Basic Engineering for Building Plans Examiners & Inspectors

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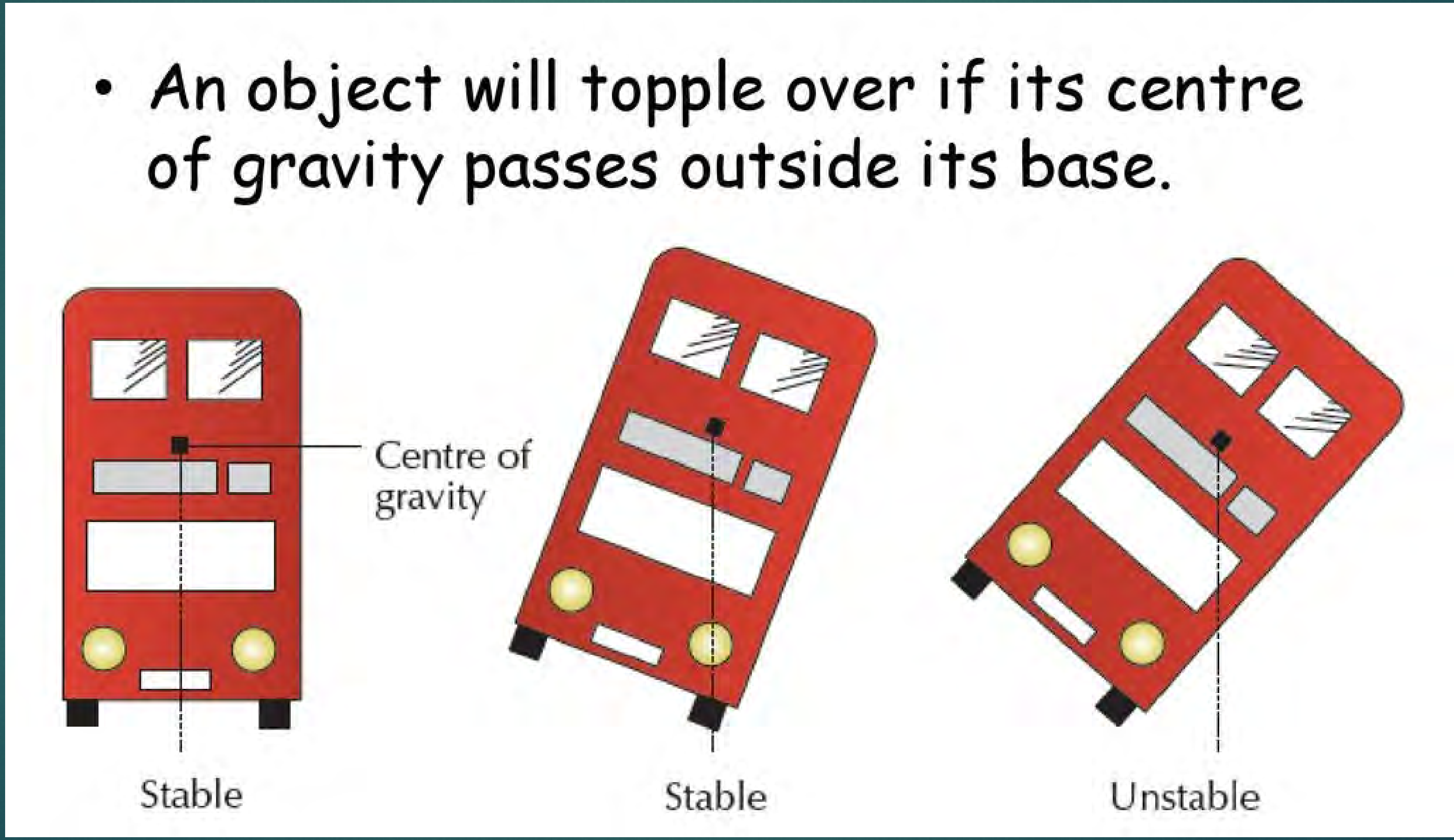
Basic Forces & Stresses

Center of gravity

- A point from which the weight of a body or system may be considered to act.
- In uniform gravity it is the same as the center of mass.

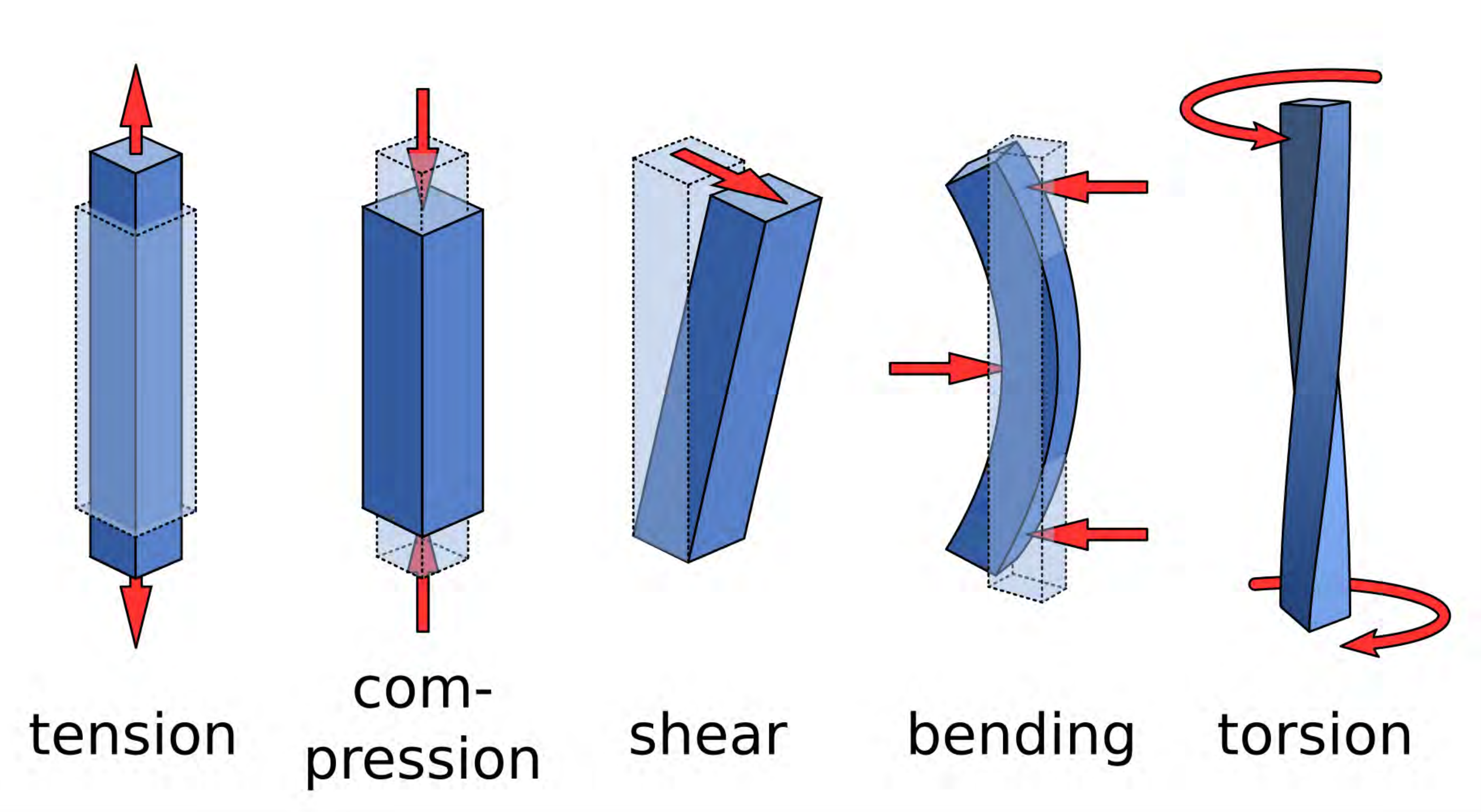
Stability



• An object will topple over if its centre of gravity passes outside its base.
Centre of gravity
Stable
Stable
Unstable

Force

Force is any action that tends to maintain or alter the motion of a body or to distort it.



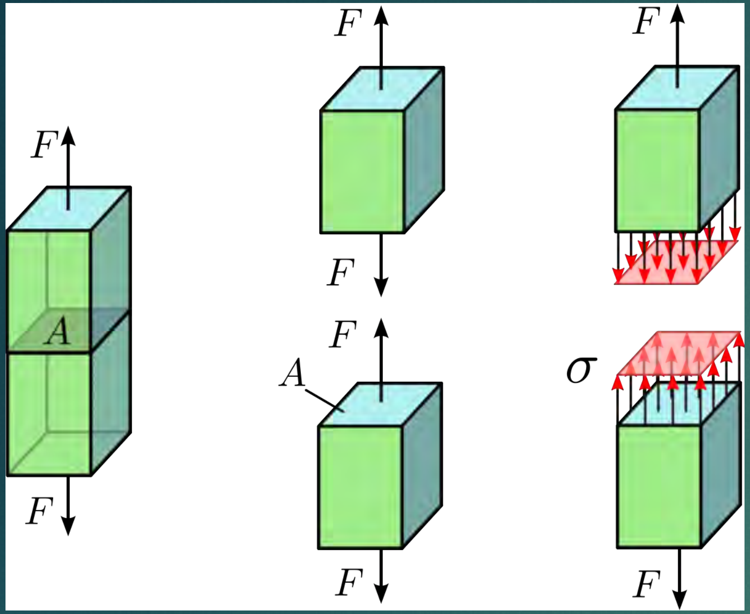
tension
com-
pression
shear
bending
torsion

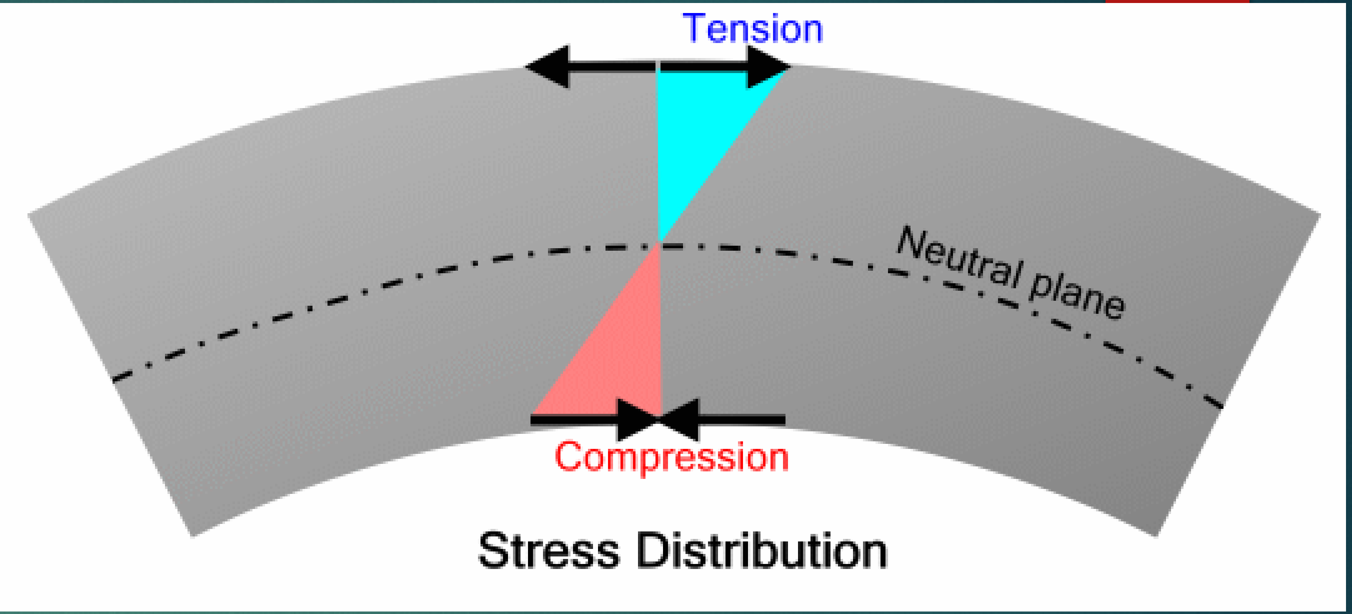
STRESS

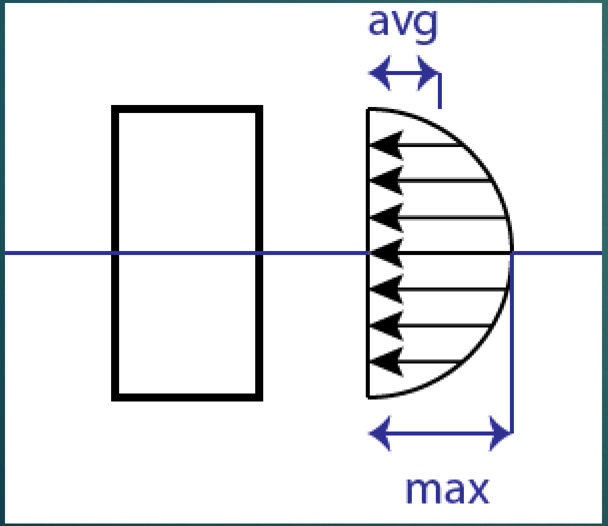
- The term stress is used to express the loading in terms of force applied to a certain cross-sectional area of an object. From the perspective of loading, stress is the applied force or system of forces that tends to deform a body.
- Stress is the internal distribution of forces within a body that balance and react to the loads applied to it. The stress distribution may or may not be uniform, depending on the nature of the loading condition.
- Expressed in units of force per area.

