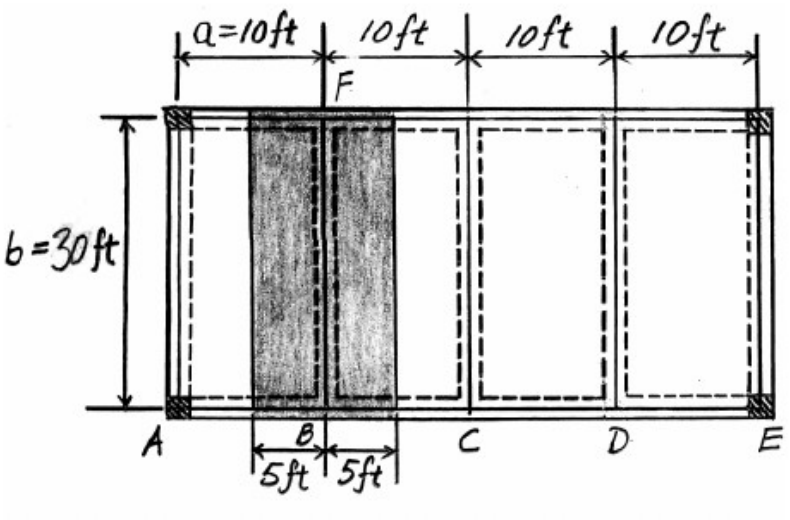
ONE WAY DISTRIBUTION



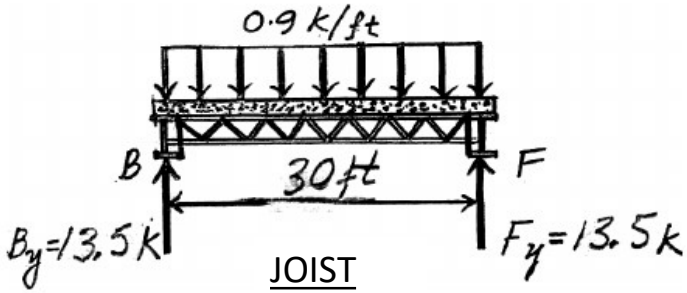
TWO WAY DISTRIBUTION

Floor Framing Example (1 Way)

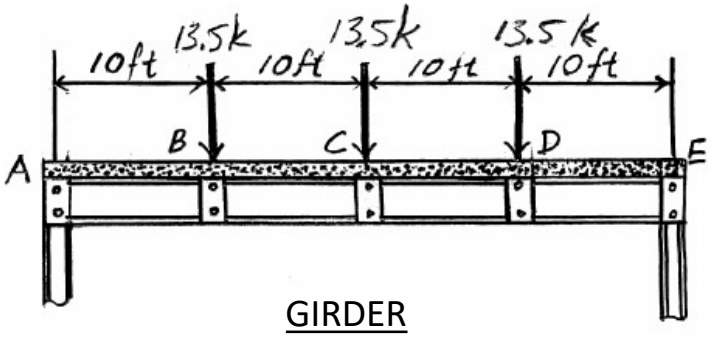
Floor DL = 50psf Floor LL = 40psf



FLOOR PLAN



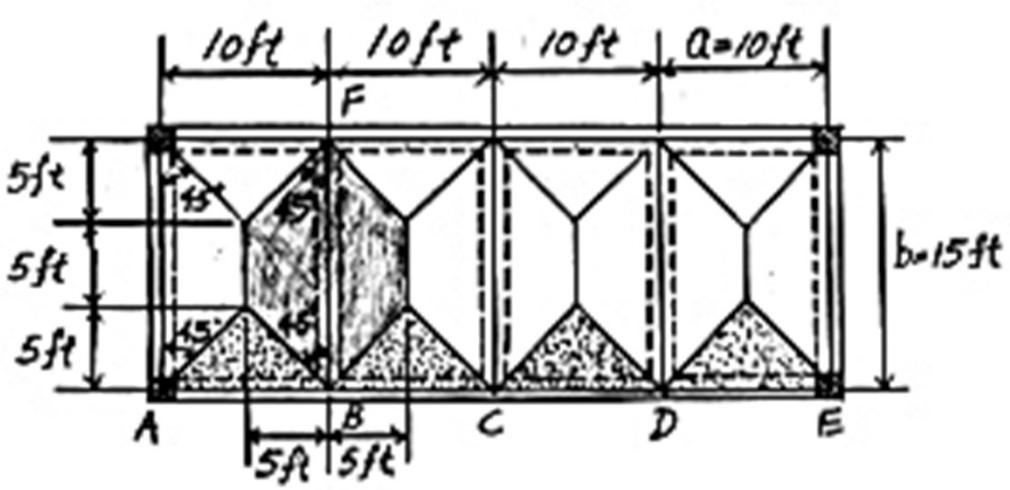
JOIST



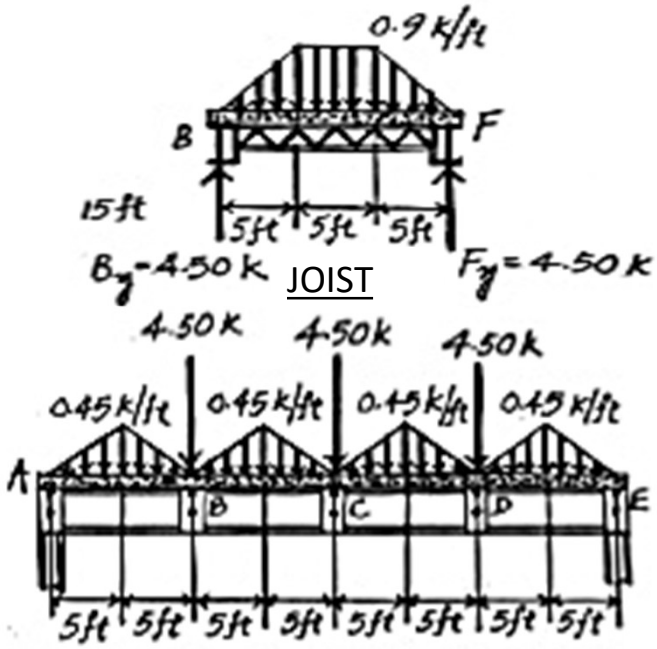
GIRDER

Floor Framing Example – 2 Way

Floor DL = 50psf Floor LL = 40psf



FLOOR PLAN



GIRDER

Load Types

Dead Load (D)	Live Load (L)	Wind (W)	Earthquake (E)
Snow (S)	Earth Pressure & Hydrostatic (H)	Flood (F)	Rain (R)

