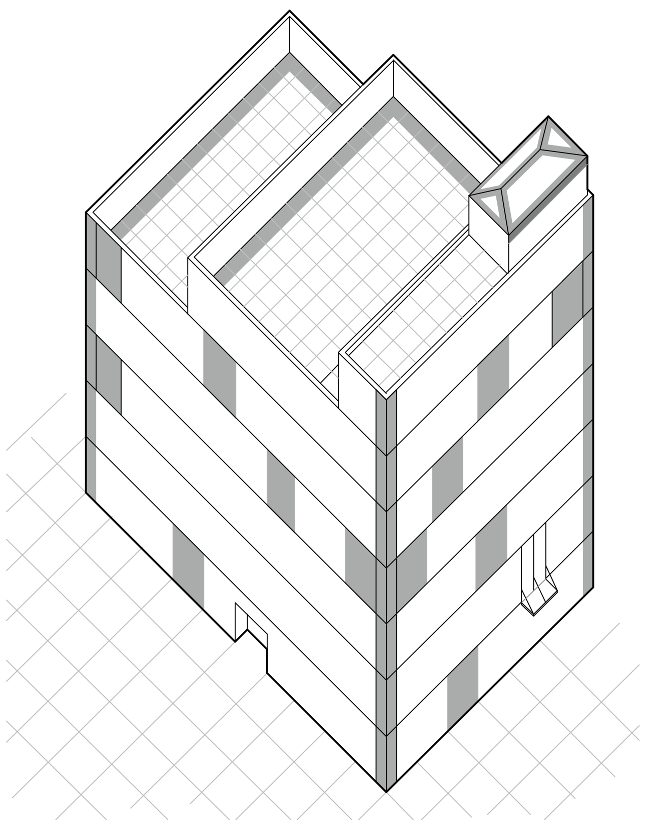
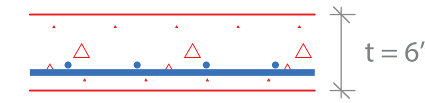
ARE **WORKBOOK**

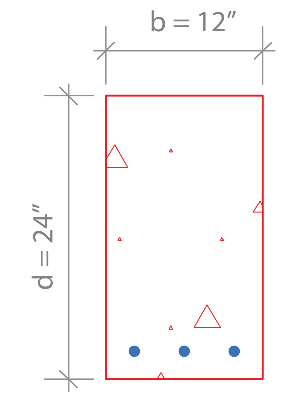
(the coloring book)

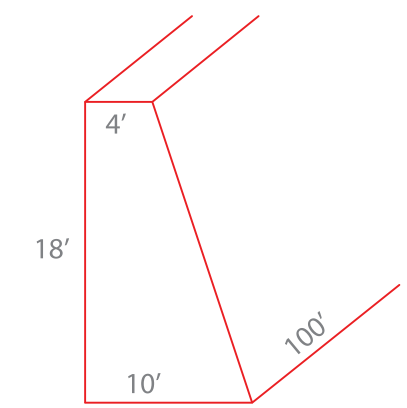
ARE Workbook
Contents

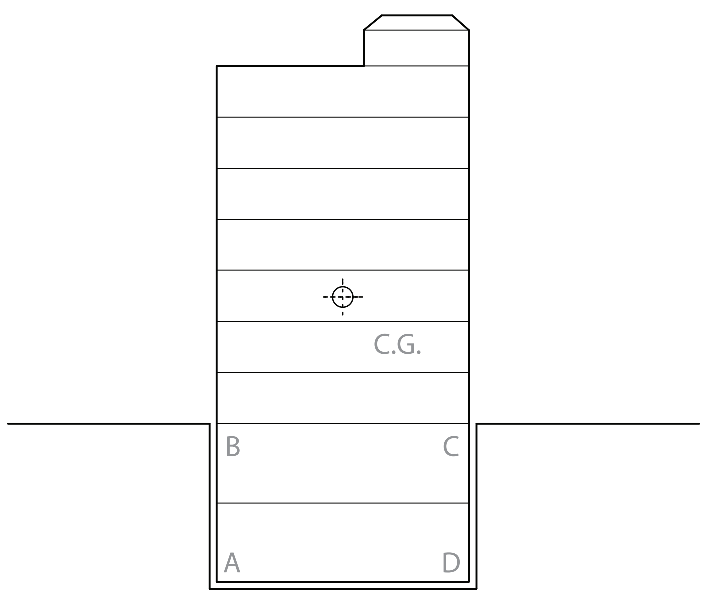


	Gravitational	Environmental	Lateral
Roof			
Floor			
Envelope			
Foundation			









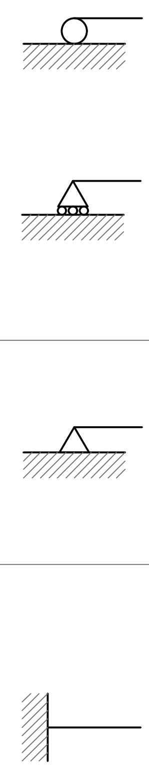
Water	
Wood	
Steel	
Concrete	

GRAPHIC REPRESENTATION OF FORCES

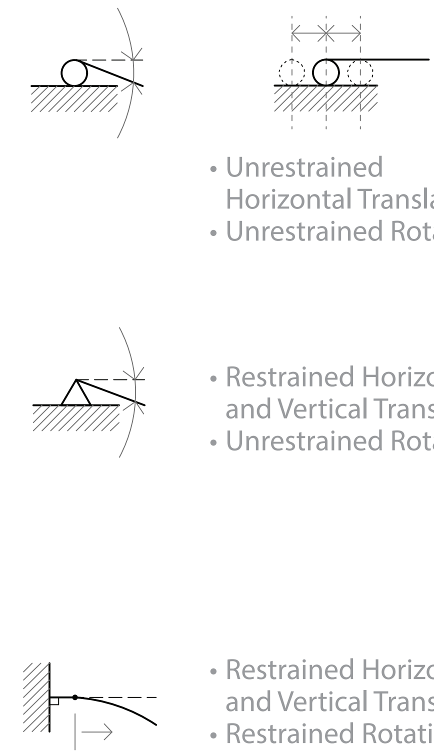
Please see Reference PG. R-1

Support Description

Description	Symbol
• Roller	
• Rocker	
• Pin • Hinge	
• Fixed Moment-Resisting Monolithic	



Response to Loading



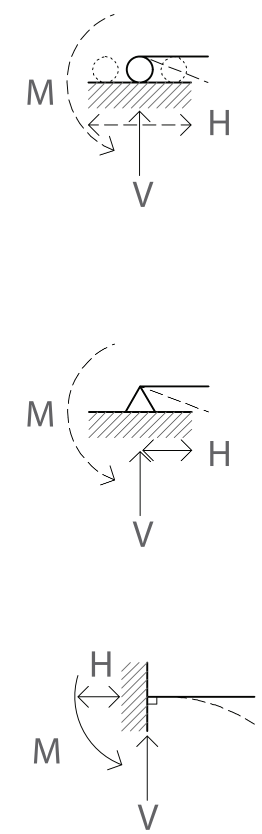
• Moves Horizontally

• Unrestrained Horizontal Translation
• Unrestrained Rotation

• Restrained Horizontal and Vertical Translation
• Unrestrained Rotation

• Restrained Horizontal and Vertical Translation
• Restrained Rotation

Reactions



• $\sum H = 0$
• $\sum V = 0$
• $\sum M = 0$

Equilibrium

How many unknown reactions:

2: Unstable (U)

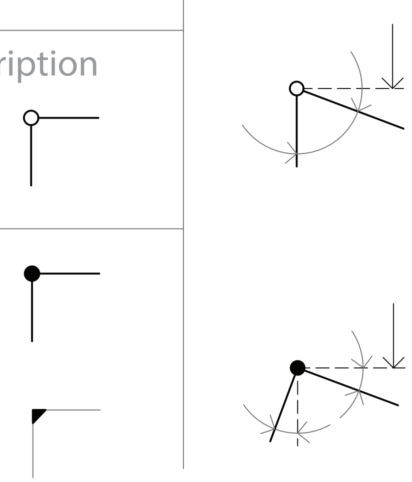
3: Stable & Determinate (S&D)

> 3: Indeterminate (I)

Joint Description

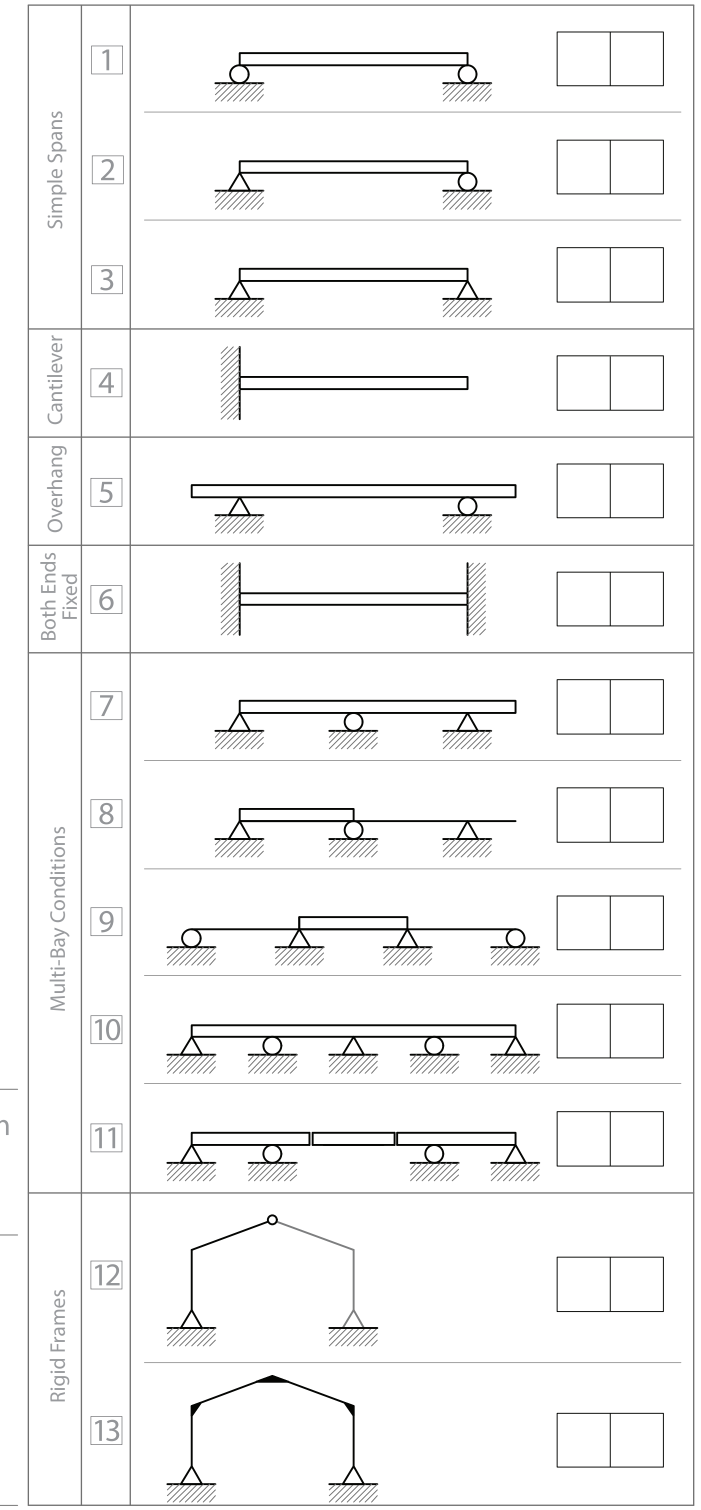
• Pin Joint

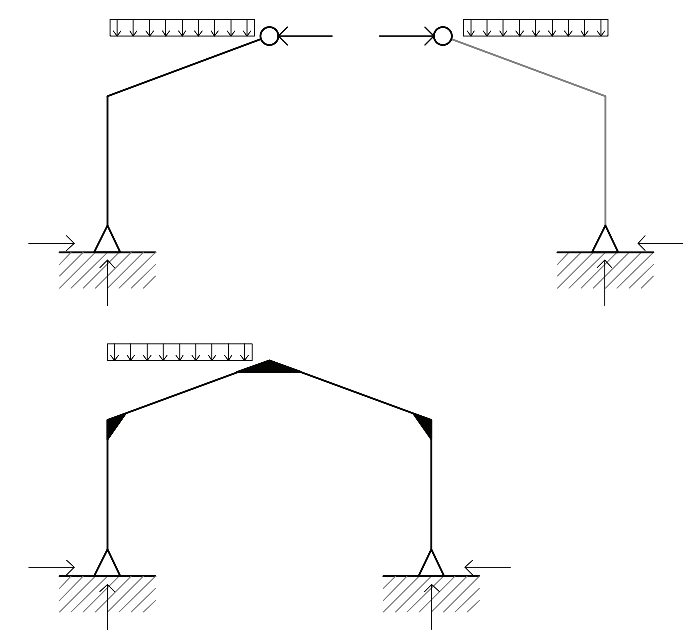
• Rigid Joint

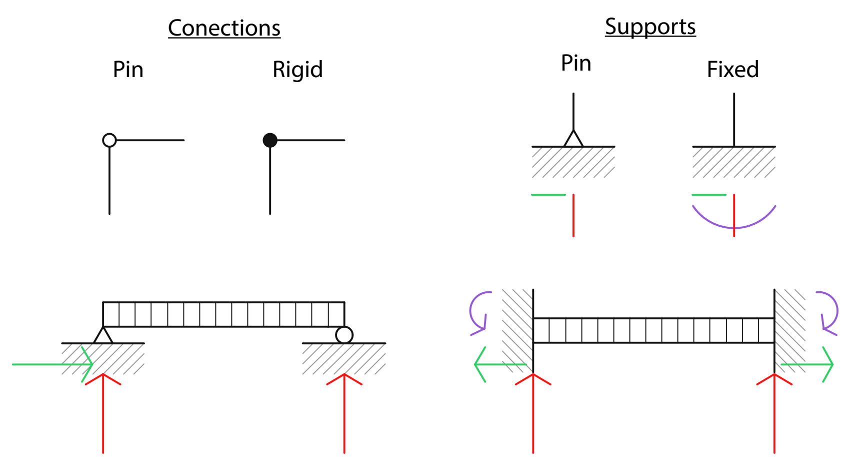


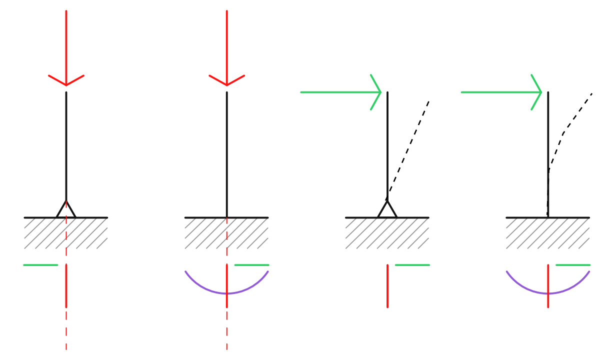
• Joint allows beam to rotate
• Beam / Column angle < 90º

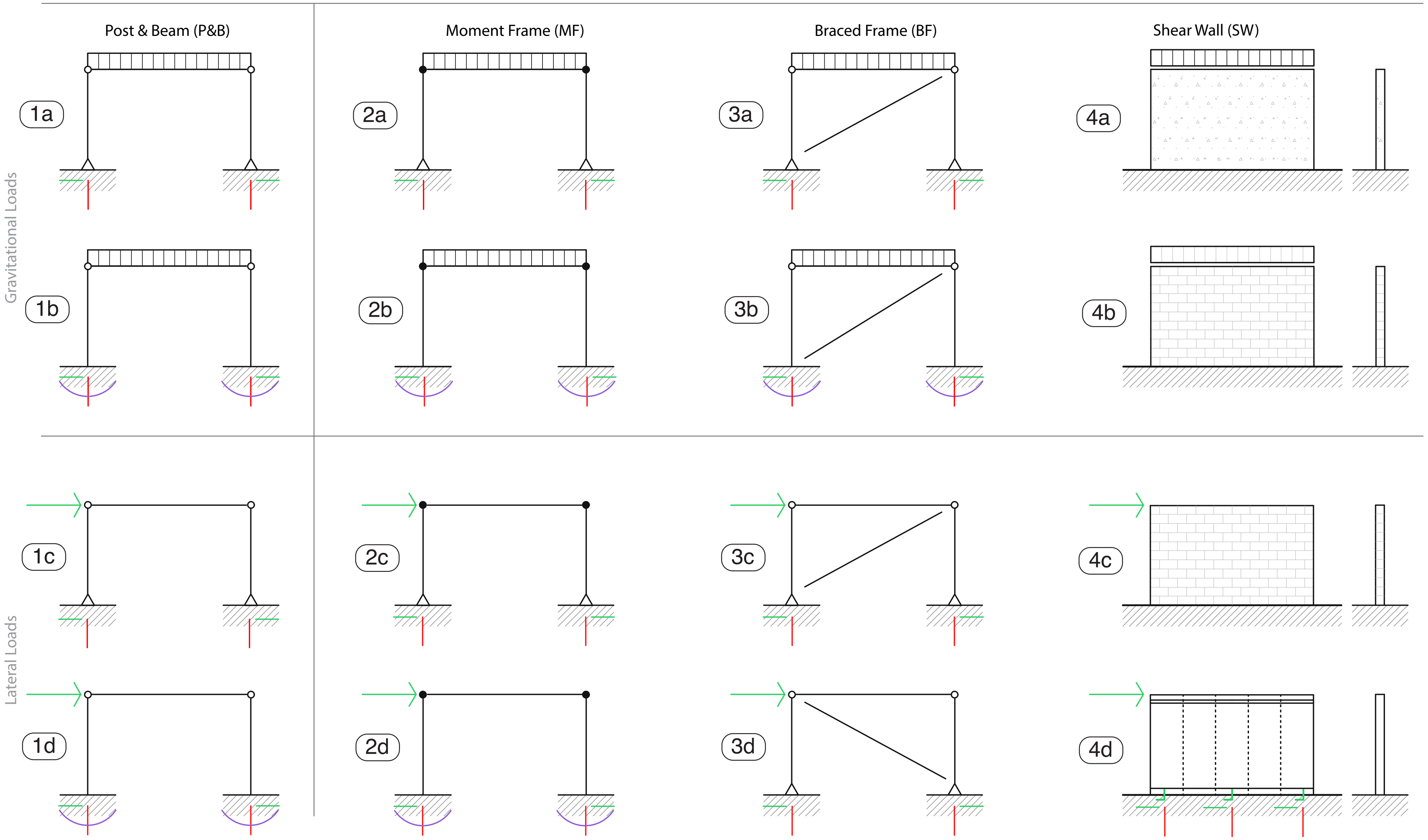
• Beam and column rotate
• Beam / Column angle remains 90º

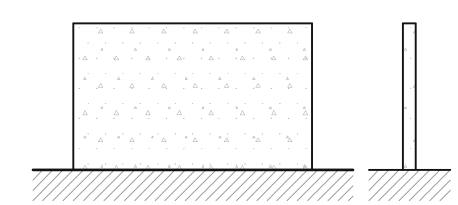








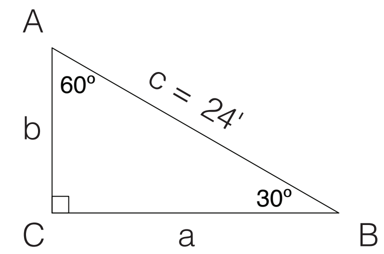


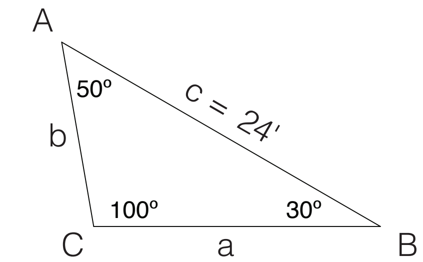


T H A D D E U S

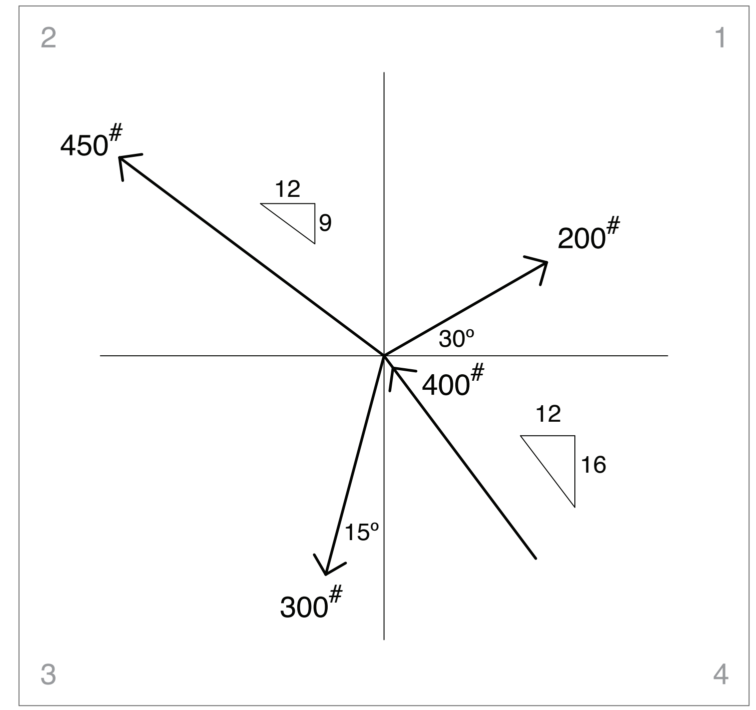
PB MF BF SW

Calculate the Resultant and Equilibrant for the Forces shown.

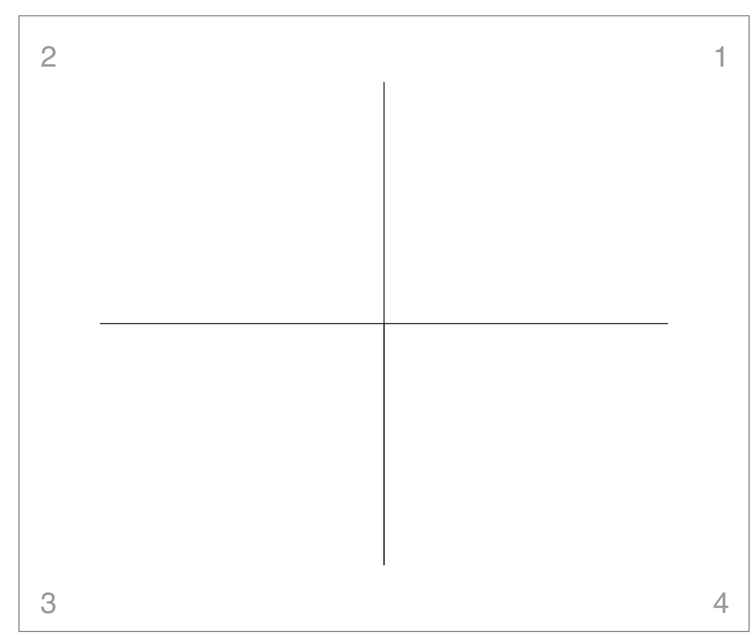


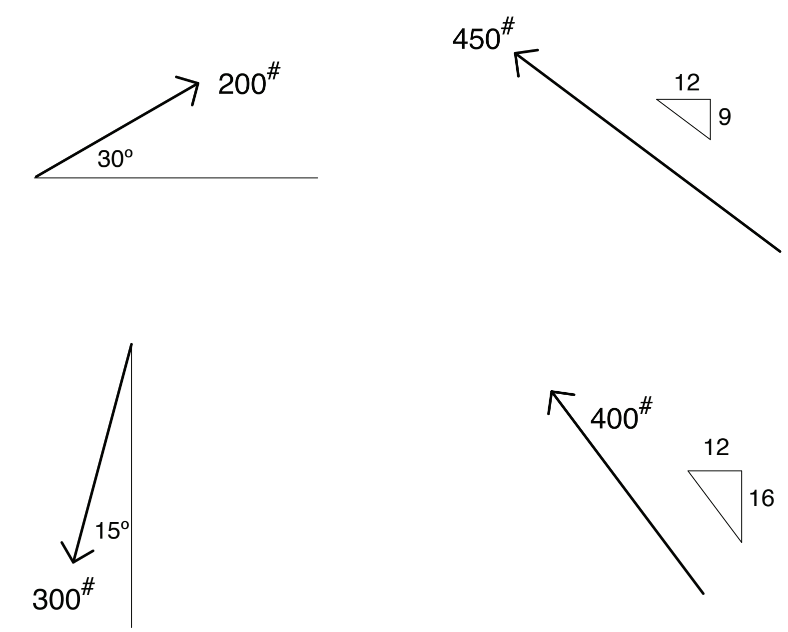


Force	Horizontal Component	Vertical Component
200#		
450#		
300#		
400#		
Resultant R =		



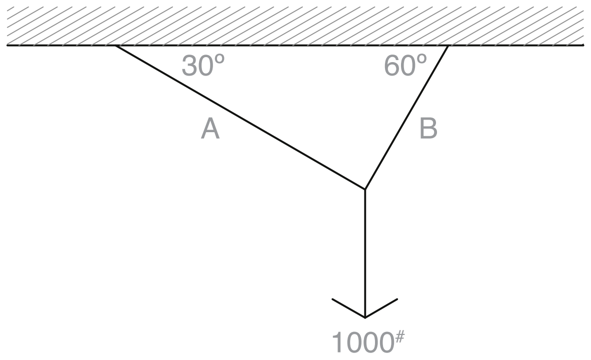
a.) 619# @ 38°   b.) 722# @ 200°
c.) 722# @ -38°   d.) 643# @ 142°

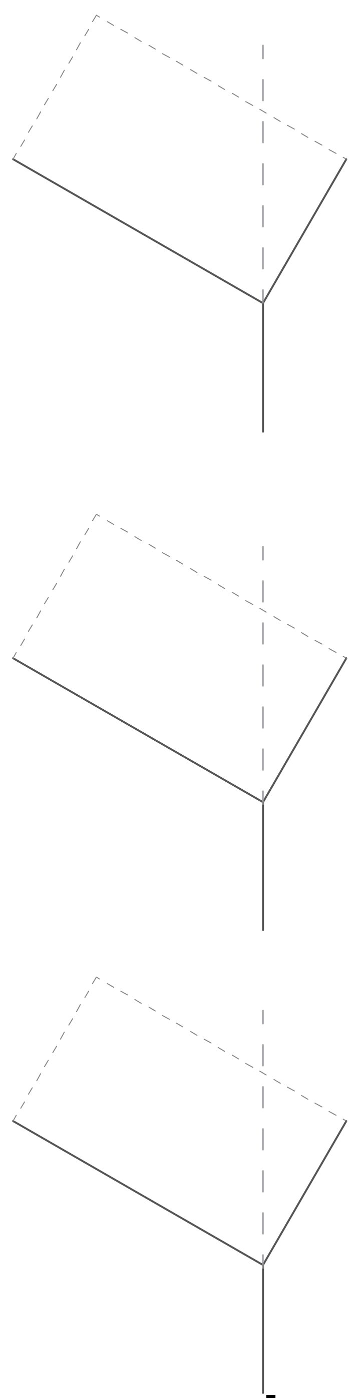


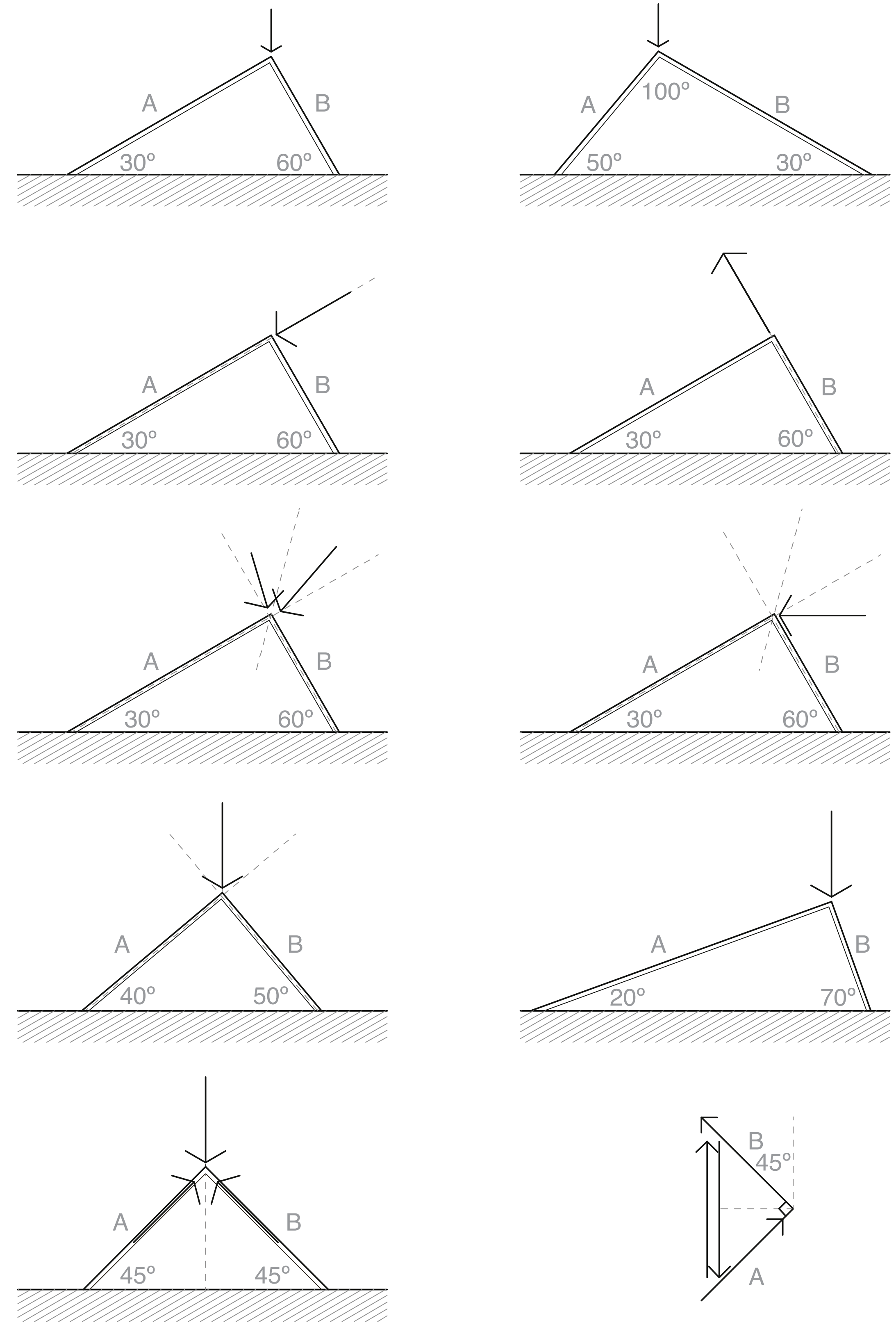


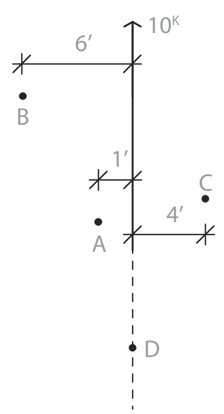
Calculate force in cables 'A' & 'B'

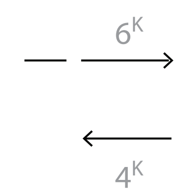
	A	B
1.	700#	300#
2.	600#	400#
3.	500#	500#
4.	350#	650#
5.	450#	550#
6.	-	-