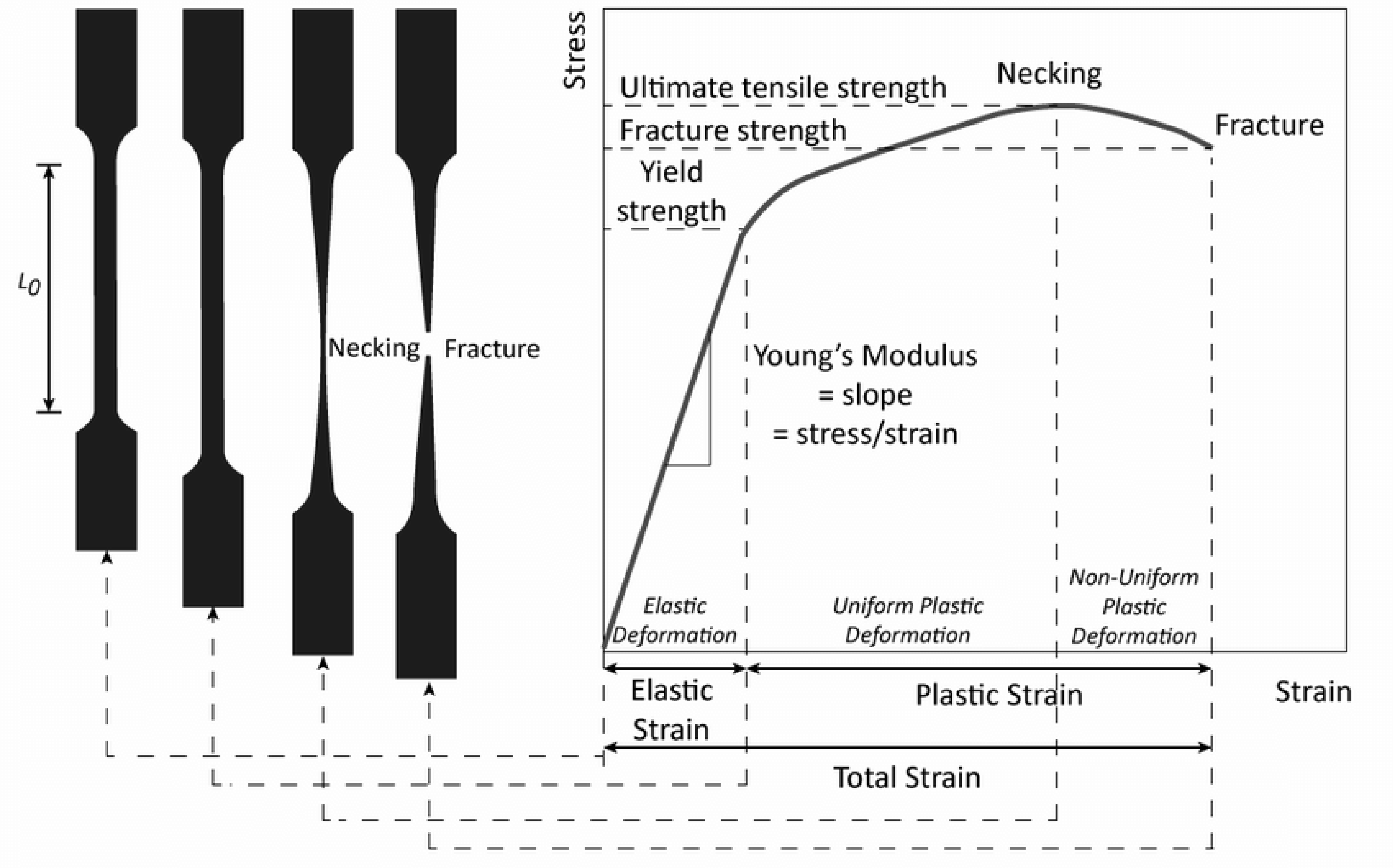
Strain

- Strain is the response of a system to an applied stress
- Engineering strain is defined as the amount of deformation in the direction of the applied force divided by the initial length of the material. This results in a unitless number, although it is often left in the unsimplified form, such as inches per inch or meters per meter.
- the strain distribution may or may not be uniform in a complex structural element, depending on the nature of the loading condition.

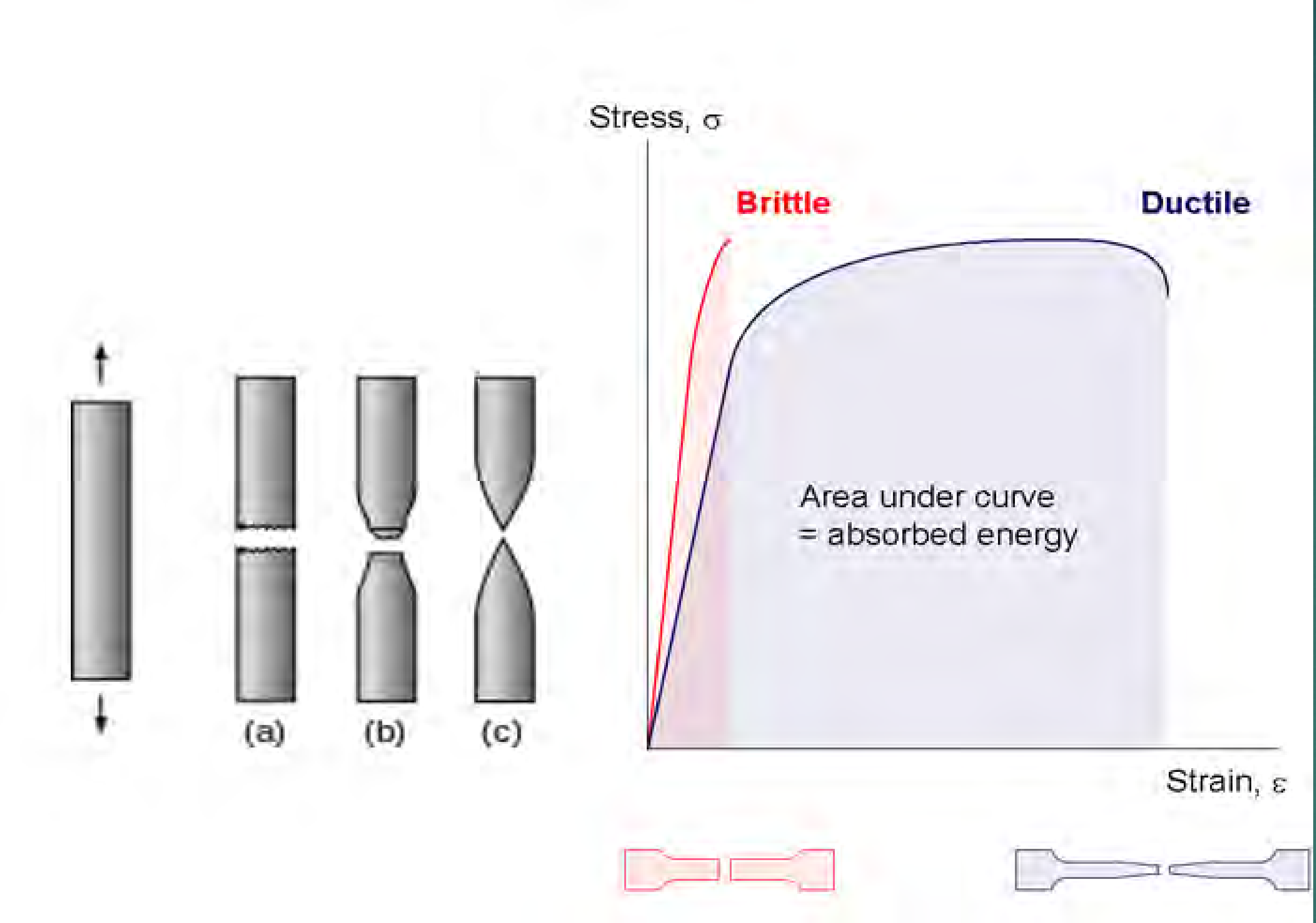

F
F
A
F
F
A
F
F
F
σ
F


Tension
Neutral plane
Compression
Stress Distribution

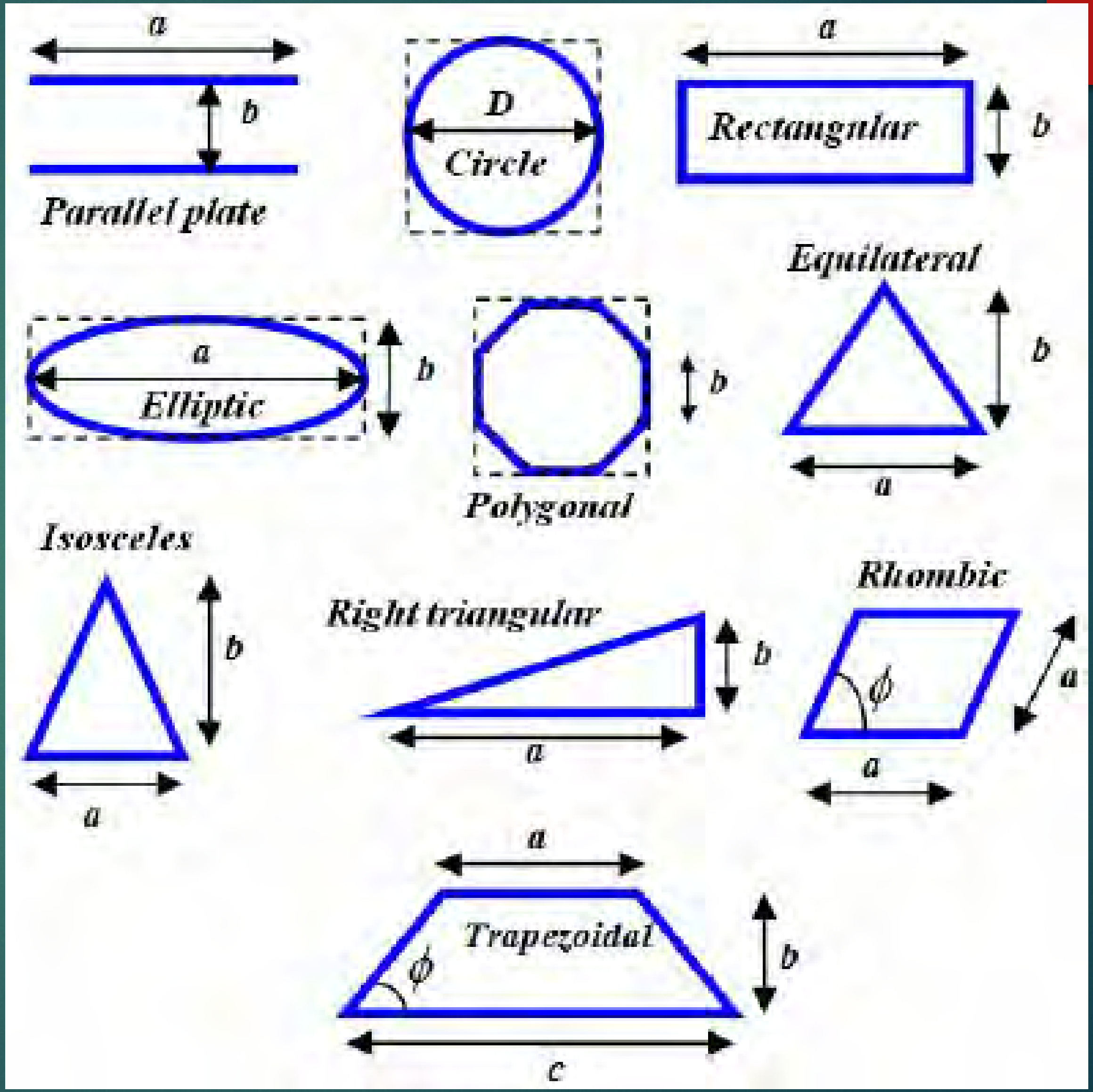

avg
max



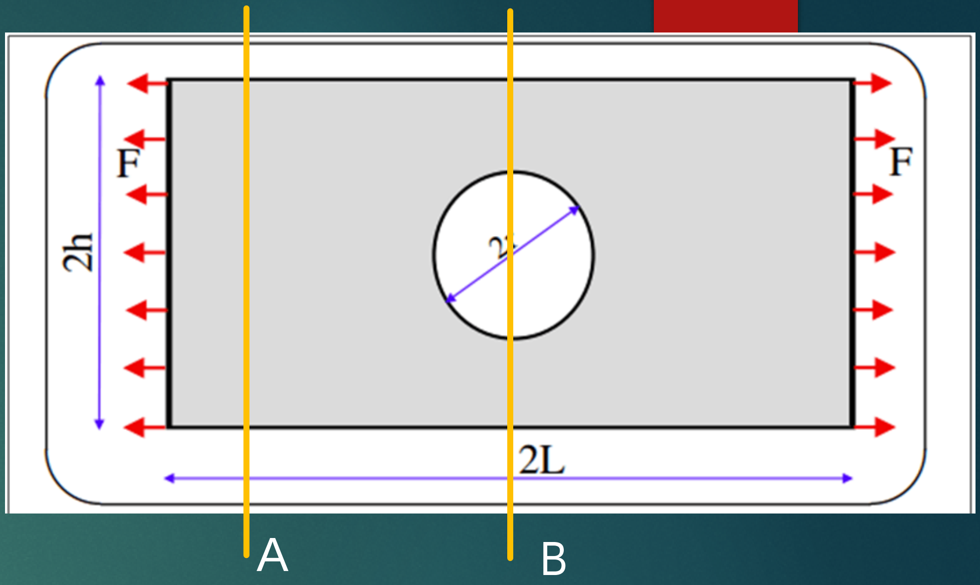
L_0
Necking
Fracture
Stress
Ultimate tensile strength
Necking
Fracture strength
Fracture
Yield strength
Young's Modulus
= slope
= stress/strain
Elastic Deformation
Uniform Plastic Deformation
Non-Uniform Plastic Deformation
Elastic Strain
Plastic Strain
Strain
Total Strain