Dead and Live Loads

Dead Load – Reference ASCE 7

Live Loads – Reference IBC first and ASCE 7 second

Uniform & Concentrated Loads per Table 1607.1

Ice is considered a Dead Load

Dead Load – *"The weight of materials of construction incorporated into the building, including but not limited to walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding and other similarly incorporated architectural and structural items, and the weight of fixed service equipment, such as cranes, plumbing stacks and risers, electrical feeders, heating, ventilating and air-conditioning systems and automatic sprinkler systems."* – IBC Chapter 2

Live Load – *"A load produced by the use and occupancy of the building or other structure that does not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load or dead load."* – IBC Chapter 2

ASCE 7 - Table C3.1

Minimum Dead Loads broken down by building component

Table C3.1-1a (*Continued*)

Component					Load (psf)
Slate (per mm thickness)					15
Solid flat tile on 1-in. mortar base					23
Subflooring, 3/4-in.					3
Terrazzo (1-1/2-in.) directly on slab					19
Terrazzo (1-in.) on stone–concrete fill					32
Terrazzo (1-in.), 2-in. stone concrete					32
Wood block (3-in.) on mastic, no fill					10
Wood block (3-in.) on 1/2-in. mortar base					16
FLOORS, WOOD-JOIST (NO PLASTER)					
DOUBLE WOOD FLOOR					
Joint sizes (in.)	12-in. spacing (psf)	16-in. spacing (psf)	24-in. spacing (psf)		
2 × 6	6	5	5		
2 × 8	6	6	5		
2 × 10	7	6	6		
2 × 12	8	7	6		
FRAME PARTITIONS					
Movable steel partitions					4
Wood or steel studs, 1/2-in. gypsum board each side					8
Wood studs, 2 × 4, unplastered					4
Wood studs, 2 × 4, plastered one side					12
Wood studs, 2 × 4, plastered two sides					20
FRAME WALLS					
Exterior stud walls:					
2 × 4 @ 16-in., 5/8-in. gypsum, insulated, 3/8-in. siding					11
2 × 6 @ 16-in., 5/8-in. gypsum, insulated, 3/8-in. siding					12
Exterior stud walls with brick veneer					48
Windows, glass, frame, and sash					8
Clay brick wythes:					
4 in.					39
8 in.					79
12 in.					115
16 in.					155
Hollow concrete masonry unit wythes:					
Wythe thickness (in inches)	4	6	8	10	12
Density of unit (105 pcf) with grout spacing as follows:					
No grout	22	24	31	37	43
48 in. o.c.		29	38	47	55
40 in. o.c.		30	40	49	57
32 in. o.c.		32	42	52	61
24 in. o.c.		34	46	57	67
16 in. o.c.		40	53	66	79
Full grout		55	75	95	115
Density of unit (125 pcf) with grout spacing as follows:					
[illegible]	26	28	36	44	50

IBC Table 1607.1 Minimum Live Loads

Loading provided by Occupancy or Use

Uniform and Concentrated Load requirements

TABLE 1607.1
MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS[g]

OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (pounds)
1. Apartments (see residential)	—	—
2. Access floor systems Office use Computer use	 50 100	 2,000 2,000
3. Armories and drill rooms	150[f]	—
4. Assembly areas Fixed seats (fastened to floor) Follow spot, projections and control rooms Lobbies Movable seats Stage floors Platforms (assembly) Other assembly areas	 60[e] 50 100[e] 100[e] 150[f] 100[e] 100[e]	 —
5. Balconies and decks[h]	1.5 times the live load for the area served, not required to exceed 100	—
6. Catwalks	40	300
7. Cornices	60	—
8. Corridors First floor Other floors	 100 Same as occupancy served except as indicated	 —
9. Dining rooms and restaurants	100[e]	—
10. Dwellings (see residential)	—	—
11. Elevator machine room and controlroom grating (on area of 2 inches by 2 inches)	—	300
12. Finish light floor plate construction (on area of 1 inch by 1 inch)	—	200
13. Fire escapes On single-family dwellings only	100 40	—
14. Garages (passenger vehicles only) Trucks and buses	40[e] See Section 1607.7	Note a
15. Handrails, guards and grab bars	See Section 1607.8	
16. Helipads	See Section 1607.6	

TABLE 1607.1—continued
MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS[g]

OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (pounds)
23. Penal institutions Cell blocks Corridors	 40 100	 —
24. Recreational uses: Bowling alleys, poolrooms and similar uses Dance halls and ballrooms Gymnasiums Ice skating rink Reviewing stands, grandstands and bleachers Roller skating rink Stadiums and arenas with fixed seats (fastened to floor)	 75[m] 100[m] 100[m] 250[k] 100[c, m] 100[m] 60[c, m]	 —
25. Residential One- and two-family dwellings Uninhabitable attics without storage[i] Uninhabitable attics with storage[i, j, k] Habitable attics and sleeping areas[k] Canopies, including marquees All other areas Hotels and multifamily dwellings Private rooms and corridors serving them Public roomsm and corridors serving them	 10 20 30 20 40 40 100	 —
26. Roofs All roof surfaces subject to maintenance workers Awnings and canopies: Fabric construction supported by a skeleton structure All other construction, except one- and two-family dwellings Ordinary flat, pitched, and curved roofs (that are not occupiable) Primary roof members exposed to a work floor Single panel point of lower chord of roof trusses or any point along primary structural members	 5[m] 20 20 	 300

Other Live Loads per IBC

Office Partitions	Helipads	Fire Truck and Emergency Vehicles
Vehicular and Vehicle Barriers	Handrails and Guards	Façade Access and Fall Arrest

Live Load Reduction

IBC Section 1607.11

Reductions based on if it is a horizontal or vertical element

Live Loads over 100psf typically cannot be reduced

Many Live Loads cannot be reduced.

Reduction is based upon structural element and supporting area.

Has largest impact on columns and foundations.