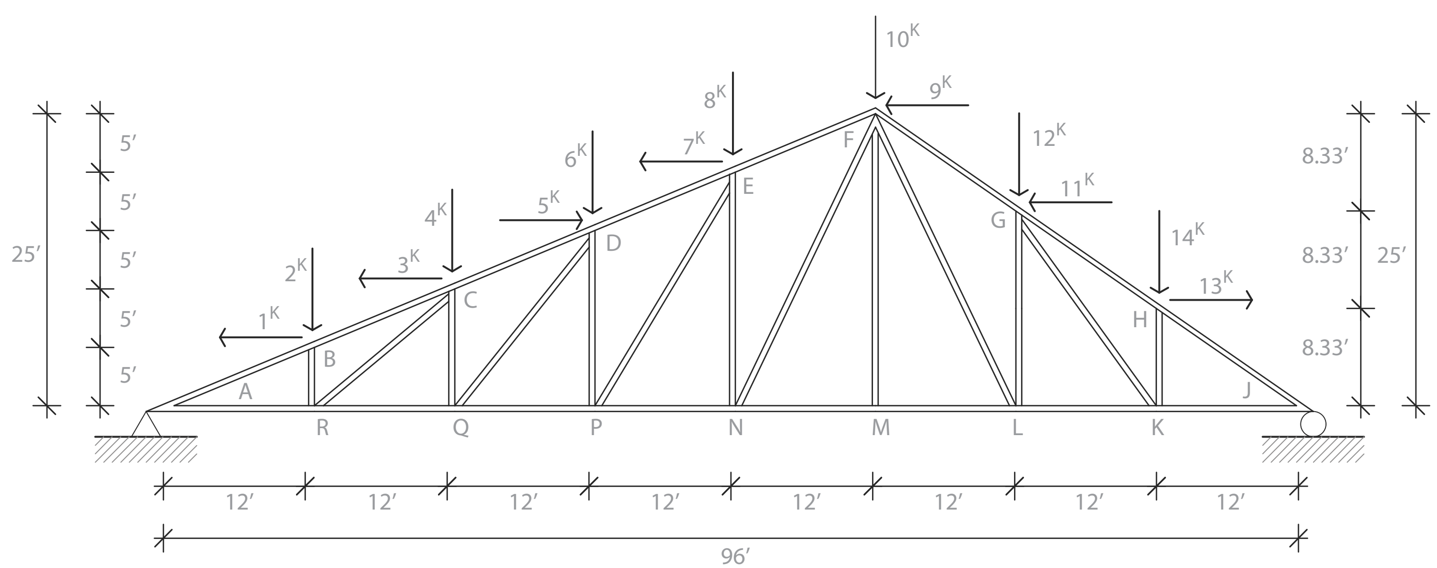


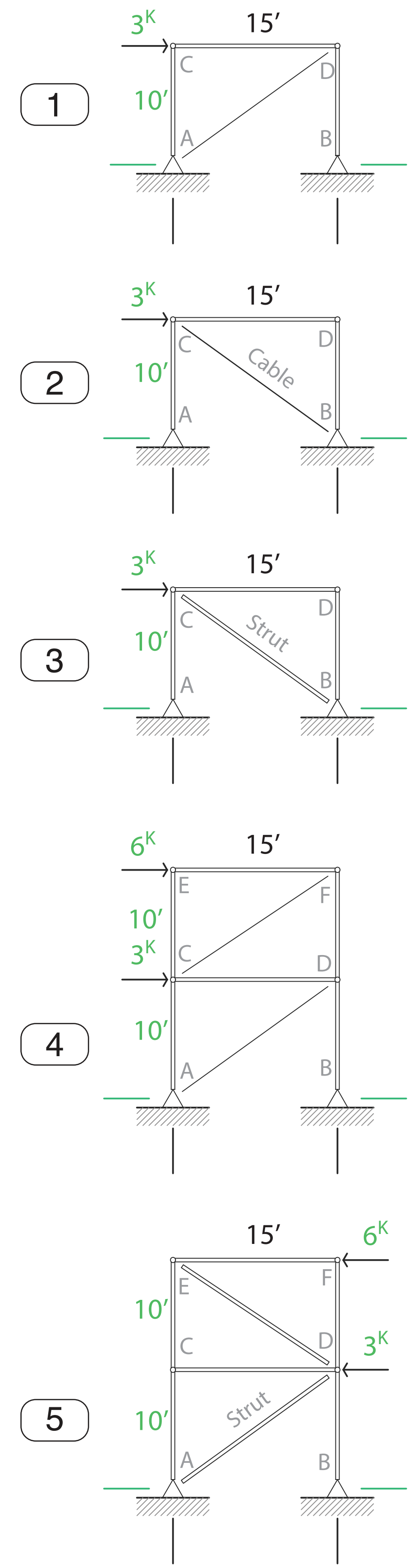


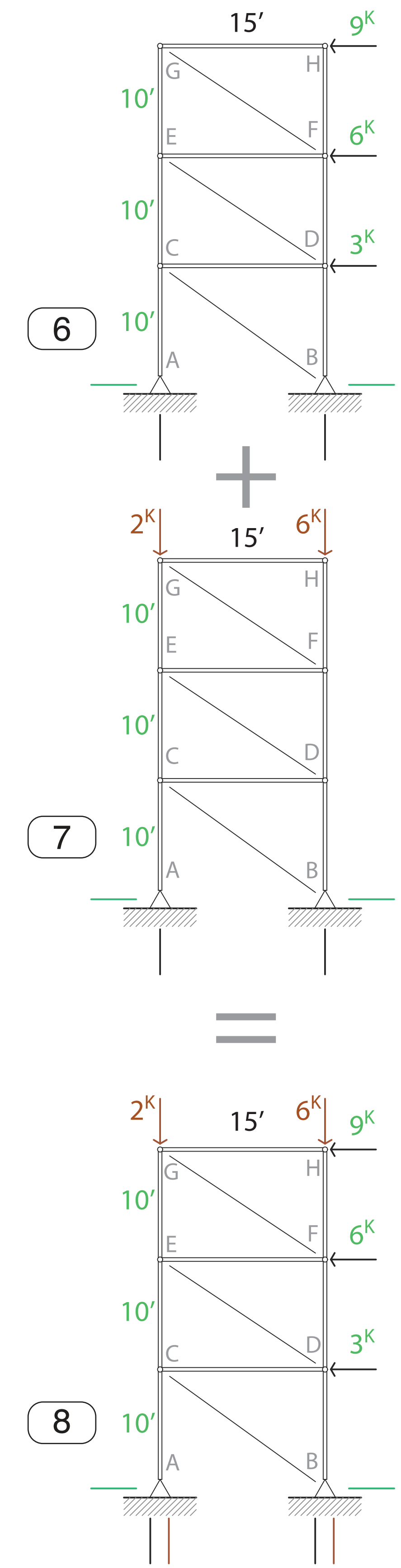




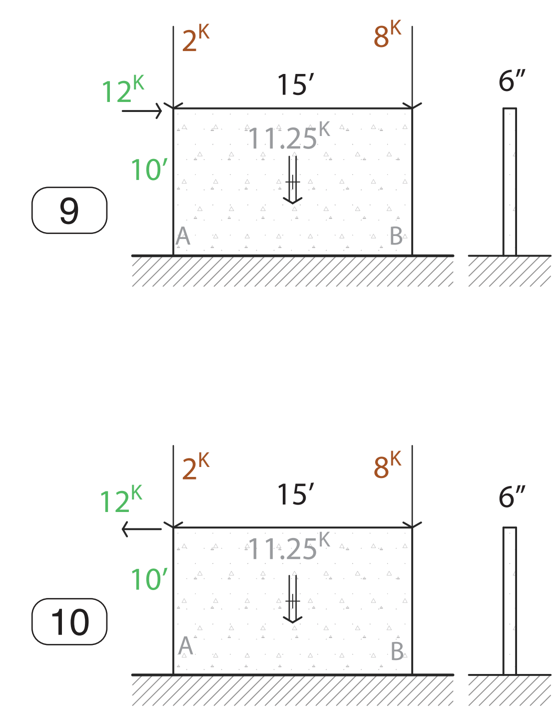


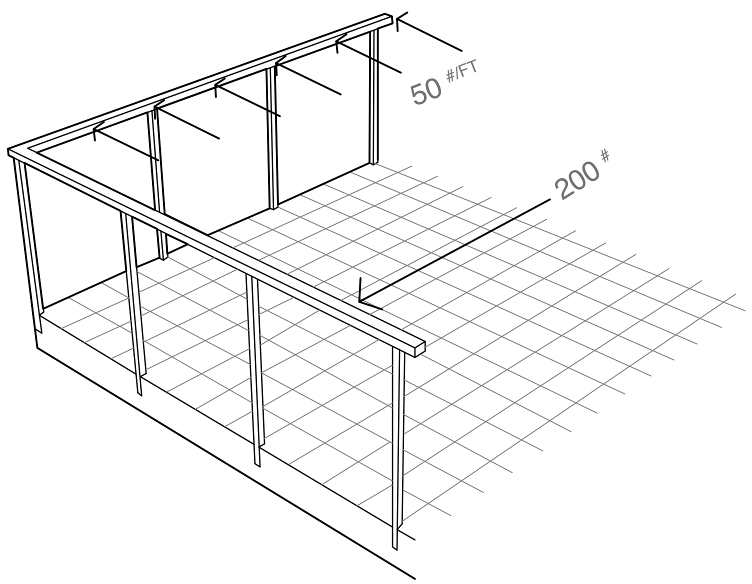


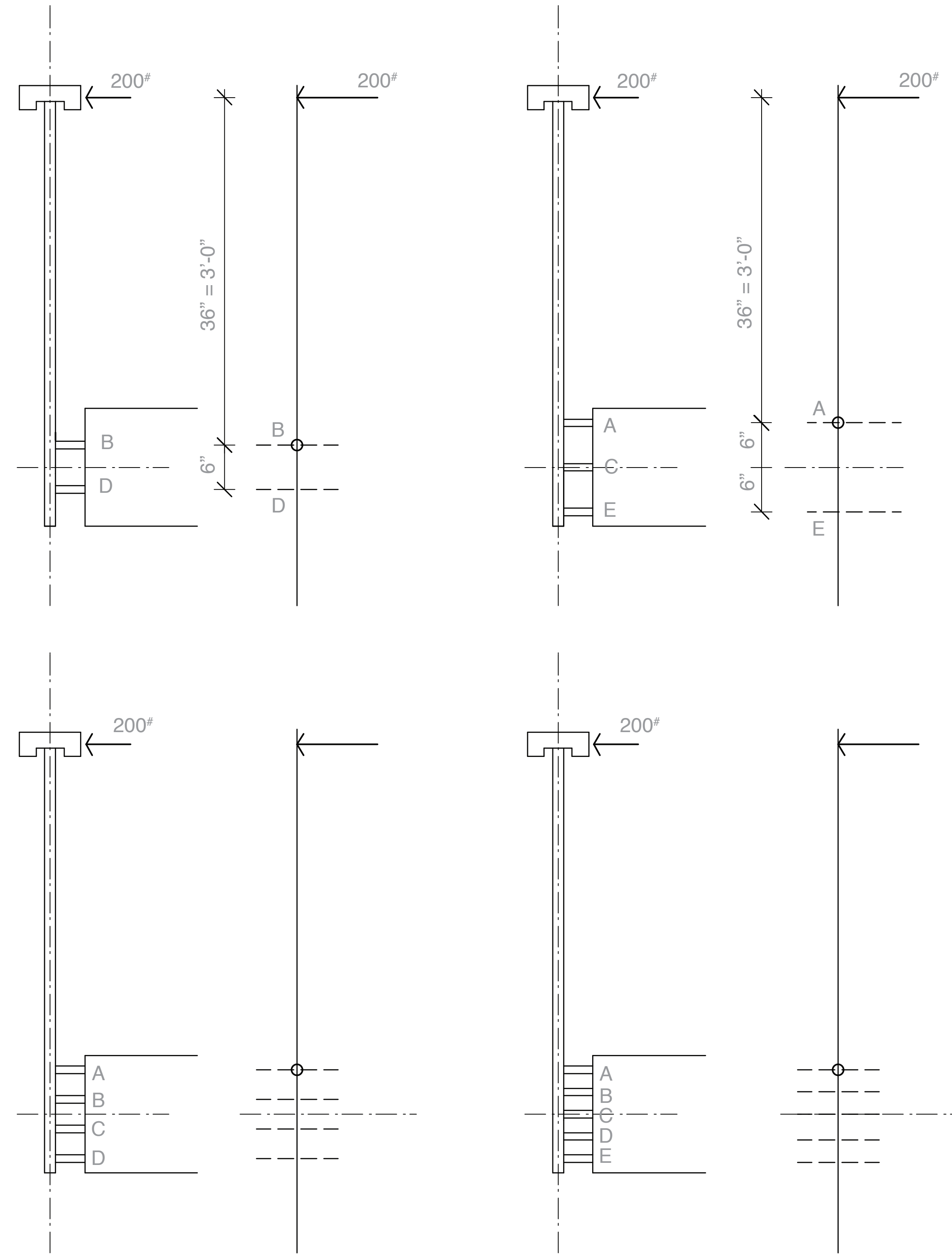


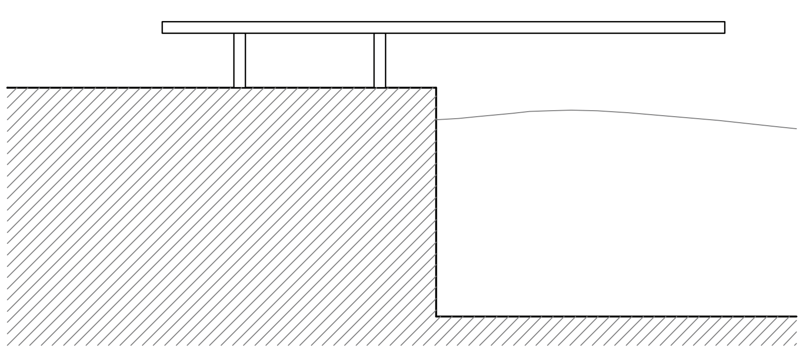


1. Calculate the Base Shear at *A* & *B*
2. Identify the Pivot
3. Calculate the Overturning Moment (OTM) at the Pivot
4. Calculate the Tiedown Force. Identify the Location.



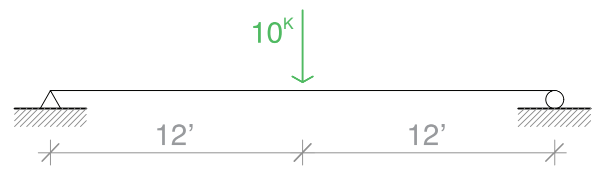






BENDING MOMENTS : HANDRAILS

1



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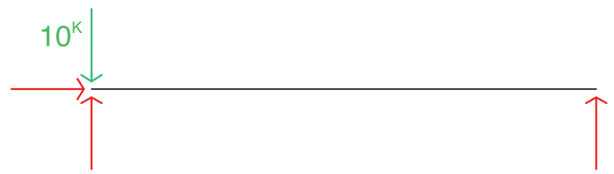

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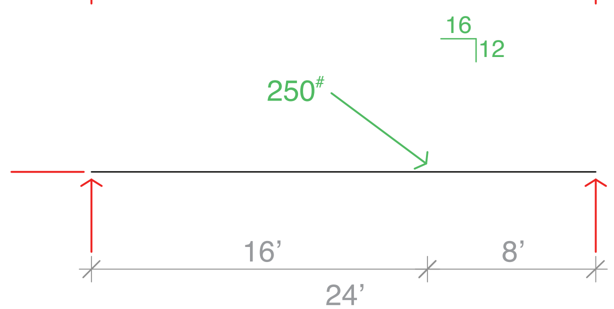

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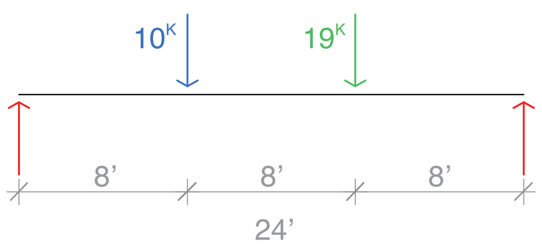
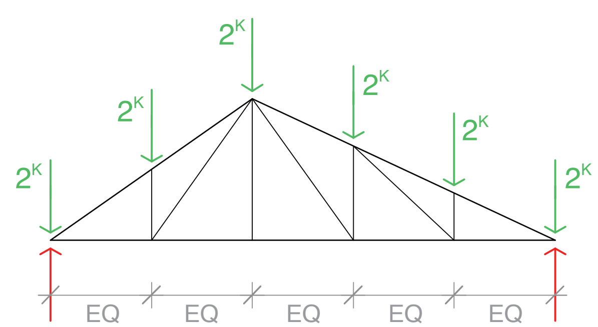
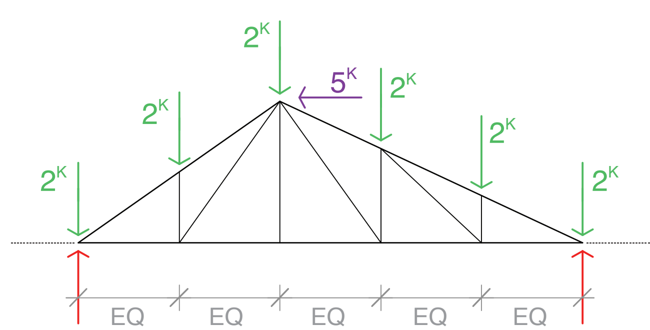


L	R
10 K	19 K
14.5 K	14.5 K
8 K	21 K
13 K	16 K
17 K	12 K

5



5a



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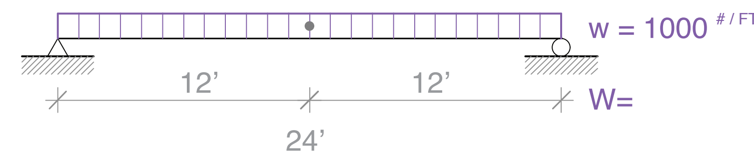

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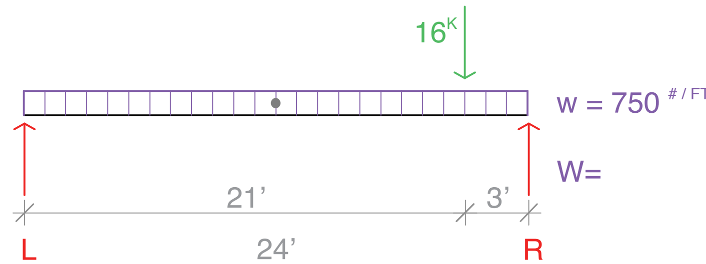

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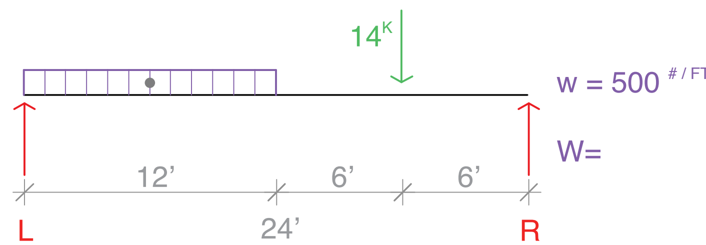

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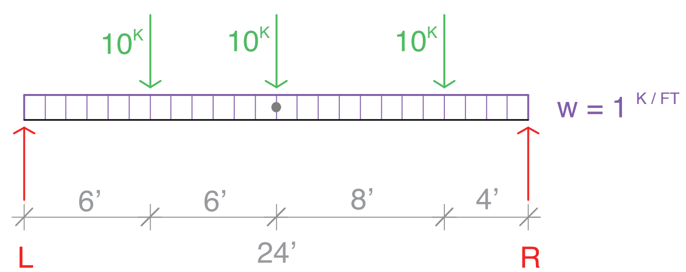

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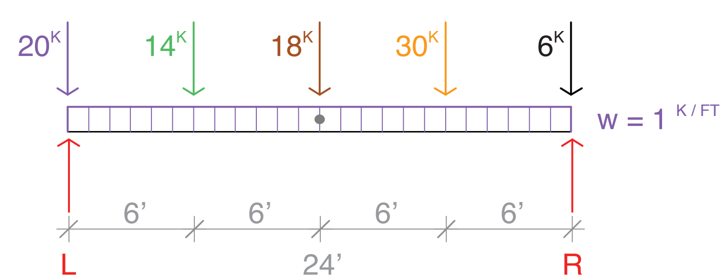

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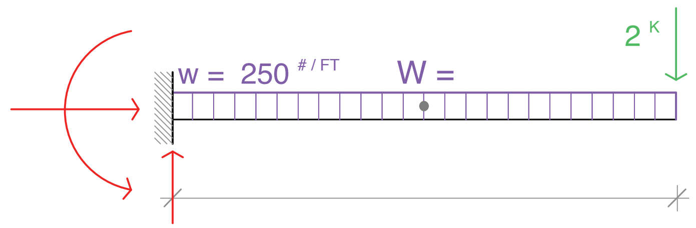
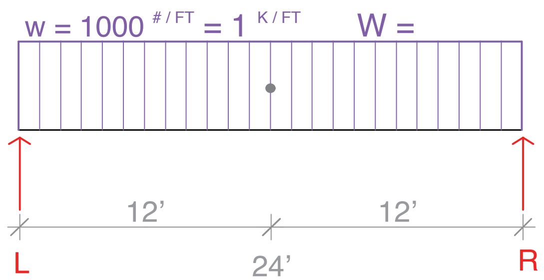


Reactions:

	Left	Right
a.	5.5 K	17 K
b.	10 K	12.5 K
c.	3.5 K	19 K
d.	5.25 K	9.75 K

(12)



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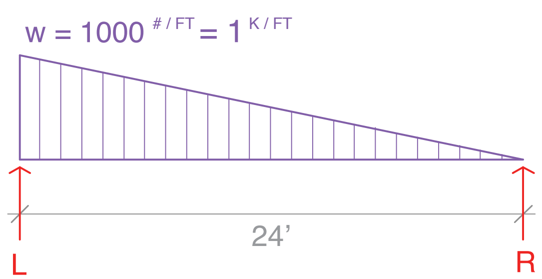

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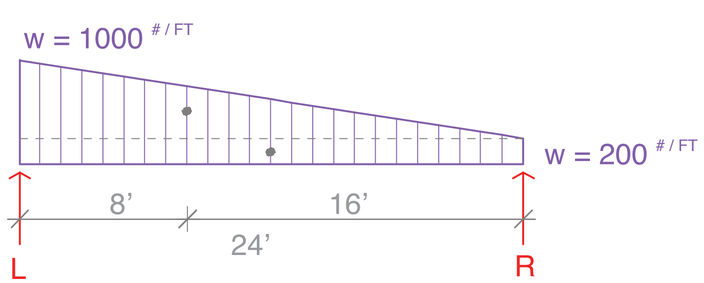

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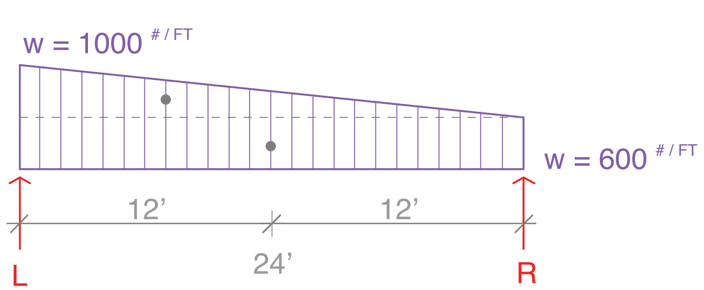

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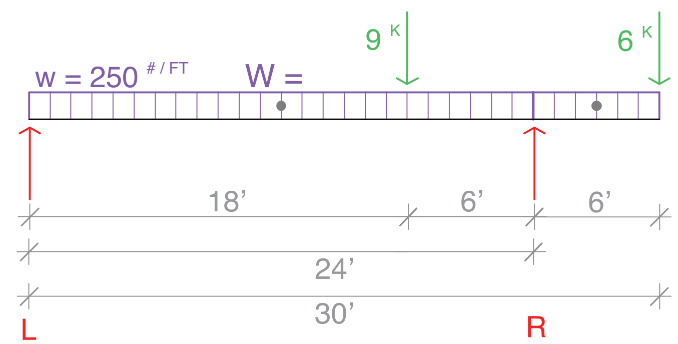

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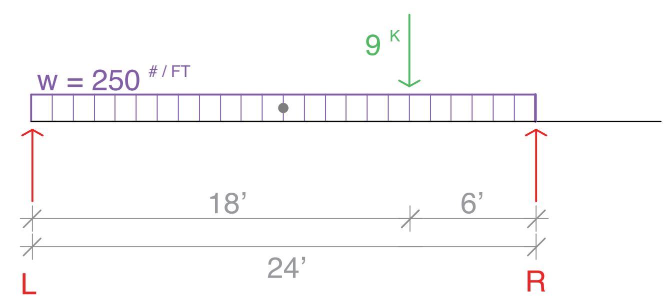

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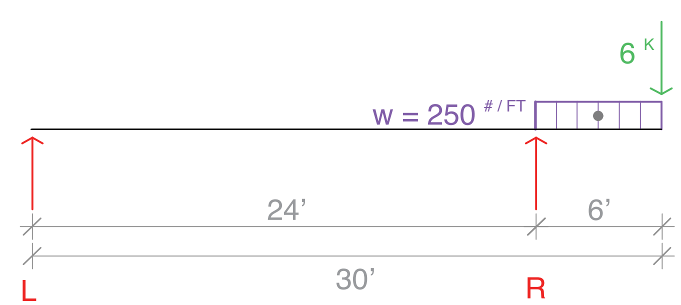
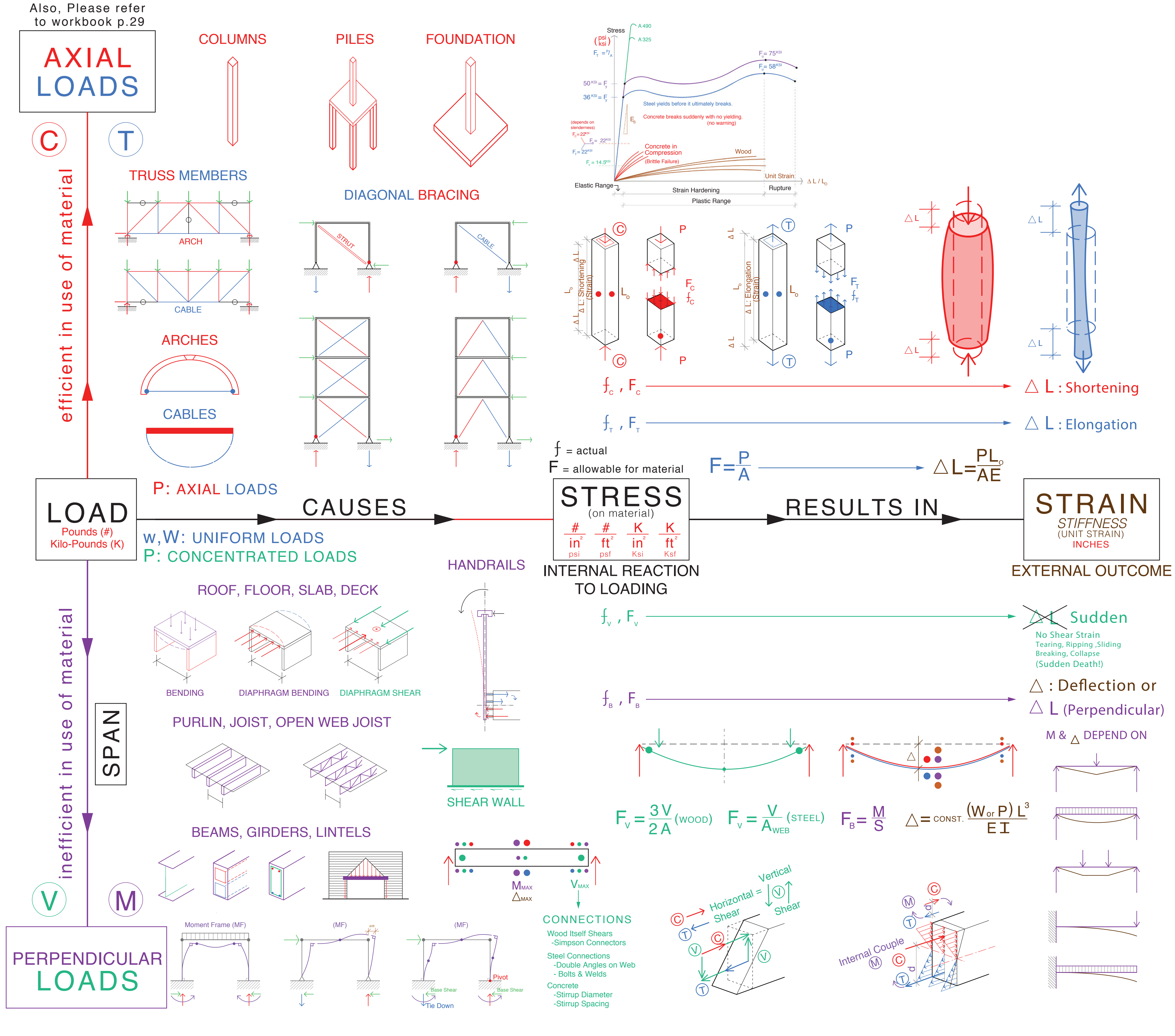
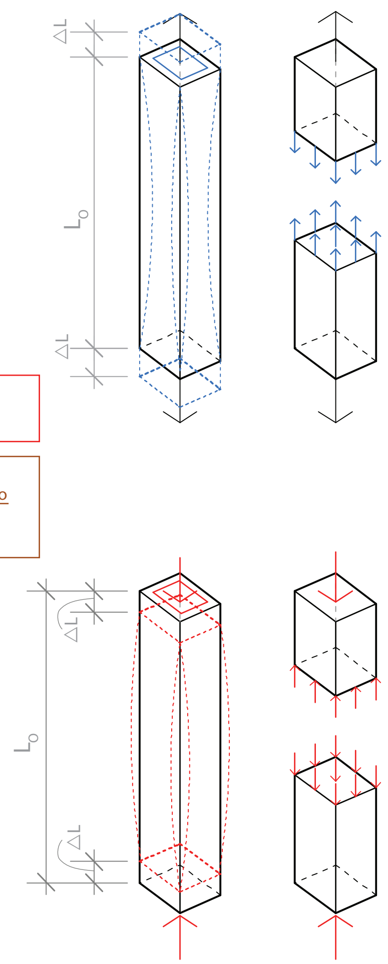


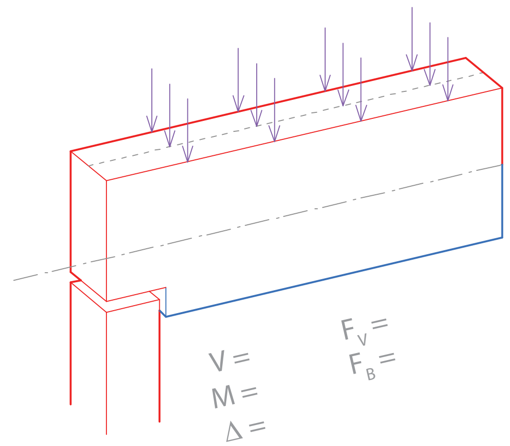

Also, Please refer to workbook p.29
AXIAL LOADS
C
T
efficient in use of material
COLUMNS
PILES
FOUNDATION
TRUSS MEMBERS
ARCH
CABLE
DIAGONAL BRACING
STRUT
CABLE
ARCHES
CABLES
Stress
Steel yields before it ultimately breaks.
Concrete breaks suddenly with no yielding (no warning)
Concrete in Compression (Brittle Failure)
Wood
Unit Strain
Elastic Range
Strain Hardening
Plastic Range
Rupture
P
ΔL : Shortening
ΔL : Elongation
ƒ = actual
F = allowable for material
F = P/A
ΔL = PLo/AE
LOAD
Pounds (#)
Kilo-Pounds (K)
P: AXIAL LOADS
CAUSES
STRESS
(on material)
in² psi
ft² psf
K in² Ksi
K ft² Ksf
RESULTS IN
STRAIN
STIFFNESS
(UNIT STRAIN)
INCHES
w,W: UNIFORM LOADS
P: CONCENTRATED LOADS
INTERNAL REACTION TO LOADING
EXTERNAL OUTCOME
HANDRAILS
ROOF, FLOOR, SLAB, DECK
BENDING
DIAPHRAGM BENDING
DIAPHRAGM SHEAR
Sudden
No Shear Strain
Tearing, Ripping, Sliding
Breaking, Collapse
(Sudden Death!)
Δ : Deflection or
Δ L (Perpendicular)
M & Δ DEPEND ON
SPAN
PURLIN, JOIST, OPEN WEB JOIST
SHEAR WALL
inefficient in use of material
BEAMS, GIRDERS, LINTELS
Fv = 3V/2A (WOOD)
Fv = V/AWEB (STEEL)
FB = M/S
Δ = CONST. (W or P) L³/EI
MMAX
ΔMAX
VMAX
CONNECTIONS
Wood Itself Shears
-Simpson Connectors
Steel Connections
-Double Angles on Web
- Bolts & Welds
Concrete
-Stirrup Diameter
-Stirrup Spacing
Horizontal Shear = Vertical Shear
Internal Couple
V
M
PERPENDICULAR LOADS
Moment Frame (MF)
(MF)
(MF)
Base Shear
Tie Down
Pivot
Base Shear