Stress, σ
Brittle
Ductile
Area under curve
= absorbed energy
Strain, ε
(a)
(b)
(c)

Area

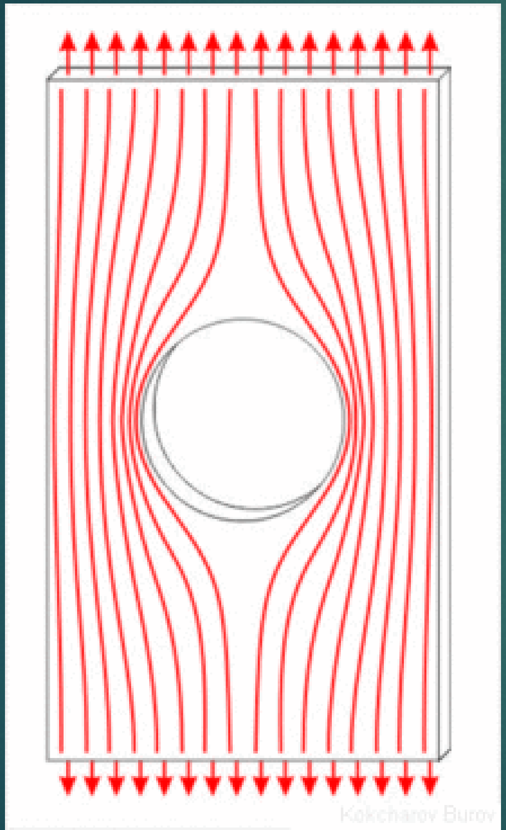

a
b
Parallel plate
D
Circle
a
Rectangular
b
Equilateral
a
Elliptic
b
b
Polygonal
b
a
Isosceles
b
a
Right triangular
b
a
Rhombic
a
a
a
Trapezoidal
b
c

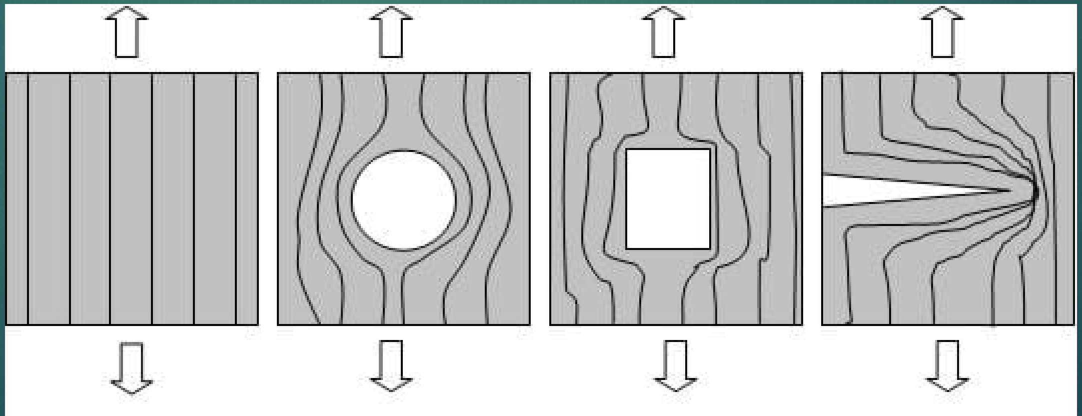
Gross Area vs. Net area



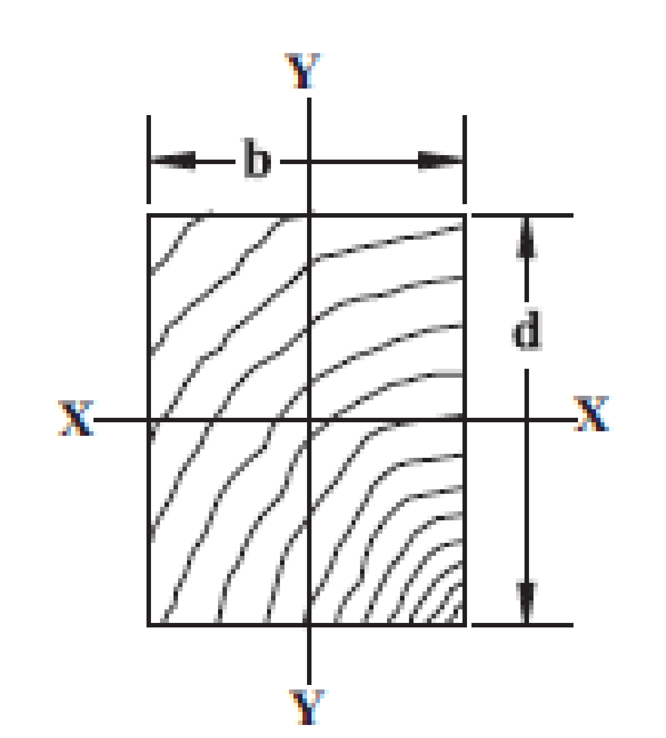
Area = 0.625

Area = 0.5





Moment of Inertia



$$I_{xx} = \frac{bd^3}{12}$$

$$I_{yy} = \frac{db^3}{12}$$

Section Modulus

$$S_{xx} = \frac{I_{xx}}{d/_2} = \frac{bd^3}{12}\frac{2}{d} = \frac{bd^2}{6}$$

$$S_{yy} = \frac{I_{yy}}{b/_2} = \frac{db^3}{12}\frac{2}{b} = \frac{db^2}{6}$$

Cross-Sectional Properties

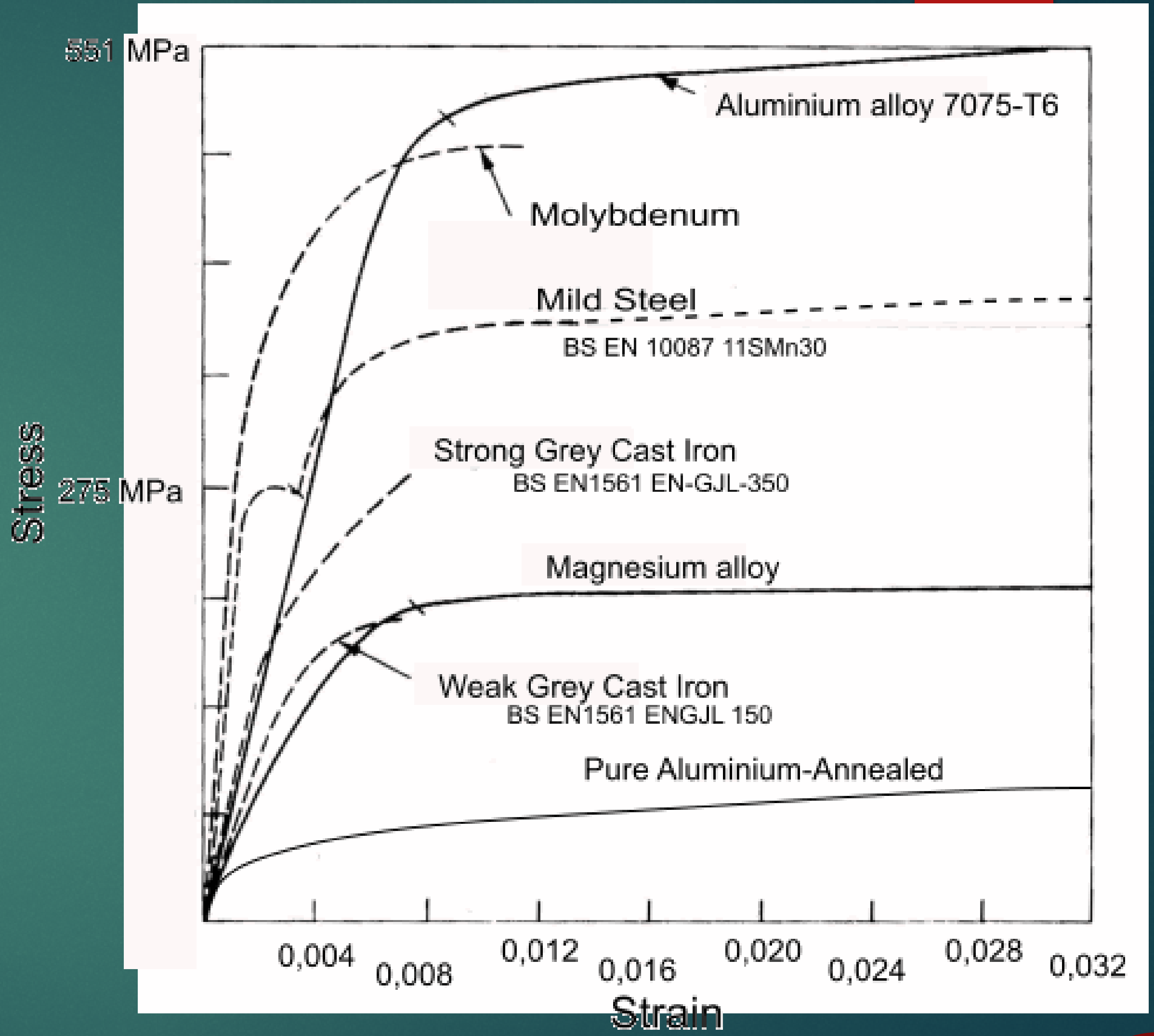
Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.^{2}	X-X AXIS Section Modulus S_{xx} in.^{3}	X-X AXIS Moment of Inertia I_{xx} in.^{4}	Y-Y AXIS Section Modulus S_{yy} in.^{3}	Y-Y AXIS Moment of Inertia I_{yy} in.^{4}
Boards[1]						
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 x 3-1/2	2.625	1.531	2.680	0.328	0.123
1 x 6	3/4 x 5-1/2	4.125	3.781	10.40	0.516	0.193
1 x 8	3/4 x 7-1/4	5.438	6.570	23.82	0.680	0.255
1 x 10	3/4 x 9-1/4	6.938	10.70	49.47	0.867	0.325
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396
Dimension Lumber (see NDS 4.1.3.2) and Decking (see NDS 4.1.3.5)						
2 x 3	1-1/2 x 2-1/2	3.750	1.56	1.953	0.938	0.703
2 x 4	1-1/2 x 3-1/2	5.250	3.06	5.359	1.313	0.984
2 x 5	1-1/2 x 4-1/2	6.750	5.06	11.39	1.688	1.266
2 x 6	1-1/2 x 5-1/2	8.250	7.56	20.80	2.063	1.547
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727
3 x 4	2-1/2 x 3-1/2	8.75	5.10	8.932	3.646	4.557
3 x 5	2-1/2 x 4-1/2	11.25	8.44	18.98	4.688	5.859
3 x 6	2-1/2 x 5-1/2	13.75	12.60	34.66	5.729	7.161
3 x 8	2-1/2 x 7-1/4	18.13	21.90	79.39	7.552	9.440
3 x 10	2-1/2 x 9-1/4	23.13	35.65	164.9	9.635	12.04
3 x 12	2-1/2 x 11-1/4	28.13	52.73	296.6	11.72	14.65
3 x 14	2-1/2 x 13-1/4	33.13	73.15	484.6	13.80	17.25
3 x 16	2-1/2 x 15-1/4	38.13	96.90	738.9	15.89	19.86
4 x 4	3-1/2 x 3-1/2	12.25	7.15	12.51	7.146	12.51
4 x 5	3-1/2 x 4-1/2	15.75	11.81	26.58	9.188	16.08
4 x 6	3-1/2 x 5-1/2	19.25	17.65	48.53	11.23	19.65
4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90
4 x 10	3-1/2 x 9-1/4	32.38	49.91	230.8	18.89	33.05
4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
4 x 14	3-1/2 x 13-1/4	46.38	102.41	678.5	27.05	47.34
4 x 16	3-1/2 x 15-1/4	53.38	135.66	1034	31.14	54.49