Wind and Earthquake Loads - ASCE 7

Wind Loads

- Basic Wind Speed
- Exposure Category
- Loads based from Influence Area

Earthquake Loads

- Soil Profile
- Structure Type
- Structure Ductility & Response
- Loads based from Building Mass

Load Combinations

IBC Section 1605

Strength (LRFD)

Service (ASD)

STRENGTH
IBC 1605.2

$1.4(D + F)$ **(Equation 16-1)**

$1.2(D + F) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R)$ **(Equation 16-2)**

$1.2(D + F) + 1.6(L_r \text{ or } S \text{ or } R) + 1.6H + (f_1 L \text{ or } 0.5W)$ **(Equation 16-3)**

$1.2(D + F) + 1.0W + f_1 L + 1.6H + 0.5(L_r \text{ or } S \text{ or } R)$ **(Equation 16-4)**

$1.2(D + F) + 1.0E + f_1 L + 1.6H + f_2 S$ **(Equation 16-5)**

$0.9D + 1.0W + 1.6H$ **(Equation 16-6)**

$0.9(D + F) + 1.0E + 1.6H$ **(Equation 16-7)**

SERVICE
IBC 1605.3.1

$D + F$ **(Equation 16-8)**

$D + H + F + L$ **(Equation 16-9)**

$D + H + F + (L_r \text{ or } S \text{ or } R)$ **(Equation 16-10)**

$D + H + F + 0.75(L) + 0.75(L_r \text{ or } S \text{ or } R)$ **(Equation 16-11)**

$D + H + F + (0.6W \text{ or } 0.7E)$ **(Equation 16-12)**

$D + H + F + 0.75(0.6W) + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$ **(Equation 16-13)**

$D + H + F + 0.75\,(0.7\,E) + 0.75\,L + 0.75\,S$ **(Equation 16-14)**

$0.6D + 0.6W + H$ **(Equation 16-15)**

$0.6(D + F) + 0.7E + H$ **(Equation 16-16)**

What does ASD and LRFD mean?

Allowable Stress Design (ASD), aka Service Design

- principle of that stresses should not exceed a certain fraction of their elastic limit. Older method of design which only considers the elastic strength of a material. Can be more conservative.

Load and Resistance Factor Design (LRFD), aka Strength Design

- principle that the strength is scaled down by a resistance factor formed on the predictability of the material while the loads are scaled up by defined factors. More rational approach which considers utilization of elastic, plastic and strain hardening.

Limits of Design

Basic Design Limit States

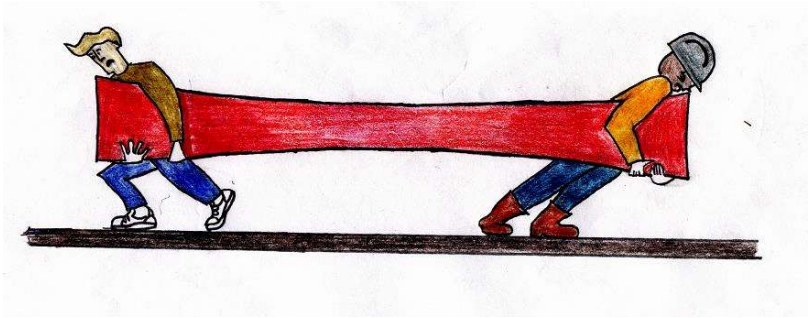
Stability – the condition in which gravity and lateral loads are resisted such that as a whole are in balance.

Strength - the capacity of the individual elements, which together make up a structural system, to withstand the load that are applied to them.

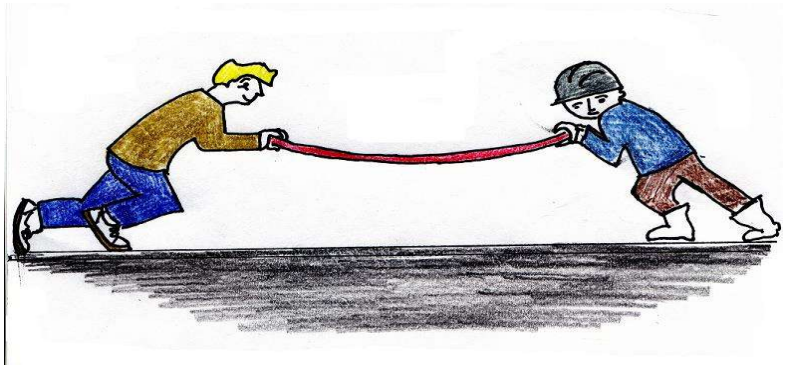
Serviceability – the condition under which a structure or structural element is considered useful.