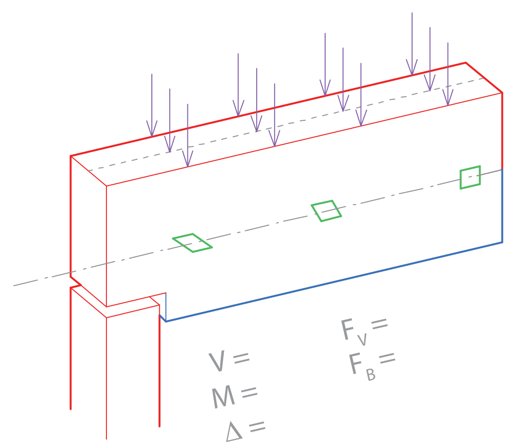


Axial

$F_{T/C} = P / A$

$\Delta L = \dfrac{PL_o}{AE}$



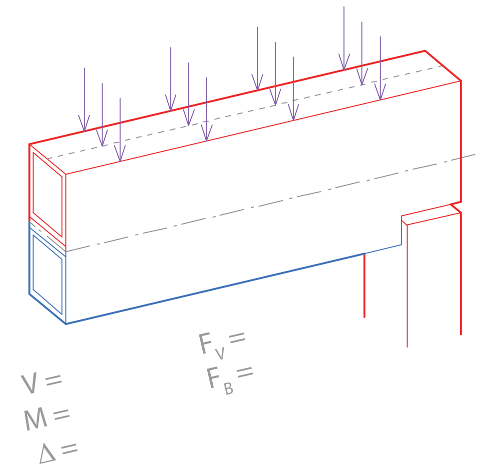


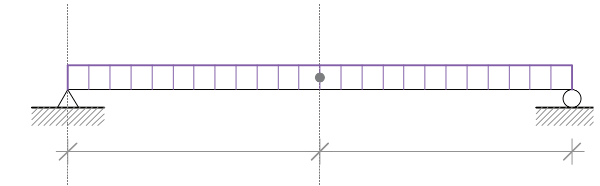
Bending / Flexure

$F_B = \dfrac{M_{max}}{S}$

Deflection

$\Delta = \text{constant} \times \dfrac{(W \text{ OR } P) \times L^3}{EI}$



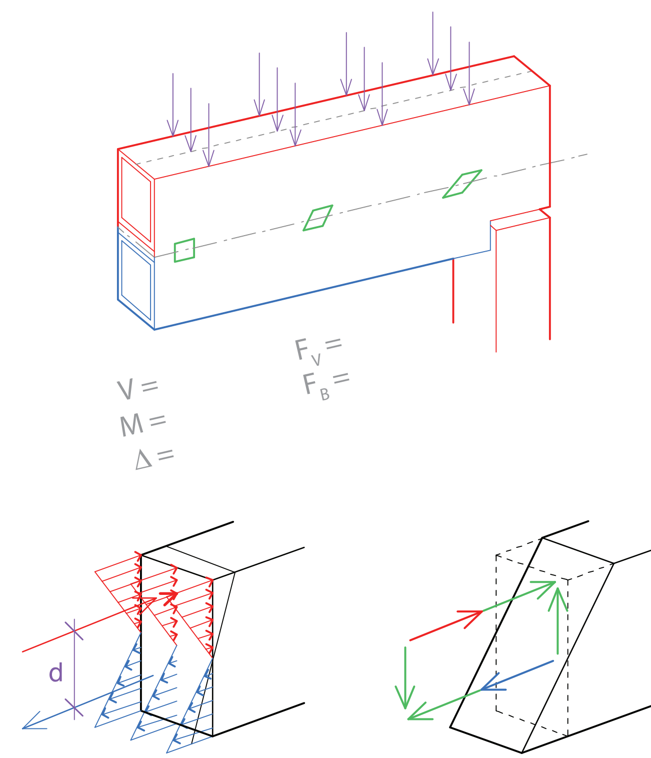


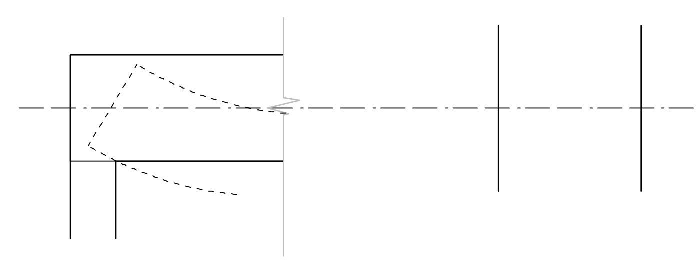
Shear

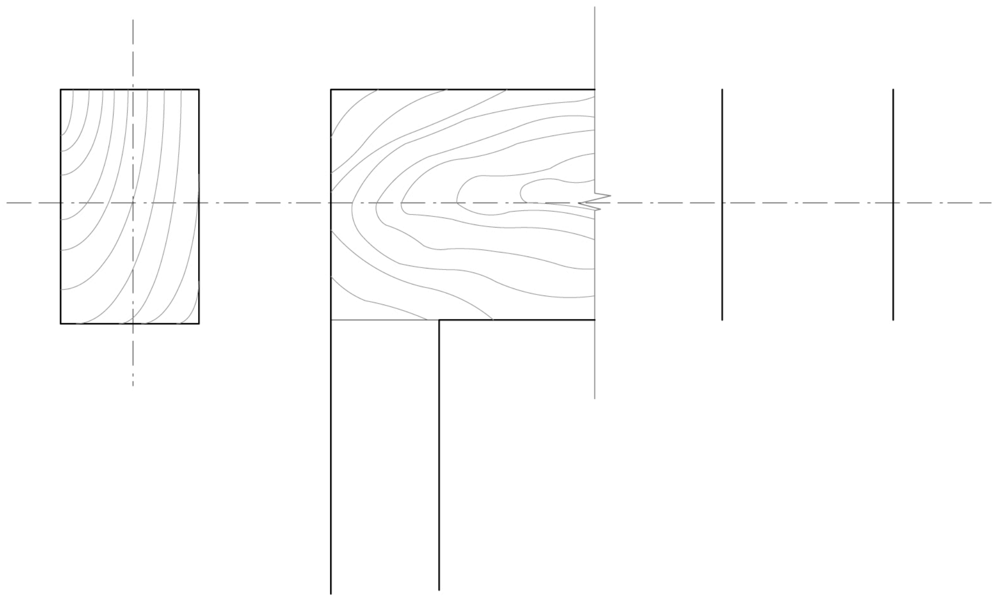
$F_v \, \alpha \, \dfrac{V_{max}}{A}$

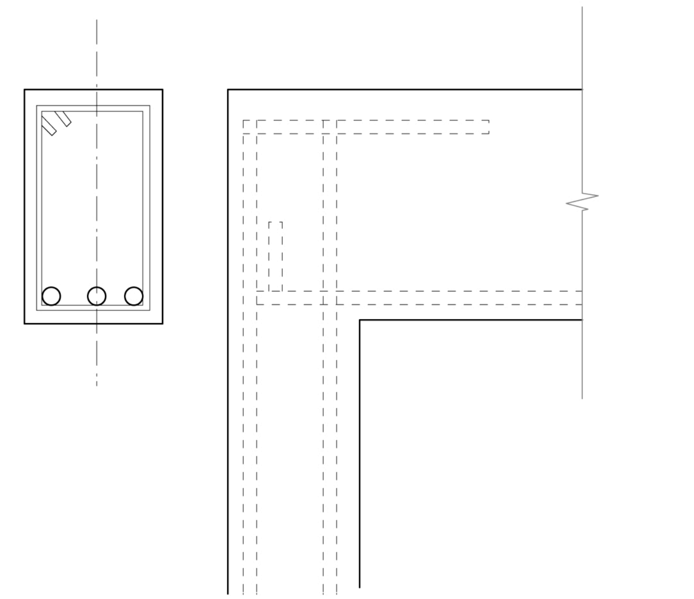
$F_v = \dfrac{3 V_{max}}{2A}$

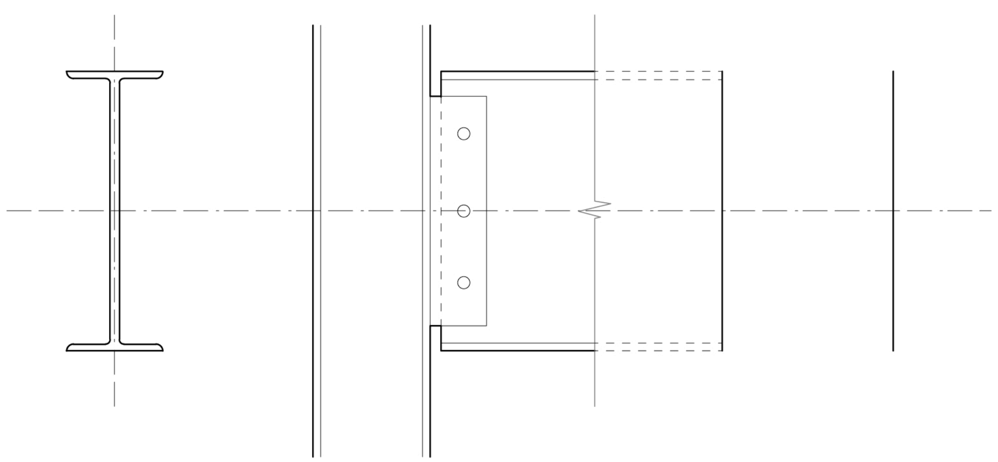
$F_v = \dfrac{V_{max}}{A_{web}}$

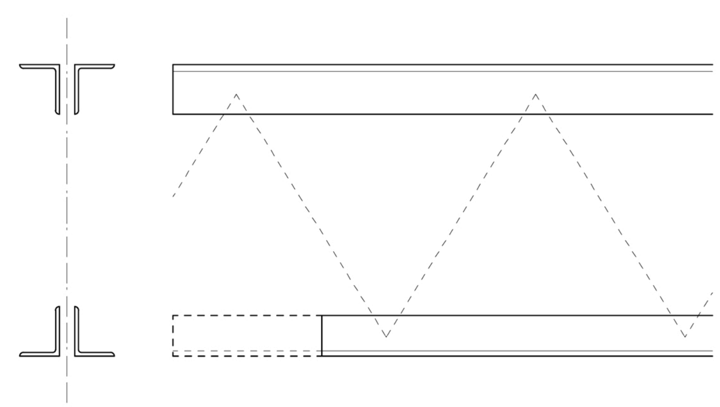


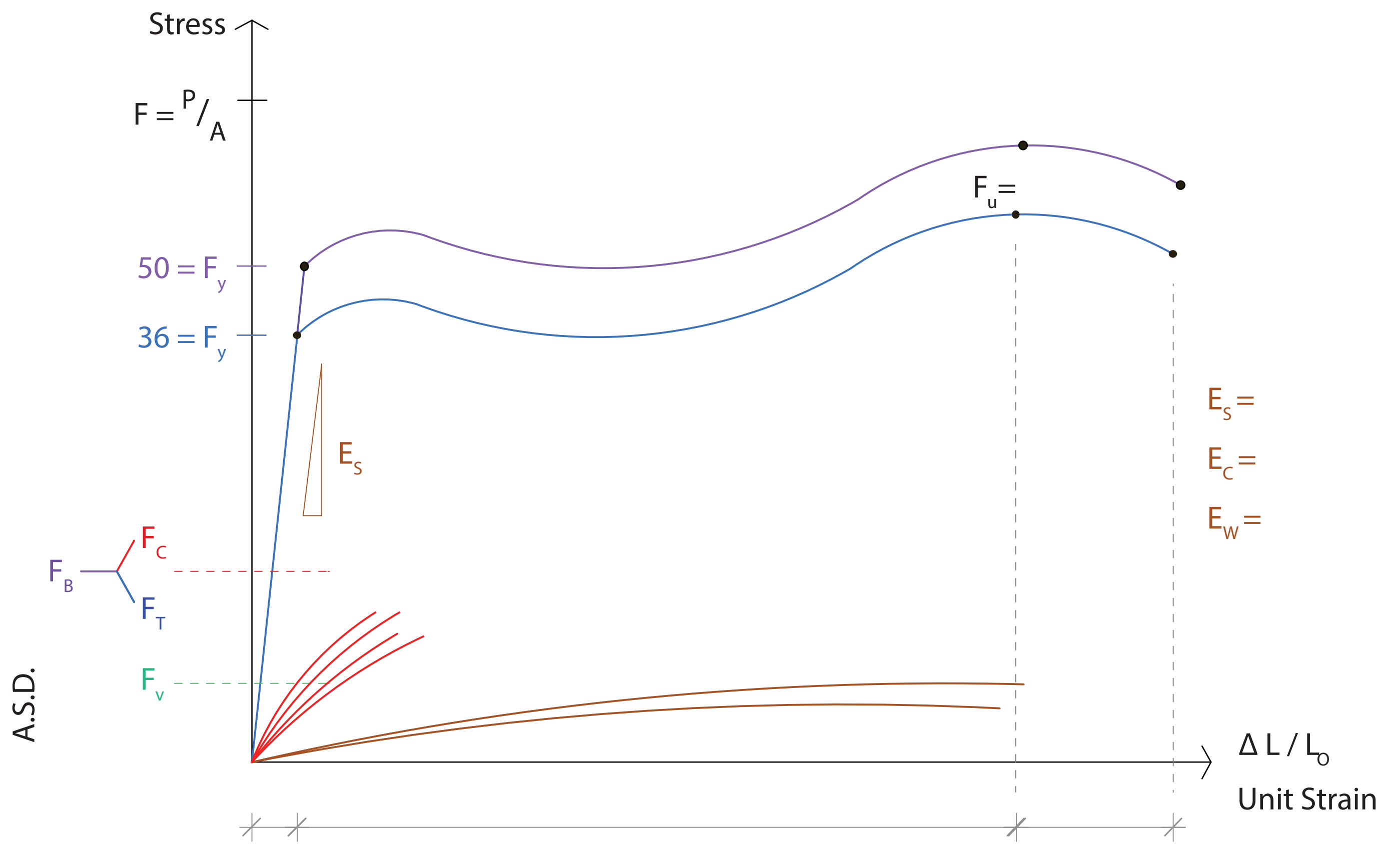


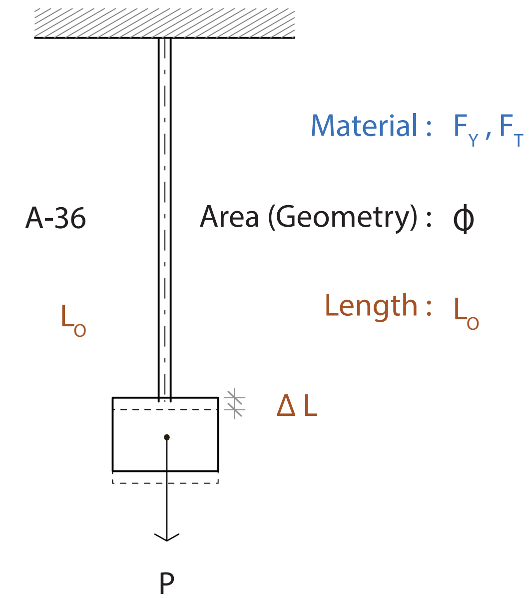


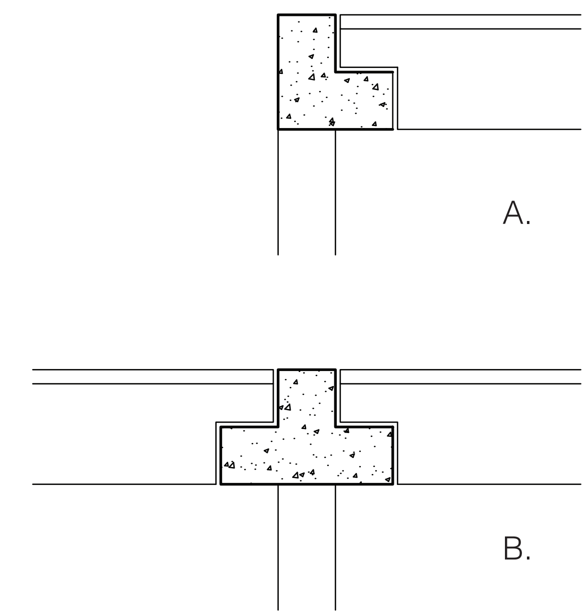












Stress : F =

Unit Strain : Δ L / L_o =

Modulus of Elasticity : E =
(Young's Modulus)

Axial Elongation / Shortening Δ L =

Thermal Elongation : Δ L =

P :

A :

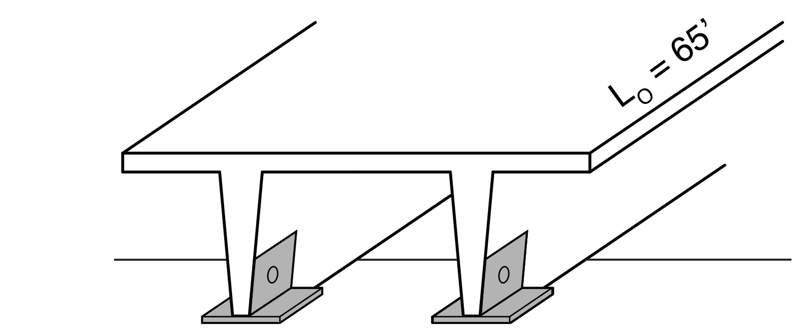
F :

Δ L :

L_o :

Δ L / L_o :

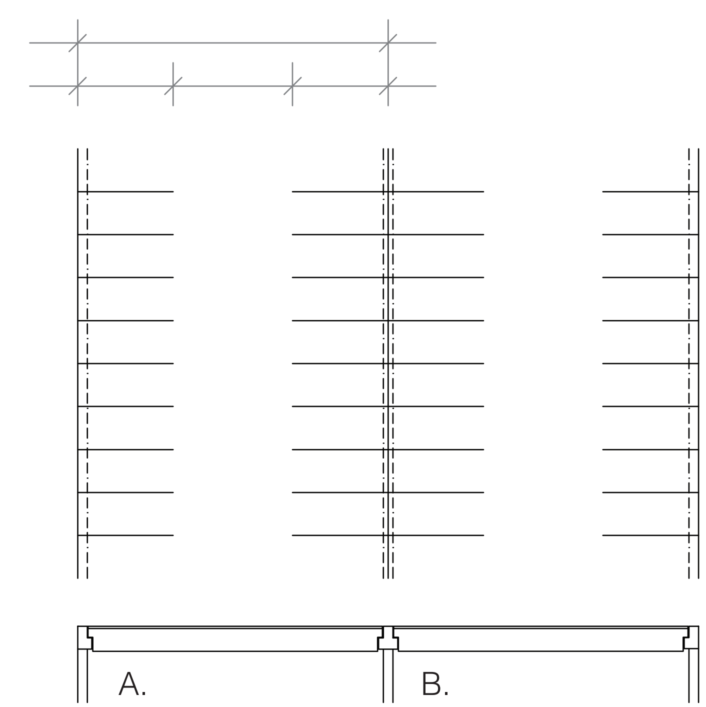
E :



	∝= Coefficient of Thermal Expansion and Contraction (IN / IN / ºF)
Aluminum	0.0000128*
Steel	0.0000065ᵗ
Concrete	0.0000055
Glass	0.0000044
Wood	0.0000033

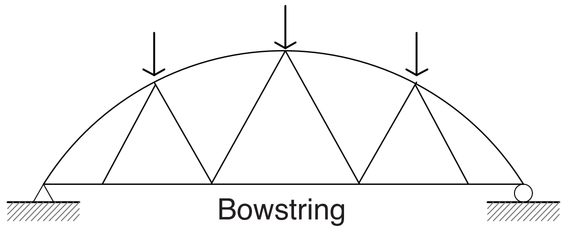
**Aluminum expands twice as much as steel

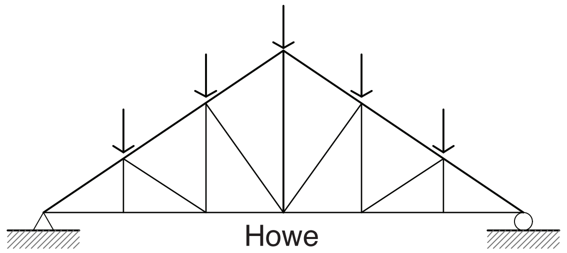
ᵗ Steel and Concrete are thermally similar

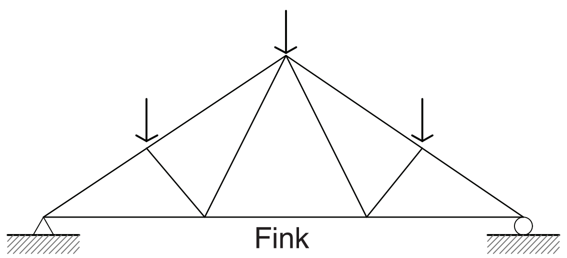


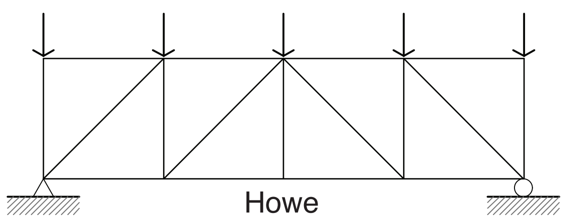
For an Honest Truss / Diagonal Bracing

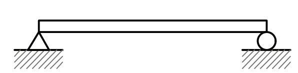
- All Joints must be Pinned
- All Loads must be Applied on Joints Only
- All Panels must be Triangles

1

Bowstring

2

Howe

3

Fink

4

Howe



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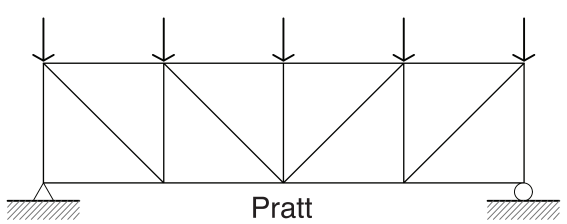
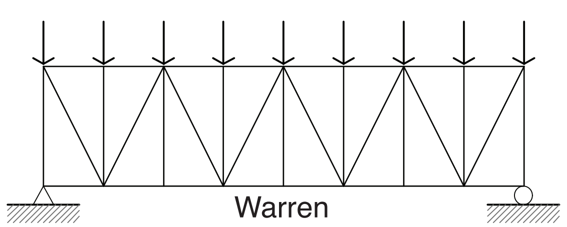
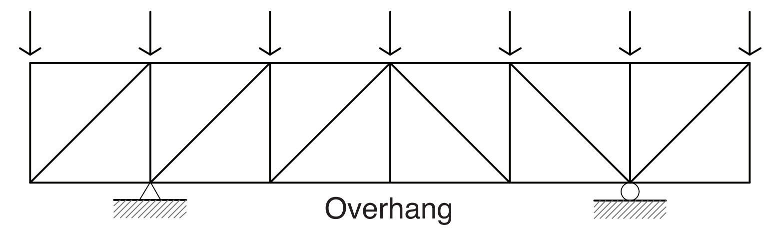
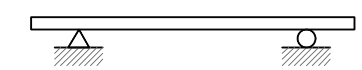
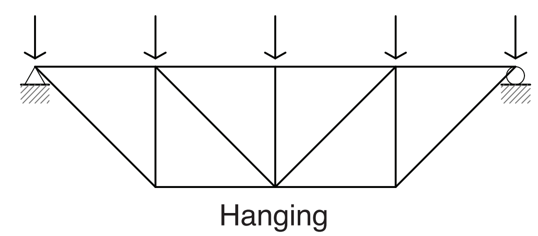
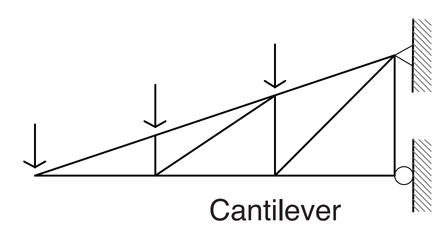