Cross-Sectional Properties

Nominal Size b x d	Standard Dressed Size (S4S) b x d in. x in.	Area of Section A in.²	X-X AXIS Section Modulus S_{xx} in.³	X-X AXIS Moment of Inertia I_{xx} in.⁴	Y-Y AXIS Section Modulus S_{yy} in.³	Y-Y AXIS Moment of Inertia I_{yy} in.⁴
Timbers (5" x 5" and larger)[2]						
Post and Timber (see NDS 4.1.3.4 and NDS 4.1.5.3)						
5 x 5	4-1/2 x 4-1/2	20.25	15.19	34.17	15.19	34.17
6 x 6	5-1/2 x 5-1/2	30.25	27.73	76.26	27.73	76.26
6 x 8	5-1/2 x 7-1/2	41.25	51.56	193.4	37.81	104.0
8 x 8	7-1/2 x 7-1/2	56.25	70.31	263.7	70.31	263.7
8 x 10	7-1/2 x 9-1/2	71.25	112.8	535.9	89.06	334.0
10 x 10	9-1/2 x 9-1/2	90.25	142.9	678.8	142.9	678.8
10 x 12	9-1/2 x 11-1/2	109.3	209.4	1204	173.0	821.7
12 x 12	11-1/2 x 11-1/2	132.3	253.5	1458	253.5	1458
12 x 14	11-1/2 x 13-1/2	155.3	349.3	2358	297.6	1711
14 x 14	13-1/2 x 13-1/2	182.3	410.1	2768	410.1	2768
14 x 16	13-1/2 x 15-1/2	209.3	540.6	4189	470.8	3178
16 x 16	15-1/2 x 15-1/2	240.3	620.6	4810	620.6	4810
16 x 18	15-1/2 x 17-1/2	271.3	791.1	6923	700.7	5431
18 x 18	17-1/2 x 17-1/2	306.3	893.2	7816	893.2	7816
18 x 20	17-1/2 x 19-1/2	341.3	1109	10813	995.3	8709
20 x 20	19-1/2 x 19-1/2	380.3	1236	12049	1236	12049
20 x 22	19-1/2 x 21-1/2	419.3	1502	16150	1363	13285
22 x 22	21-1/2 x 21-1/2	462.3	1656	17806	1656	17806
22 x 24	21-1/2 x 23-1/2	505.3	1979	23252	1810	19463
24 x 24	23-1/2 x 23-1/2	552.3	2163	25415	2163	25415

Material stiffness

- Steel – 29000 ksi
- Concrete – 3605 ksi (f'c=4000 psi)
- Wood – 1600 ksi(Varies by sp/gr)
- 6061 Aluminum – 10000 ksi

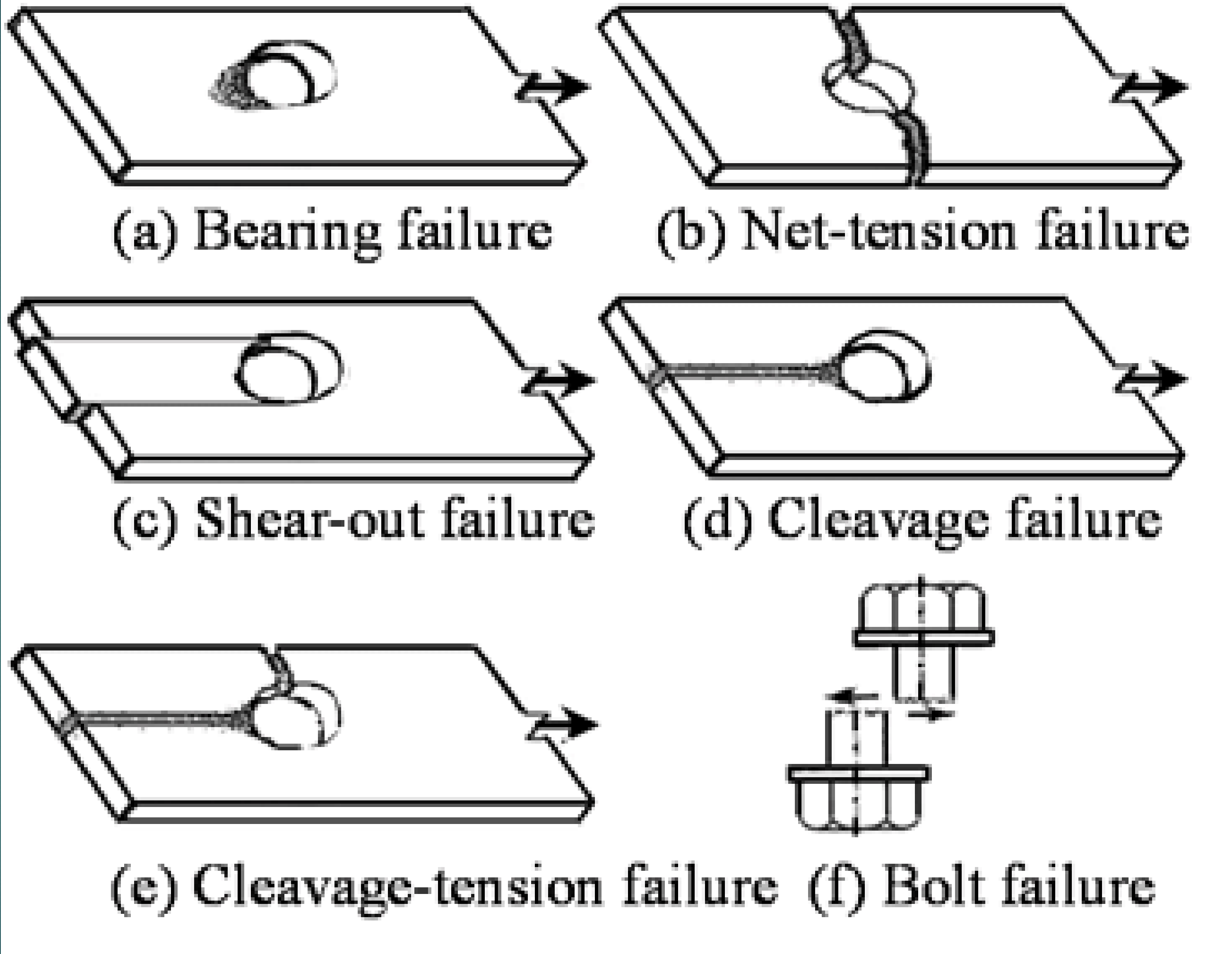


Material strength

Tension Failure

Failure based on

- Material strength properties
- Cross-sectional area
- Net Area
- relatively independent of shape

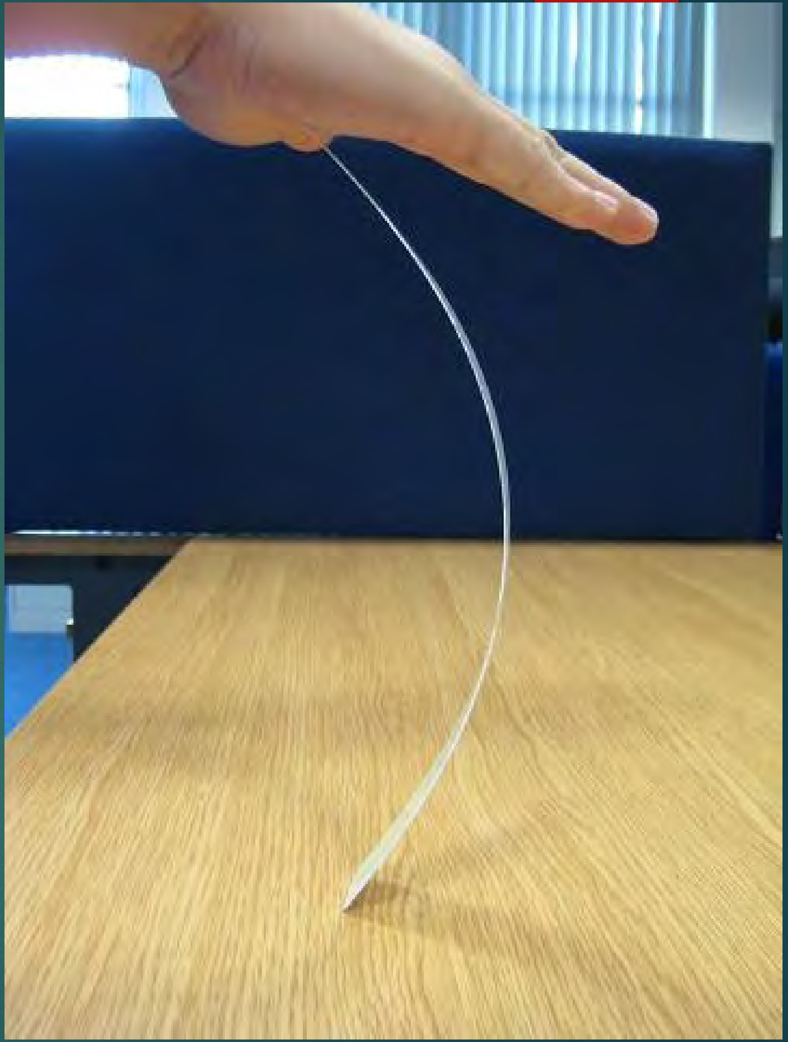

(a) Bearing failure
(b) Net-tension failure
(c) Shear-out failure
(d) Cleavage failure
(e) Cleavage-tension failure
(f) Bolt failure

Compression Failure

- Short Members (Columns)
  - Crushing failure
  - Failure based on
    - Material strength properties
    - Cross-sectional area & relatively independent of shape
    - Sudden progressive failure type
- Long Members (Columns)
  - Buckling failure
  - Failure based On
    - Column length
    - Member stiffness, geometric configuration & material load-deformation relationships
    - Sudden progressive failure type