Structural Forces

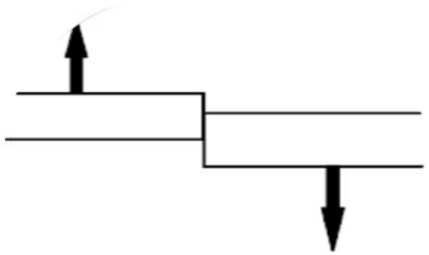
TENSION



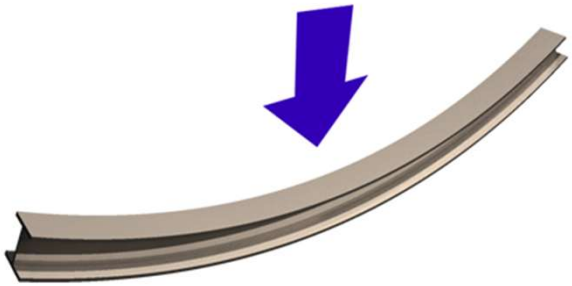
COMPRESSION



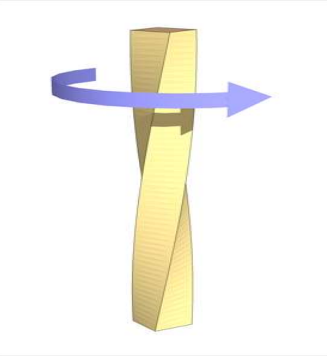
Structural Forces



SHEAR

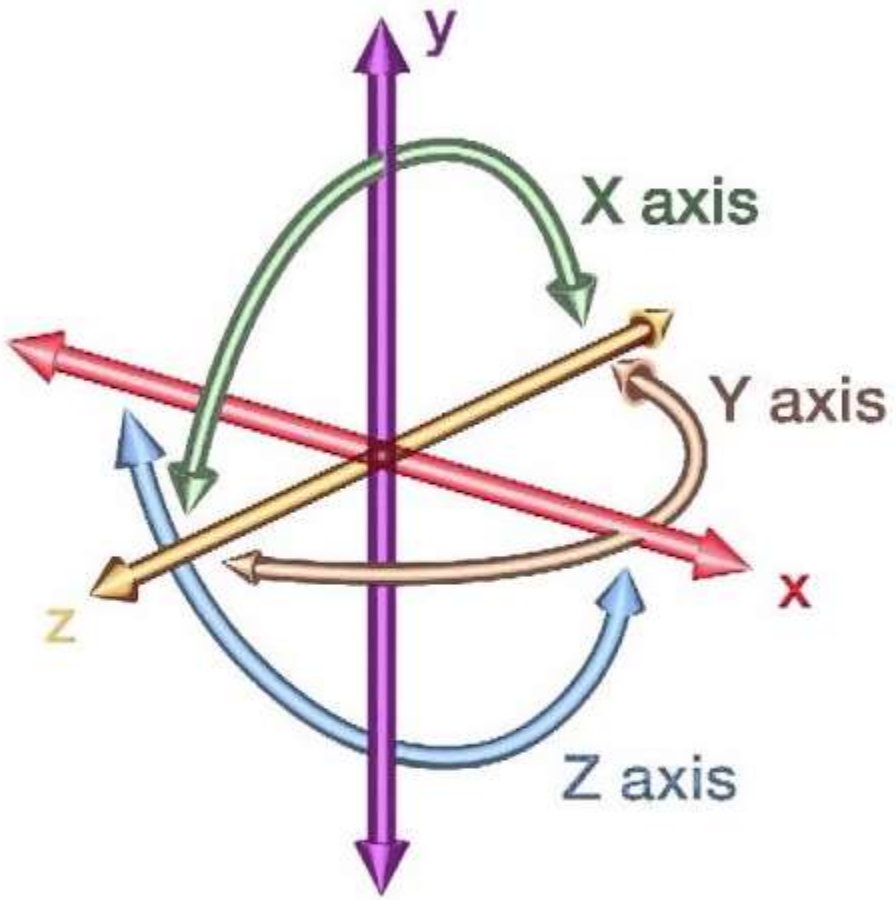


BENDING

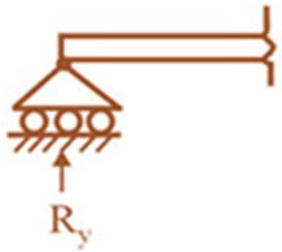


TORSION

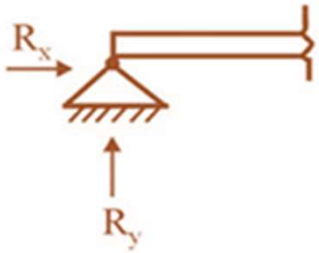
Degrees of Freedom



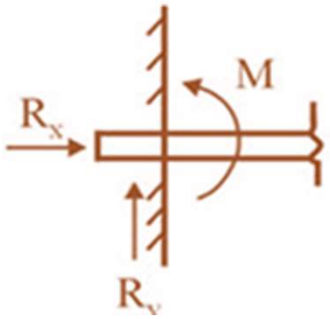
Supports and Boundary Restraint



Roller – Frictionless support free rotate and translate along the surface it rests

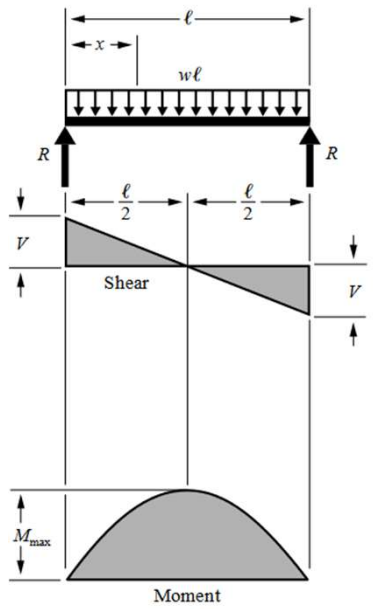


Pin – Provides translational but free to rotate



Fixed – Provides both translational and rotational support

Simple Beam Formulas (NDS Design Aid No. 6)



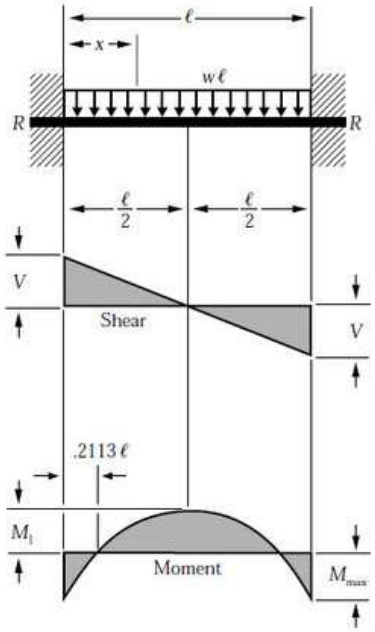
Uniform – Pinned

$$R = V \quad \ldots \ldots = \frac{w\ell}{2}$$

$$V_x \quad \ldots \ldots = w\left(\frac{\ell}{2} - x\right)$$

$$M_{max} \text{ (at center)} = \frac{w\ell^2}{8}$$

$$M_x \quad \ldots \ldots = \frac{wx}{2}(\ell - x)$$



Uniform – Fixed

$$R = V \quad \ldots \ldots = \frac{w\ell}{2}$$

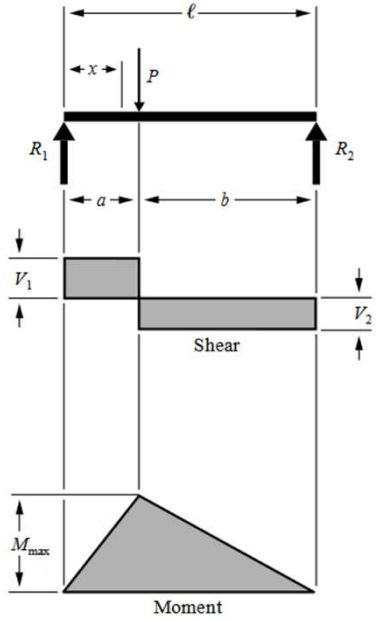
$$V_x \quad \ldots \ldots = w\left(\frac{\ell}{2} - x\right)$$

$$M_{max} \text{ (at ends)} = \frac{w\ell^2}{12}$$

$$M_1 \text{ (at center)} = \frac{w\ell^2}{24}$$

$$M_x \quad \ldots \ldots = \frac{w}{12}(6\ell x - \ell^2 - 6x^2)$$

Simple Beam Formulas (NDS Design Aid No. 6)