Pratt

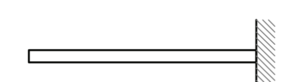
6

Warren

7

Overhang

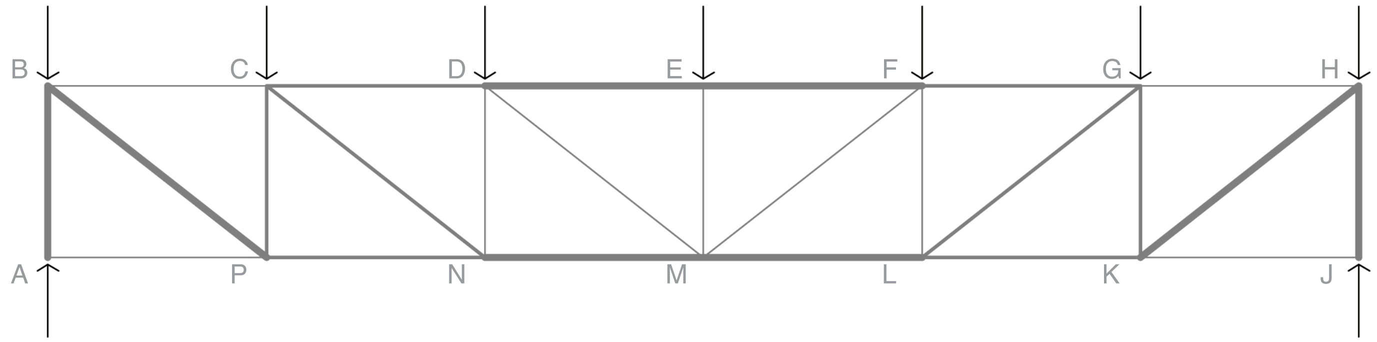


8

Hanging

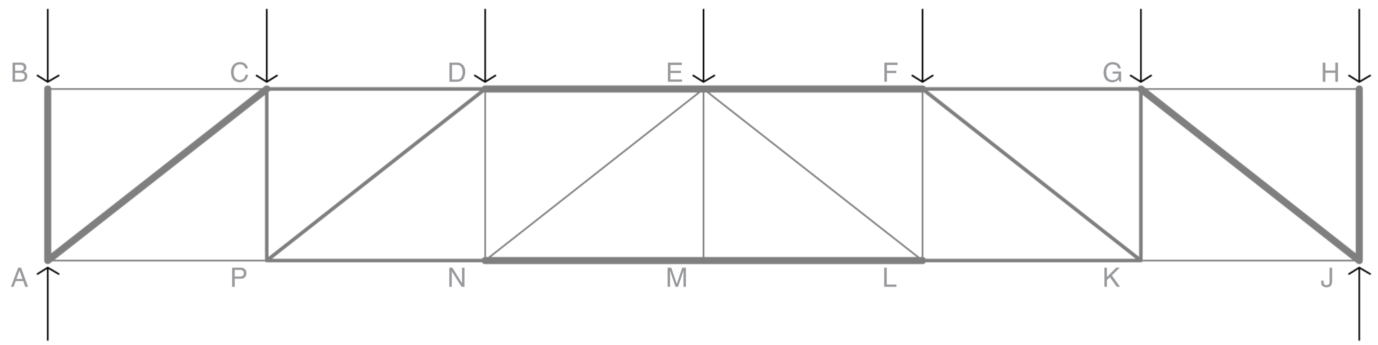
9

Cantilever



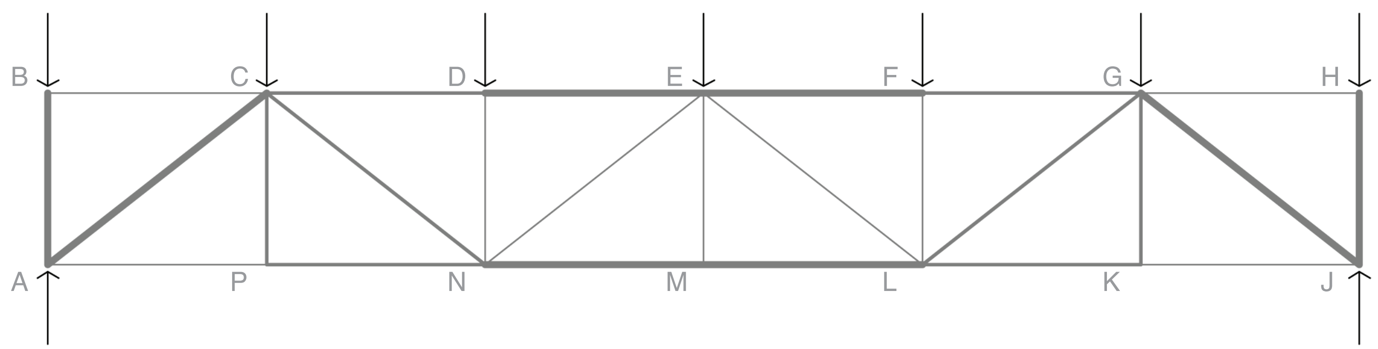
Pratt



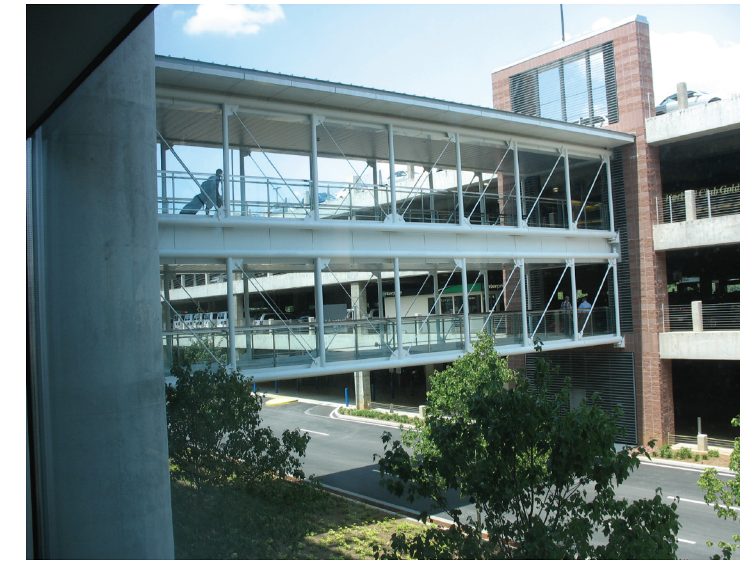
Howe

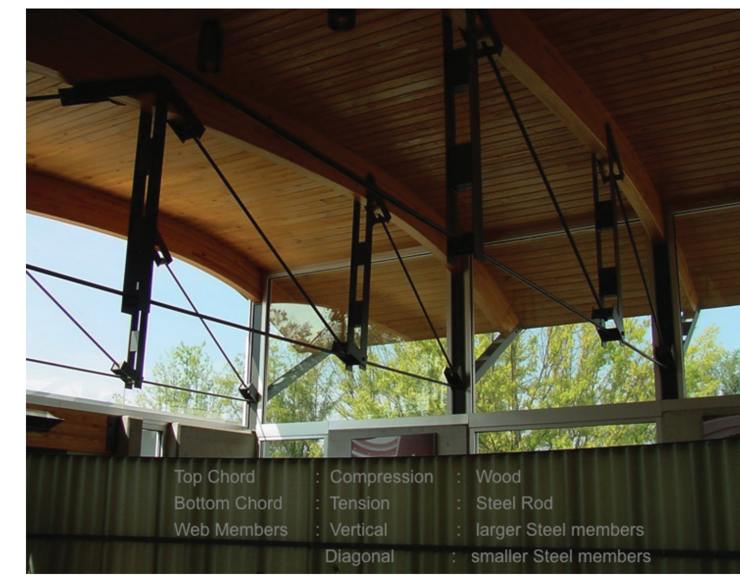


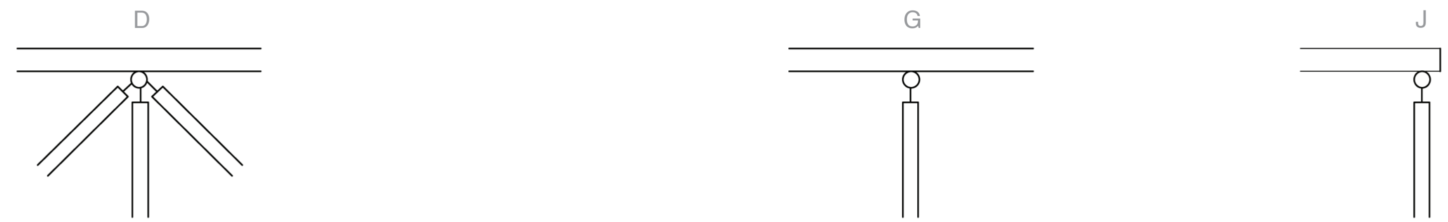
Warren

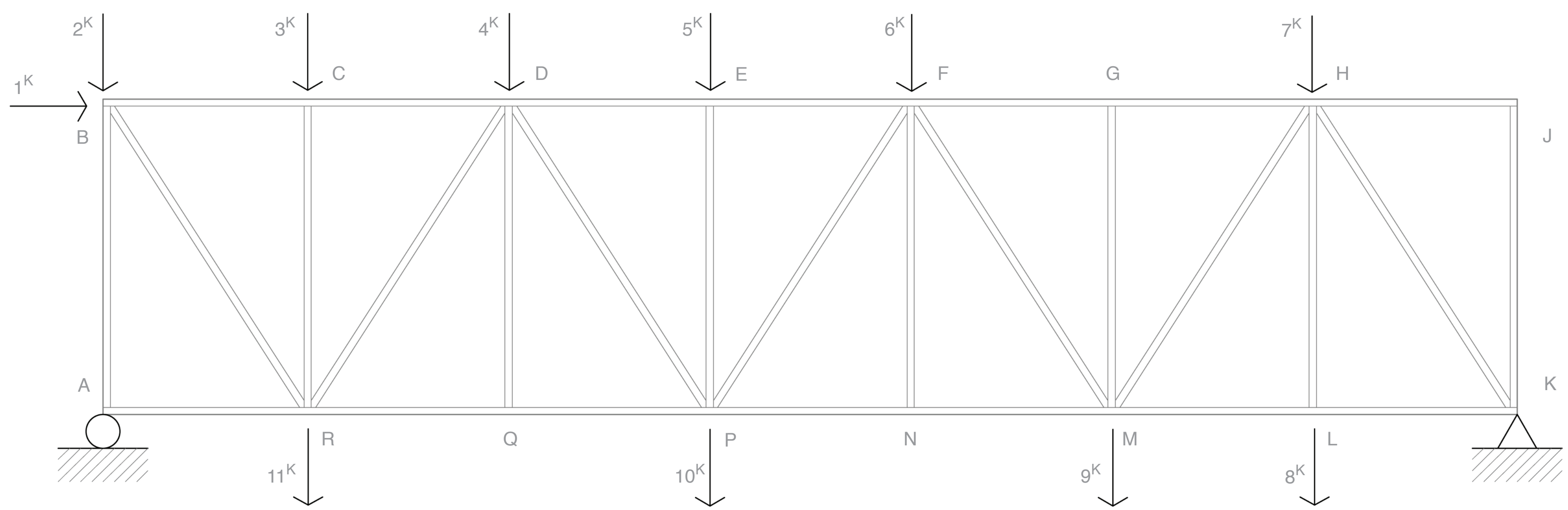


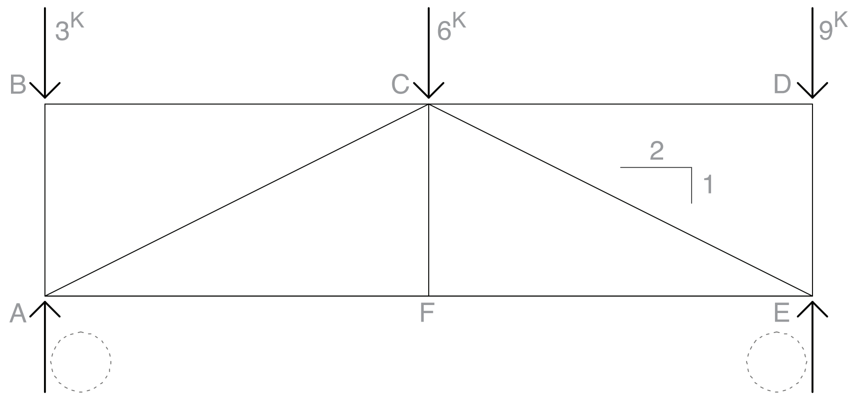
Cantilever



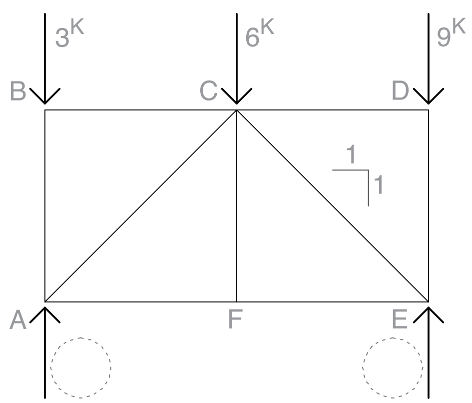



D
G
J

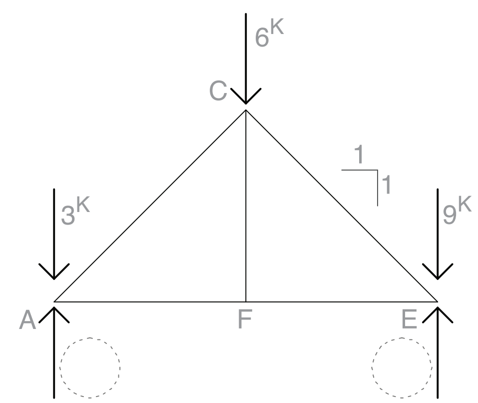

1K
2K
3K
4K
5K
6K
7K
B
C
D
E
F
G
H
J
A
K
R
Q
P
N
M
L
11K
10K
9K
8K


3^K
6^K
9^K
B
C
D
2
1
A
F
E

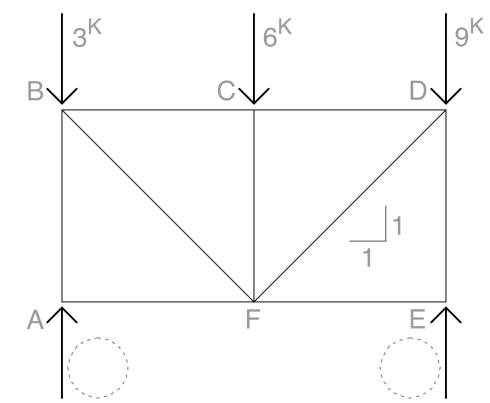
1


3^K
6^K
9^K
B
C
D
1
1
A
F
E

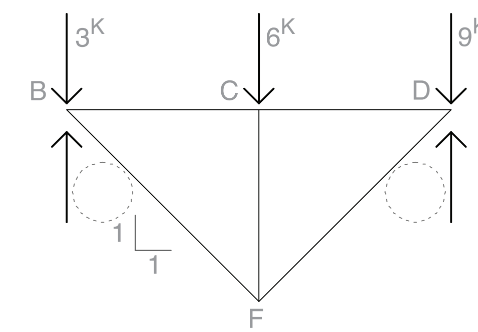
2


6^K
C
1
1
3^K
9^K
A
F
E

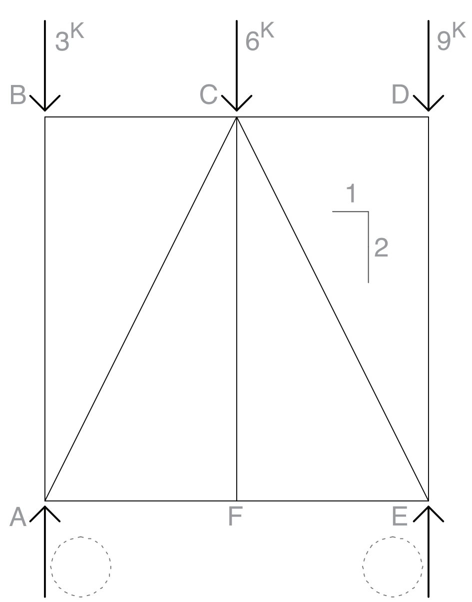
3


3^K
6^K
9^K
B
C
D
1
1
A
F
E

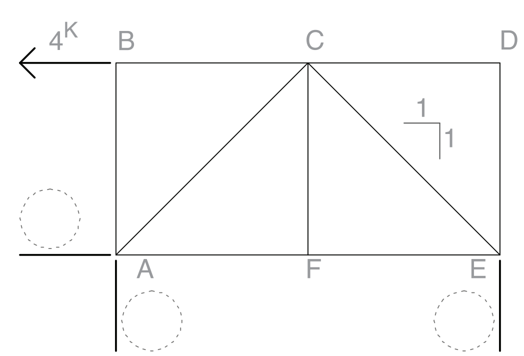
4


3^K
6^K
9^K
B
C
D
1
1
F

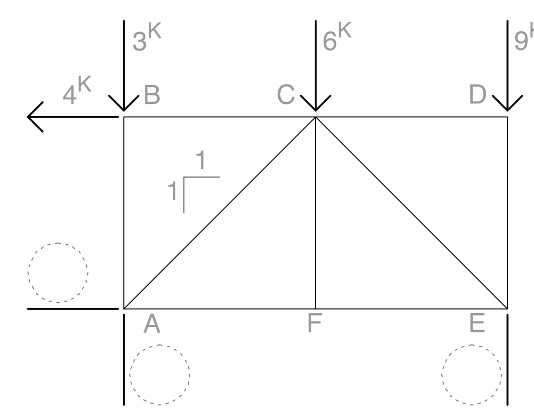
5


3^K
6^K
9^K
B
C
D
1
2
A
F
E

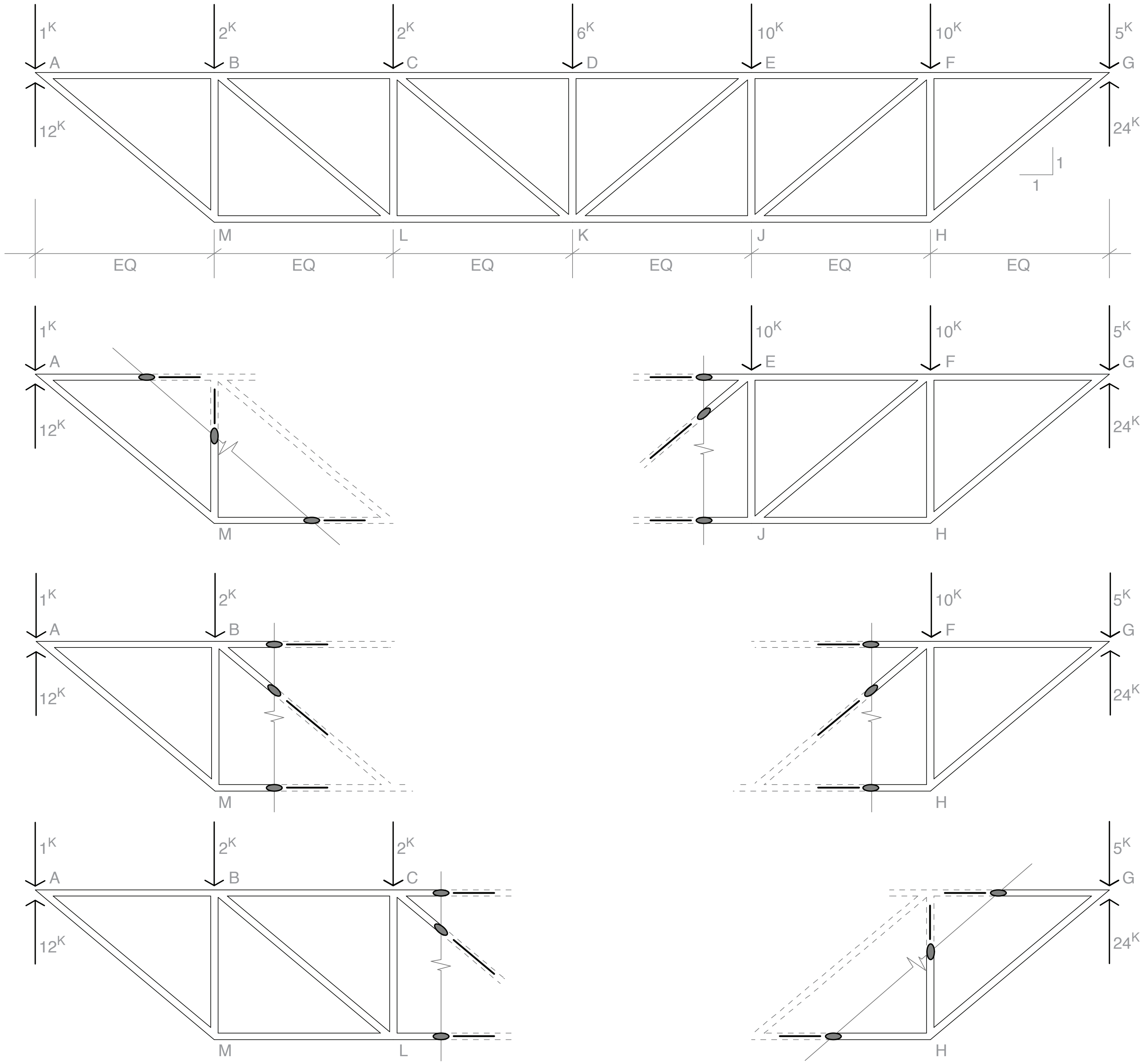
6


4^K
B
C
D
1
1
A
F
E

7


3^K
6^K
9^K
4^K
B
C
D
1
1
A
F
E

8

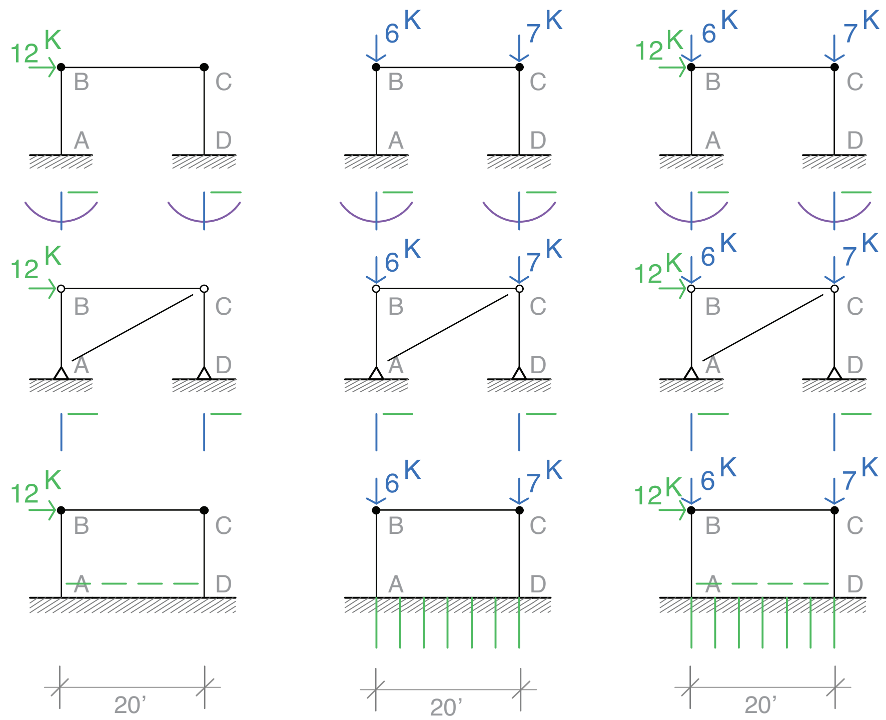


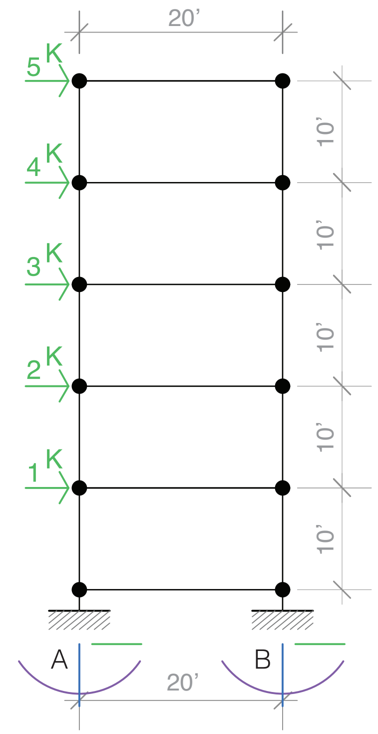
Roof truss has been partially cleared of snow load resulting in load diagram shown.

Calculate the internal force in members EK, FJ, FH, BM, BL, & CK

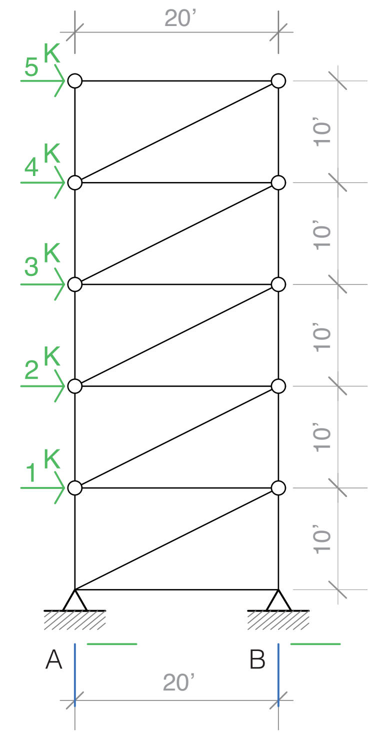
Adopted from NCARB 3.1

All diagonal bracing on this page is tension only bracing.

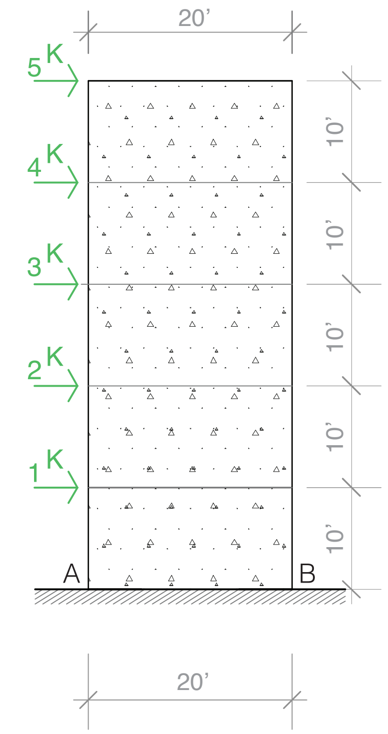




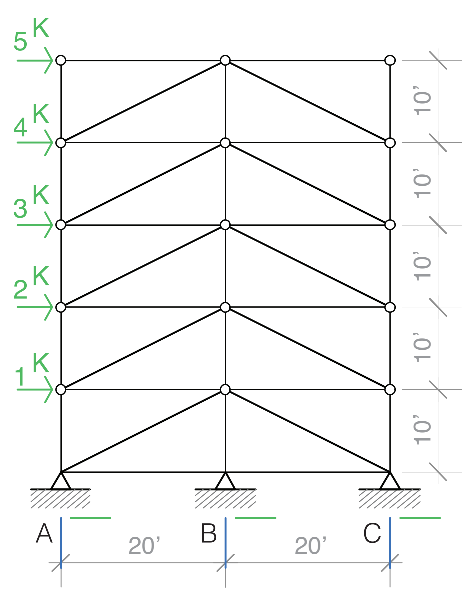
1



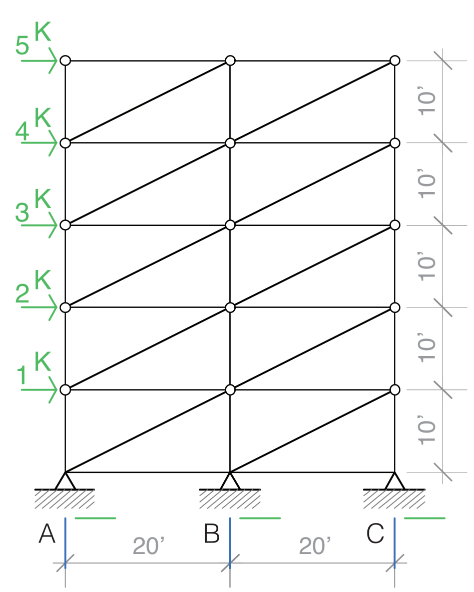
2



3



4



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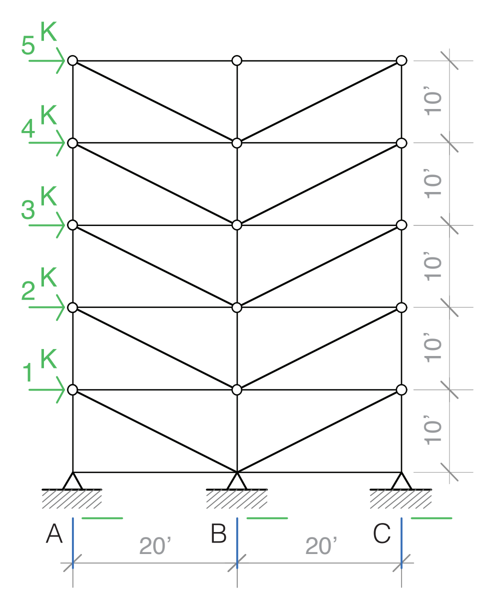

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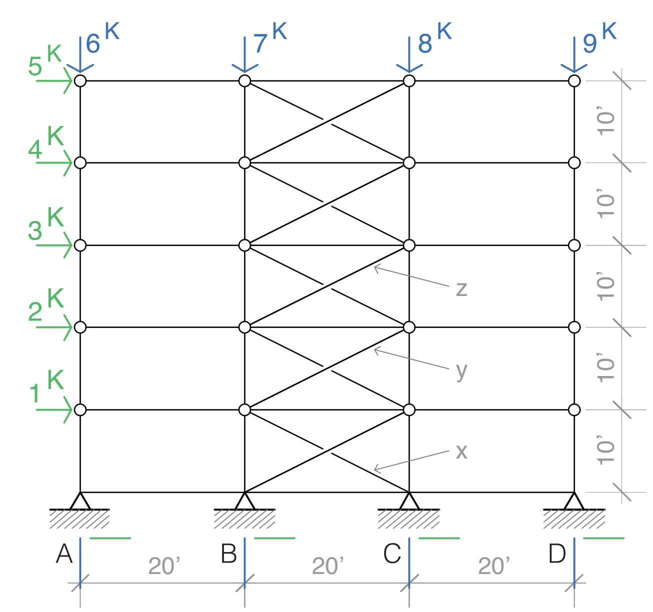
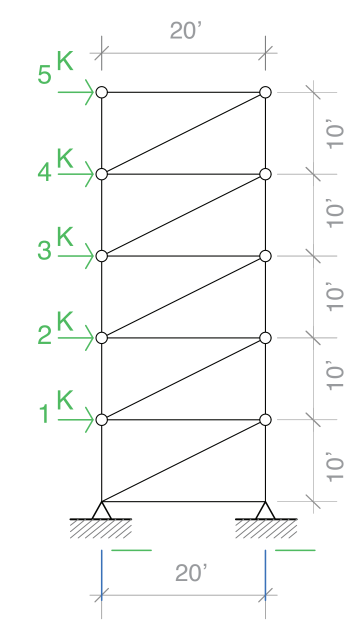
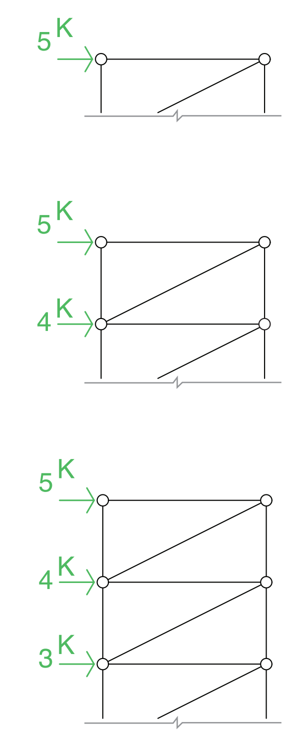
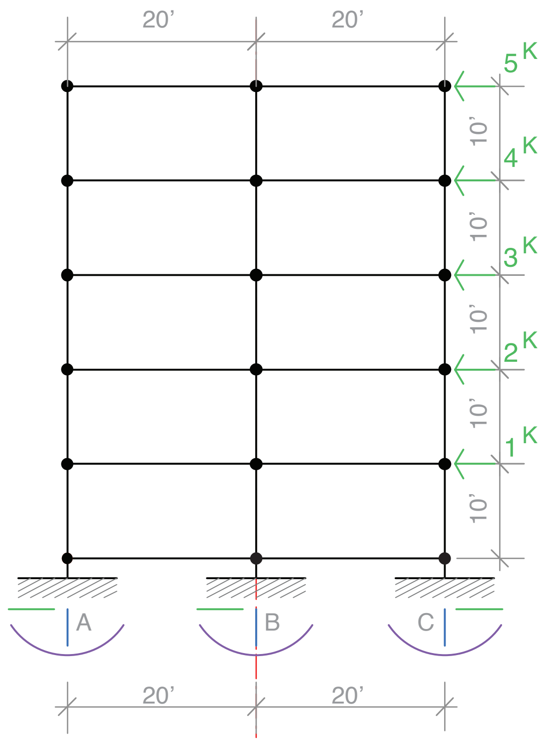


7

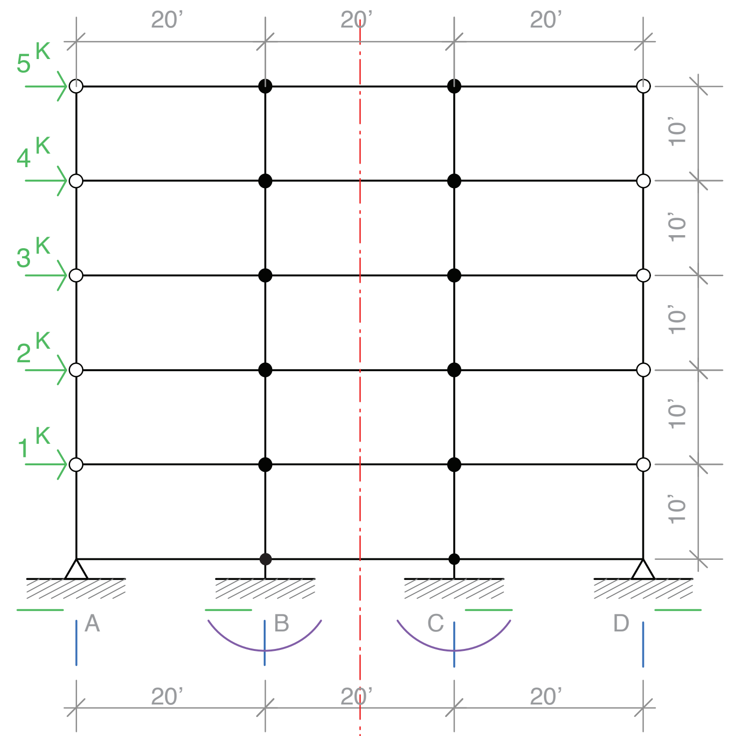
Calculate internal forces in cables 'X' , 'Y', and 'Z'.



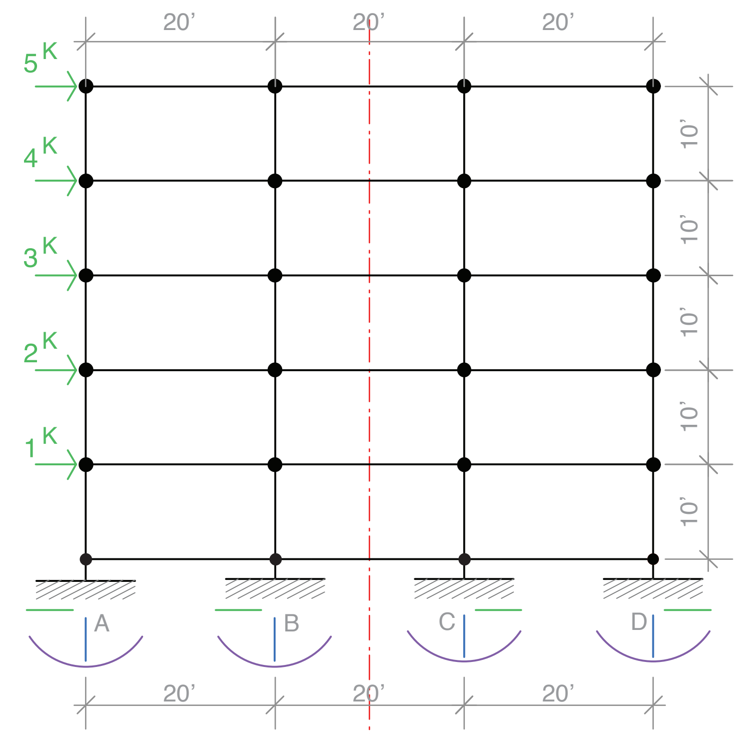



20'
20'
5 K
4 K
3 K
2 K
1 K
10'
A
B
C

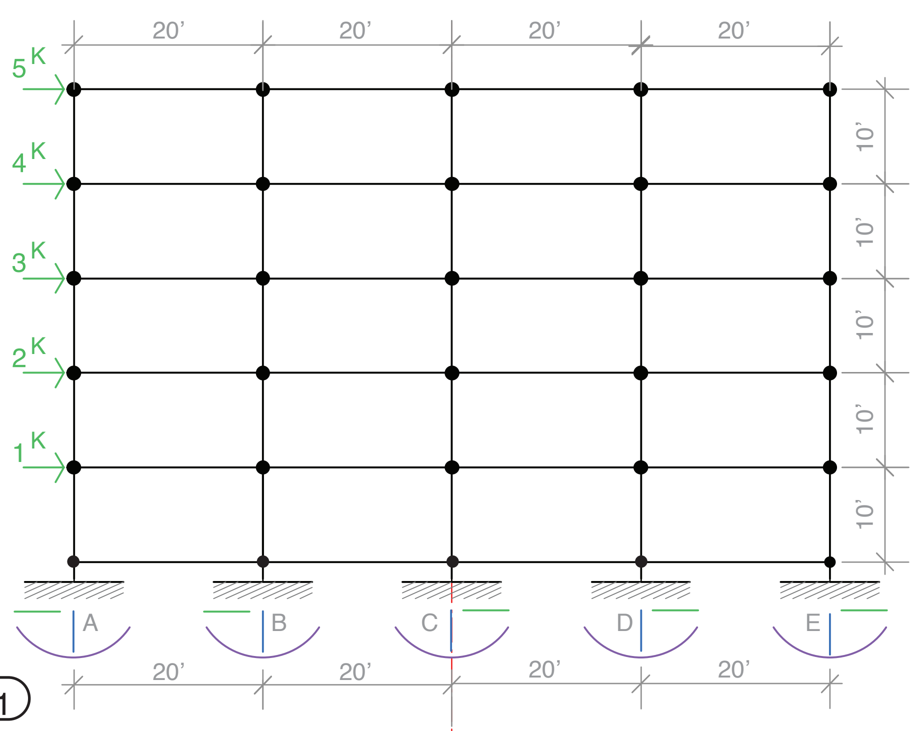
8


20'
20'
20'
5 K
4 K
3 K
2 K
1 K
10'
A
B
C
D

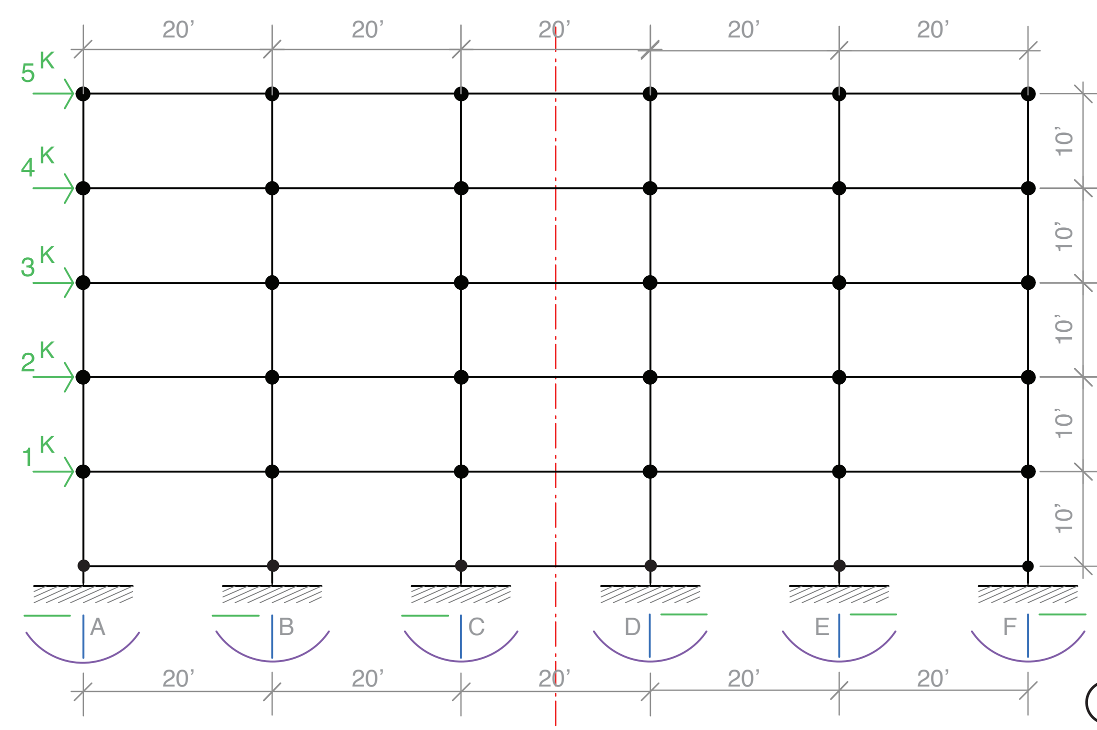
9


20'
20'
20'
5 K
4 K
3 K
2 K
1 K
10'
A
B
C
D

10

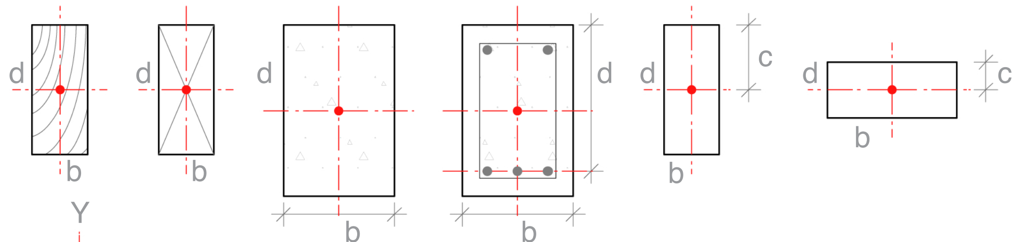

20'
20'
20'
20'
5 K
4 K
3 K
2 K
1 K
10'
A
B
C
D
E

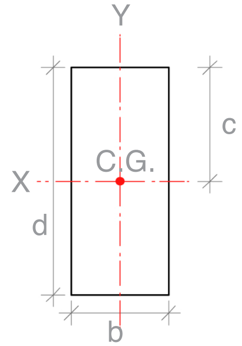
11


20'
20'
20'
20'
20'
5 K
4 K
3 K
2 K
1 K
10'
A
B
C
D
E
F

12

1 Rectangles (Please See Reference p. 15-20)





V : (Shear) A = Area

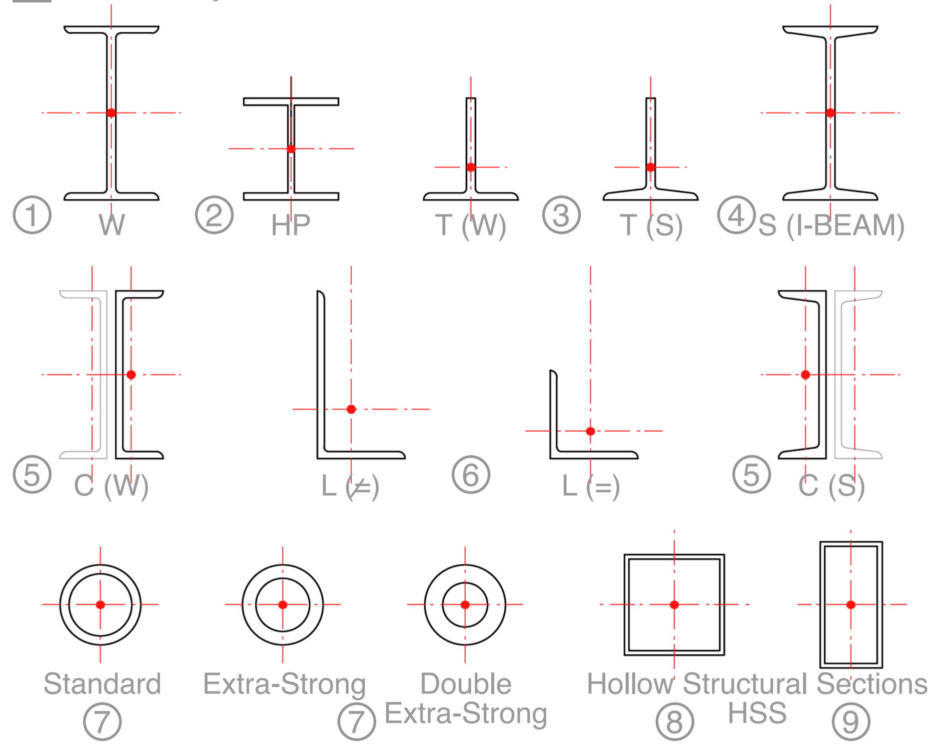
M: (Bending) S = Section Modulus

Δ: (Deflection) I = Moment of Inertia

Shear	: V	:	A	IN^2	Area
Bending	: M	:	S	IN^3	Section Modulus
Deflection	: Δ	:	I	IN^4	Moment of Interia

Area: A = IN^2 Shear (A)→(V)	Section Modulus: S = IN^3 Bending Moment (Flexure) (S)→(M)	Moment of Inertia: I = IN^4 Deflection (Stiffness) (I)→(Δ)

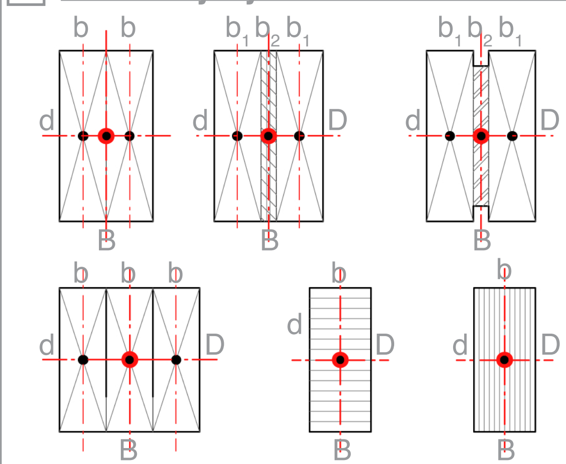
6 Steel Shapes: All properties listed in AISC Manual



Best profile for a beam:

Best profile for a diagonal brace|column:

2 Bilaterally Symmetrical Combinations (solid)

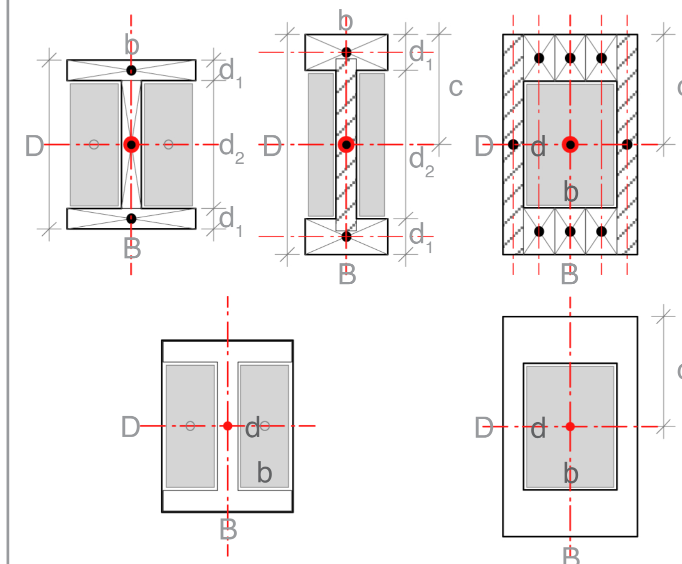


$A = \Sigma A_{parts} = BxD$

$I = \Sigma I_{parts} = \frac{BxD^3}{12}$

$S = \frac{\Sigma I}{c} = \frac{BxD^2}{6} = \Sigma S_{parts}$

3 Bilaterally Symmetrical Combinations (with voids)



$A_{comb.} = \Sigma A_{parts}$

$= A_{whole} - A_{hole}$

$I_{comb.} \neq \Sigma I_{parts}$

$I_{comb.} = I_{whole} - \Sigma I_{hole}$

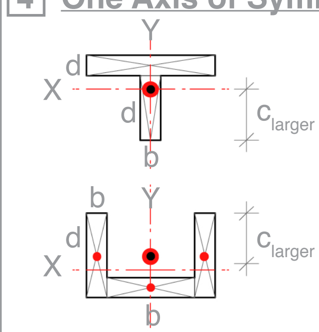
$= \frac{BD^3 - \Sigma(bd^3/12)}{12}$

$S_{comb.} \neq \Sigma S_{parts}$

$\neq S_{Whole} - \Sigma S_{Hole}$

$S_{comb.} = \frac{I_{comb.}}{c}$

4 One Axis of Symmetry



Symmetry about Y-Y axis.
No Symmetry about X-X axis.

Must find $C.G._{comb.}$

$A_{comb.} = \Sigma A_{parts}$

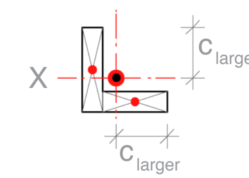
$= A_{whole} - A_{hole}$

$I_{comb.} \neq \Sigma I_{parts}$; $I_{whole} = \Sigma I_0 + Ah^2$ (Transfer Formula)

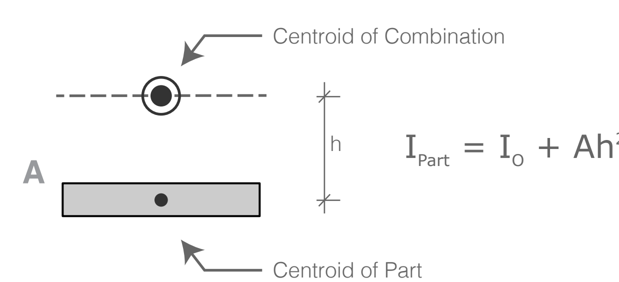
$S_{comb.} \neq \Sigma S_{parts}$

$S_{comb.} = \frac{I_{comb.}}{c_{larger}}$

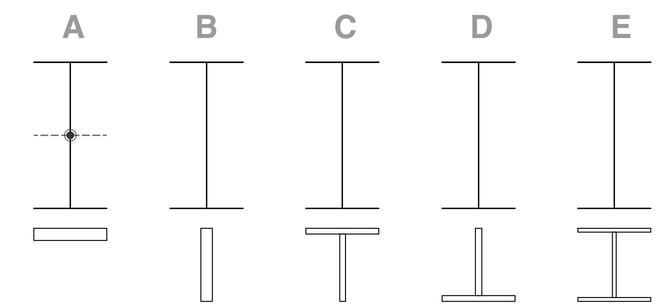
5 No Axis of Symmetry



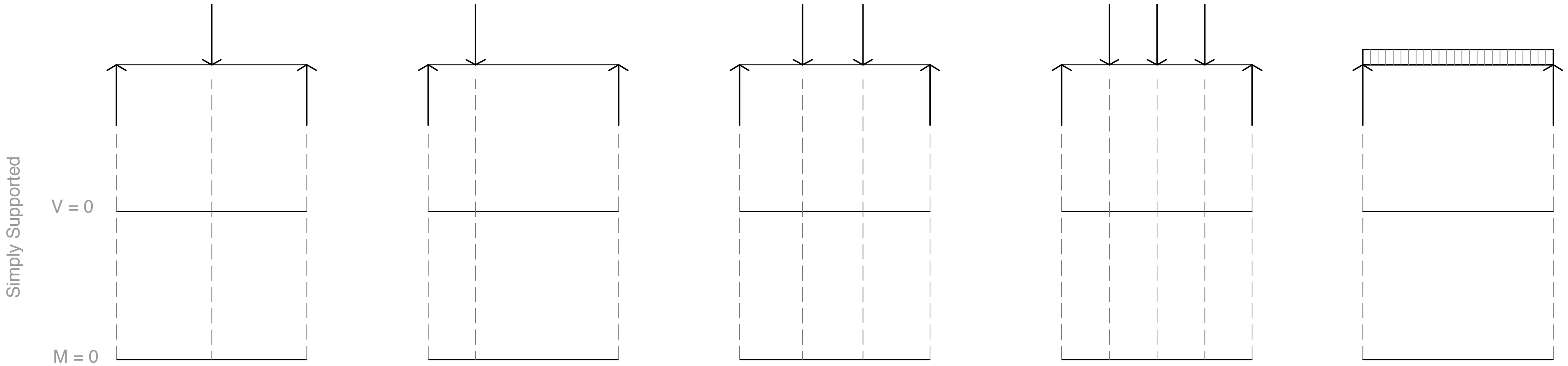
No symmetry about Y-Y axis.
No Symmetry about X-X axis.