Crushing

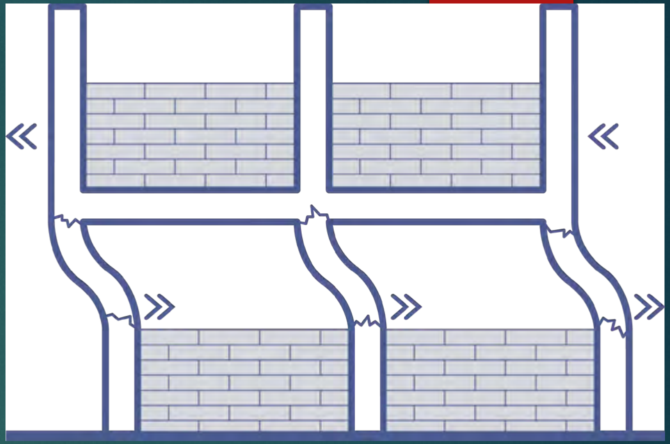
Buckling



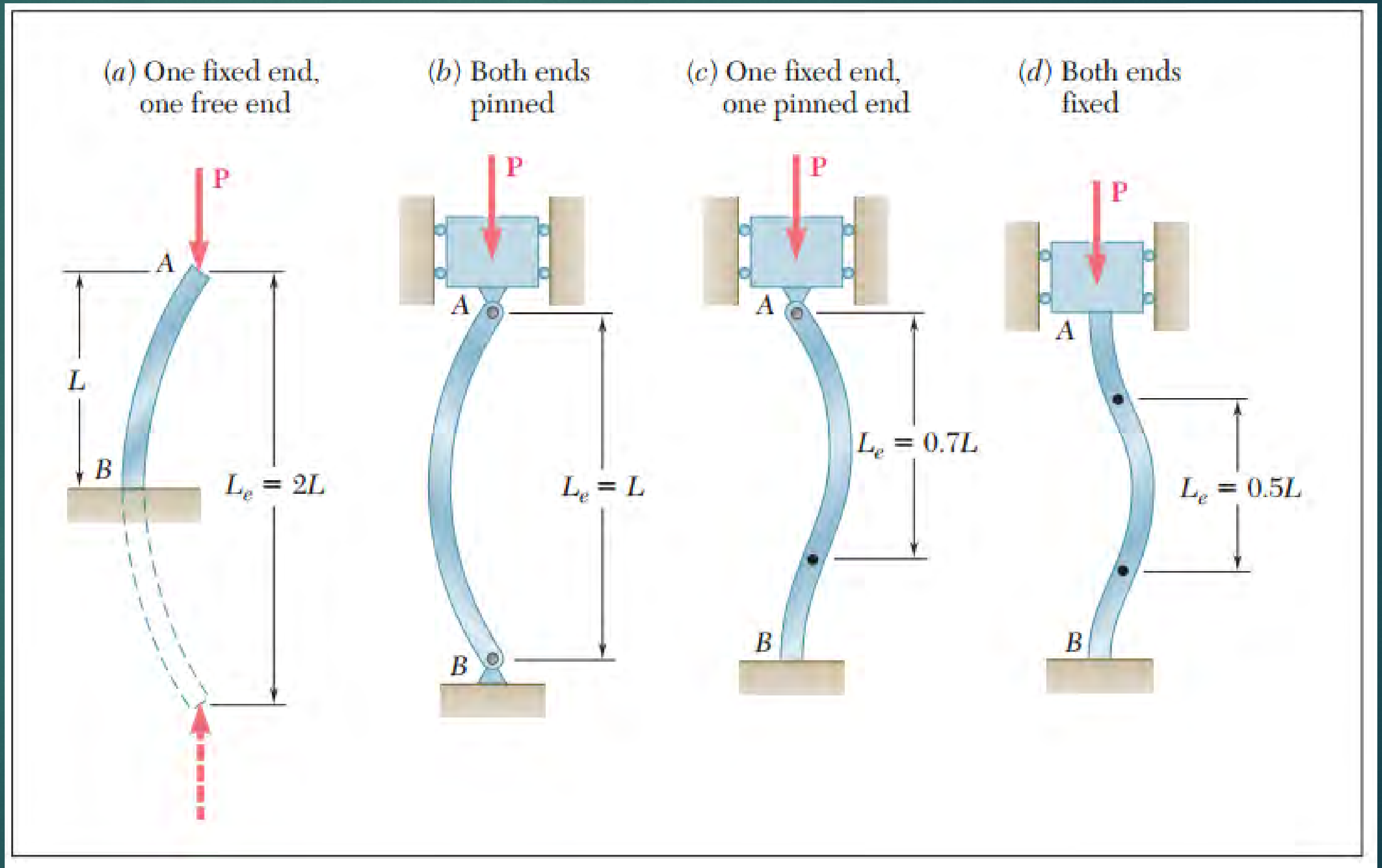
Euler Formula

$$P_{cr} = \frac{\pi^2 EI}{L_e^2}$$

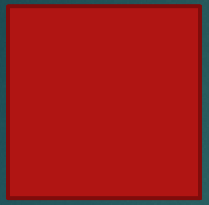
Length



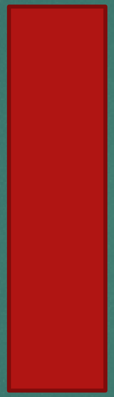
End conditions



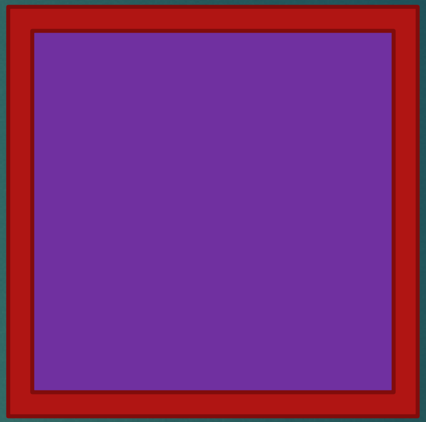
Cross-sectional configuration



1.0 x 1.0
A=1
Ix = Iy = 0.083



2 x 0.5
A=1
Ix = 0.33
Iy = 0.021



2.125 x 2.125 x 0.125
A=1
Ix = Iy = 0.67

Euler Formula

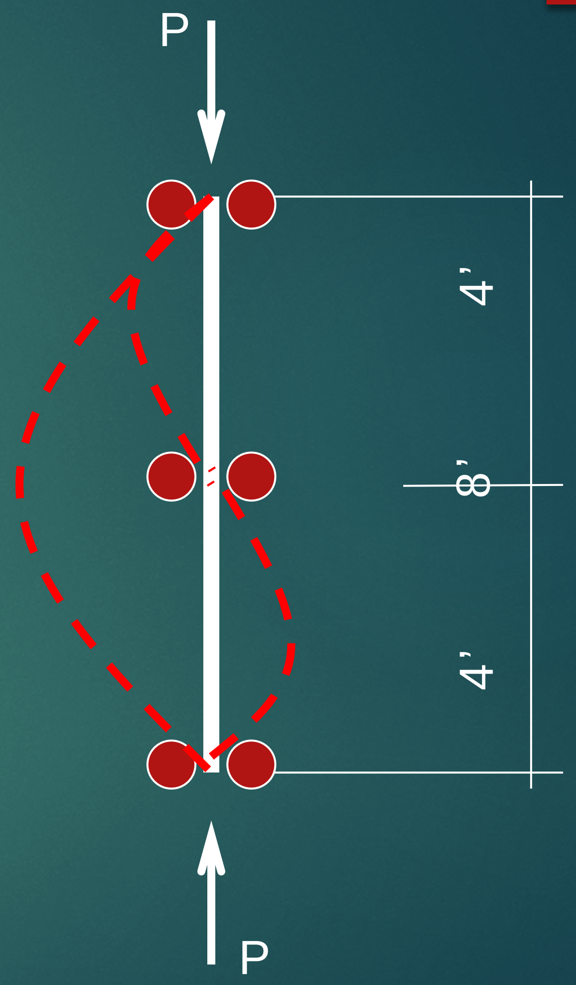
$$P_{cr} = \frac{\pi^2 EI}{L_e^2}$$

Long Column Capacity

2 x 4

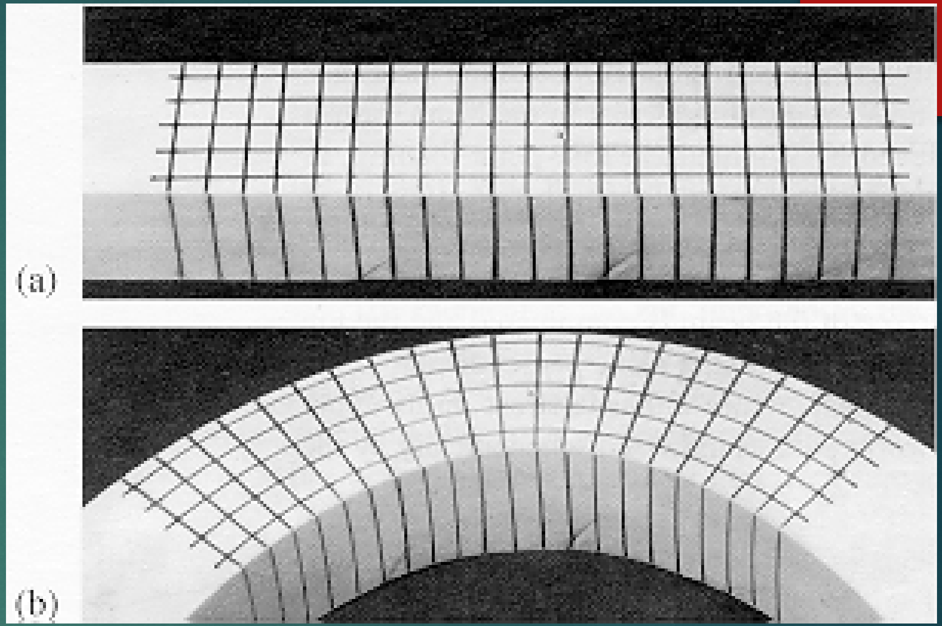
L_e = 4' P_{cr} = 11,900 lbs

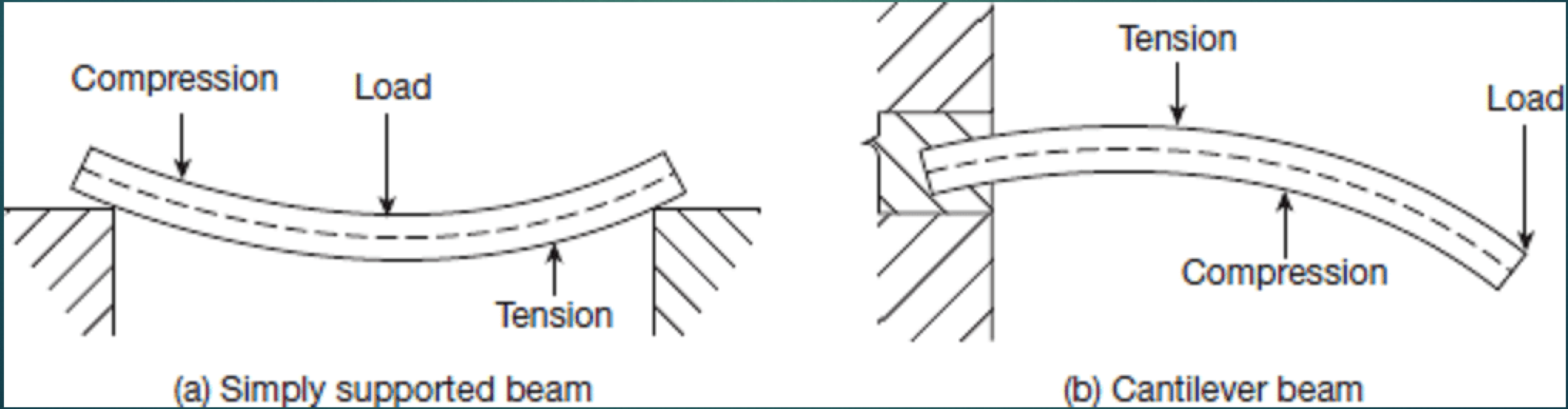
L_e = 8' P_{cr} = 2,980 lbs



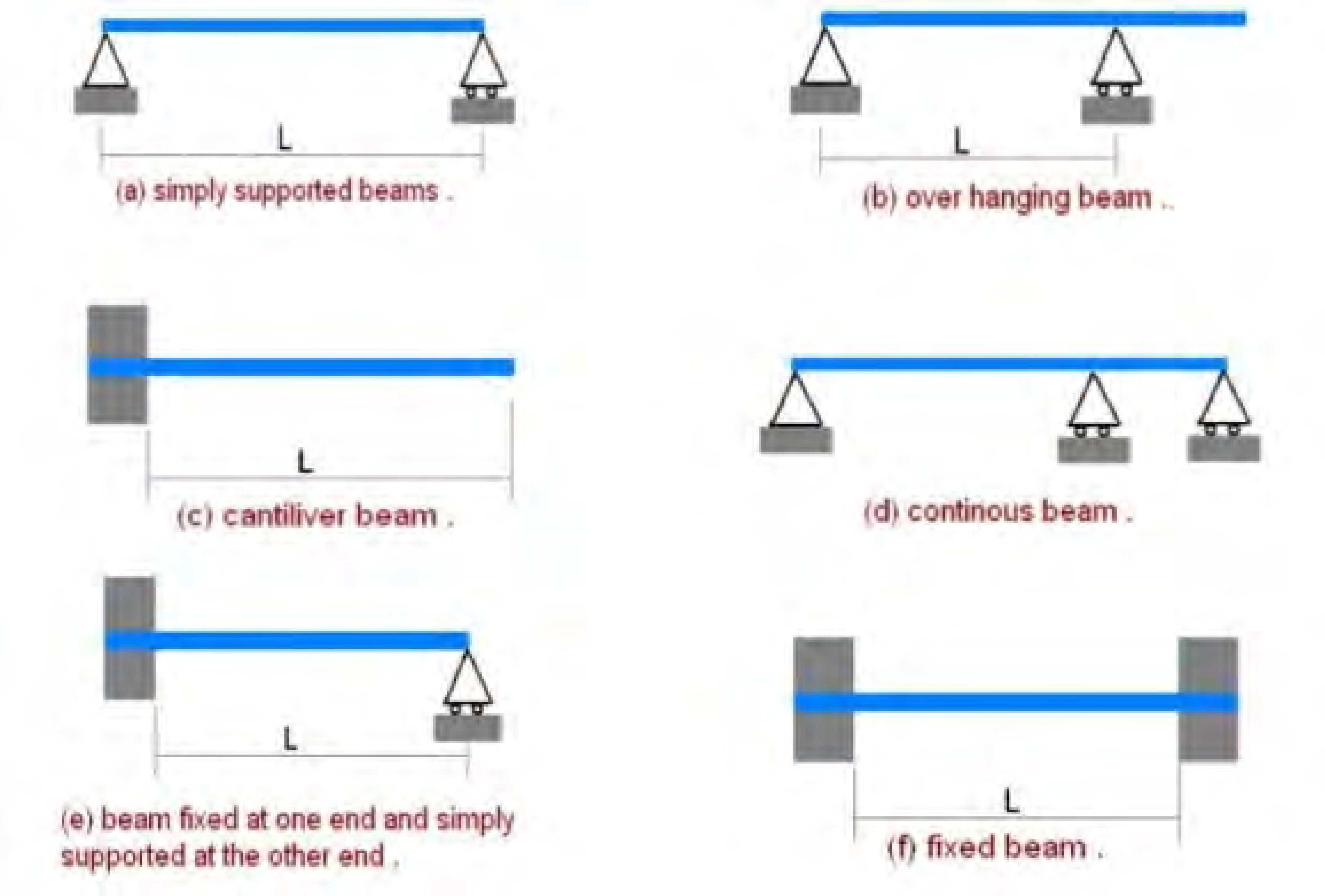
Bending

- Combination of tension and compression
- Not efficient
- Neutral Axis





Beam types


L
(a) simply supported beams .
L
(b) over hanging beam ..
L
(c) cantiliver beam .
(d) continous beam .
L
(e) beam fixed at one end and simply supported at the other end .
L
(f) fixed beam .