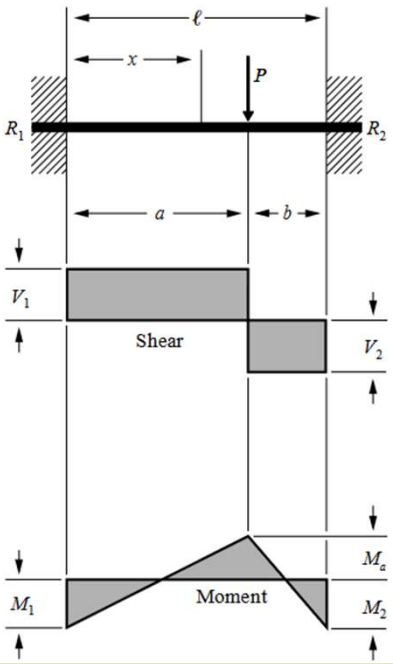
Single Concentrated - Pinned

$R_1 = V_1$ (max when $a < b$) $= \frac{Pb}{\ell}$

$R_2 = V_2$ (max when $a > b$) $= \frac{Pa}{\ell}$

M_{max} (at point of load) . $= \frac{Pab}{\ell}$

M_x (when $x < a$) . . . . $= \frac{Pbx}{\ell}$



Single Concentrated - Fixed

$R_1 = V_1$ (max when $a < b$) $= \frac{Pb^2}{\ell^3}(3a + b)$

$R_2 = V_2$ (max when $a > b$) $= \frac{Pa^2}{\ell^3}(a + 3b)$

M_1 (max when $a < b$) . . $= \frac{Pab^2}{\ell^2}$

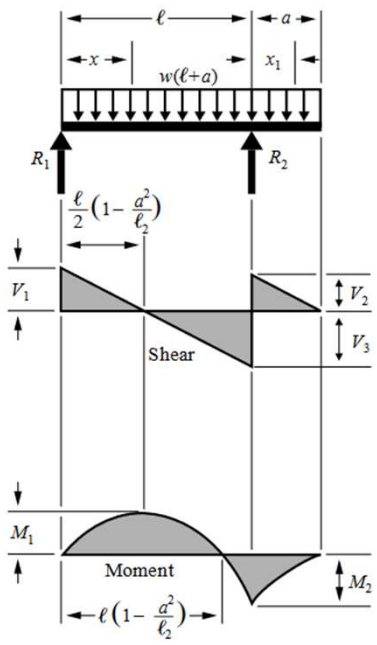
M_2 (max when $a > b$) . . $= \frac{Pa^2b}{\ell^2}$

M_a (at point of load) . . . $= \frac{2Pa^2b^2}{\ell^3}$

M_x (when $x < a$) . . . . $= R_1x - \frac{Pab^2}{\ell^2}$

Simple Beam Formulas (NDS Design Aid No. 6)

Uniform Cantilever



$R_1 = V_1 \quad = \frac{w}{2\ell}(\ell^2 - a^2)$

$R_2 = V_2 + V_3 \quad = \frac{w}{2\ell}(\ell + a)^2$

$V_2 \quad = wa$

$V_3 \quad = \frac{w}{2\ell}(\ell^2 + a^2)$

V_x (between supports) $\quad = R_1 - wx$

V_{x_1} (for overhang) $\quad = w(a - x_1)$

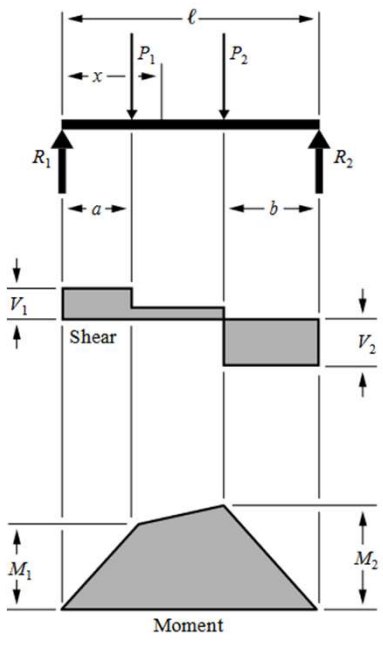
$M_1 \left(\text{at } x = \frac{\ell}{2}\left[1 - \frac{a^2}{\ell^2}\right]\right) \quad = \frac{w}{8\ell^2}(\ell + a)^2(\ell - a)^2$