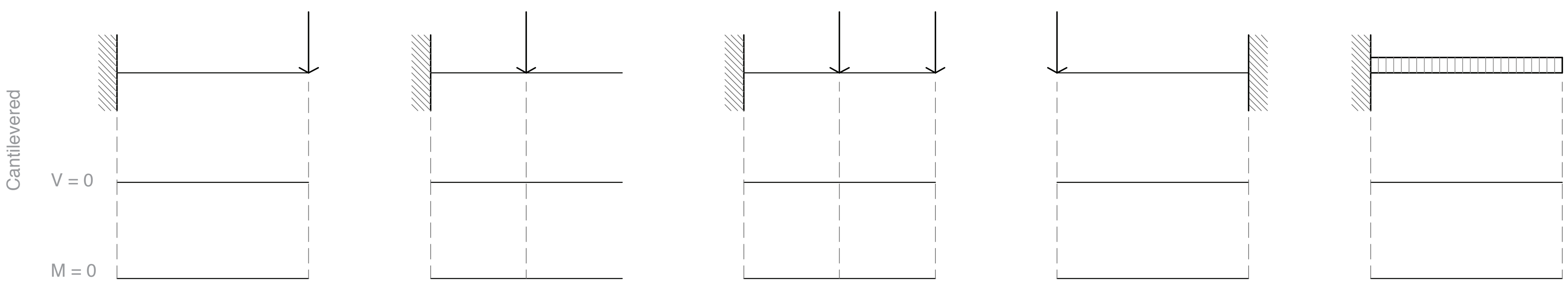


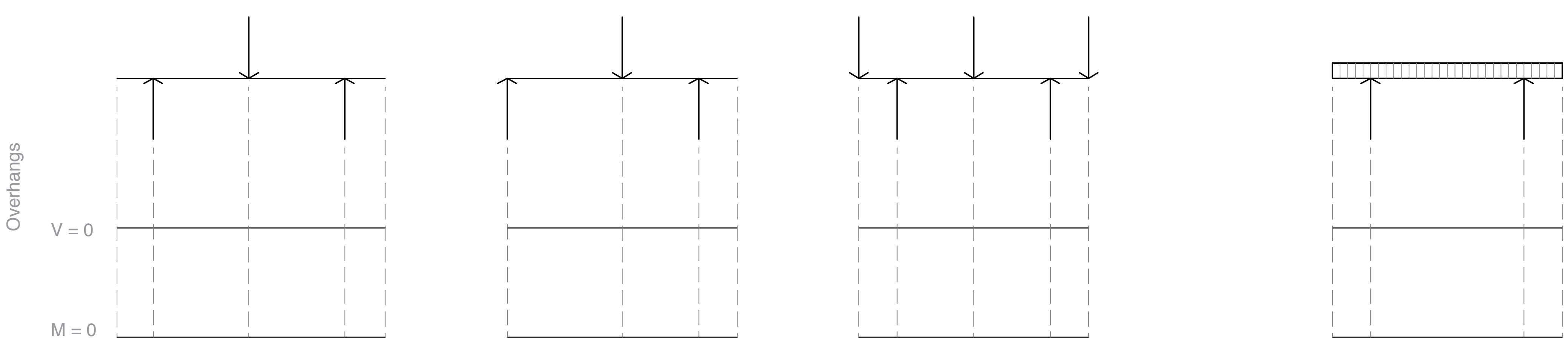
$I_{Part} = I_o + Ah^2$



Existing wide flange in warehouse deflects excessively. Which option reduces the deflection the most?



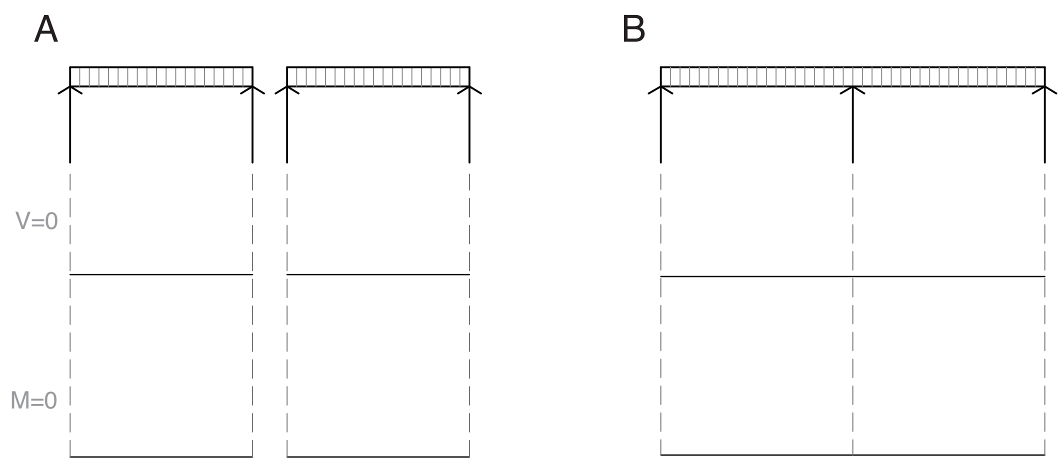




T H A D D E U S

SHEAR (V) & BENDING MOMENT (M) DIAGRAMS

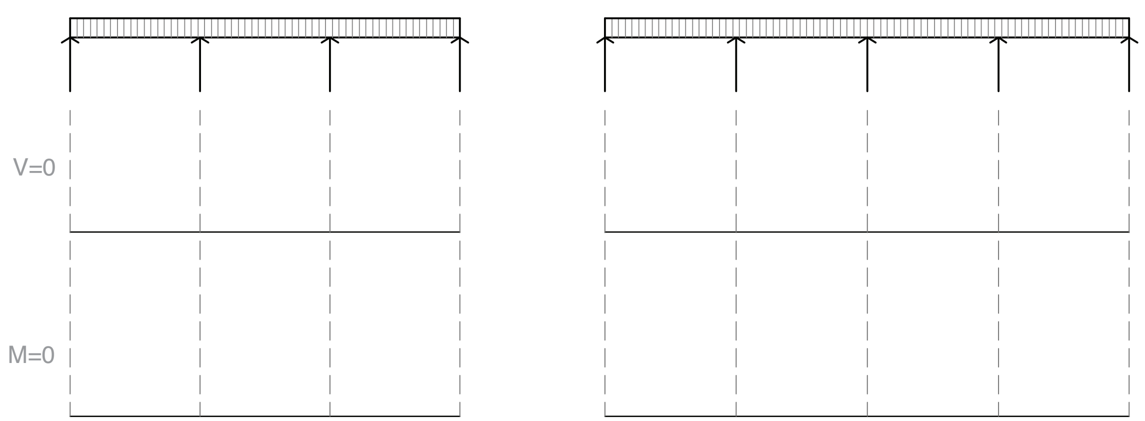
Multiple Span



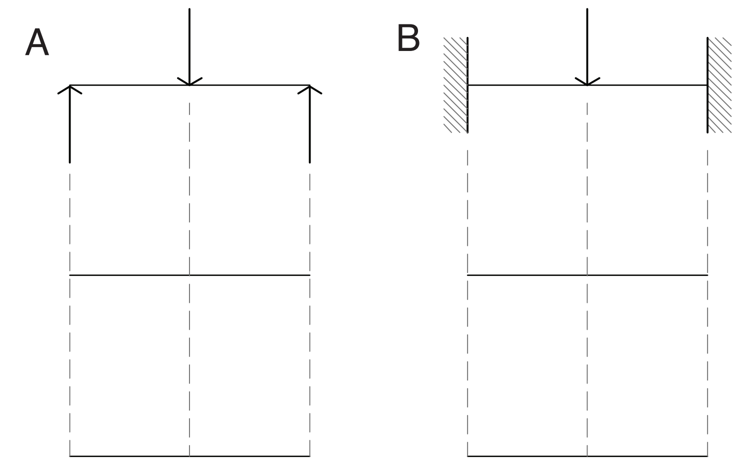
1. Greatest Maximum Shear? A, B ?

2. Greatest Maximum Positive Moment? A, B ?

3. Greatest Maximum Negative Moment? A, B ?



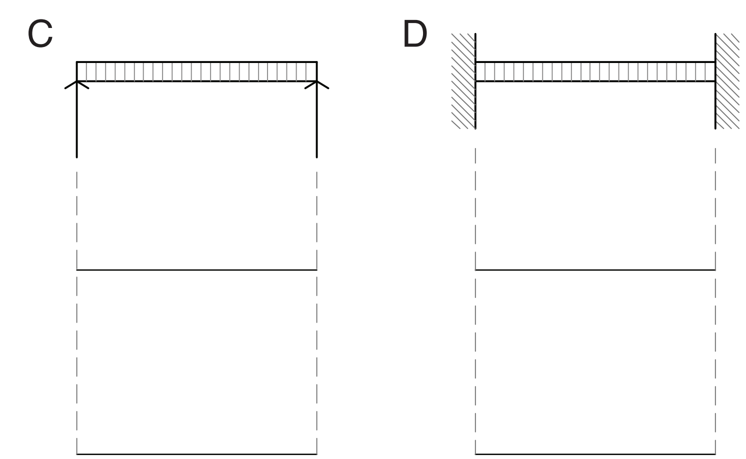
Fixed Ends

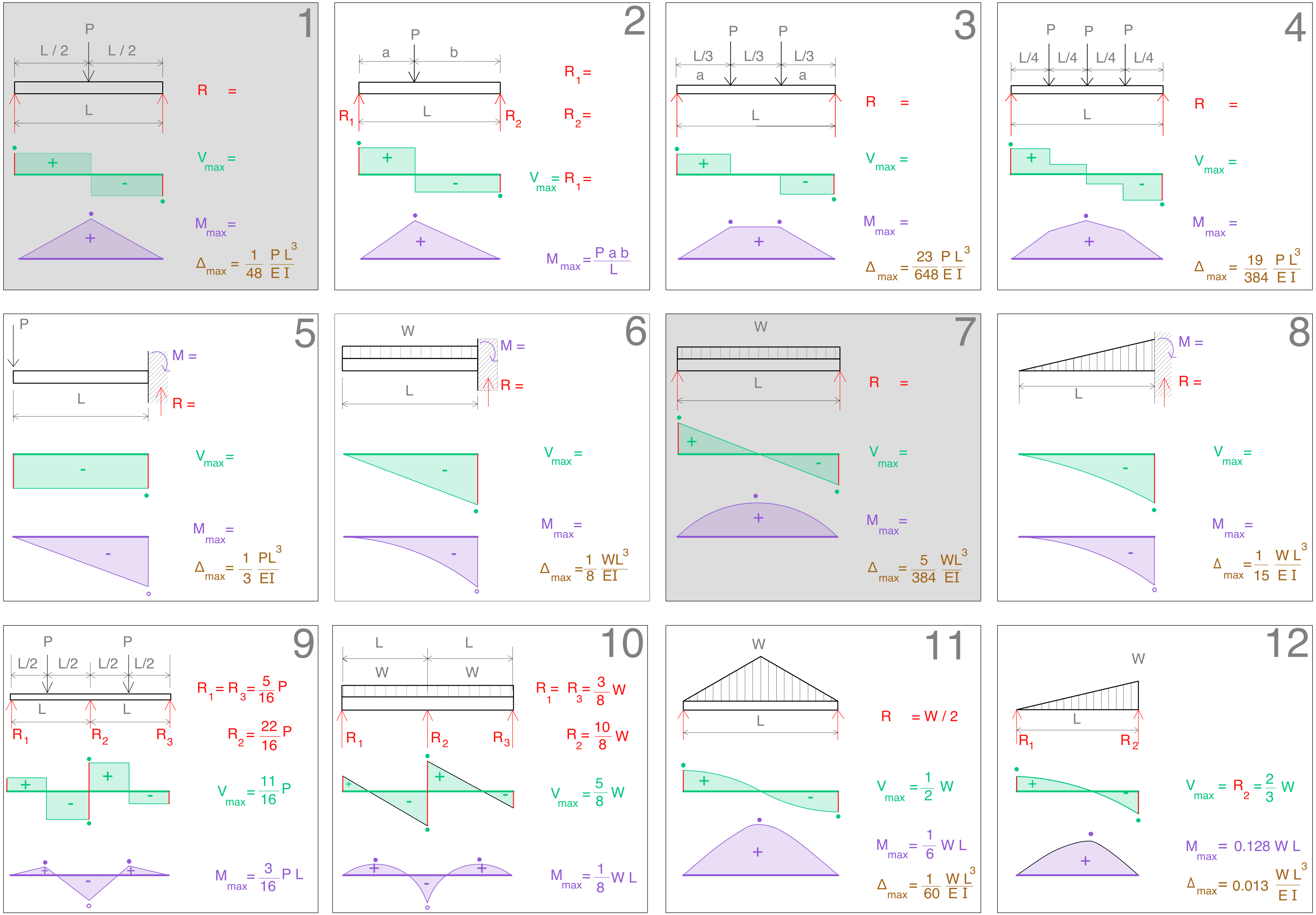


1. Greatest Maximum Shear? A, B, C, D ?

2. Greatest Maximum Positive Moment? A, B, C, D ?

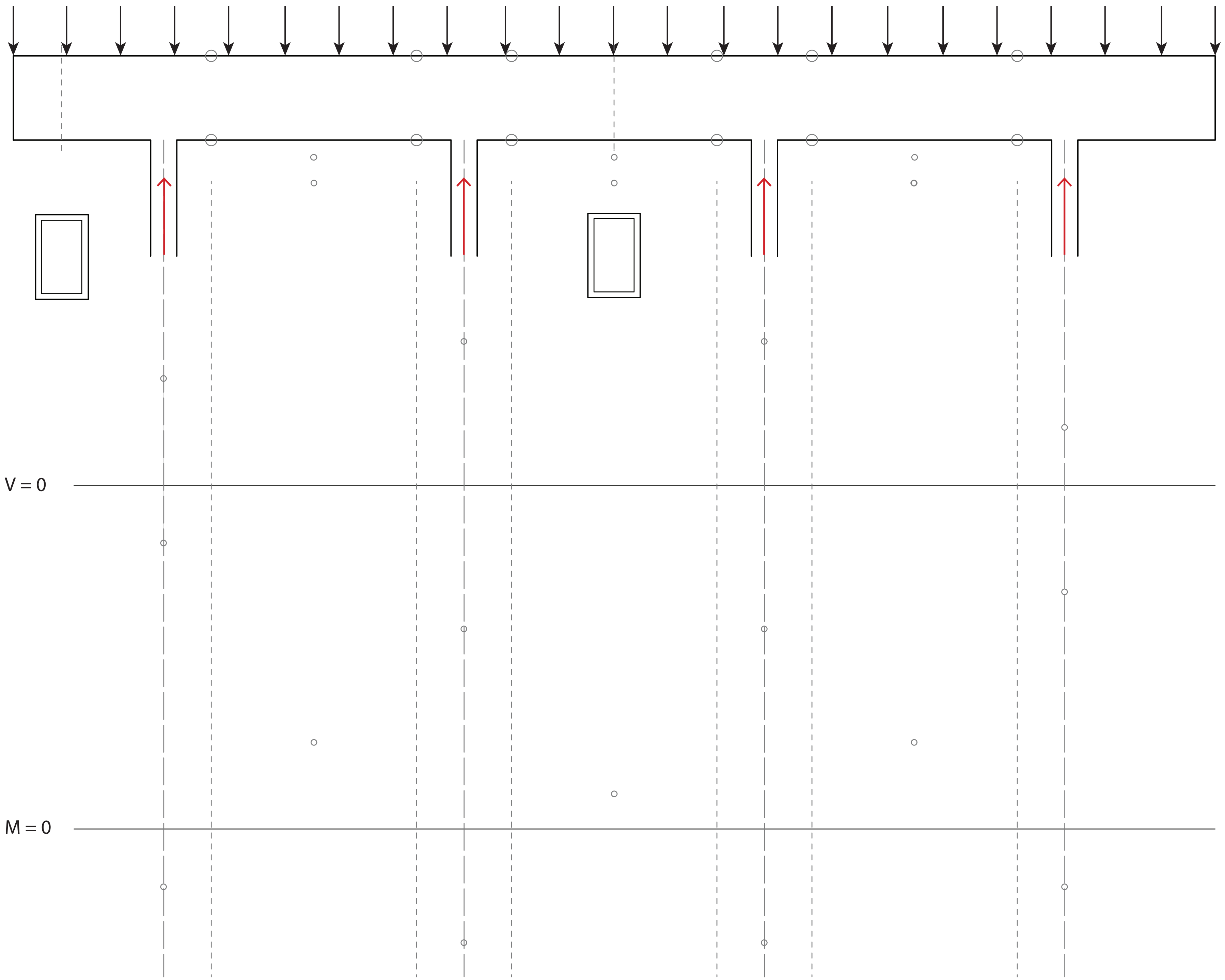
3. Greatest Maximum Negative Moment? A, B, C, D ?

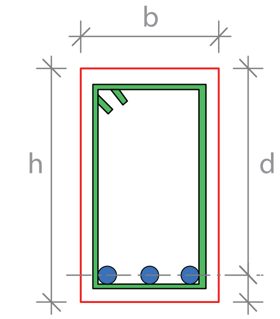




T H A D D E U S

TYPICAL LOADING CONDITIONS

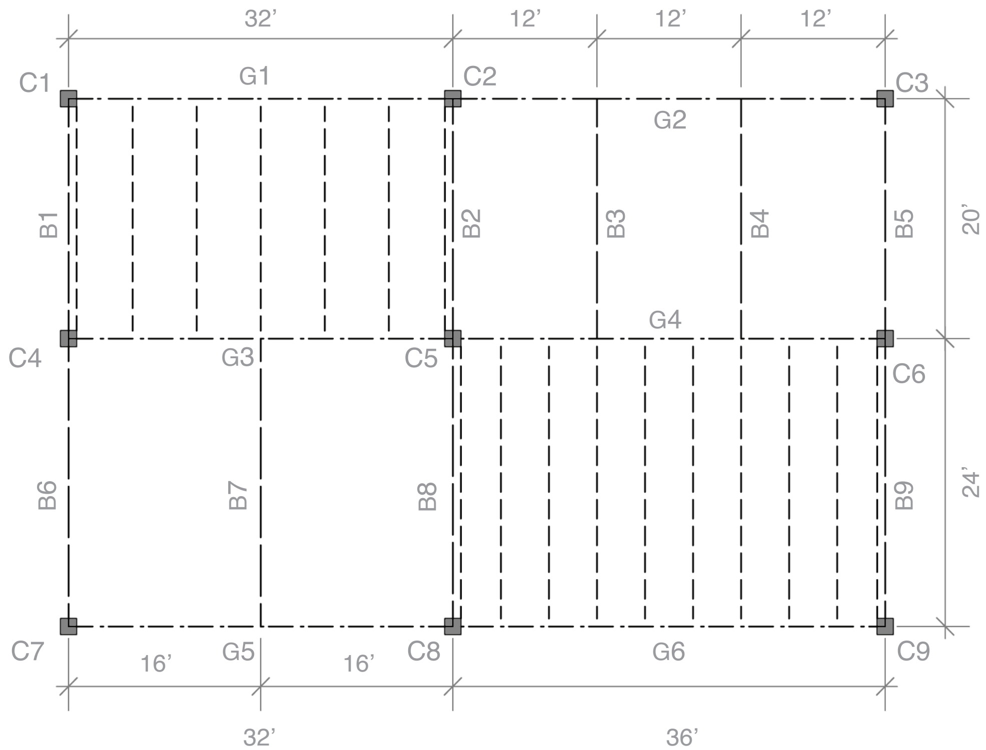




b: Width
h: Overall Depth
d: Effective (Structural) Depth

American Concrete Institute (ACI)
Recomendations for Minimum Cover:

1. Walls & Slabs: .... 3/4″
2. Beams & Columns:
   - Interior .... 1-1/2″
   - Exterior .... 2″
3. Permanently in contact with earth (Foundations) .... 3″

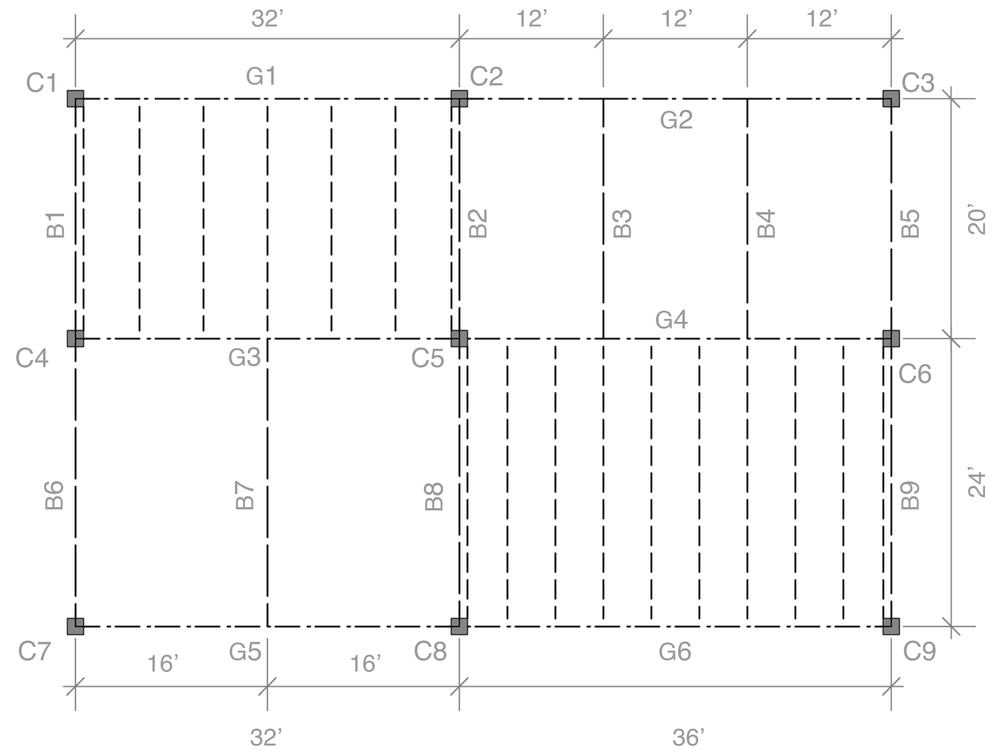


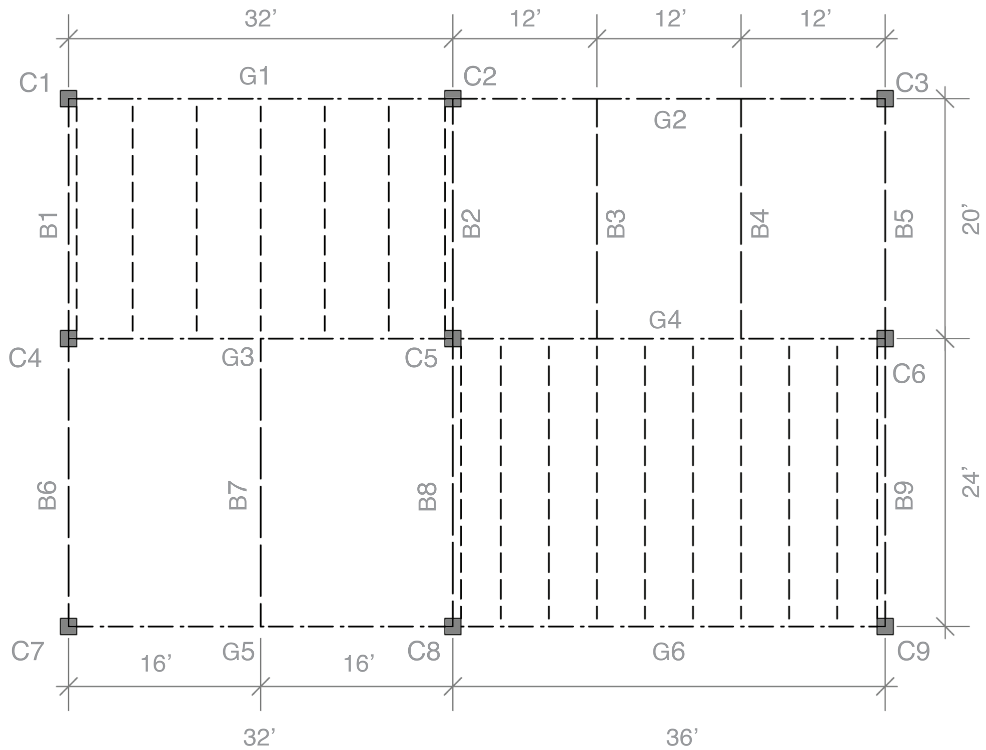
Given:

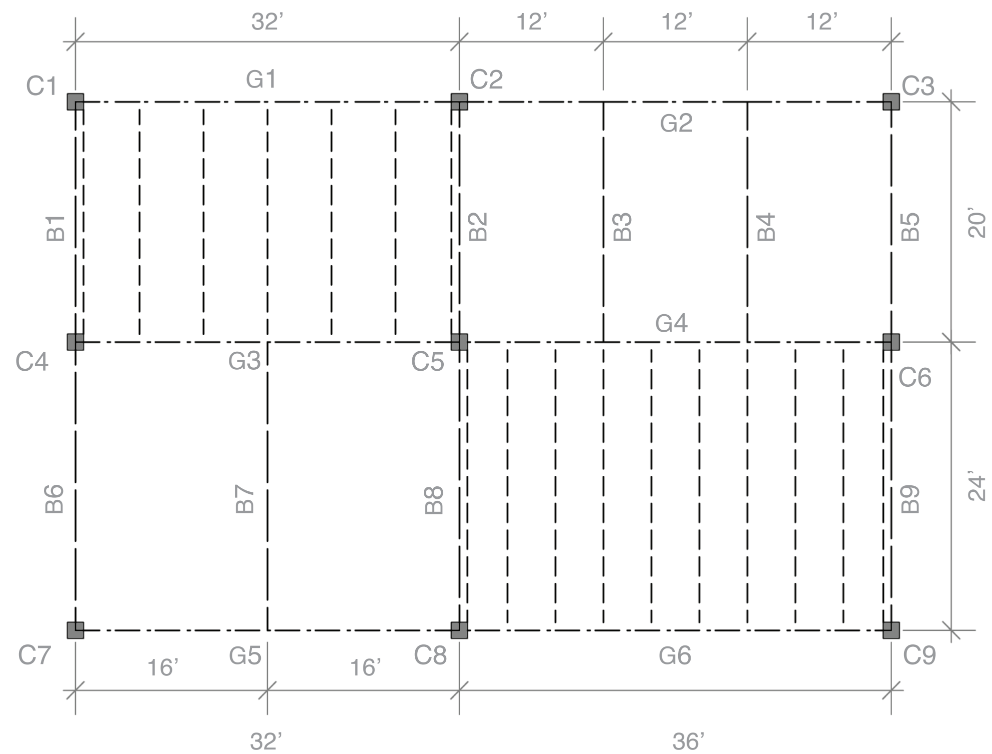
DL =
LL =
TL =

A - 36 Steel

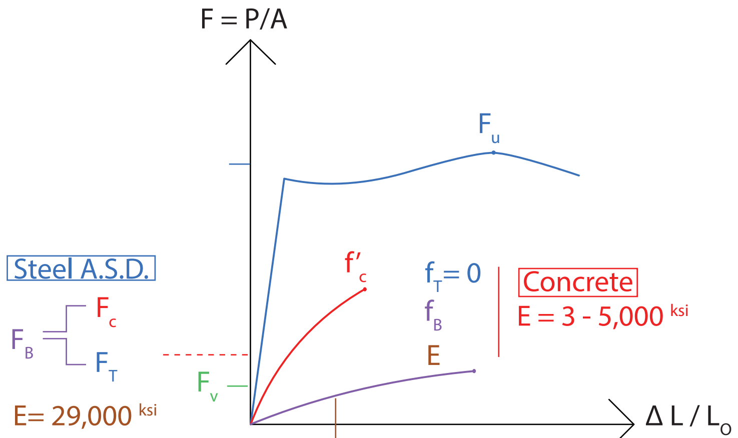
$\triangle_{Allow}$ =


32'
12'
12'
12'
C1
G1
C2
C3
G2
B1
B2
B3
B4
B5
20'
G4
C4
G3
C5
C6
B6
B7
B8
B9
24'
C7
16'
G5
16'
C8
G6
C9
32'
36'


32'
12'
12'
12'
C1
G1
C2
C3
G2
B1
B2
B3
B4
B5
20'
G4
C4
G3
C5
C6
B6
B7
B8
B9
24'
C7
G5
C8
G6
C9
16'
16'
32'
36'


32'
12'
12'
12'
C1
G1
C2
C3
G2
B1
B2
B3
B4
B5
20'
G4
C4
G3
C5
C6
B6
B7
B8
B9
24'
C7
G5
C8
G6
C9
16'
16'
32'
36'

Material



F_c ⊥ E = 1 - 2,000 ksi

F_c F_T F_B — Very weak in horizontal shear F_v

F_c, F_T	Axial Loads
F_v, F_B	Perpendicular Loads

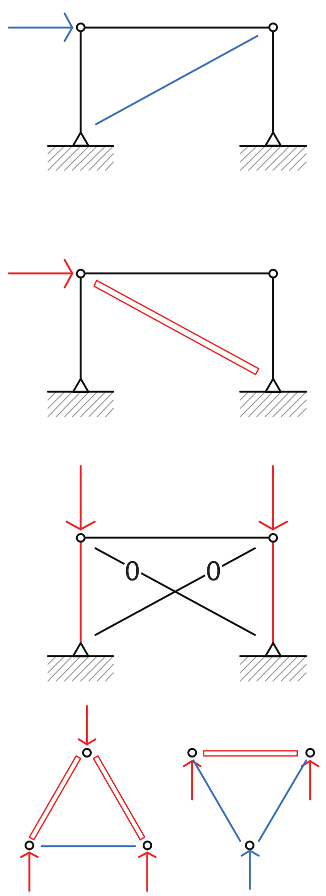
E : Δ : ⊥ (Perp.)
ΔL : Axial

Sizing Axially-Loaded Members

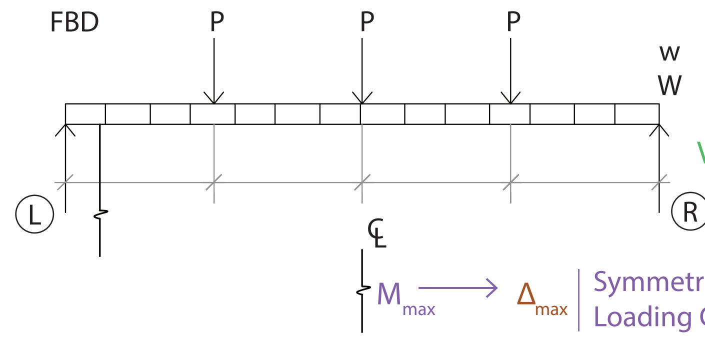
$F_{C/T} = P/A$

$\Delta L = \frac{PL_o}{AE}$

columns, piles
foundations
cables
diagonal bracing
truss members

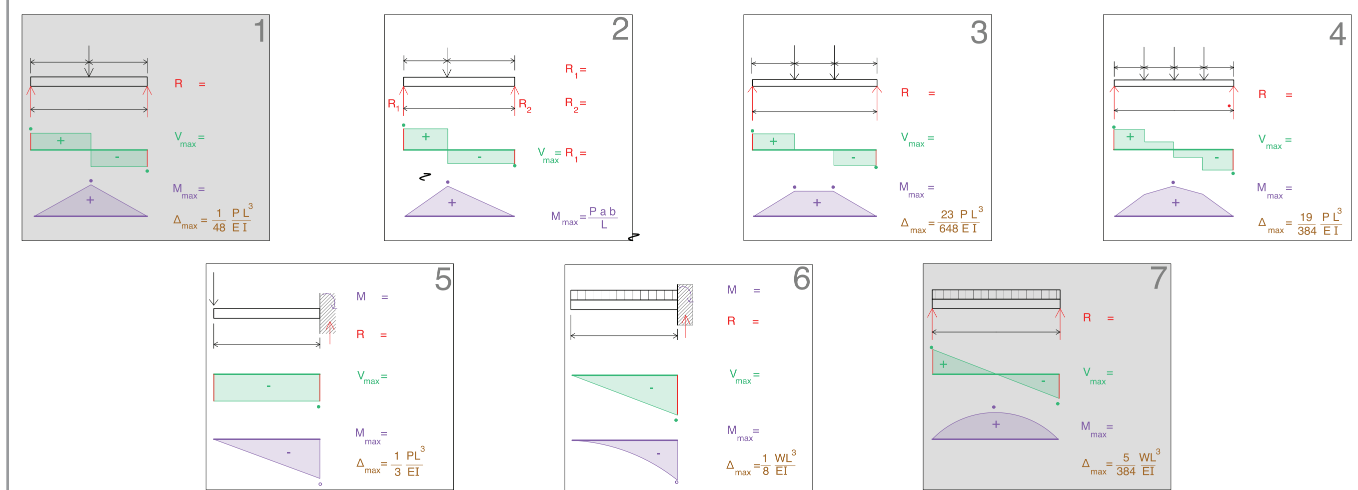


Tributary Load



V_{max} = Reaction

$M_{max} \longrightarrow \Delta_{max}$ | Symmetrical Loading Cases or V & M Diagrams



Sizing Members Perpendicularly to Their Axis

slab . floor . deck   joist . purlin   beam . girder

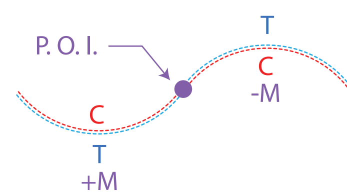
strength

1. Shear :
- Critical at support / connection
- V_{max} = Reaction
- $F_v \propto \frac{V_{max}}{Ⓐ}$

Wood
* Very weak in horizontal shear

$F_v = \frac{3\,V_{max}}{2\,A}$

2. Bending Flexure



$F_B = \frac{M_{max}}{Ⓢ}$

wood is good in — Ⓒ & Ⓣ
⟹ good in Ⓜ

3. Deflection (Stiffness)

$\Delta_{allowable}$ specified by code: for different load combinations

$\Delta_{allowable} = \frac{L}{180}, \frac{L}{240}, \frac{L}{360}, \frac{L}{480}, \frac{L}{600}, \frac{L}{720}$

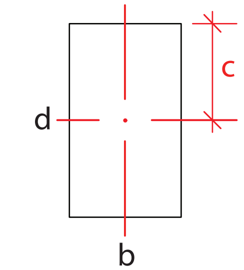
$\Delta_{actual} = \text{constant} \times \frac{\text{Load (W or P)} \times L^3}{EI}$

E = Modulus of Elasticity
Material Stiffness

W = Uniform Load
P = Concentrated Load
L = Span
I = Moment of Inertia
Stiffness of Shape

E_W = 1 - 2,000,000 psi
E_W = 1 - 2,000 ksi
E_C = 3 - 5,000 ksi
E_S = 29,000 ksi

Size/Shape



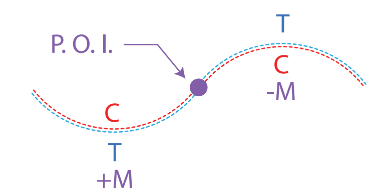
$A = b \times d \longrightarrow V_{max}$

A = area $F_v \propto \frac{V_{max}}{A}$

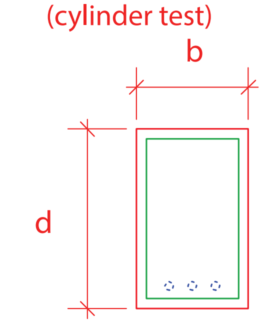
$S = I / c = \frac{bd^2}{6} \longrightarrow M_{max}$

$F_B = \frac{M_{max}}{S}$

$I = bd^3 / 12 \longrightarrow M_{max}$



Concrete : f'_c
(cylinder test)

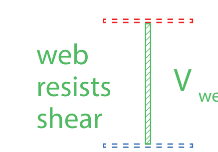


f_v : stirrup strength

A_v : Ø stirrup & spacing

Steel

* Very strong in shear

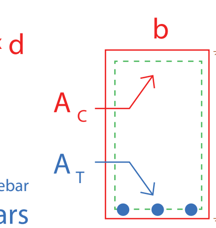


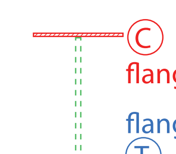
$F_v = \frac{V_{max}}{A_{web}}$

Together resist shear | Concrete $A_c = b \times d / f'_c \rightarrow _v$
Stirrup A_v : (π r ²)
spacing & f_y (Yield stress)