Lateral torsional buckling

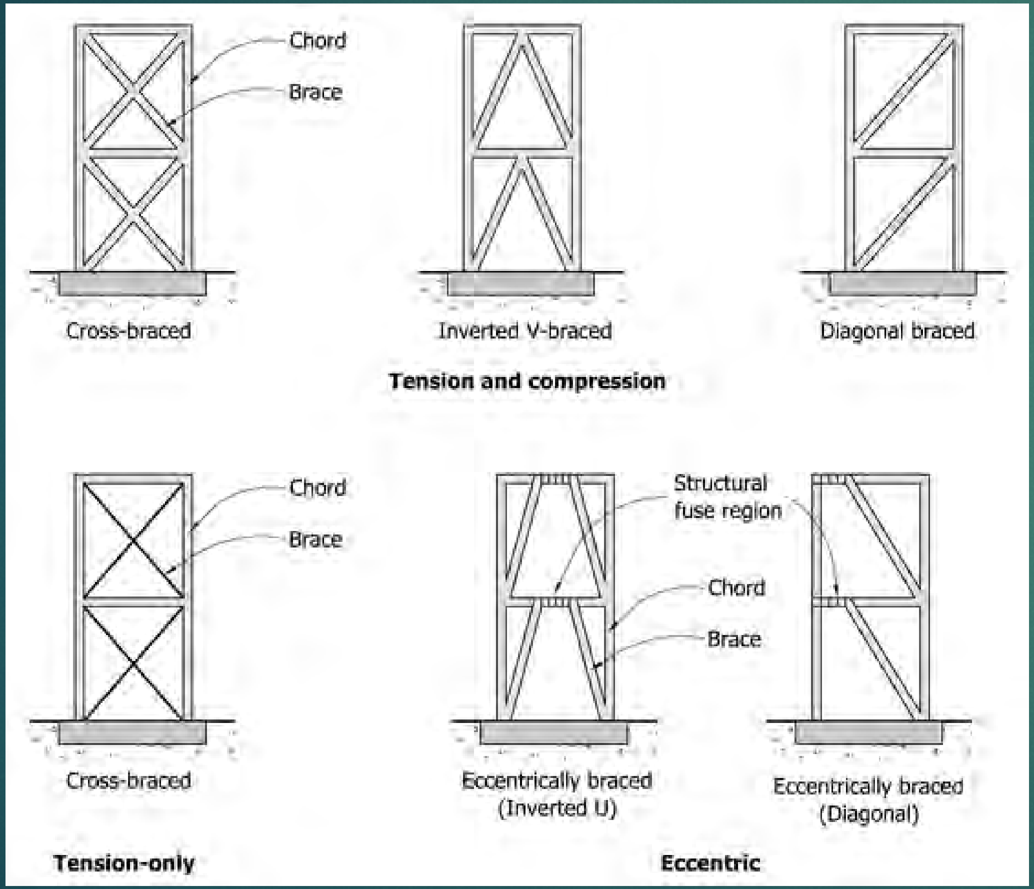
Redundancy

- The inclusion of extra components which are not strictly necessary to functioning, in case of failure in other components.
- Adds cost

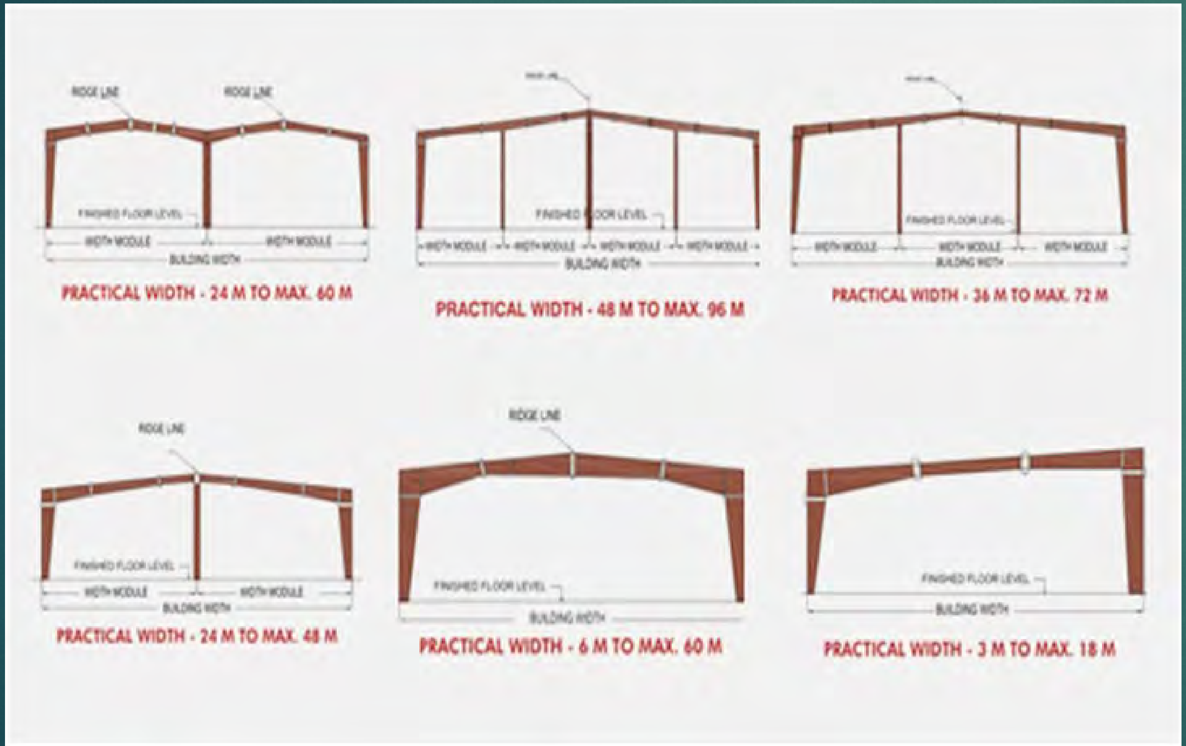
Frame types

- Braced
- Rigid
- Diaphragms

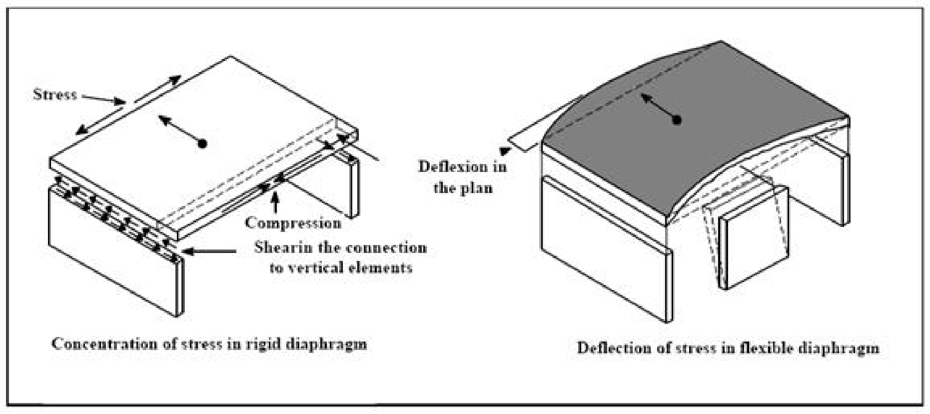
Braced frames



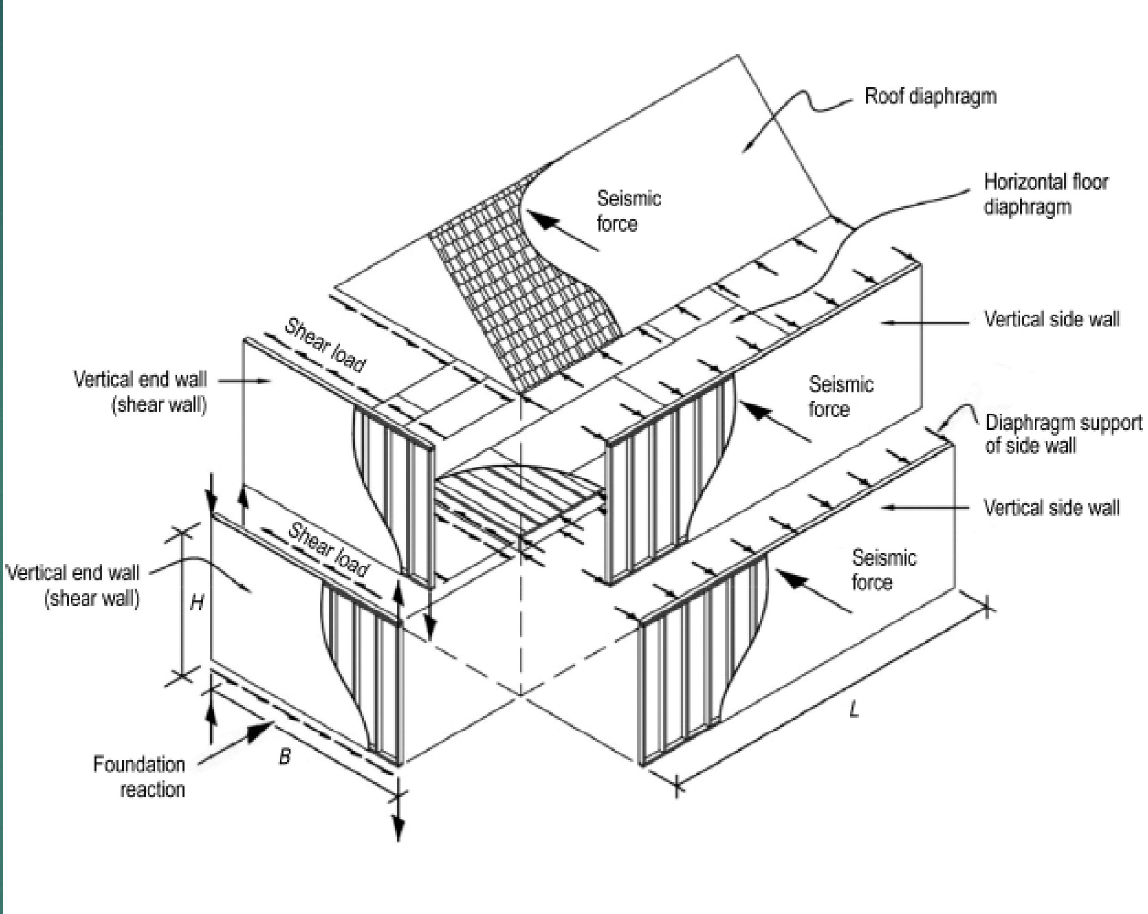
Rigid frames



diaphragms



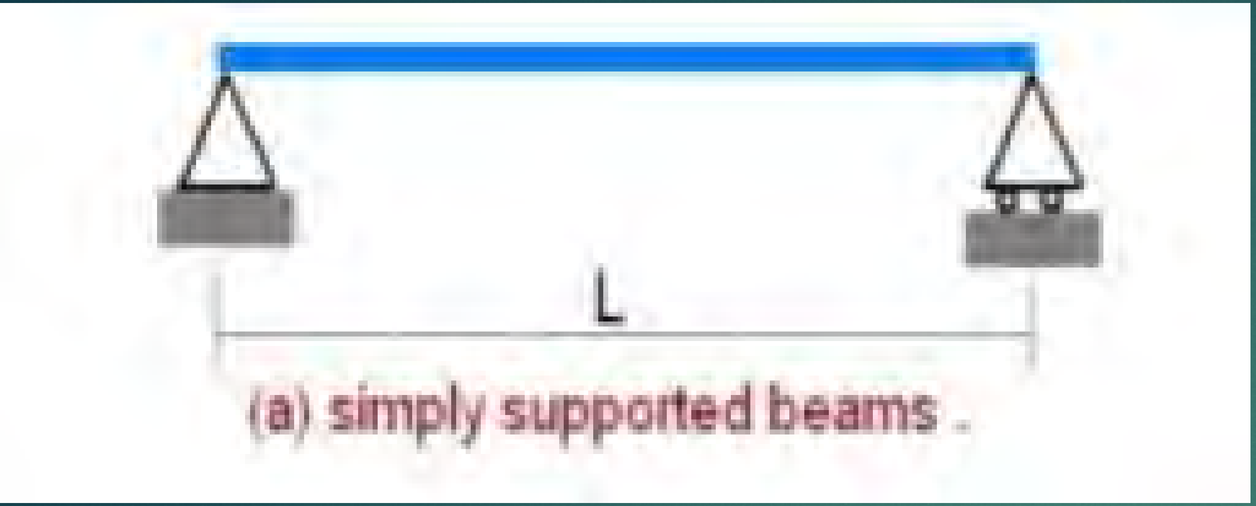
Stress
Compression
Shearin the connection to vertical elements
Deflexion in the plan
Concentration of stress in rigid diaphragm
Deflection of stress in flexible diaphragm

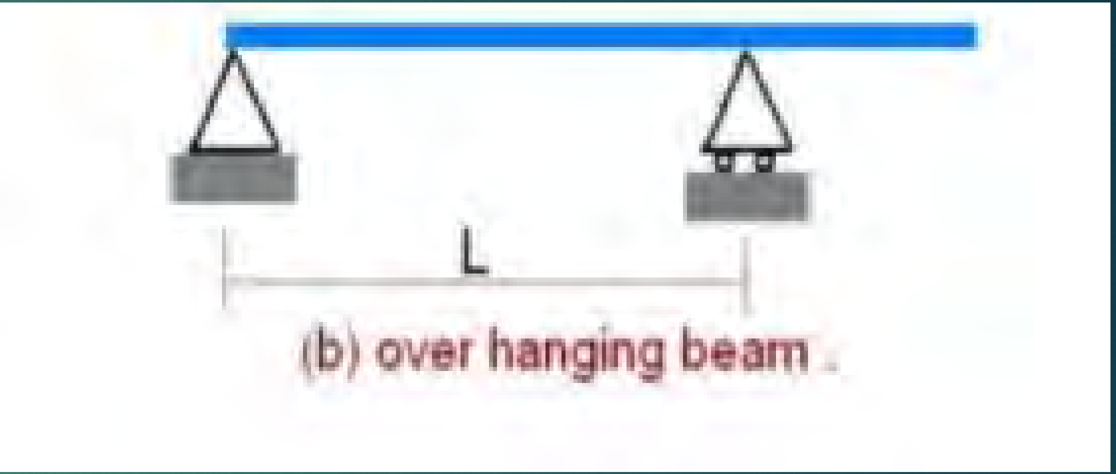


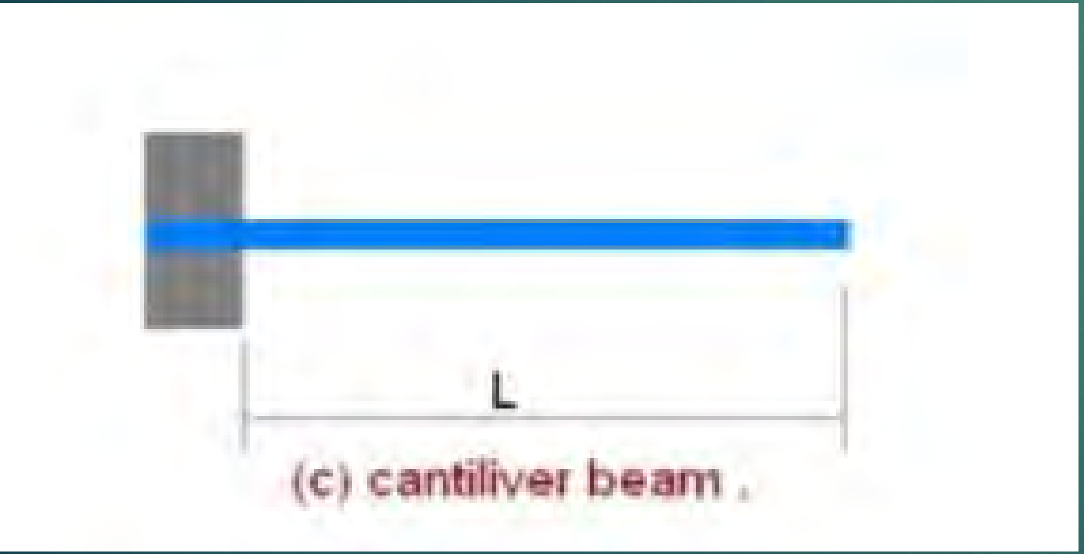
Roof diaphragm
Horizontal floor diaphragm
Seismic force
Shear load
Vertical end wall (shear wall)
Vertical side wall
Seismic force
Diaphragm support of side wall
Vertical side wall
Shear load
Vertical end wall (shear wall)
Seismic force
H
L
B
Foundation reaction