M_2 (at R_2) $\quad = \frac{wa^2}{2}$

M_x (between supports) $\quad = \frac{wx}{2\ell}(\ell^2 - a^2 - x\ell)$

M_{x_1} (for overhang) $\quad = \frac{w}{2}(a - x_1)^2$

Double Concentrated



$R_1 = V_1 \quad = \frac{P_1(\ell - a) + P_2 b}{\ell}$

$R_2 = V_2 \quad = \frac{P_1 a + P_2(\ell - b)}{\ell}$

$V_x \left(\text{when } x > a \text{ and } < (\ell - b)\right) = R_1 - P_1$

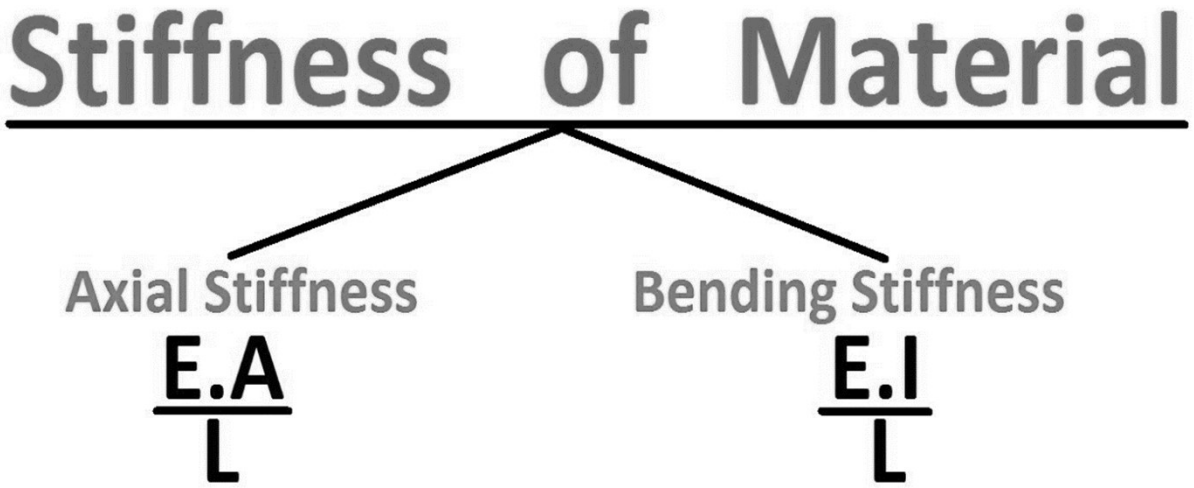
M_1 (max when $R_1 < P_1$) $\quad = R_1 a$

M_2 (max when $R_2 < P_2$) $\quad = R_2 b$

M_x (when $x < a$) $\quad = R_1 x$

$M_x \left(\text{when } x > a \text{ and } < (\ell - b)\right) = R_1 x - P_1(x - a)$

Stiffness and Deflection



Basic Elements of Stiffness

Elastic Modulus (E) - quantity that measures a materials resistance to being deformed elastically when a stress is applied to it.

Moment of Inertia, (I) - geometrical property of an area which reflects how its points are distributed about an arbitrary axis

Modulus of Elasticity of Materials

Material	E (psi)
Steel	29,000,000
Concrete	3,000,000 – 6,000,000
Masonry	1,000,000 – 2,000,000
Wood	1,000,000 – 2,000,000

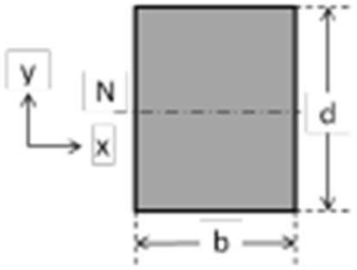
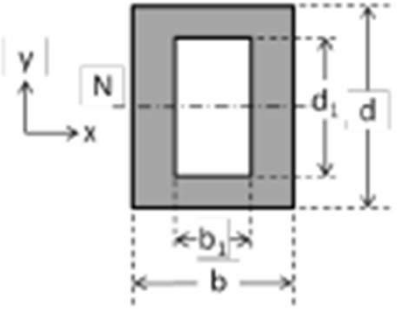
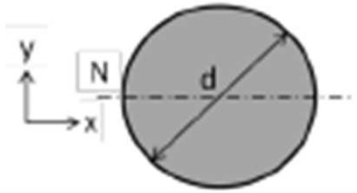
Moment of Inertia

Basic Sections – See Table

Steel Sections – Reference AISC Manual

Complex Sections – Use a computer to assist

Table 2: Moments of Inertia

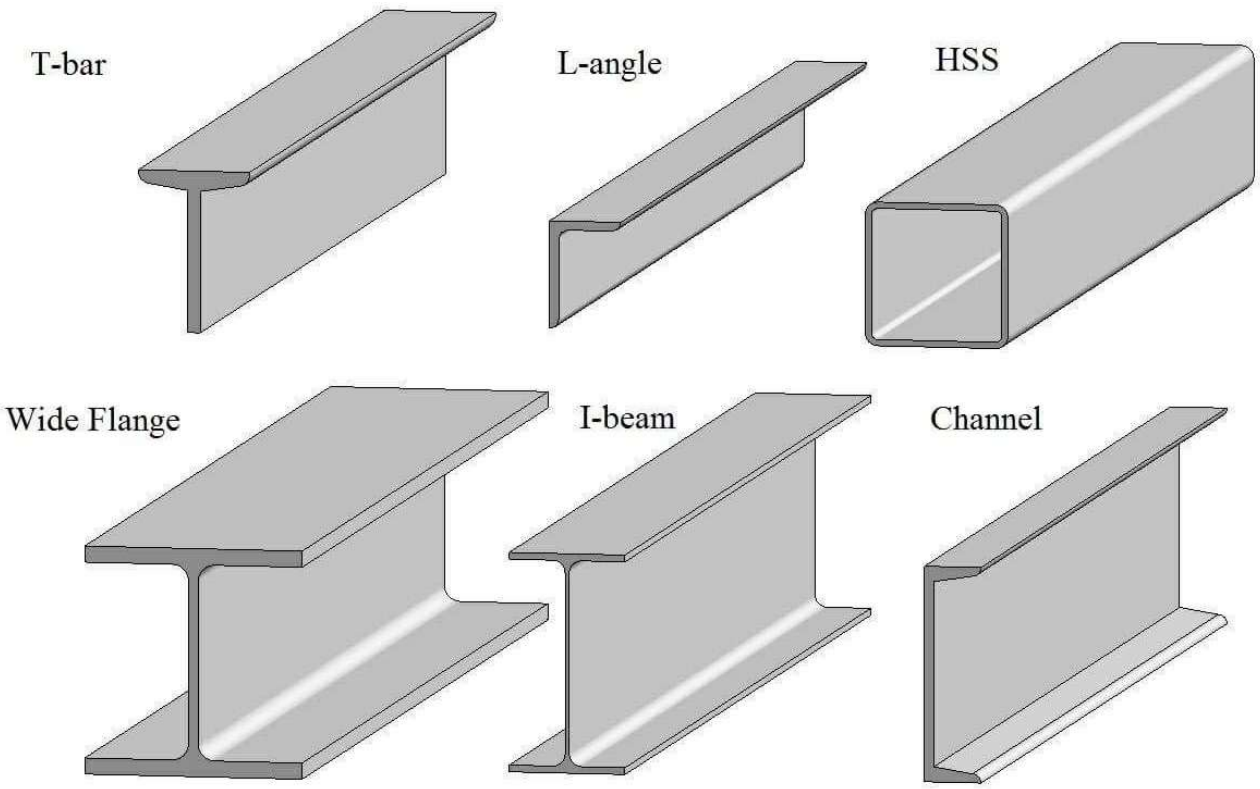
Type of Section	Moment of Inertia
Rectangle 	$I_{xx} = \frac{bd^3}{12}$ $I_{yy} = \frac{db^3}{12}$
Hollow Rectangular Section 	$I_{xx} = \frac{bd^3}{12} - \frac{b_1 d_1^3}{12}$ $I_{yy} = \frac{db^3}{12} - \frac{d_1 b_1^3}{12}$
Circle 	$I_{xx} = I_{yy} = \frac{\pi d^4}{64}$