Concrete : Ⓒ $A_c = b \times d$ f'_c

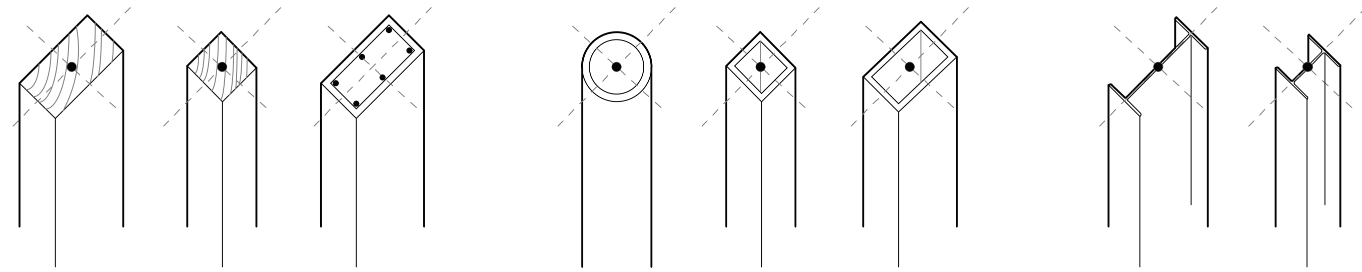
Rebar : Ⓣ $f_{y\,rebar}$ A_T : Φ / rebar & # bars

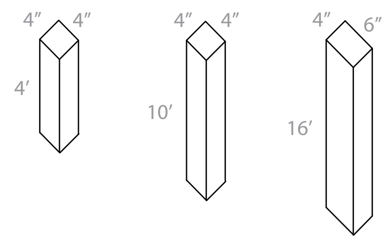


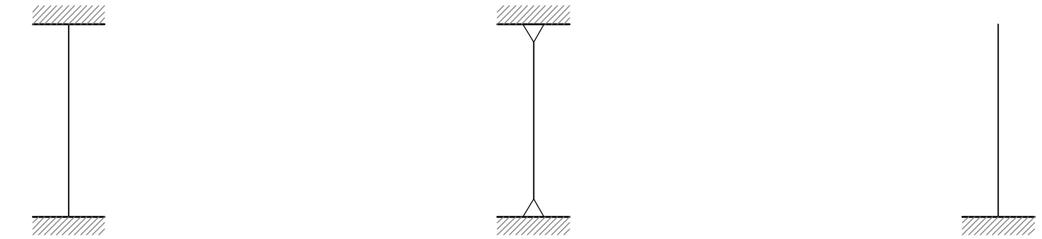


$E_{Concrete}$ depends on f'_c
3 - 5,000,000 psi =
3 - 5,000 ksi

$E_{any\ steel}$ =
= 29,000,000 psi
= 29,000 ksi







K =

KL =

K =

KL =

K =

KL =

Material (Allowable Stress)

• Wood

• Steel

• Concrete

Slenderness Ratio (SR)

Area of Section

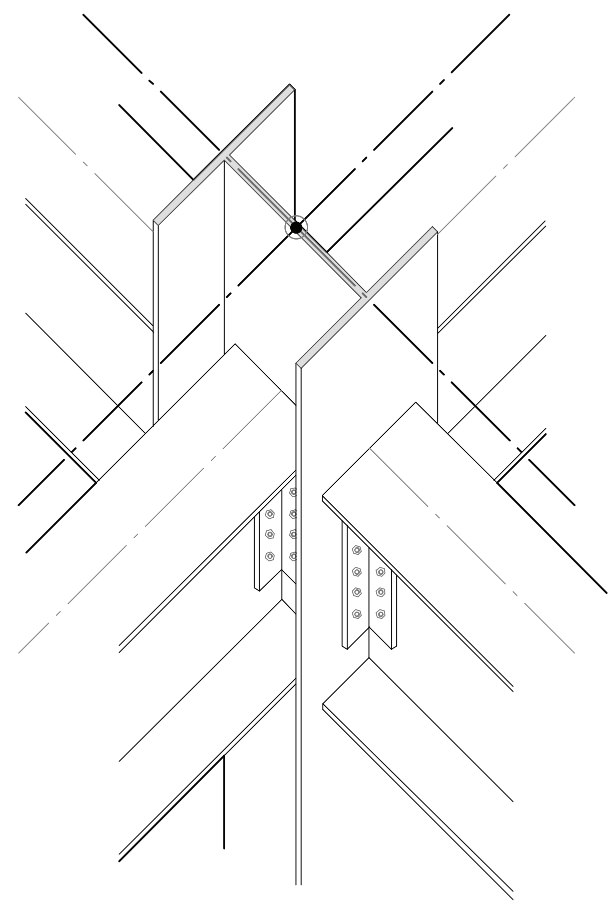
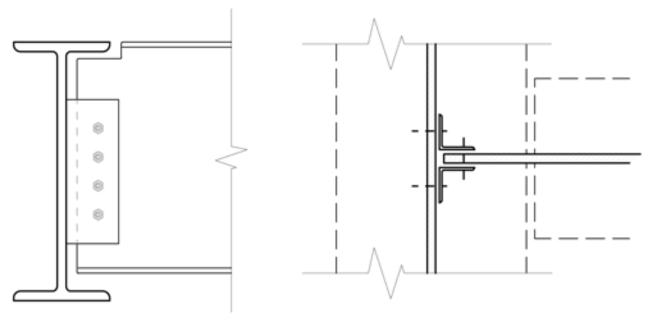
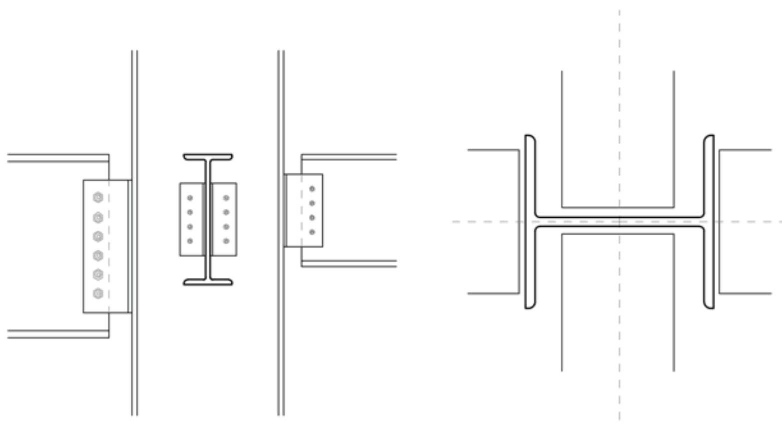


Table C-C2.1

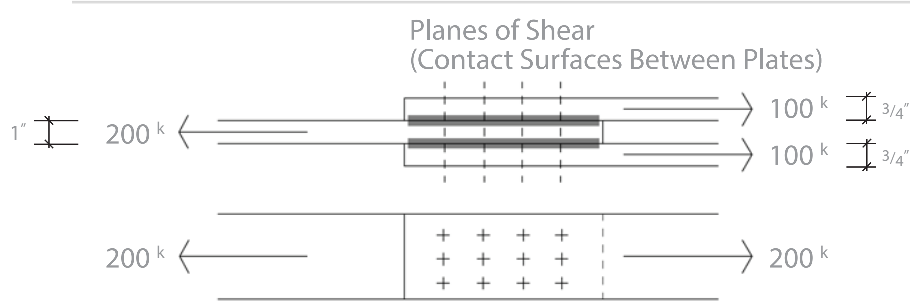
	(a)	(b)	(c)	(d)	(e)	(f)
Buckled shape of column is shown by dashed line						
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10	2.0
End condition code	Rotation fixed and translation fixed Rotation free and translation fixed Rotation fixed and translation free Rotation free and translation free					

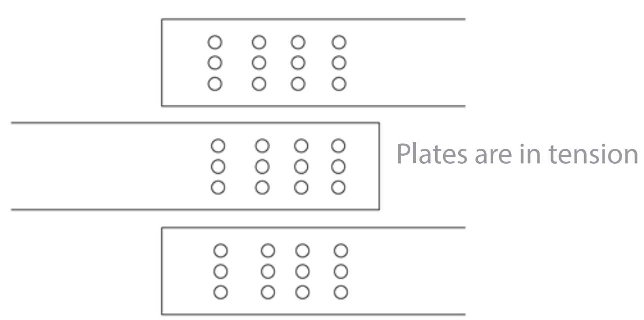


Elevation Plan



Elevation Plan





1) Type of Connection

F

N

X

2) Grade of Bolt Steel

3) Diameter / Area of Bolt

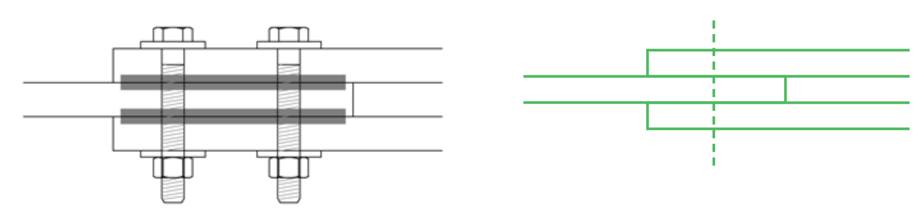
4) Number of Plates Connected: Shear Planes

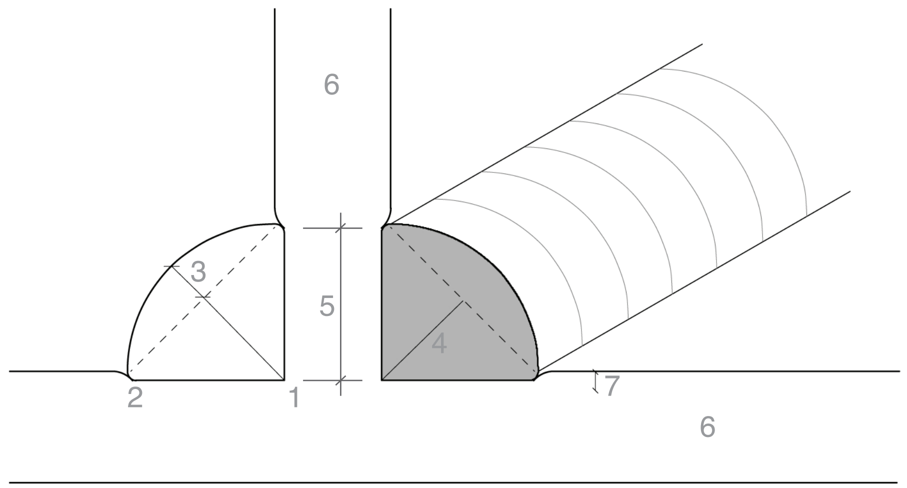
S

D

Type X
1 Plane of Shear
(Single Shear)

Type N
2 Planes of Shear
(Double Shear)





1.

2.

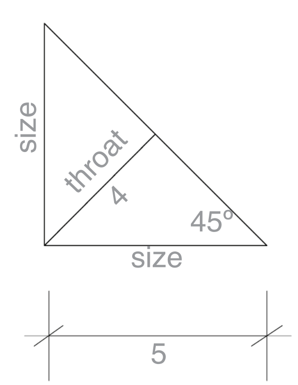
3.

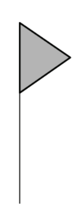
4.

5.

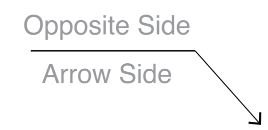
6.

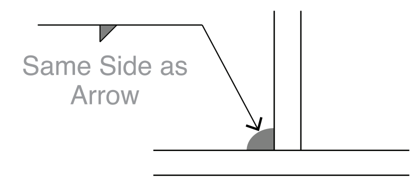
7.

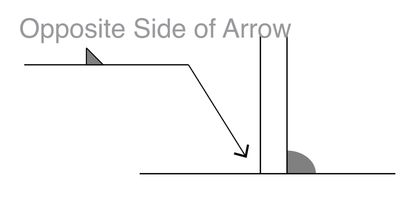


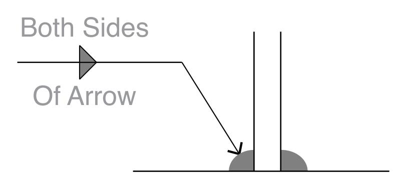


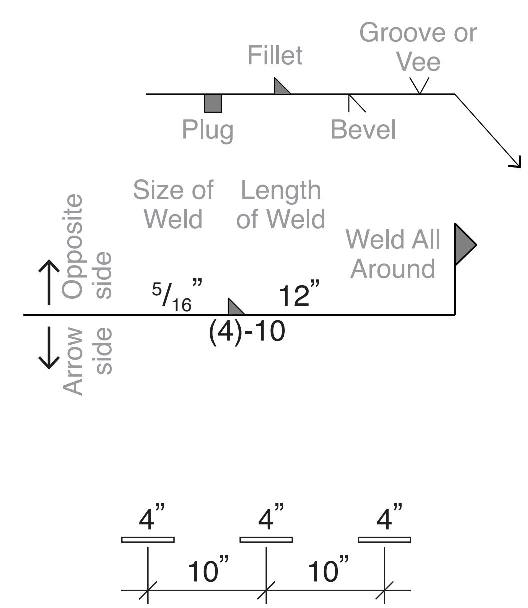
Field Weld



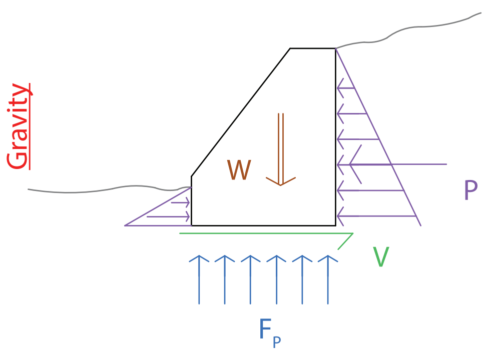








Gravity

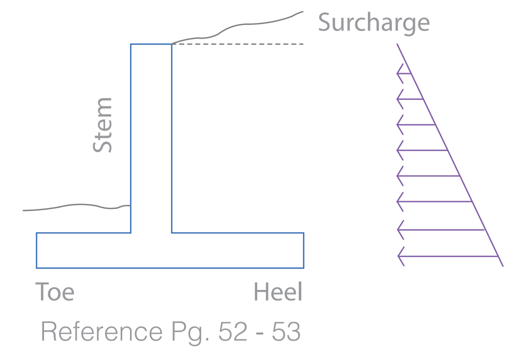


P :

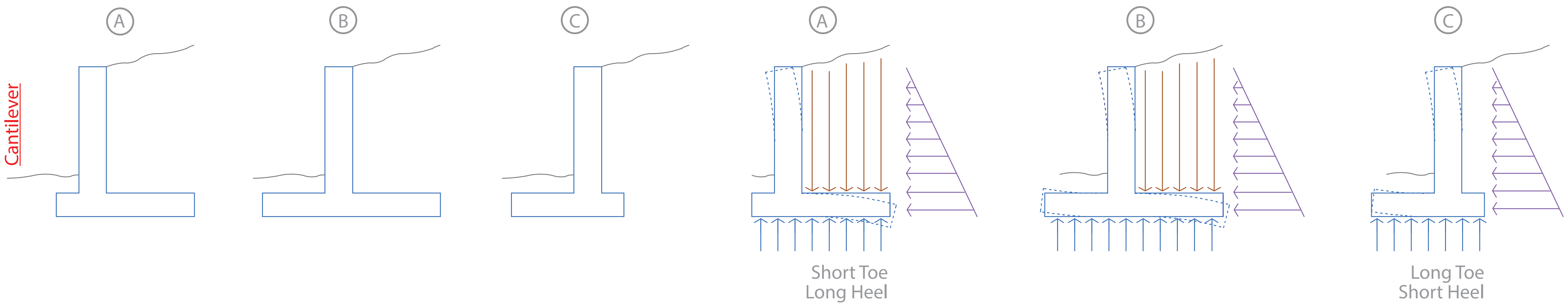
W :

F_P :

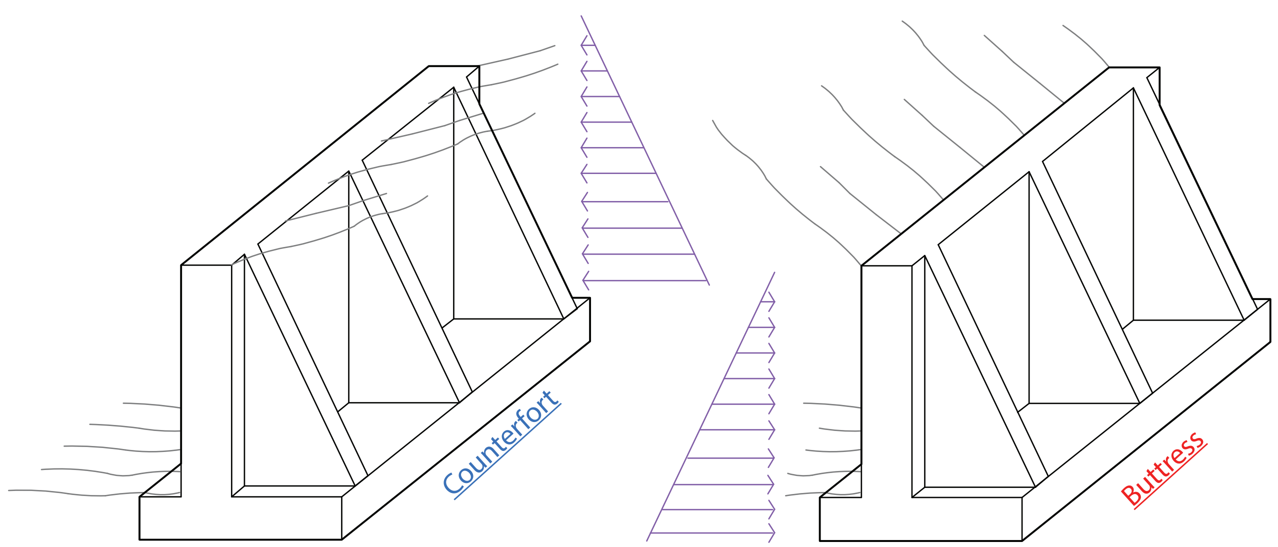
V :

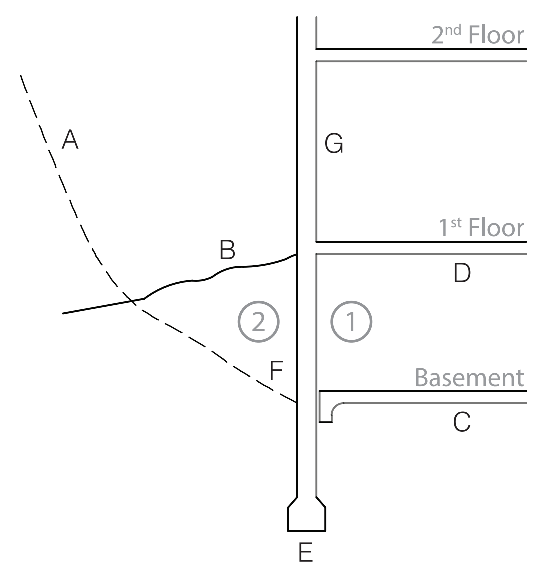


Cantilever

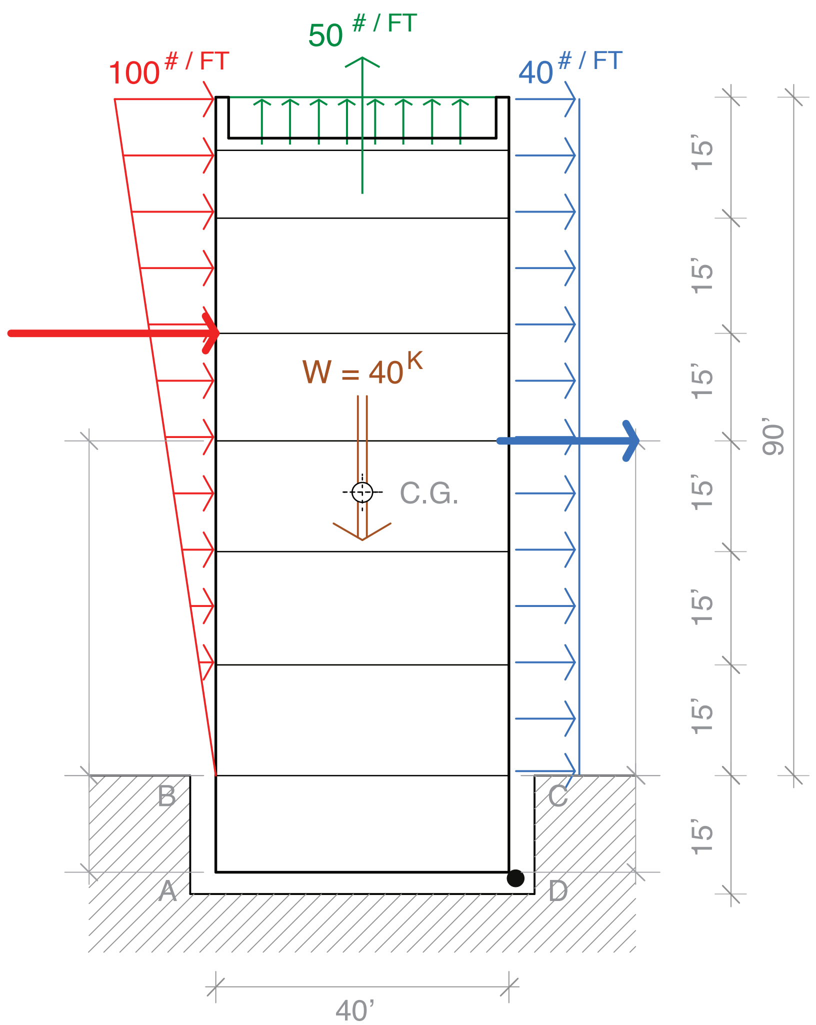


Counterfort / Buttress





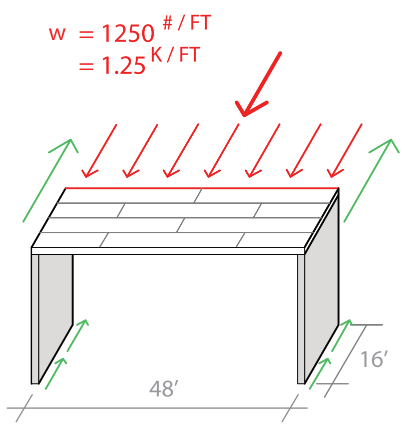
A : Cut
B : Backfill
C : Slab on Grade
D : First Floor Slab
E : Foundation
F : Basement Wall
G : First Floor Wall

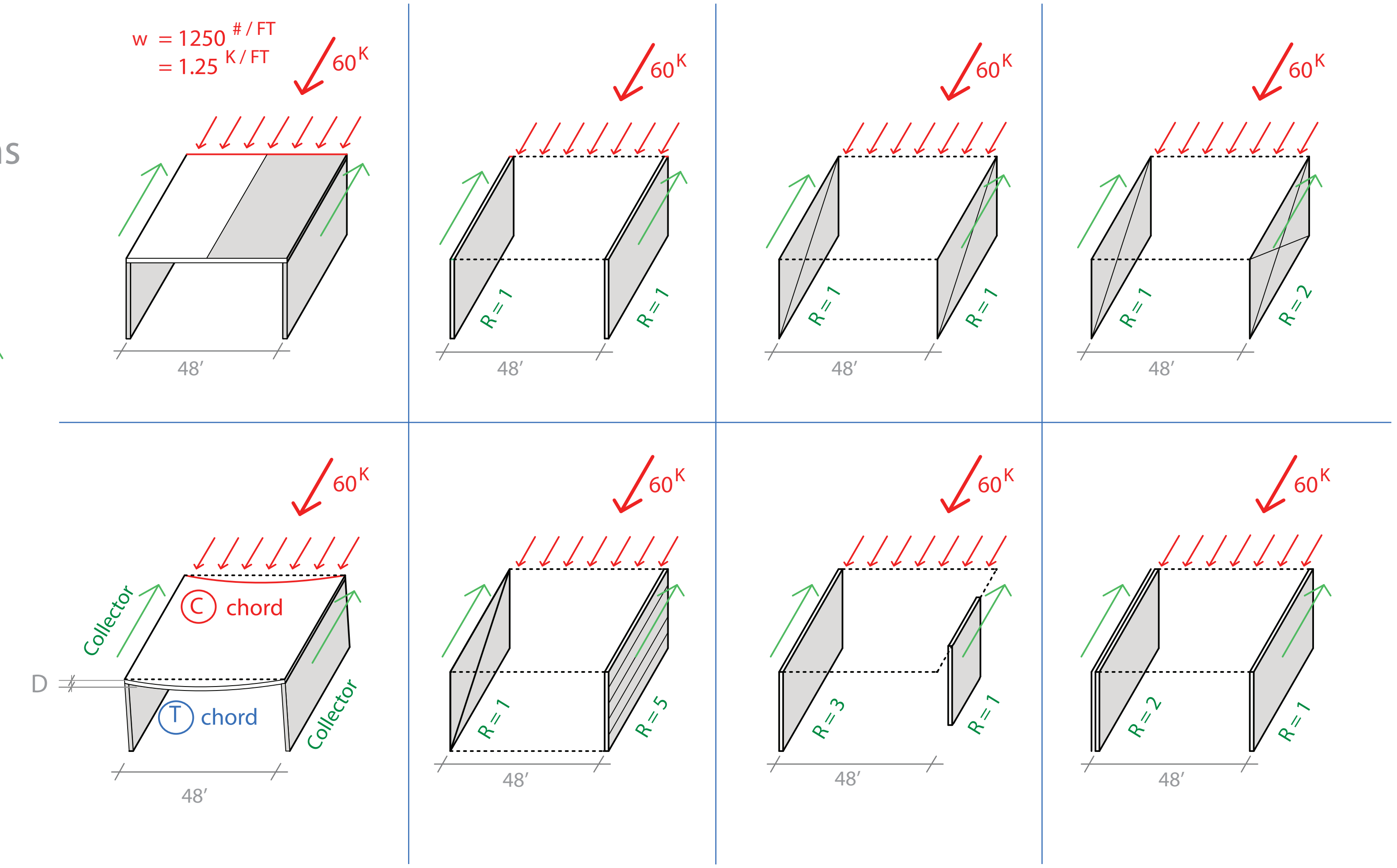


Overturning Moment	Stabilizing Moment

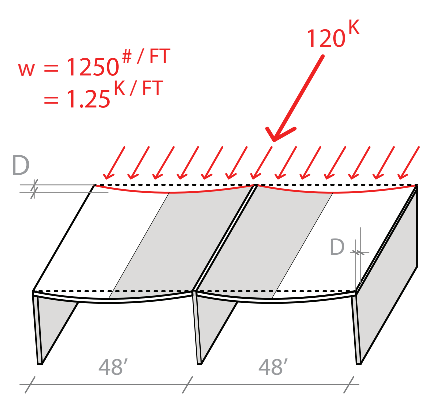
Calculate the Factor of Safety Against Overturning Due to Wind for the Loads Shown.

Flexible Diaphragms

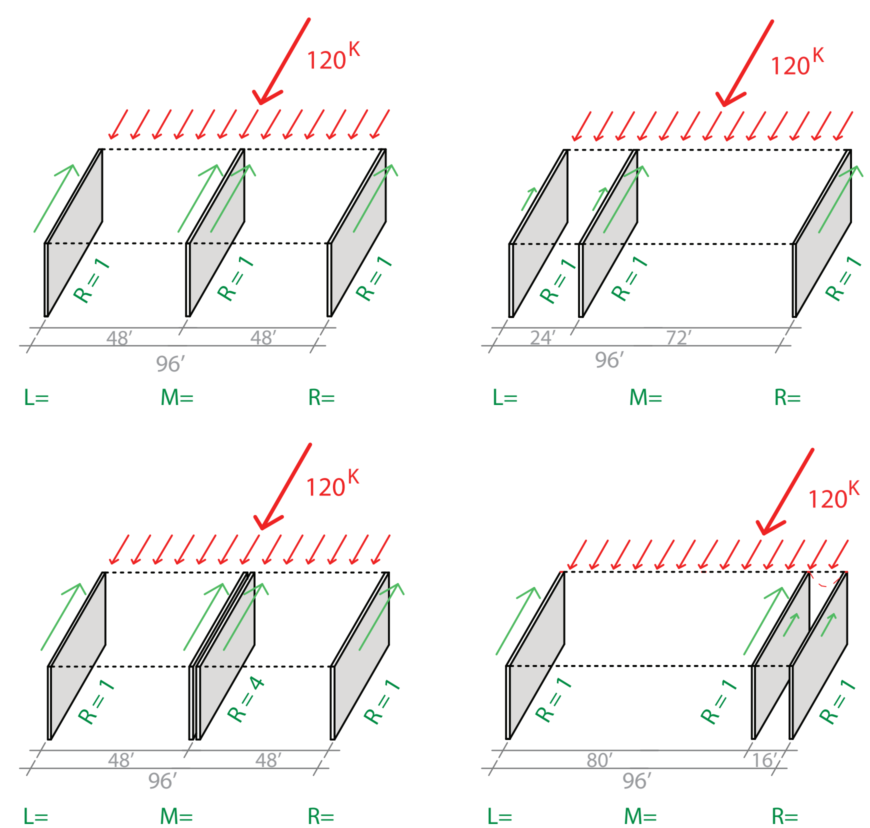


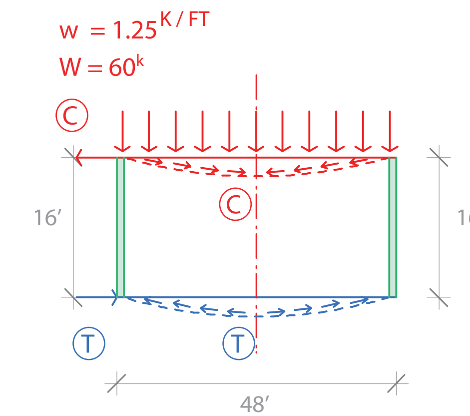


- Made of pieces.
- Typically wood, pre-cast planks, untopped decking.
- Diaphragm deforms (bends).
- Front Chord (C) chord
- Back Chord (T) chord
- Corners of diaphragm distort.
- Spacing of walls dictates load distribution to verticals.
- L > 3W
- No torsion.
- Load from diaphragm is distributed to vertical lateral-resisting members using tributary load analysis.
- Load distribution from diaphragm is independent of rigidity of vertical members.
- Diaphragm is weaker than verticals.
- In-plane deflection of diaphragm > 2 x in-plane drift of wall.

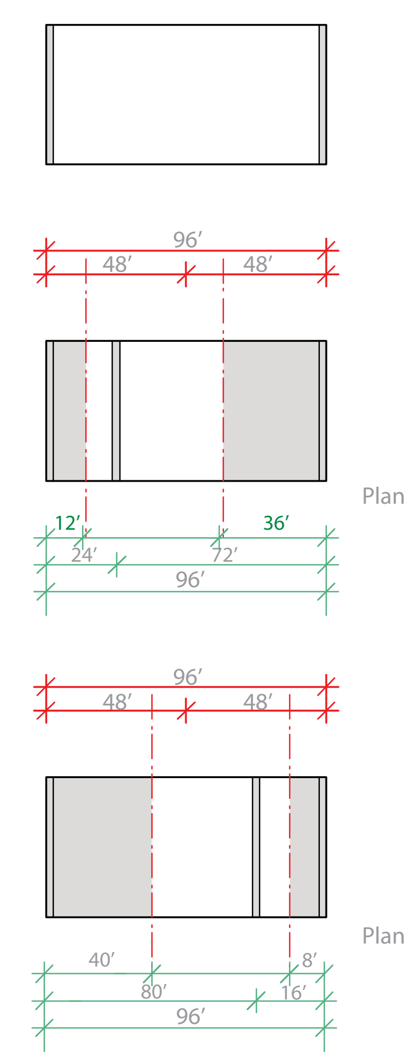


If D > 2D ----- Flexible
If D < 2D ----- Rigid

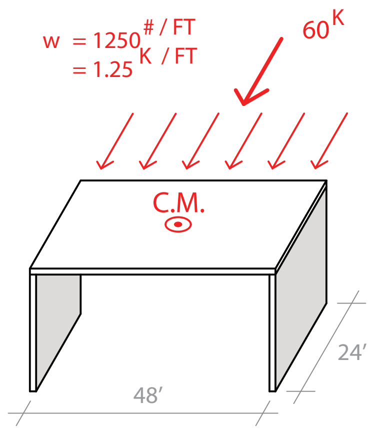




- Calculate chord force in (C) & (T)

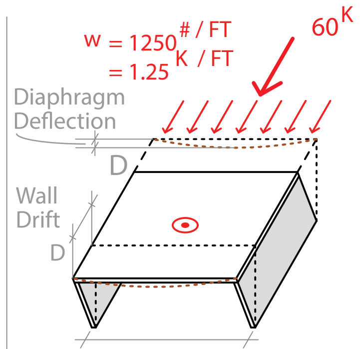


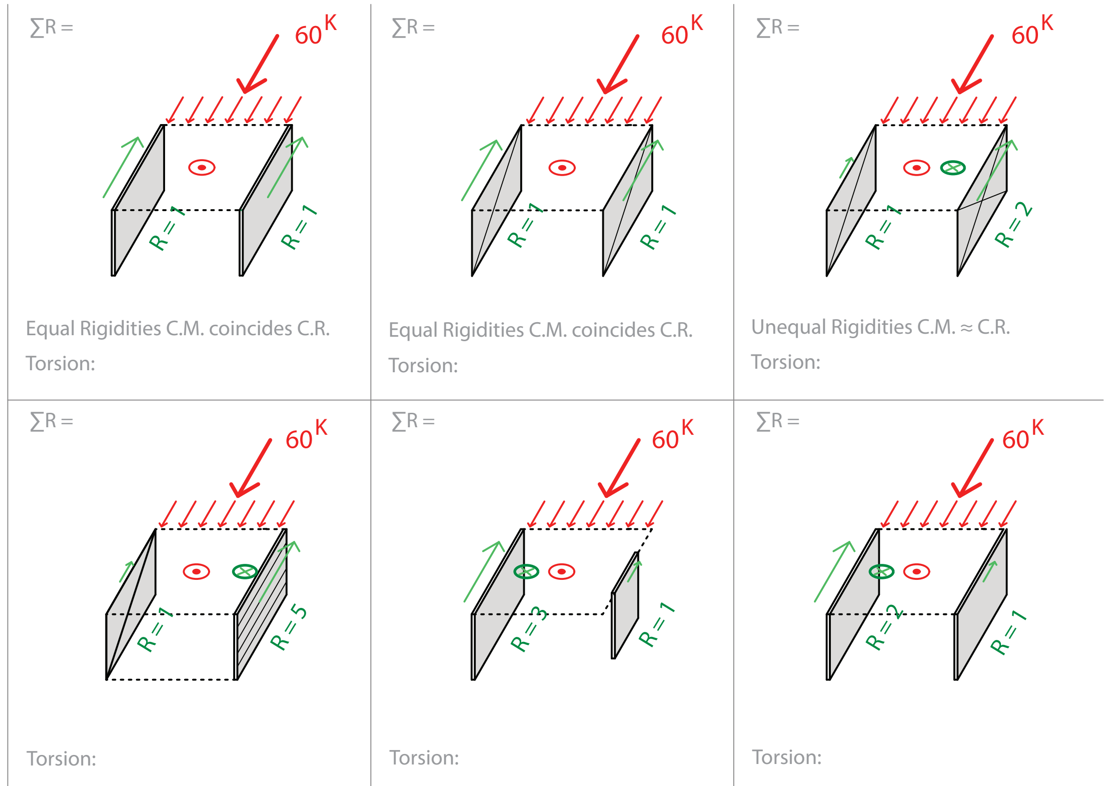
Rigid Diaphragms

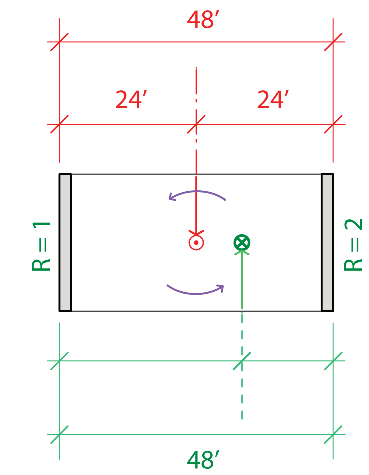


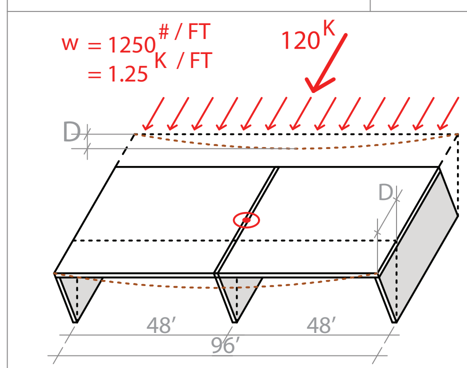
- ⊙ C.M. = Center of Mass (Center of Diaphragm) (Center of Applied Load)
- ● C.R. = Center of Rigidity (Center of Vertical Resisting Members)

- Monolithic, Continuous
- Typically cast-in-place concrete
- Verticals deform, Diaphragm does not
- Chords do not bend, they drift
- Corners of Diaphragm remain square
- Spacing of walls does not affect load distribution to verticals
- L< 3W
- Torsion Possible
- Load from diaphragm is distributed to vertical lateral-resisting members in proportion to their relative rigidities (stiffness)
- Load distribution from diaphragm is independent of spacing of vertical members.
- Diaphragm is stronger than verticals
- In-Plane deflection of diaphragm is < 2x In-Plane drift of wall.