Equilibrium

- $\sum F_H = 0$
- $\sum F_V = 0$
- $\sum M = 0$

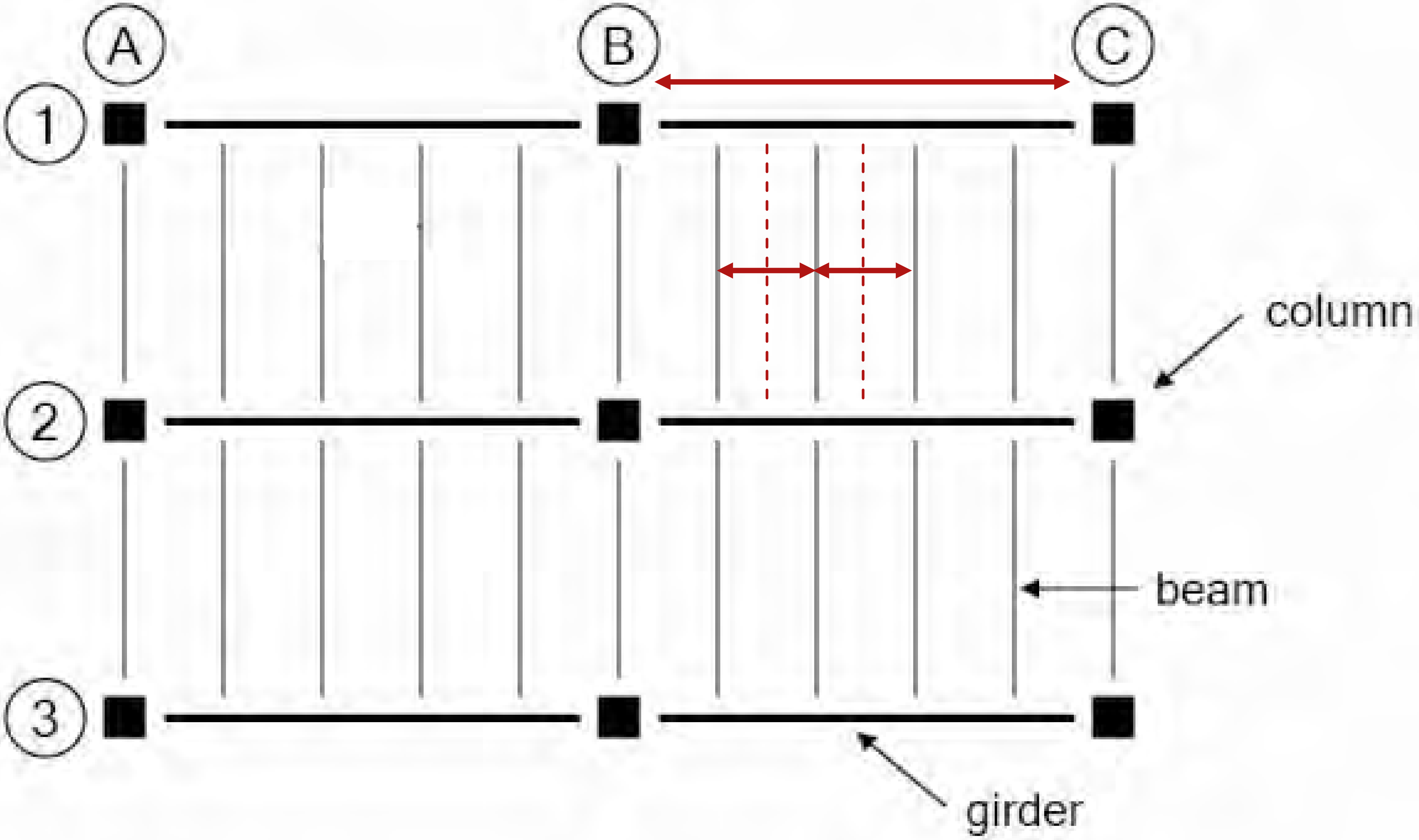

L
(a) simply supported beams .

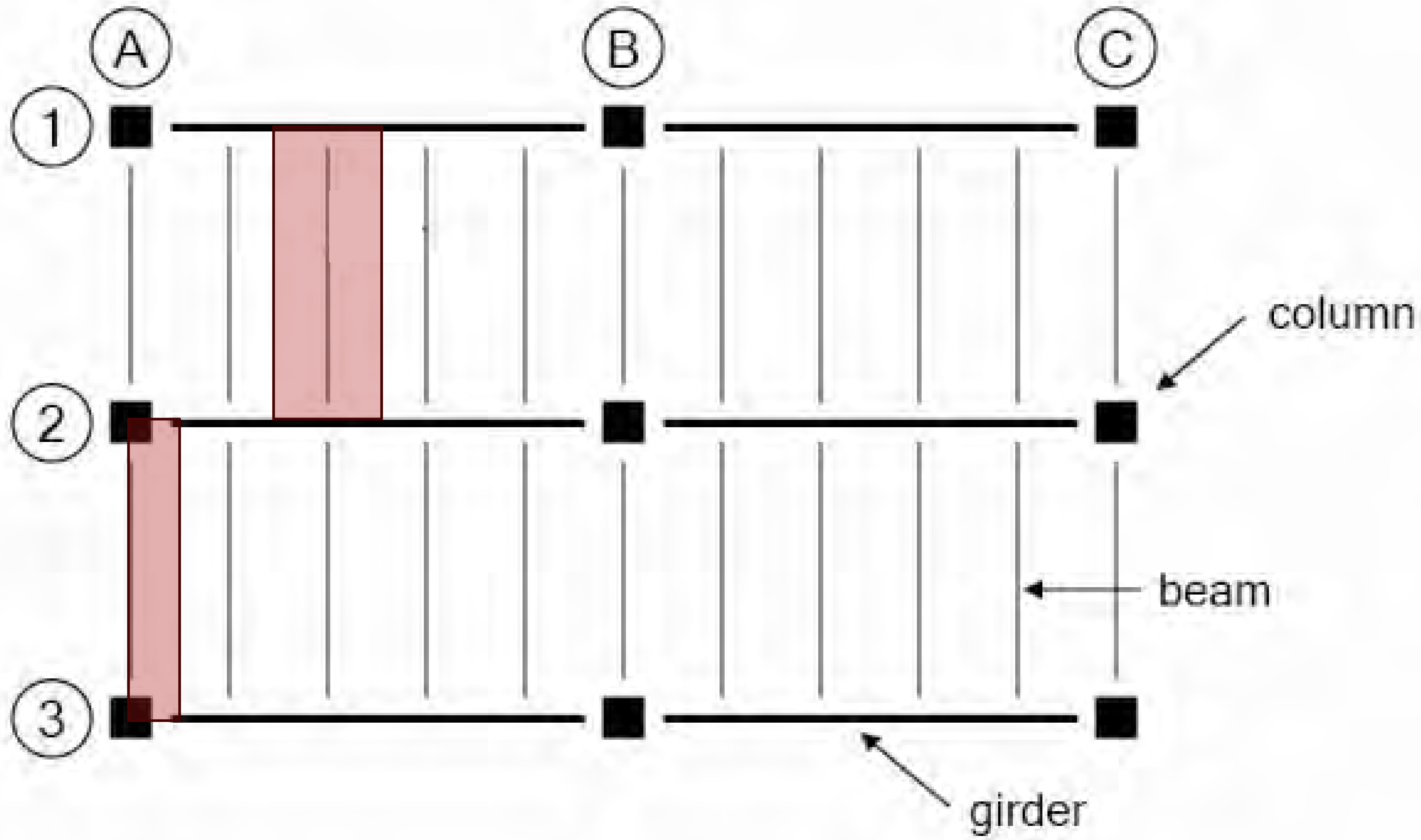

L
(b) over hanging beam .

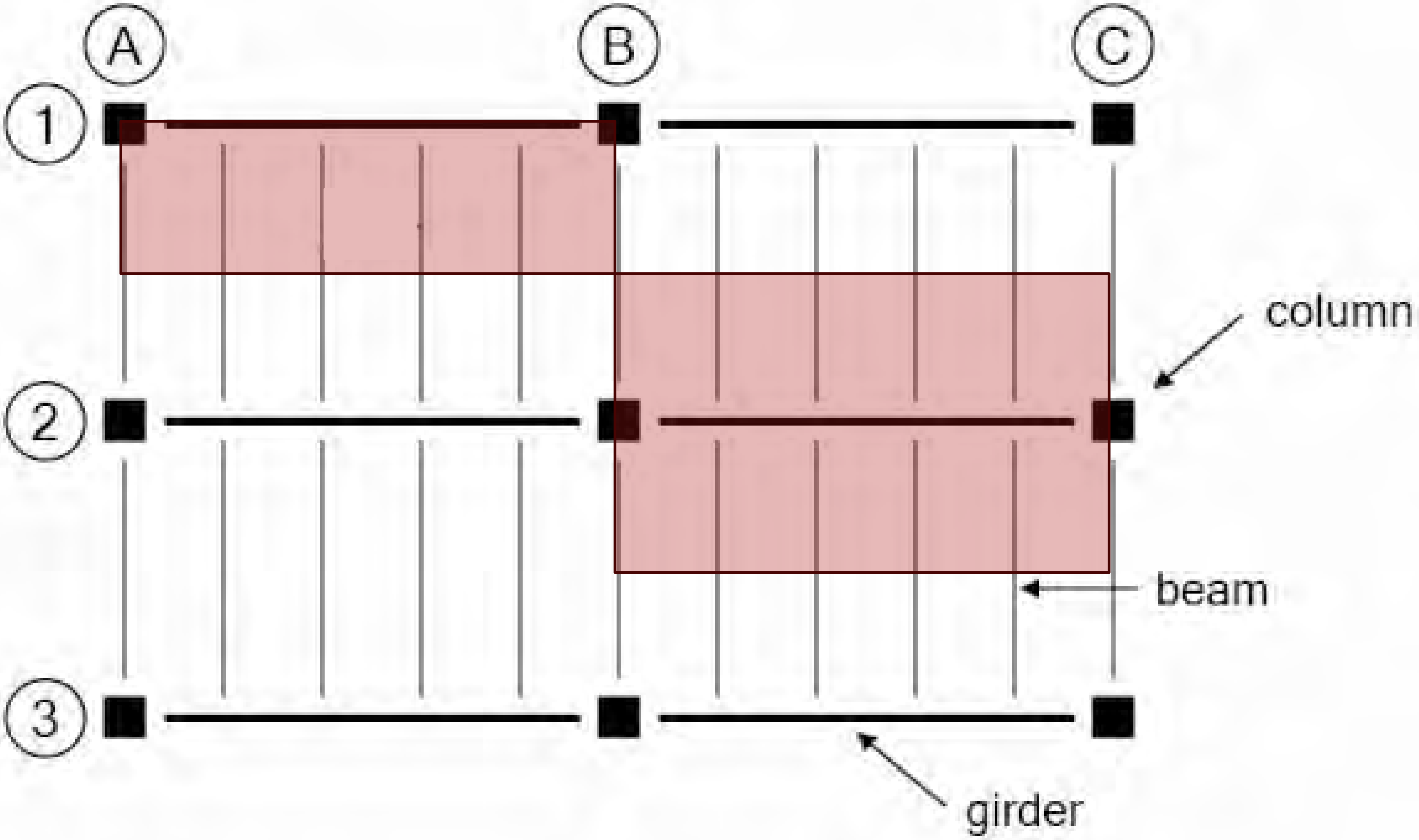

L
(c) cantiliver beam .