Efficiency of Shapes & Sections

Steel Sections

Built-Up Sections

T-Beams



Deflection Limits IBC Table 1604.3

Deflection Limits may be more restrictive and can vary

Seismic Drift limits are based on flexibility of lateral resisting system

L/120 – Roof Members w/o ceiling Total Load

L/180 – Typical Roof Members Total Load

L/240 – Typical Floor Members Total Load

L/360 – Typical Floor & Roof Members Live Load

L or H/600 – Members supporting Brittle Finishes

H/400 – Wind Deflection

Special Topics

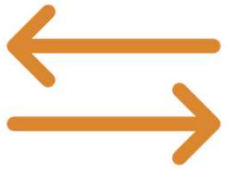
- Fire Resistance
- Vibration and Motion
- Influence of other structures
- Thermal
- Blast & Progressive Collapse
- Liquefaction

Structural Concepts

Gravity and Lateral Systems

Structural components are often affected by both gravity and lateral loads

<u>Gravity Systems</u>
Primary purpose is to resist loads acting vertically



<u>Lateral Systems</u> Primary purpose is to resist loads acting horizontally (Wind/Earthquake)

Gravity Systems

- Structural Frames
- Bearing Walls
- Post and Beam
- Slabs and Deck
- Trusses
- Space Frames/Exo Structures