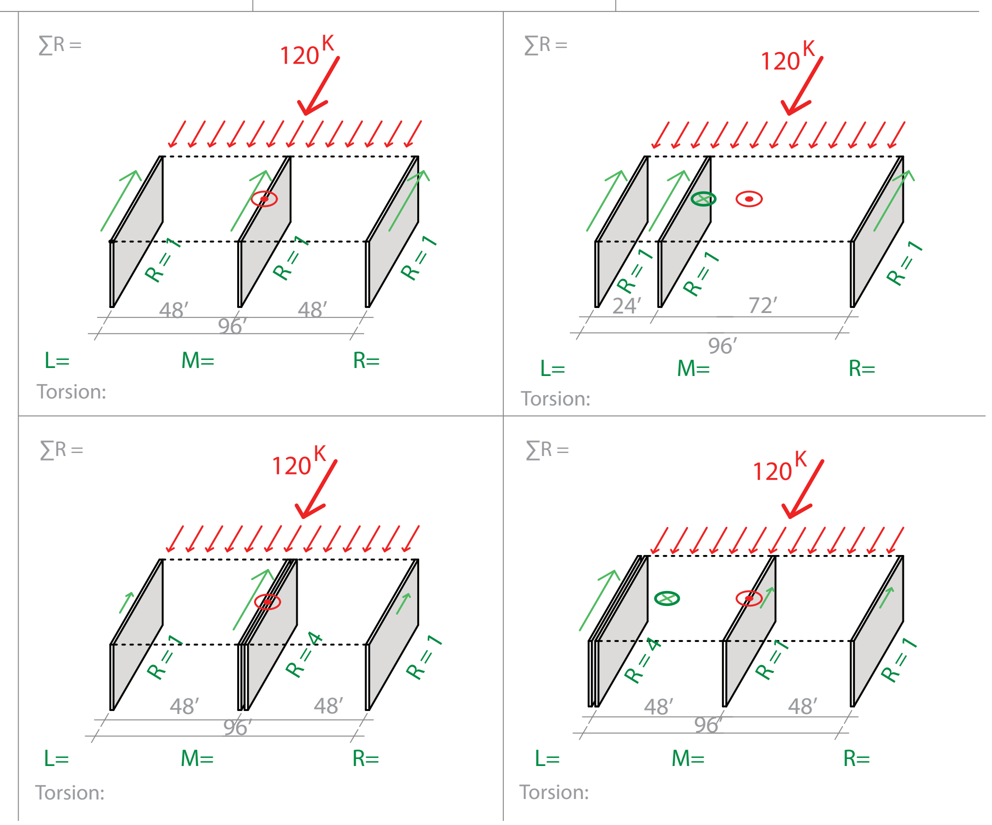


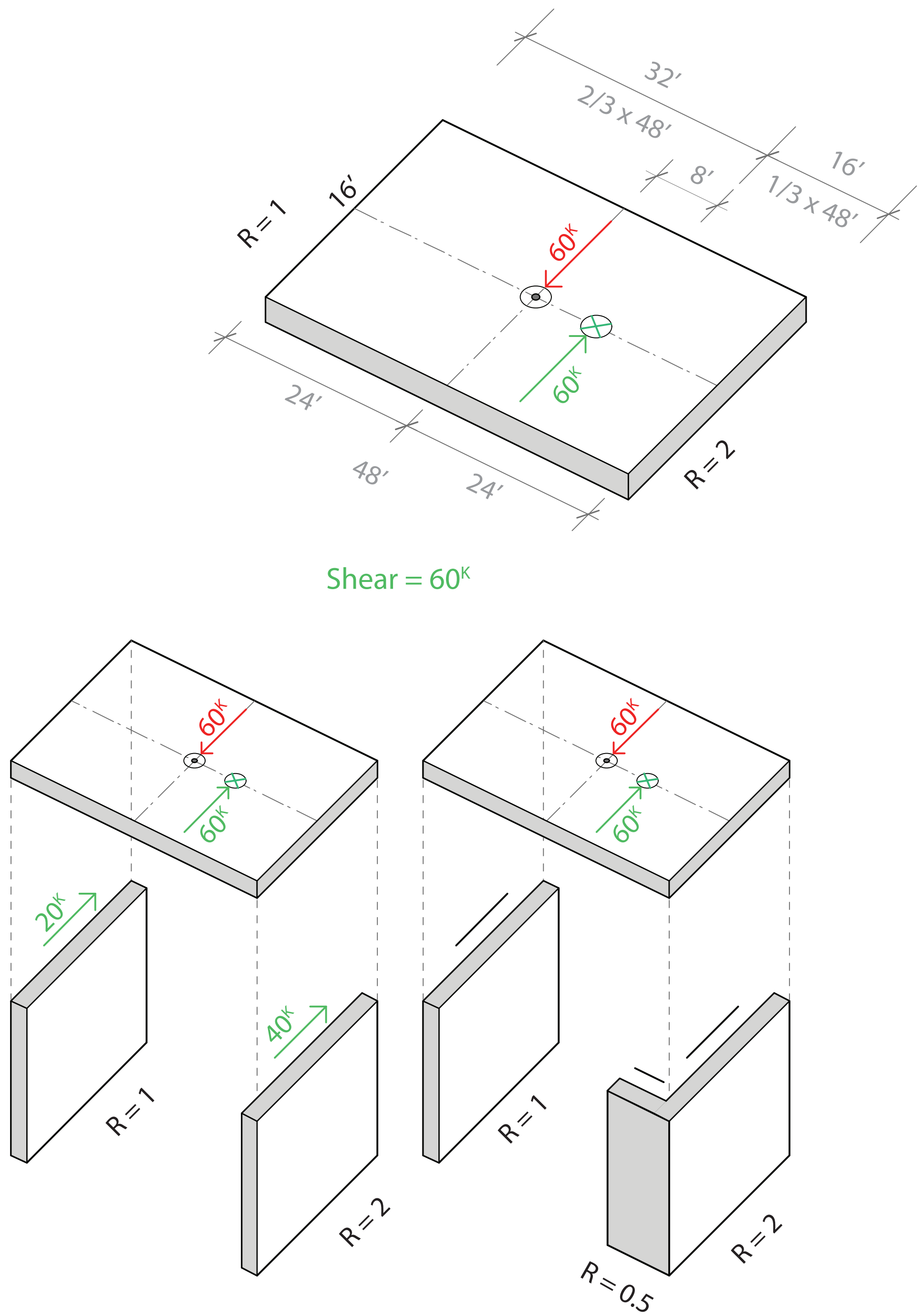


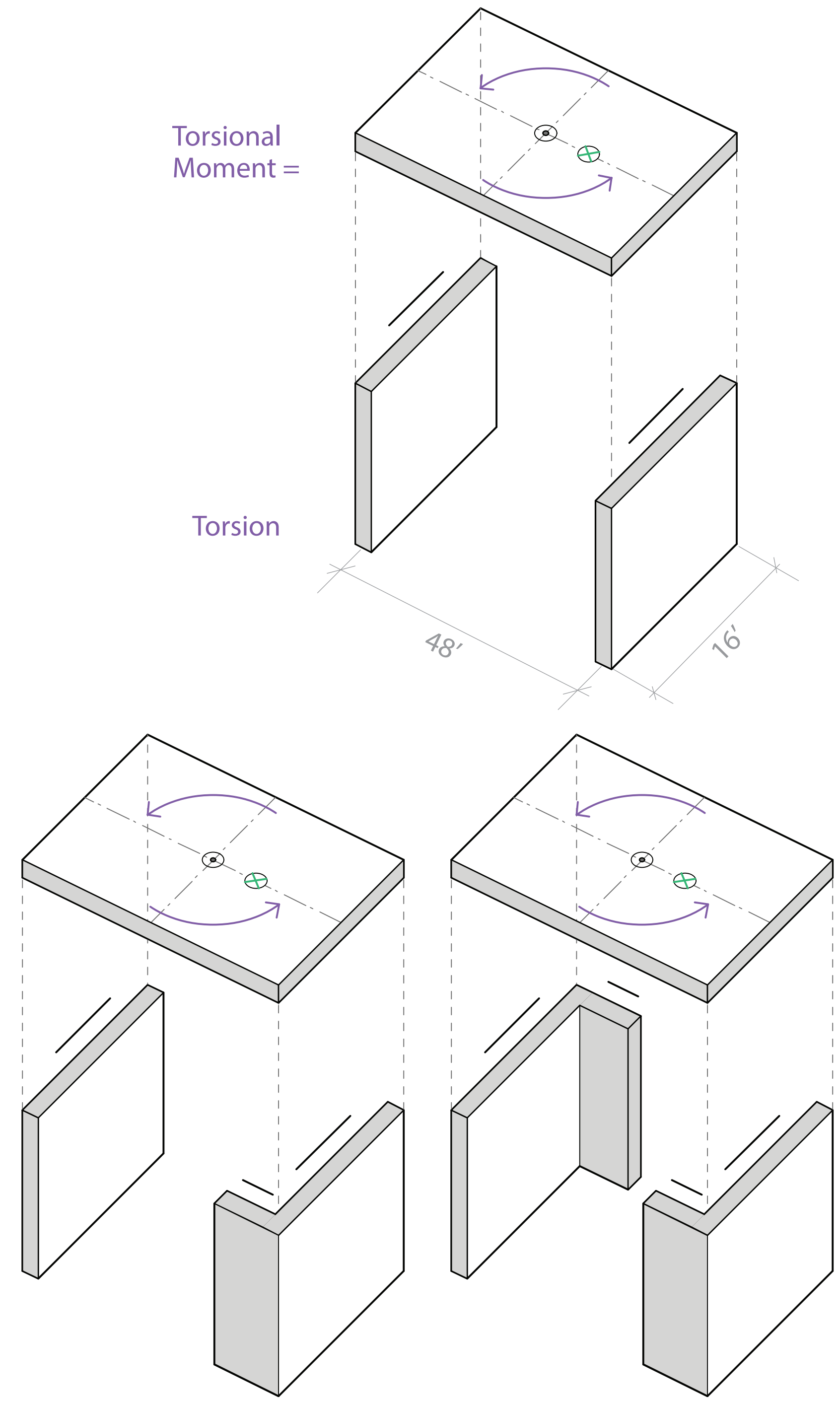




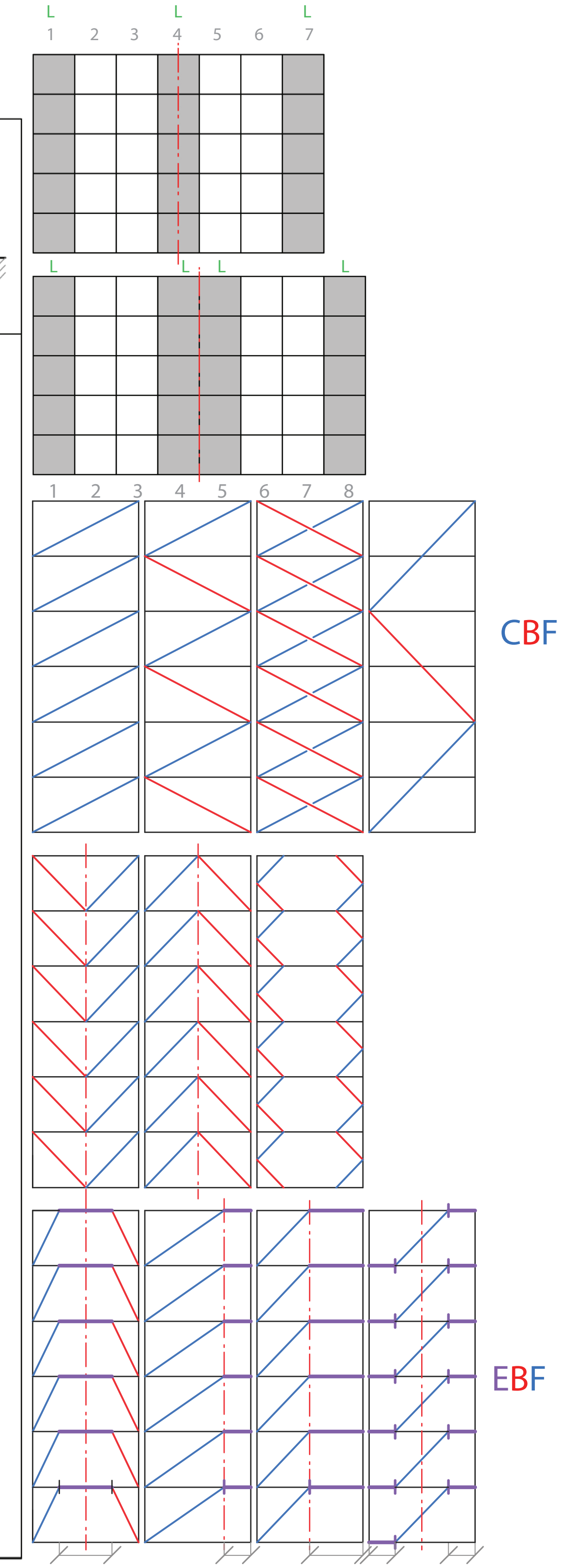
If D < 2D ----- Rigid
If D > 2D ----- Flexible




32′
2/3 x 48′
16′
1/3 x 48′
8′
R = 1
16′
60K
60K
24′
48′
24′
R = 2
Shear = 60K
60K
60K
20K
40K
R = 1
R = 2
60K
60K
R = 1
R = 0.5
R = 2

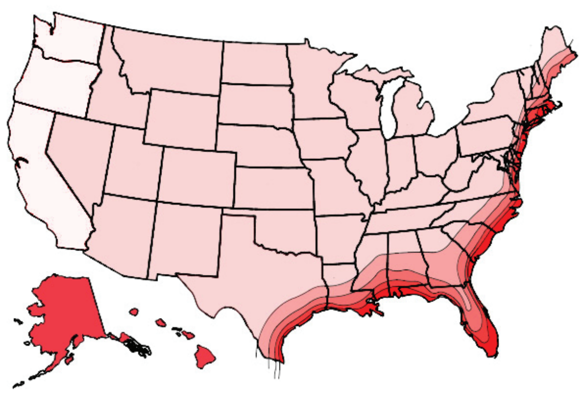

Torsional
Moment =
Torsion
48′
16′

Post & Beam – PB	Moment Frames – MF	Braced Frames – BF	Shear Walls – SW
AKA:	Rigid frame, fixed frame, moment-resisting frame	Trussed frame	Rigid mass, mass infill
Connections:	Transfer of moment from horizontal to vertical moment-resisting, rigid	Simple, pinned joints connections do NOT transfer moment	Simple, pinned joints connections do NOT transfer moment
Flexibility of Planning Space:	Full flexibility with windows, doors and other openings (Architect's best friend)	Somewhat more restrictive with location / size of opening	Restrictive with location / size of opening (Architect's nightmare) Small openings may be placed symmetrically about centroid
Ductility: R (Scale: 1 - 8) Please see Ref. p 56-59	Excellent — steel is naturally ductile; concrete needs special detailing for ductility	Good — Steel BG are less ductile than steel MF	Least ductile
Rigidity:	Low (concrete MF is more rigid than steel MF)	More rigid than MF	Most rigid
Drift (sway):	High (Engineer's nightmare)	Less drift than MF	Least drift
Damping:			
Damage to Struct. Members:	Low	Low	Low
Damage to Non-Struct. Members:	High	Medium	Least
Cost:	$$$$$$$ (in steel: welder certification, weld inspection)	$$$$	$$
Typical Materials	Steel, cast-in-place (CIP) concrete (wood cannot be made to resist moments)	Steel, wood (Concrete does NOT do tension)	Concrete SW, plywood SW, reinforced masonry (Steel Plate Shear Walls currently under development)
Building Configuration	Low, broad-based buildings, not much lateral force to resist	Taller, skinnier buildings	Tallest Buildings
Bay Size	Small column grid	Wider column grid	Largest grid
Individual Member Stresses:	Greatest	Less stress on individual members	Least stress on individual members
Structural Load Transfer Mechanism:	Bending, Flexure	Axial Tension Axial Compression	Shear
Hero:	Ludwig Mies van der Rohe	John Hancock Tower – Chicago	Le Corbusier, Ando, CIP concrete (also cores, elevators, restrooms, stairwells...)
Comments:	Must be with dual system (needs BF/SW) if tall building	Most efficient lateral system in terms of strength vs. weight	Increases Dead Load (liability in seismic design



3 Second Gusts (G)
(MRI) Recurrance Interval
50 Years (2% Exceedance)

- Atmosphere
- Air Turbulence
- Air Density
- Pressure Gradient
- High to Low Pressure



Geographic Location
(Reference Page 54)

Saffir - Simpson Hurricane Scale

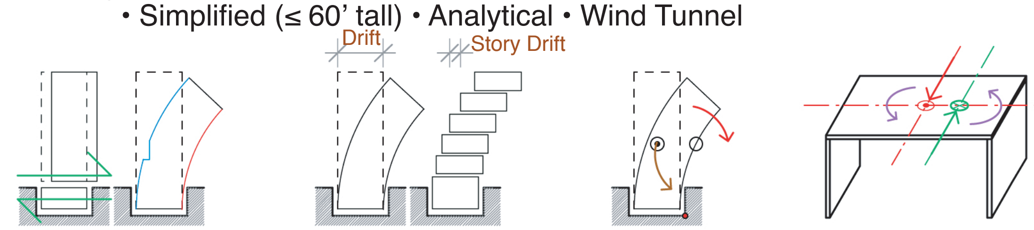
Category 5	=	> 156 mph
Category 4	=	131 - 155 mph
Category 3	=	111 - 130 mph
Category 2	=	96 - 110 mph
Category 1	=	74 - 95 mph
Tropical Storm :		39 - 73 mph
Tropical Depr. :		0 - 38 mph

The Fujita Scale _ Tornado Scale

F0	=	40 - 72 mph
F1	=	73 - 112 mph
F2	=	113 - 157 mph
F3	=	158 - 206 mph
F4	=	207 - 260 mph
F5	=	261 - 318 mph
F6	=	319 - 379 mph

Code Corner

- Protection of building inhabitants
- Reduce potential property damage to building and adjacent buildings
- Buildings and structures resist wind loads not wind speed
- Wind is assumed to come from **ANY** horizontal direction
- Wind is assumed to strike perpendicular to the surface being considered
- Shielding by other buildings is not permitted
- Designing for tornadoes is not required by code
- Main Wind Force Resisting System (MWFRS) must be provided in 2 perpendicular directions
- Minimum Wind Pressure = 10 PSF
- Allowable Storey Drift / Overall Drift = L/400 - L/600 to maintain inhabitant comfort and protect cladding and components from damage
- Design Methods :
  - Simplified (≤ 60' tall) • Analytical • Wind Tunnel



Adequate **Strength** V & M

Adequate **Stiffness** Drift / Story Drift $\Delta_{ALLOW} \sim L / 500$

Adequate **Stability (SM)** Against Overturning Moment (OTM) S.M. = (F.S) x OTM

Symmetical Layout of Lateral-Resisting System / Minimize **Torsion**

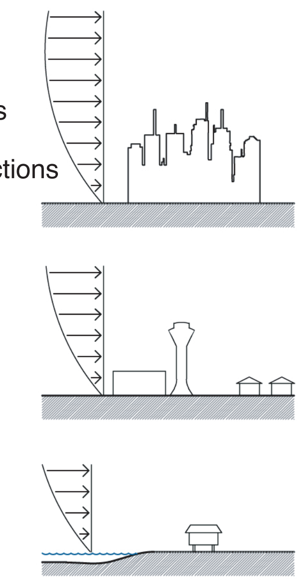
Exposure at Certain Height (K_Z)

Exposure Categories

Exposure B
- urban and suburban areas
- many closely spaced obstructions

Exposure C
- open terrain
- scattered obstructions

Exposure D
- flat terrain
- unobstructed
- near water



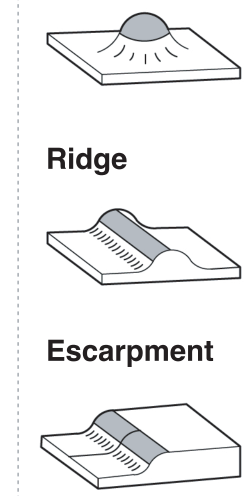
Topographic Factor (K_{ZT})

Wind Speed-up

Isolated Hill

Ridge

Escarpment



Wind speed V (MPH)

$q = 0.00256\ V^2 \cdot K_Z \cdot K_{ZT} \cdot K_D \cdot I_W$ (Analytical Method)

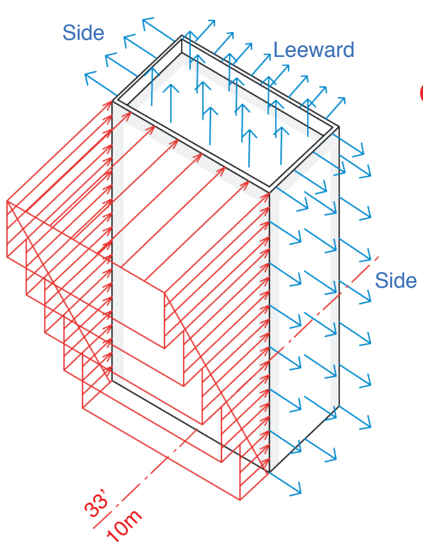
$q = 0.00256\ V^2$

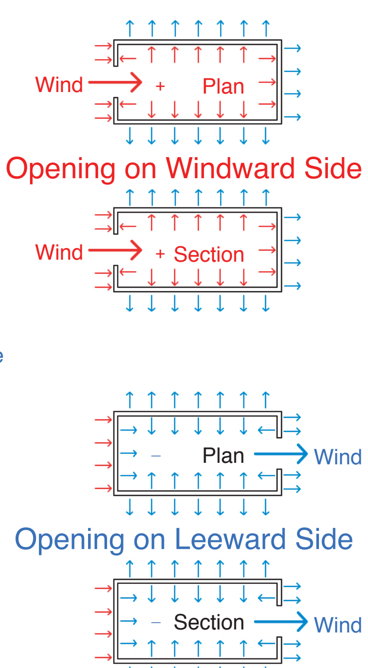
Wind Velocity pressure q (PSF)

$(MPH)^2$ x 0.00256 = q

90 mph	=	20.7 psf
100 mph	=	25.6 psf
110 mph	=	31.0 psf
120 mph	=	36.9 psf
140 mph	=	50.2 psf
150 mph	=	57.6 psf

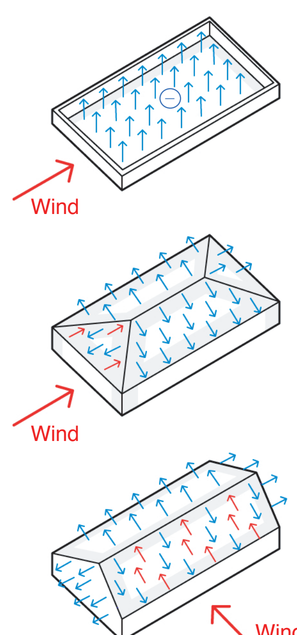
(Reference Page 54)

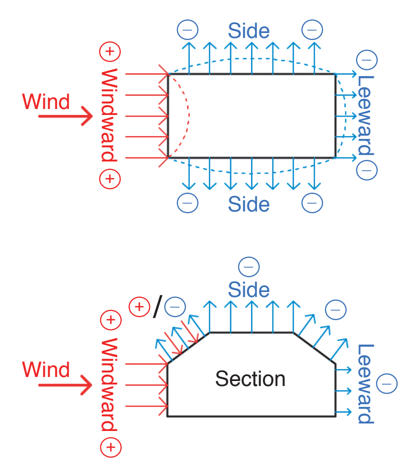




Buildings Enclosure: Open (Each Wall 80% Open; Partially Enclosed; Enclosed

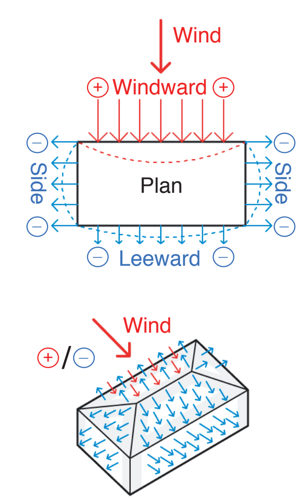
Glazed Openings: H < 30' Large Missile Test; 30' < H < 60' Small Missile Test





Building Components and Cladding

- Cladding	- Eave	- Overhangs
- Corners	- Rake	- Purlins
- Parapets	- Ridge	- Girts

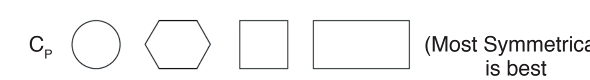


Hip Roof better than Gable Roof for resisting wind loads

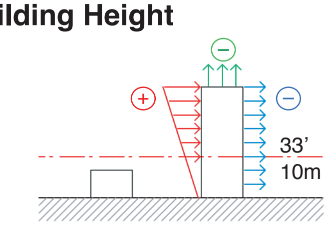
Importance Factor = I_W (Reference Page 55)
Degree of Hazard to Human Life & Damage to Property (I_W = 1.15)
- Substantial hazard to human life in the event of failure (I_W = 1.15)
- Essential Facilities (I_W = 1.15)
- Other (I_W = 1.0)
- Agricultural (I_W < 1)

Directionality Factor = K_D = 0.85 (For Buildings)
To be used with load combinations = 0.6 D + W
- Reduce probability of maximum winds coming from any direction
- Reduced probability of maximum pressure coefficients occurring for any given wind direction.

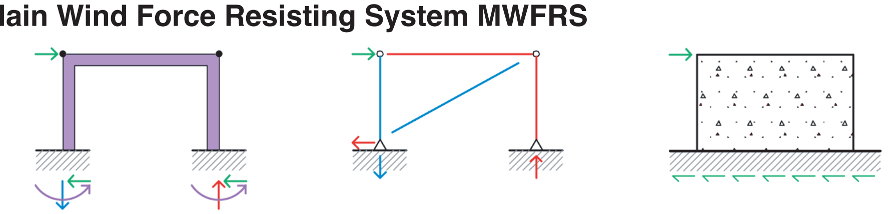
Building Shape / Configuration
How aerodynamic is the shape? Wind does not negotiate corners well.



Building Height



Main Wind Force Resisting System MWFRS



Moment Frame (MF)

Braced Frame (BF)

Shear Wall (SW)

SEISMIC FLOW CHART

Ground Movement

1 Acceleration S_S, S_1 (Ref. Pg. 56)
- Velocity
- Displacement

2 Dynamic Shaking
- Any and All Directions ↑↓ ⇄

3 Duration (Seconds)
↗ Duration T ↗ Damage

4 Magnitude (Size of EQ)
- Richter Scale (0-10)
- Logarithmic Scale (30^1, 30^2, 30^3...)

5 Intensity
- How it felt & damage caused
- Modified Mercalli Scale (I-XII)

RICHTER MAGNITUDE	DESCRIPTION
< 2.0	Micro
2.0 - 3.9	Minor
4.0 - 4.9	Light
5.0 - 5.9	Moderate
6.0 - 6.9	Strong
7.0 - 7.9	Major
8.0 - 9.9	Great
10.0 +	Epic

Modified Mercalli Intensity Scale

I. Instrumental	Not felt by many people.
II. Feeble	Felt only by a few. Suspended objects may swing
III. Slight	Felt noticeably by people indoors. Cars rock slightly, similar to passing truck.
IV. Moderate	Felt indoors by many walls make cracking sounds. Cars rock noticeably.
V. Rather Strong	
VI. Strong	Felt by all. Windows broken. Damage slight.
VII. Very Strong	Difficult to stand. Considerable damage to poorly built structures.
VIII. Destructive	Considerable damage in ordinary buildings with partial collapse. Fall of chimneys, monuments,etc.
IX. Ruinous	General panic. Damage great in ordinary buildings. Buildings shifted off foundation.
X. Disasterous	Some well built wooden structures destroyed. Most masonry and frame structures destroyed.

Soil

Liquefaction

SITE CLASS	DESCRIPTION	AVERAGE PERIOD
A	Hard Rock	0.5 sec
B	Rock	1 sec
C	Soft Rock / Dense Soils	1.5 sec
D	Stiff Soil	2.0 sec
E	Soft Clay Soil	2.5 sec
F	Liquefiable Soils Clay, Landslides	

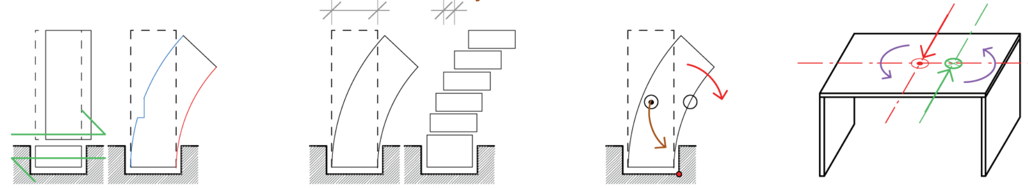
Maximum Considered EQ (MCE)

C_S
Spectral Response
$V = C_S W$

Building Dead Load (W)

W↗ → V↗

W↘ → V↘



Adequate **Strength** V & M

Adequate **Stiffness**
Drift / Story Drift
$\Delta_{allow} = \frac{L}{400} - \frac{L}{600}$

Adequate **Stability (SM)** Against Overturning Moment (OTM)
SM = (FS) x OTM

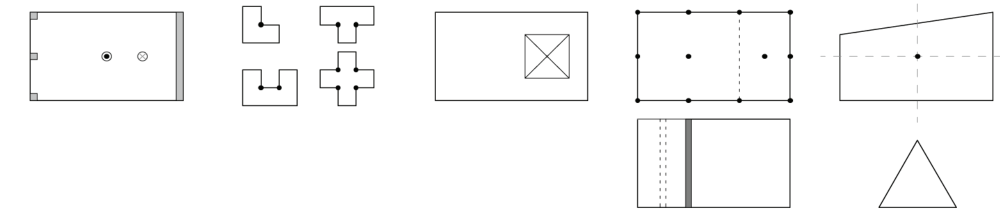
Symmetical Layout of Lateral-Resisting System / Minimize **Torsion**

DAMAGE LEVEL (Code)	MILD	MODERATE	STRONG
Primary	NONE	NONE	SOME
Secondary	NONE	SOME	SOME
			NO COLLAPSE

Plan Irregularities (See also REF pg.51)

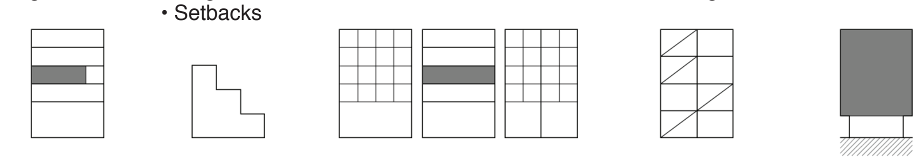
Direct Load Path

- Torsional Irregularities
- Re-Entrant Corners
- Discontinuous Diaphragms
- Out of Plane Offsets
- Non-Parallel Offsets



Vertical Irregularities

- Weight / Mass Irregularities
- Geometric Irregularities
- Setbacks
- Soft Story
- Discontinuous Bracing
- Weak Story: Discontinuous SW



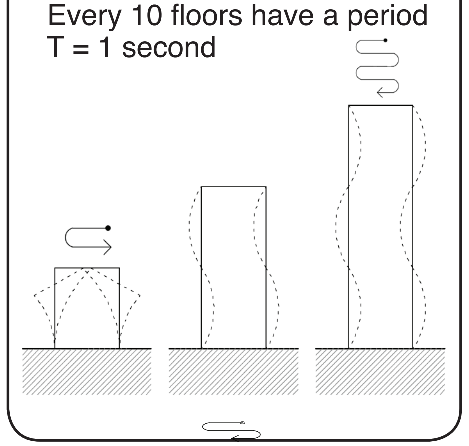
Building Components

(Non-Structural damage must be stabilized)

- Cladding / Curtain Wall
- Partitions
- Equipment
- Canopies / Overhangs
- Suspended Ceilings
- Parapets
- Chimneys / Stacks
- MEP / HVAC

Building Period (T) Seconds

- Frequency 1 / T
  - Hz = 1 / sec
- Depends on:
  - Height : ↗ = T↗
  - Weight : ↗ = T↗
  - Ductility : ↗ = T↗
- Rule of Thumb: Every 10 floors have a period T = 1 second

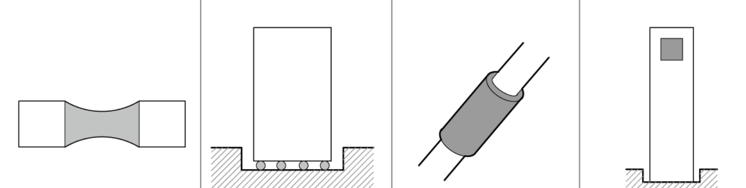


Damping

- Rate at which natural vibration is absorbed
- Reduction of vibration intensity with time
- Depends on:
  - Surface between structural materials
  - Joints / Detailing
  - Architectural finishes
  - Non-Structural members
  - Vibration Amplitude

Damping Strategies to Reduce Impact on Building

Reduced Beam Section (RBS)	Base Isolation	Fluid Viscous Damper	Tuned Mass Damper



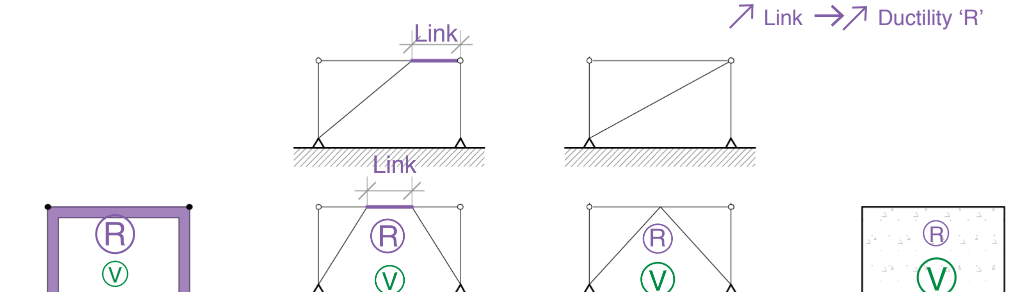
Ductility: Response Modification Coefficient (R) (Ref. Pg. 57 - 61)

- How much the structure can deform beyond elastic range without failing.
- R ↗ → V↘
- R ↘ → V↗
- Depends on:
  - Material
  - Special Detailing

(R) Greater Ductility ←

Greater Rigidity and Base Shear (V) →

↗ Link →↗ Ductility 'R'



Moment Frame (MF)

Eccentrically Braced Frame (EBF)

Concentrically Braced Frame (CBF)

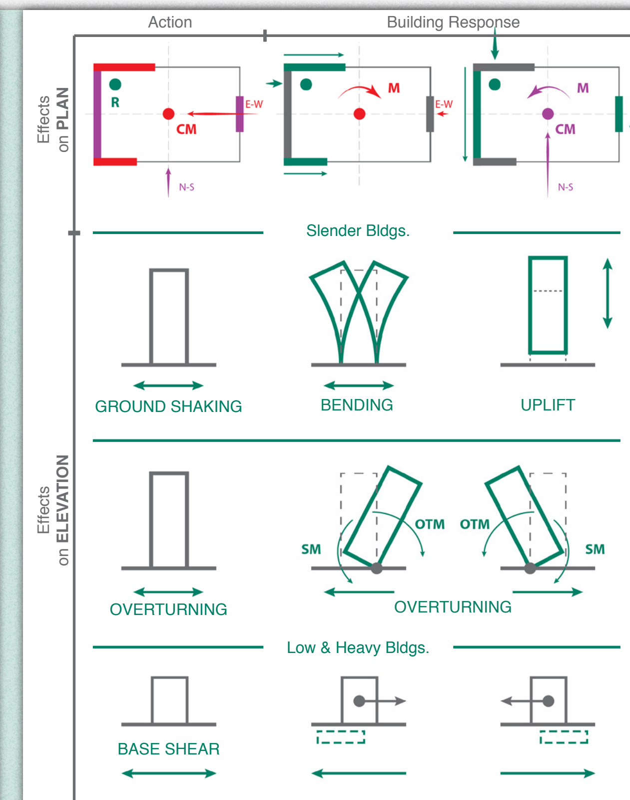
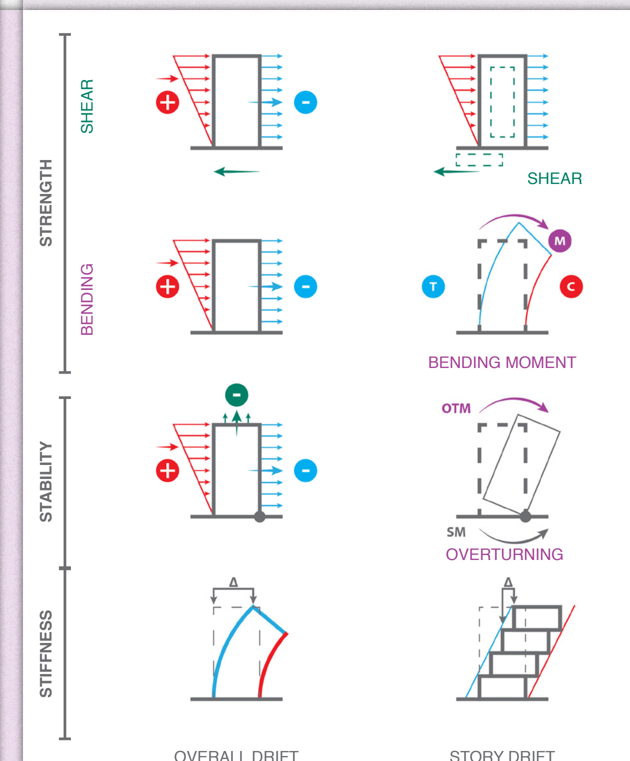
Shear Wall (SW)

WIND / SEISMIC COMPARISON

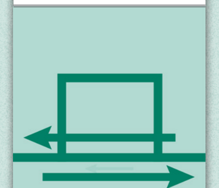
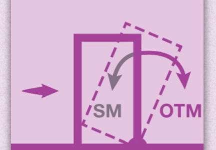
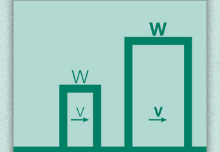
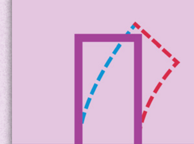
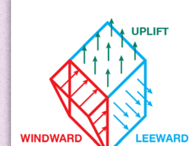
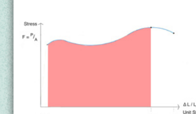
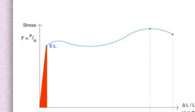
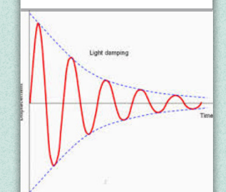
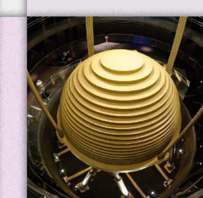
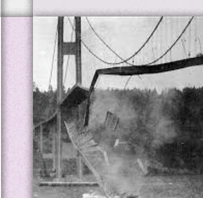
EVENT DESCRIPTION

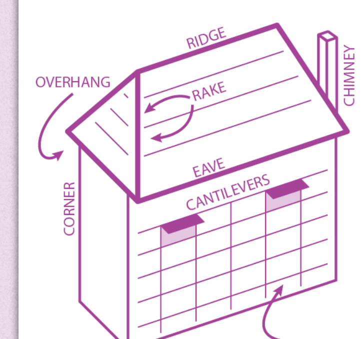
	SEISMIC	WIND
Measurement, Scale, Instruments	Strongest Magnitude Earthquakes: 9.5 Chile 1960; 9.2 Alaska 1964, 4.5 minutes; 9.1 Sumatra 2004, 10 minutes; 9.0 Moore 2011, 6 minutes. *Seismometer. Seismograph. Moment Magnitude (Richter) - Scale (1 - 10). Modified Mercalli Intensity - Scale (I - XII)*. SEISMOGRAGH	ANEMOMETER. *Simpson Saffir Hurricane Scale (Category 1 - 5). Enhanced Fujita Tornado Scale (EF0 - EF6)*. Highest Wind Speed: 175 mph Katrina C5, 11 days; 115 mph Sandy C3, 9 days; 145 mph Haiyan C5, 8 days; 301 mph Moore EF5, Oklahoma Tornado
Duration	Longest Earthquake: 9.1 Sumatra 2004, 10 minutes. *Typically a few seconds*. SHORT	LONG. *10 minutes to 1 hour*
Frequency of Occurence	Maximum Considered Earthquake - M.C.E. - *May not even happen once in the life of a building.*	*Hurricanes may happen multiple times in the life of a building.* Mean Recurring Interval - MRI - 50 year, 100 year
Geographic Location	*Alaska, British Columbia, Pacific Coast, Hawaii, Missouri, South Carolina, Puerto Rico; Mexico, Colombia, Equador, Peru, Chile*	*Atlantic Coast, Gulf Coast, Hawaii, Puerto Rico*
Forecasting	*Very limited forecasting (foreshocks)*	*Well developed forecasting*

THE NATURE OF FORCE

	SEISMIC	WIND
Magnitude & Direction	*- Dynamic - Magnitude. - Direction - Cyclical. Much greater force than wind, but less frequently*	GUSTS. *Lesser force magnitude than seismic, but more frequent. Dynamic: wind speed varies with gusts. Direction: + / - pressure. Uni-directional*
Force Excitation	Excitation: -Tectonic plate shift -Ground shaking -Bottom up. Lateral internal forces result from dynamic response of structure. **Load Path**: *Ground shaking → Foundation → MLFRS → Diaphragms → Envelope*	**Load Path**: *Air Turbulence → Envelope → Diaphragm → MLFRS → Foundation*. - Excitation - Air turbulence strikes building → Wind Stagnation pressure → Force travels from Diaphragms to Foundation.
Lateral Component		
Gravitational Component	*Building as a whole is lifted and dropped.*	UPLIFT. *Lateral force results from pressure difference between (+) pressure on windward facades and (-) pressure on leeward facades.* Uplift on Roof: Anchorage of roof to walls (hurricane clips); Anchorage of structure to foundation or hold downs (anchors)
Force Direction & Application	*Force originates in the Diaphragm.*	*Force delivered to the Diaphragm from the Envelope.*

WIND / SEISMIC COMPARISON

EVENT DESCRIPTION	SEISMIC	WIND
Action / Response	 *Action - ground moves > Reaction - building responds with inertial force. Displacement causes Shear Force.*	 *Force causes displacement (drift)*
Inertia	 *Prime generator of seismic force in building*	N / A *Little to no impact in generating wind forces*
Damage	 *Damage & yielding are both expected - collapse is unacceptable.* *No primary or secondary damage from minor earthquakes* / *Some primary and some secondary damage from strong earthquakes*	 *Structure should suffer little to no damage from 50 YR recurrence winds.* Structure should not pose a threat to large numbers of people assemblies from 100 YR recurrence winds. / Damage should not prevent building functions.
Surface Area	N / A *Surface area is not a factor in determining load (building irregularities & Dead Load of areas are significant).*	 *Surface area of facades & roofs are key in determining wind loads.*
Dead Load	DL *Most important factor in determining Base Shear*	DL Not a factor in determining wind loads (major contributor to Dead Load Stabilizing Moment)
Yielding	 *Yielding is expected. Deformation may be inelastic. - Yielding of members absorbs energy from earthquake. - Design response closer to ultimate stress.*	 Yielding is not permitted. Must remain in elastic range. - Design response must be below yield. - Economically feasible to design within elastic limit.
Stiffness *(Rigidity)*	*Significant loss of stiffness is inevitable (building will move a lot!)* Stiffness is required to reduce secondary damage.	△ Drift Affected. Significant loss of stiffness or strength not anticipated. Maintaining rigidity reduces and minimizes damage to cladding & secures inhabitant comfort.
Ductility *(Detailing for ductility is now essential for both.)*	*R* *Essential! For MLFRS. R : seismic response modification coefficient (R = 1-8)*	*R* *Not currently a requirement (Trend to make ductility required for wind as well)*
Damping	 *Damping is considered in the calculation of seismic forces. - Reduced Beam Section. Base Isolation. Fluid Viscous Dampers. Tuned Mass / Liquid Dampers.*	 *Damping is not typically considered in the calculation of wind force.*
Soil Properties	S_{DS} S_{D1} SDC *Resonance : when building period & soil period are harmonic. Amplification : damage is amplified if resonance occurs.*	N / A *Soil is not considered in calculating wind forces. Topography is considered though. Wind speed up on upper half of hill, ridge, escarpment.*
Building Period	 *Considered in the calculation of seismic forces. Possibility of building period resonating with ground shaking.*	 *Wind & structure unlikely to resonate. Exception - Tacoma Narrows Bridge (Galloping gurney).*
Direct Load Path	**Secondary Structure**: *Ceiling tiles, pipes, sprinkler, ducts, water heater, HVAC. **All** need bracing in two perpendicular directions.* **Primary Structure**: *Free of irregularities; Best shape*	*Degree of enclosure, Enclosed, Partially Open, Open*



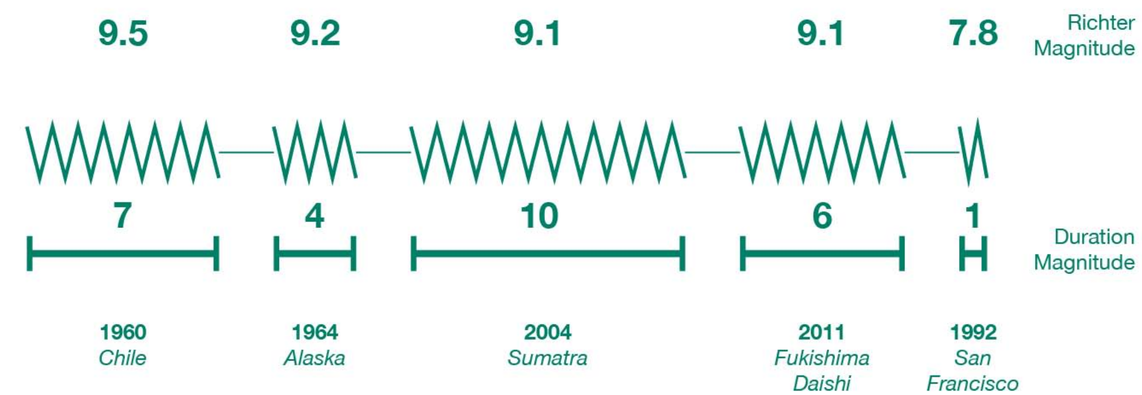
SEISMIC

1. Not forecastable: only probabilistic
2. Less frequently occurring
3. Much greater force, shorter duration
4. Force: bottom up
5. Ground movement causes force (Inertial)
6. Torsion almost certain with rigid diaphragm
7. Ground moves first.
8. Building response increases with height.
9. Seismic load proportional to *total* floor *dead load* (Mass).
10. Only the deformation relative to ground is critical.
11. Critical condition : low-rise / dense material (concrete) : Base Shear; Low-rise or mid-rise / low density material (steel) : overturning; Torsion critical in all cases (irregularities).
12. Structure designed to ultimate stress, ductile (inelastic) yielding
13. Regular structure. No plan irregularities. No elevational irregularities.
14. Ductility - essential.
15. Greater stiffness attracts more seismic force.
16. Greatest Base Shear at bottom (total mass greatest at foundation).
17. Seismic force mainly generated at base of structure.
18. Damage mostly affects interior.
19. Duration is much shorter (few seconds to 10 minutes).

Similarities

- Both are Lateral and have a Gravitational component.
- Both depend on Geography.
- Both are Dynamic.
- Both incorporate Importance / Occupancy Factors.
- The force in both is acting on the entire building (compared to gravity loads that act on individual members).
- MLFRs (MF, EBF, CBF, SW)
- The force in both is acting at the story level.
- Both are detailed for ductility.

Scales

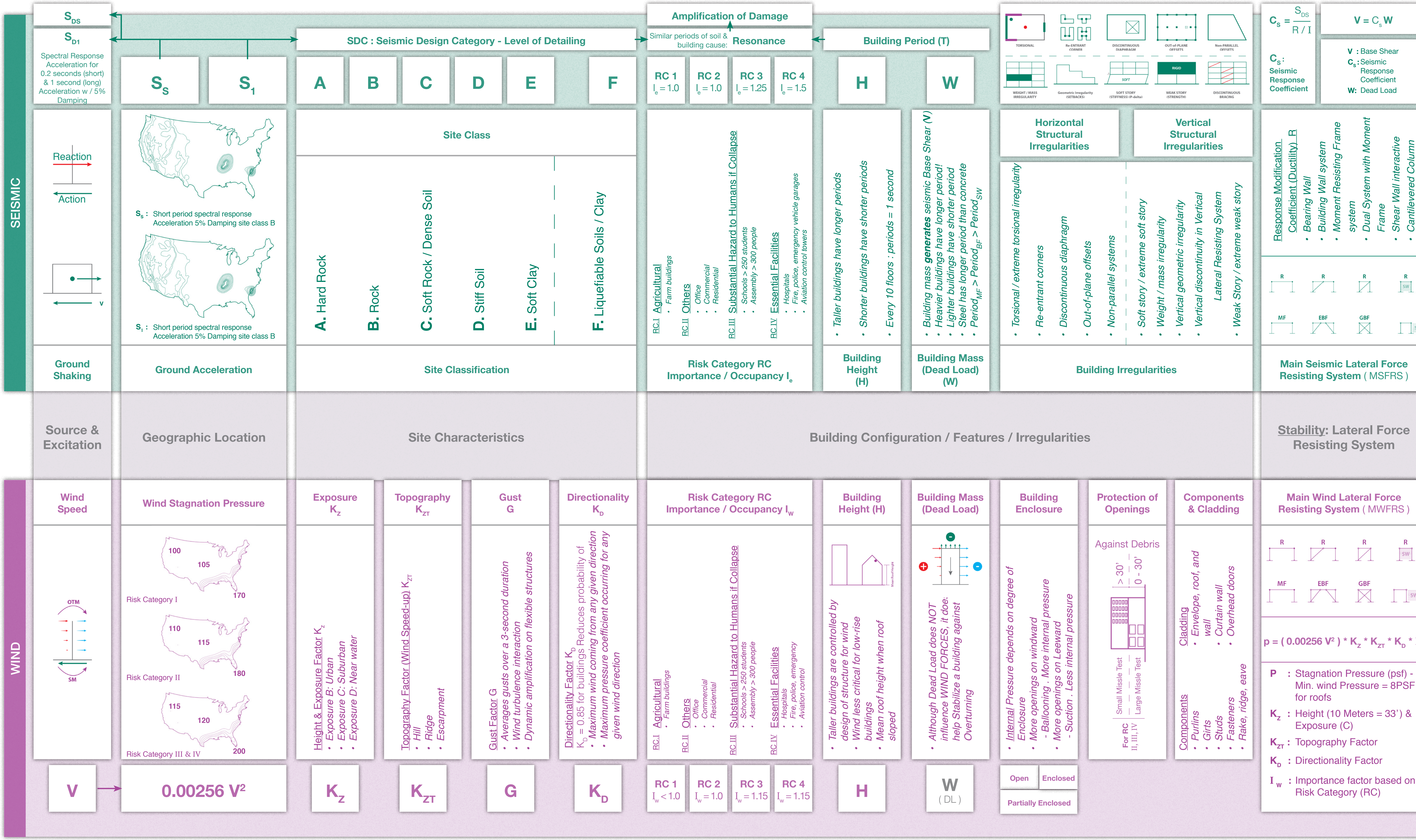


Design Philosophies

SEISMIC	Force on the foundation	Dynamic load, dynamic response	Structure is designed with enough sustained strength to respond to factored cyclical seismic loads inelastically and without collapse
SEISMIC	Design is for life safety in an extremely rare event.	Design to completely limit property damage is not feasible and not required.	Building occupancy and operation after event is desirable but not required.
WIND	Force on the envelope	Dynamic, nearly static response	Structure is designed with enough strength to respond to factored wind forces *elastically*.
WIND	Design is for life safety.	Design is also to limit property damage.	Building occupation and operation after event is required.

WIND

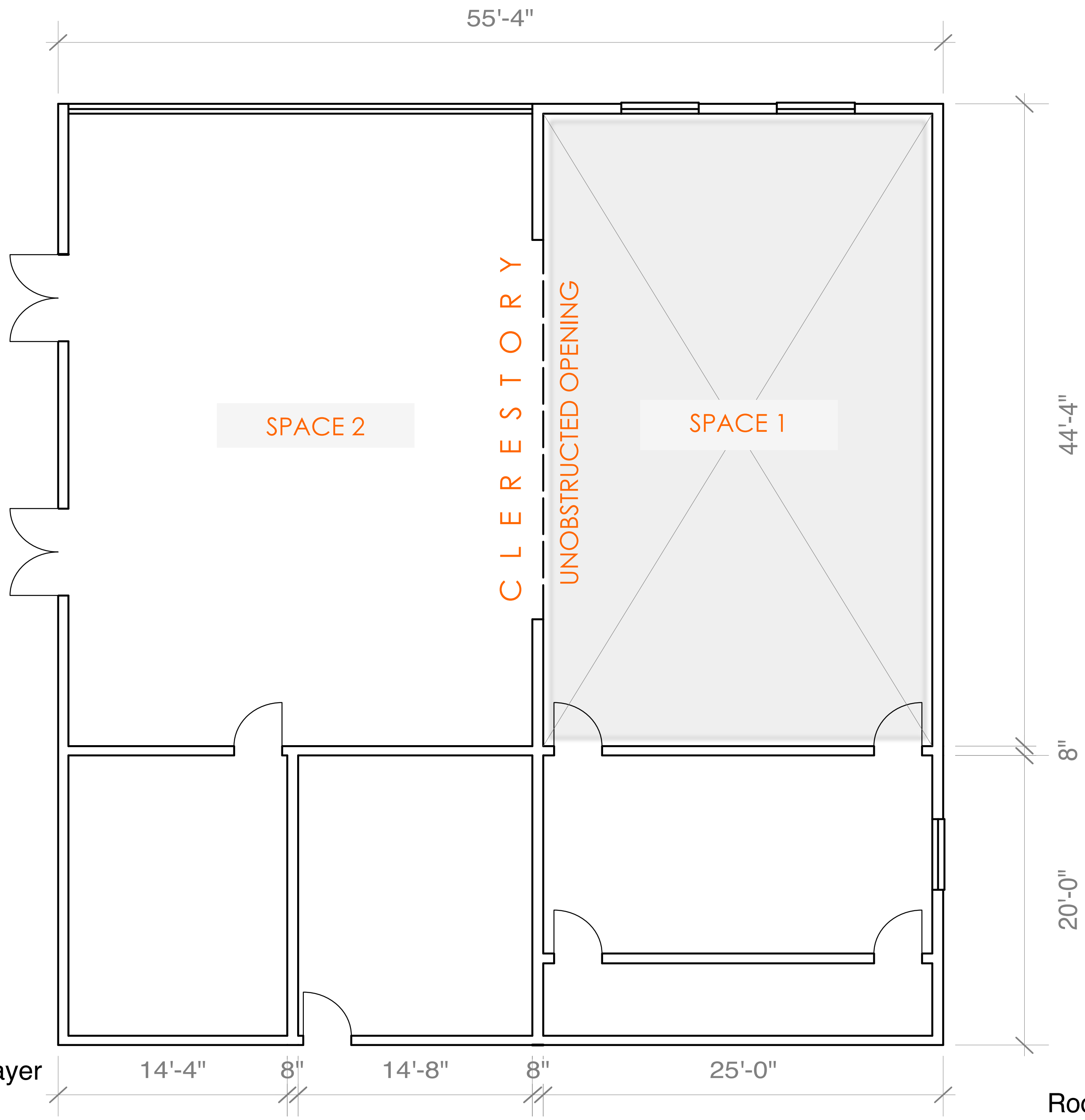
1. Accurate prediction: forecastable
2. More frequently occurring
3. Smaller force, longer duration
4. Force - top down
5. Force causes deformation (Drift)
6. Torsion less likely with wind forces
7. Building moves first.
8. Wind pressure increases with wind height.
9. Wind pressure proportional to *total area* exposed to wind.
10. Overall drift & floor-to-floor drift are critical.
11. Critical condition : structure : overturning & strength; Components & cladding : stiffness (limit drift)
12. Structure designed to retain in elastic range (less than yield).
13. Rounded corners, aerodynamic shape
14. Stiffness - essential.
15. Greater stiffness has no influence on wind load. (Has influence on drift.)
16. Greatest wind force at top.
17. Wind force generated at every point where the envelope is in contact with each diaphragm.
18. Damage typically affects cladding.
19. Duration is 10 minutes to 1 hour.



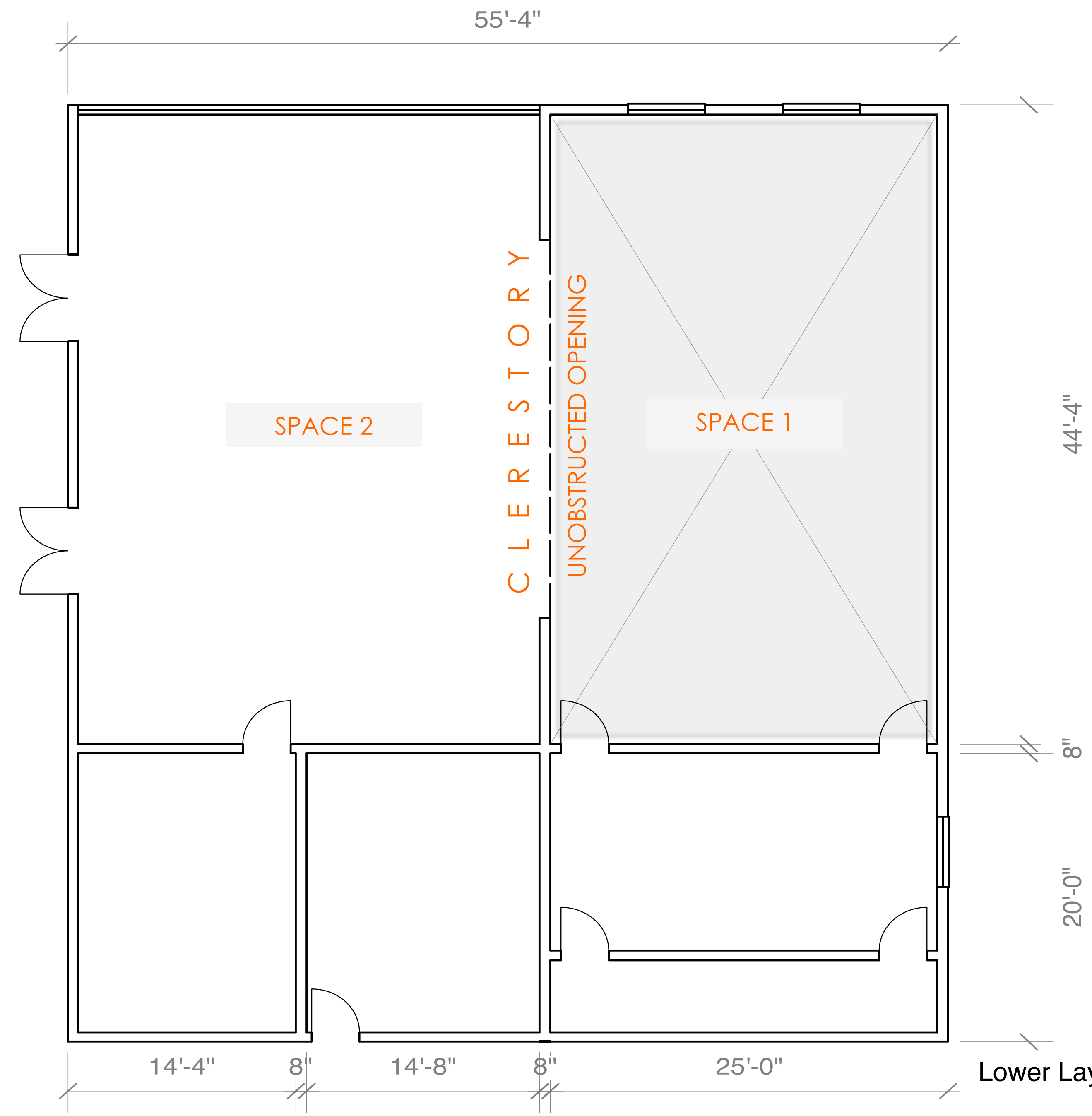
T H A D D E U S

WIND / SEISMIC COMPARISON

Upper Layer



A.R.E. 3.1
Roof Framing Vignette



Lower Layer

General:
- ☐ Correct program on correct layer
- ☐ Do not use bearing walls

Columns:
- ☐ Upper Columns Redrawn on Lower Layer
- ☐ Column in Every Corner
- ☐ Column Spacing = 40 - 42' +/-

Beams:
- ☐ Every Beam Supported by Two (2) Columns
- ☐ Beam Span 30' - 42' +/-
- ☐ Beam on Lower Layer where wall is shared between upper and lower levels

Joists:
- ☐ Joist Span in Short Direction
- ☐ Every Joist supported by Two (2) Beams / Columns
- ☐ Joist Spacing = Deck Span
- ☐ Joist Span at 20' - 30' +/-
- ☐ Joist Span Perpendicular to Beam

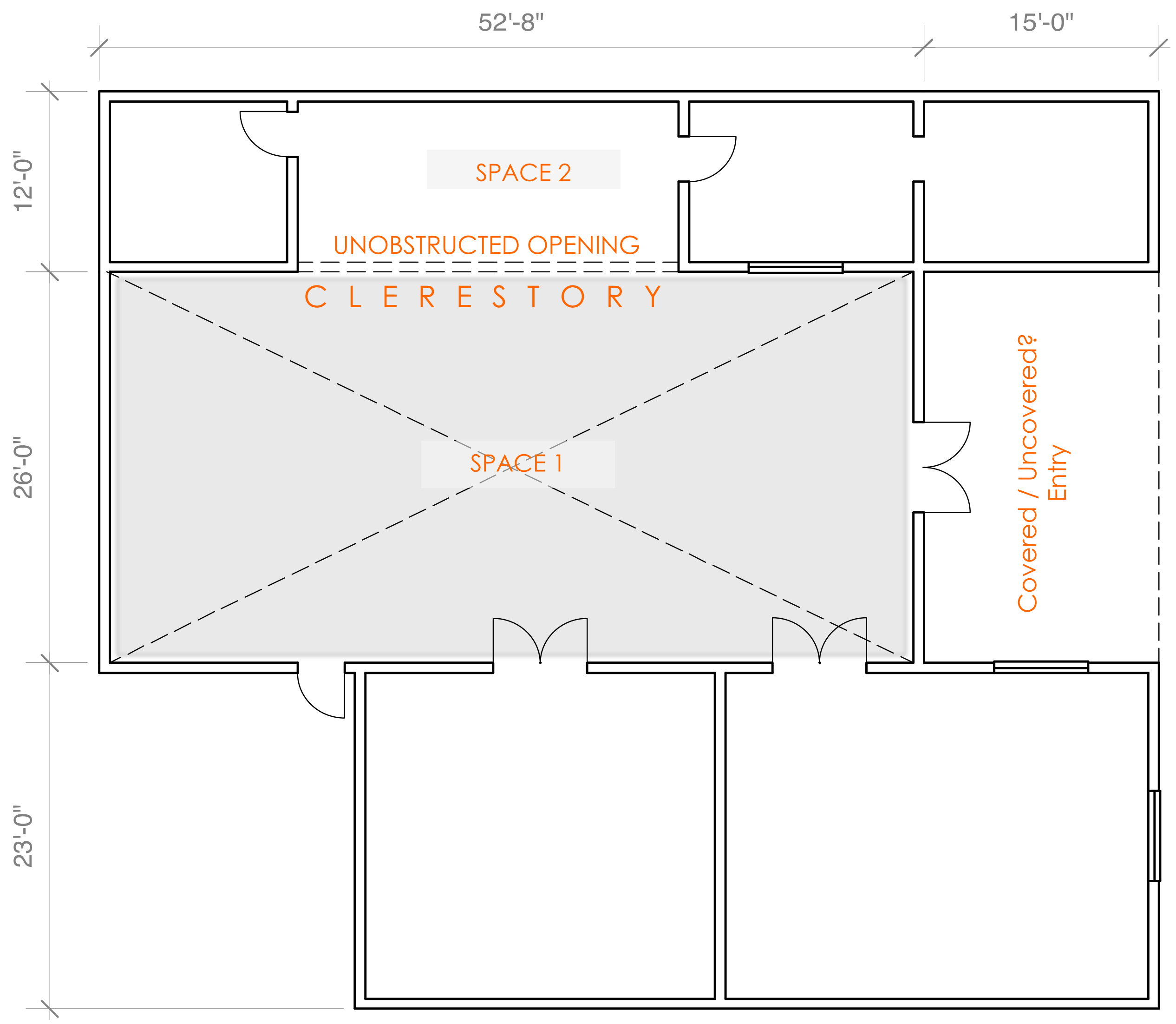
Deck:
- ☐ Deck Span Given in Program
- ☐ Deck Span Perpendicular to Joist
- ☐ Deck Span Typically 4' - 5'

Clerestory:
- ☐ Beams Under Clerestory

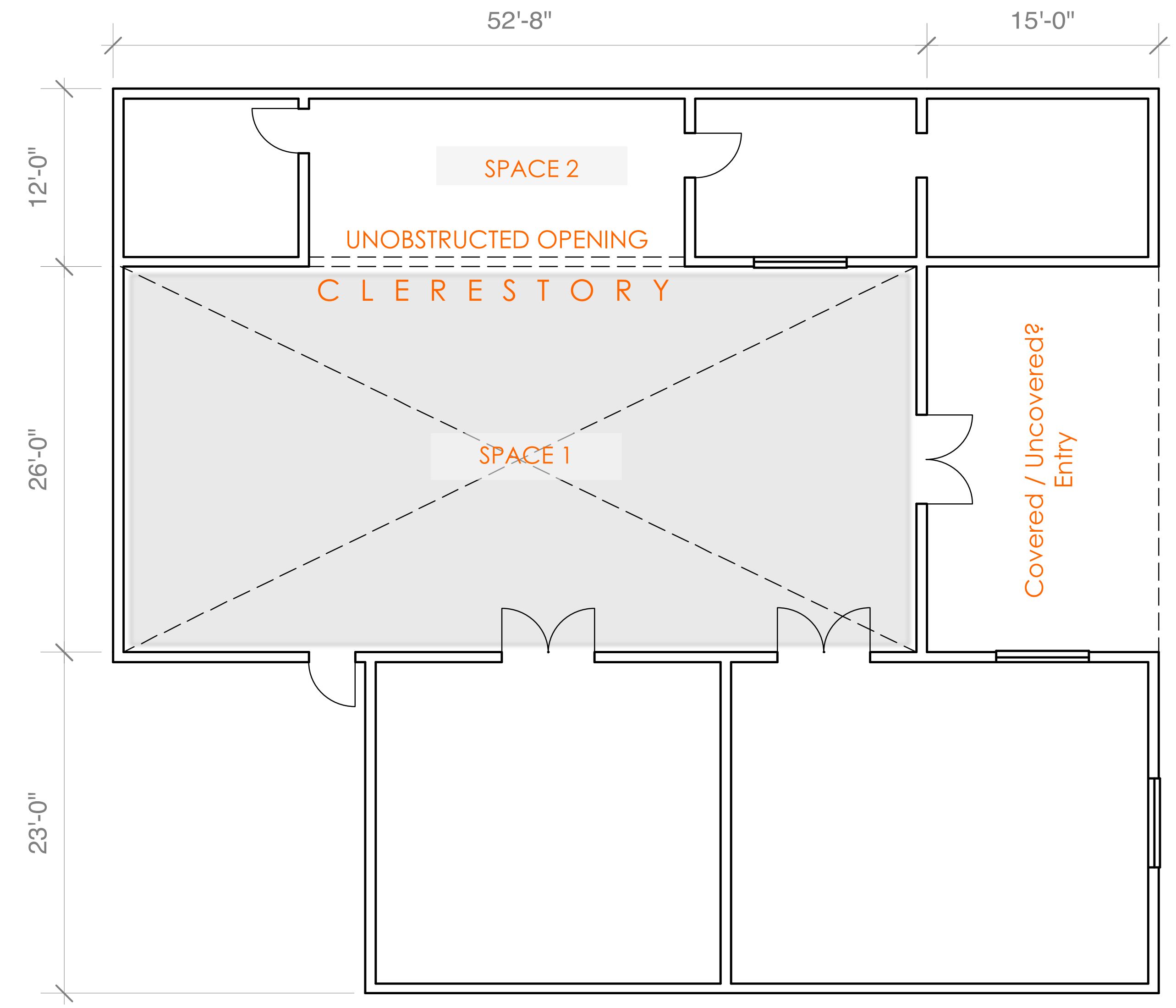
Legend:

All Members drawn to centerline of supporting member

Column	■ (red square)
Beam	━━ (purple line)
Joist	– – – – (green dashed line)
Deck	⟷ (brown arrow)



Upper Layer



Lower Layer

A.R.E. 4.0
Roof Framing Vignette

General:

- ☐ Correct program on correct layer
- ☐ Do not use bearing walls

Columns:

- ☐ Upper Columns Redrawn on Lower Layer
- ☐ Column in Every Corner
- ☐ Column Spacing = 40 - 42' +/-

Beams:

- ☐ Every Beam Supported by Two (2) Columns
- ☐ Beam Span 30' - 42' +/-
- ☐ Beam on Lower Layer where wall is shared between upper and lower levels

Joists:

- ☐ Joist Span in Short Direction
- ☐ Every Joist supported by Two (2) Beams / Columns
- ☐ Joist Spacing = Deck Span
- ☐ Joist Span at 20' - 30' +/-
- ☐ Joist Span Perpendicular to Beam

Deck:

- ☐ Deck Span Given in Program
- ☐ Deck Span Perpendicular to Joist
- ☐ Deck Span Typically 4' - 5'

Clerestory:

- ☐ Beams Under Clerestory

Legend:

All Members drawn to centerline of supporting member

- Column
- Beam
- Joist
- Deck