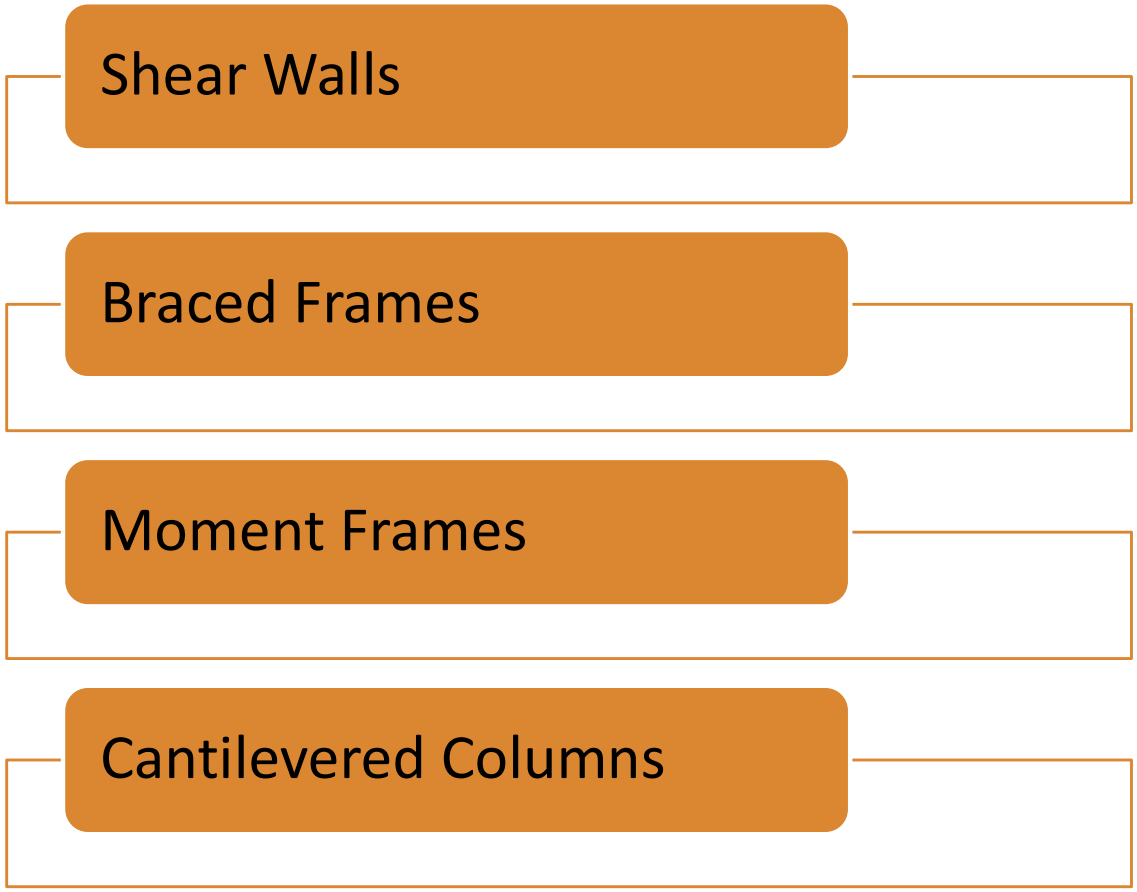
Lateral Systems

Primary systems used

Can be used in combination

Advantages/Disadvantages

More limits when used in Seismic force resisting systems



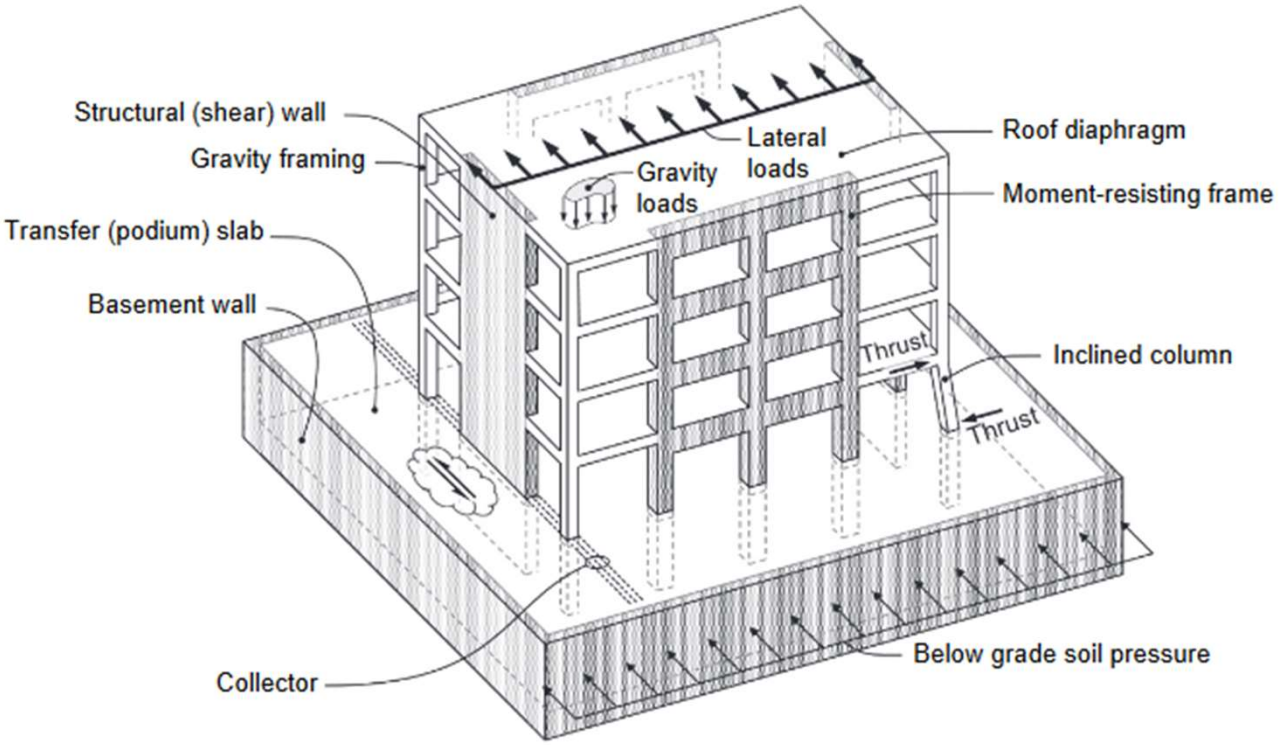
Diaphragms & Collectors

Diaphragms - Typically horizonal elements that transmit lateral loads to the vertical resisting elements.

(Rigid vs Flexible)

Collector – a.k.a. Drag Strut, are used to focus lateral loads to the lateral resisting element

Role of Diaphragms & Collectors



Structural Discontinuity

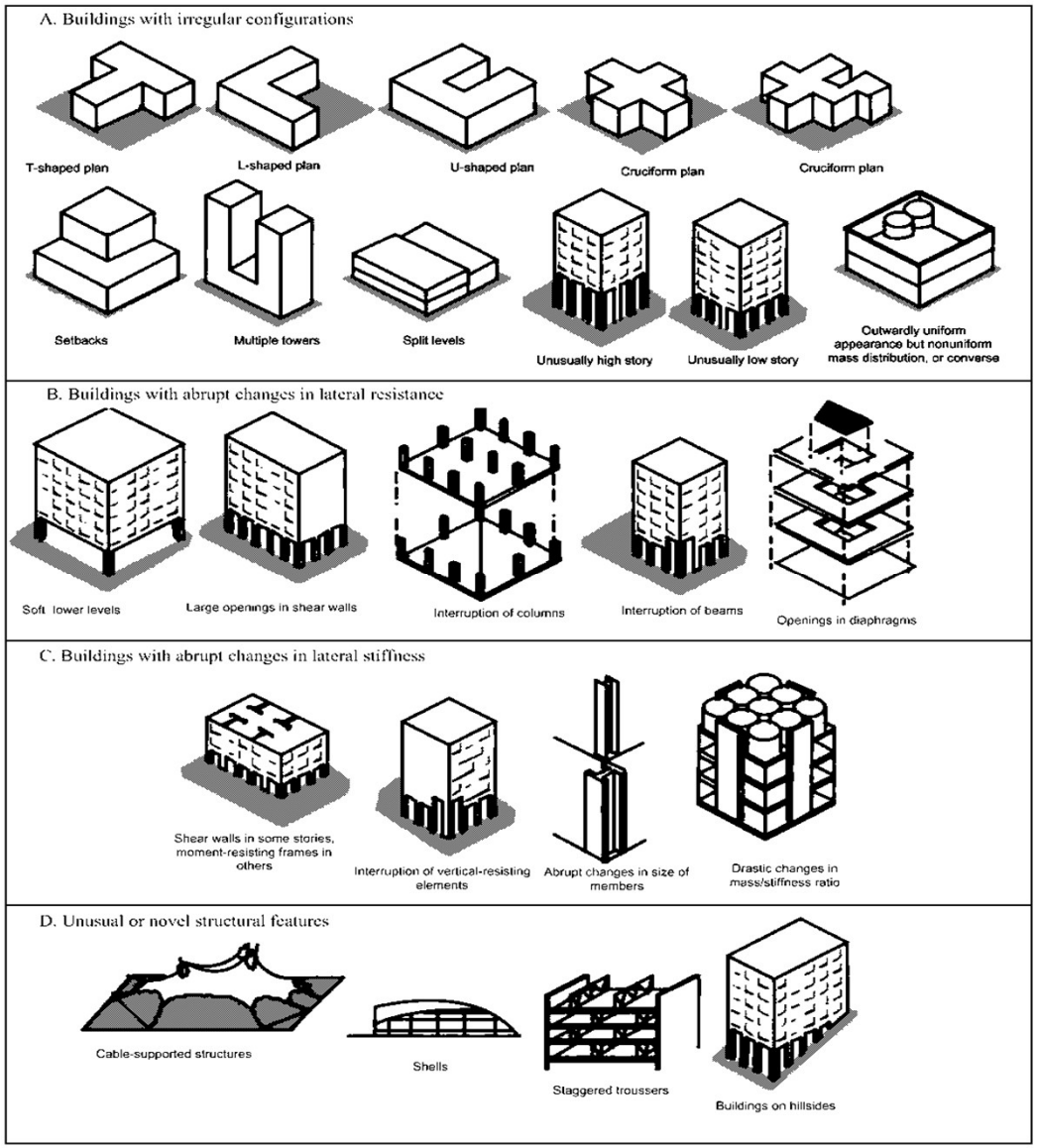
IRREGULARITIES

TRANSFERS

BUILDING SEPARATIONS

Typical Irregularities

- Plan Irregularities
- Shape Irregularities
- Support Irregularities
- Stiffness Irregularities
- Unusual Irregularities



Thank You

QUESTIONS?

Recommended Resources