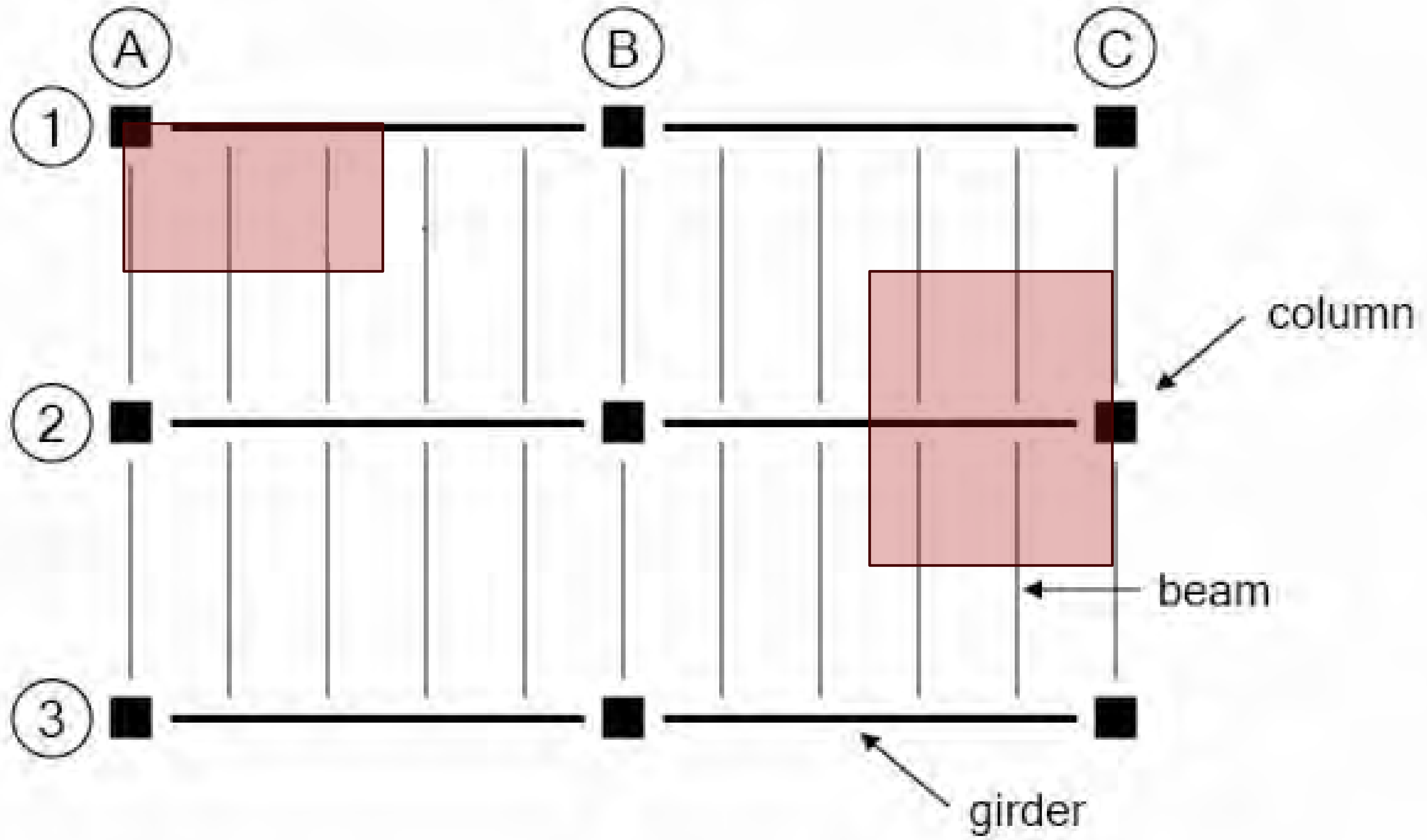
Tributary area/width

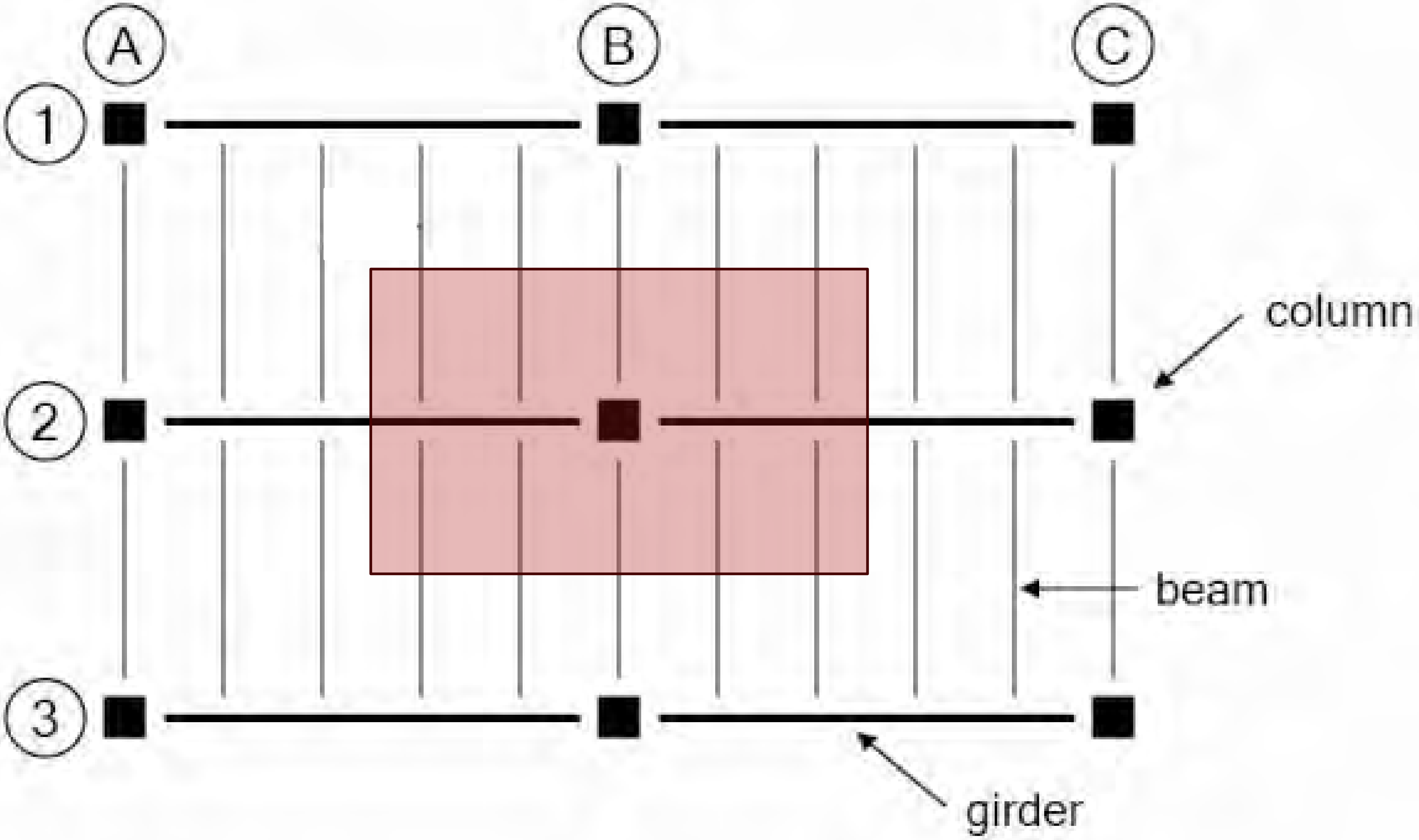
The area of a plane (floor, roof, or wall)that causes loading on a particular structural element.


A
B
C
1
2
3
column
beam
girder


A
B
C
1
2
3
column
beam
girder


A
B
C
1
2
3
column
beam
girder

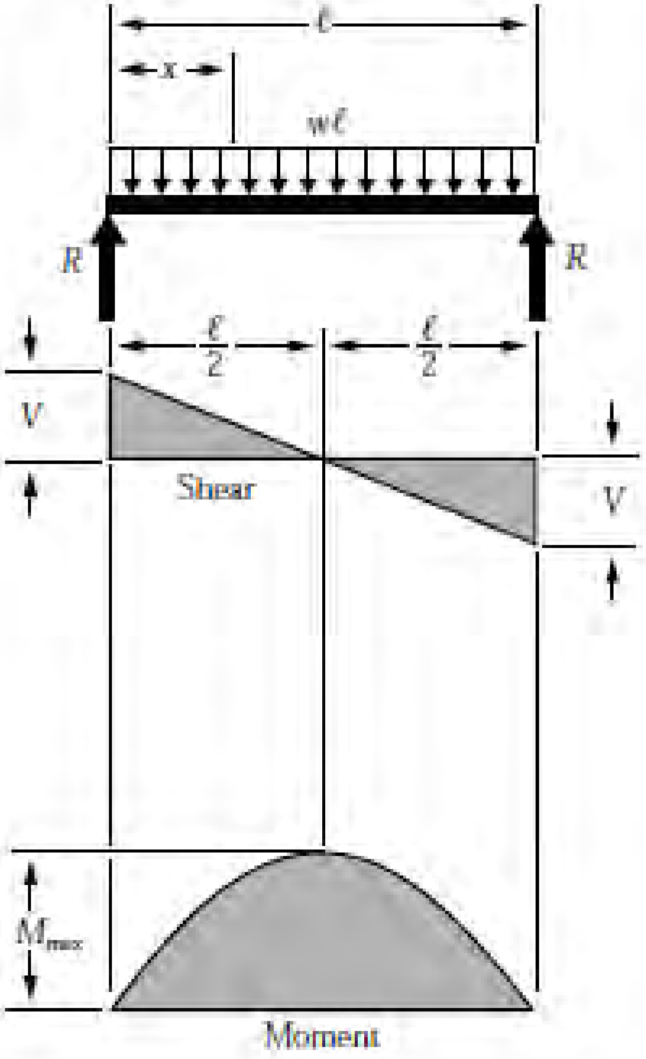

A
B
C
1
2
3
column
beam
girder


A
B
C
1
2
3
column
beam
girder

Minimum performance standards

- Stability
- Strength
- Service (Deflection)

Figure 1 Simple Beam – Uniformly Distributed Load



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

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

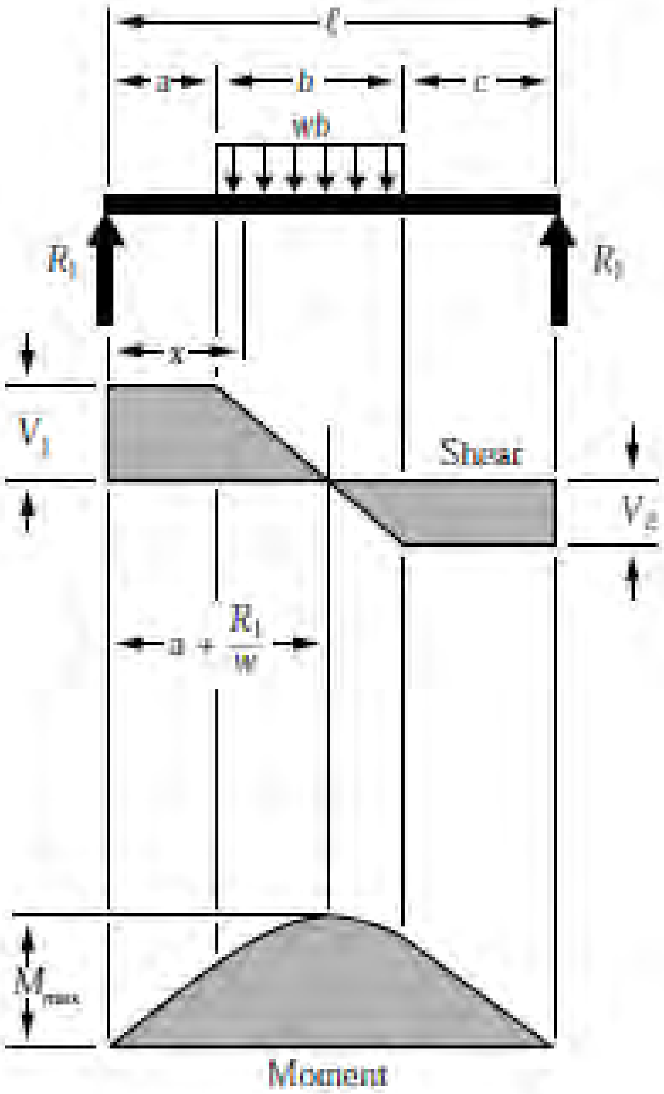
$$M_{max} \text{ (at center)} \quad \dots\dots\dots = \frac{w\ell^2}{8}$$

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

$$\Delta_{max} \text{ (at center)} \quad \dots\dots\dots = \frac{5w\ell^4}{384\,EI}$$

$$\Delta_x \quad \dots\dots\dots\dots = \frac{wx}{24\,EI}(\ell^3 - 2\ell x^2 + x^3)$$

Figure 2 Simple Beam – Uniform Load Partially Distributed



$$R_1 = V_1 \text{ (max when } a < c) \quad \ldots\ldots \quad = \frac{wb}{2\ell}(2c + b)$$

$$R_2 = V_2 \text{ (max when } a > c) \quad \ldots\ldots \quad = \frac{wb}{2\ell}(2a + b)$$

$$V_x \left(\text{when } x > a \text{ and } < (a + b)\right) \quad \ldots \quad = R_1 - w(x - a)$$

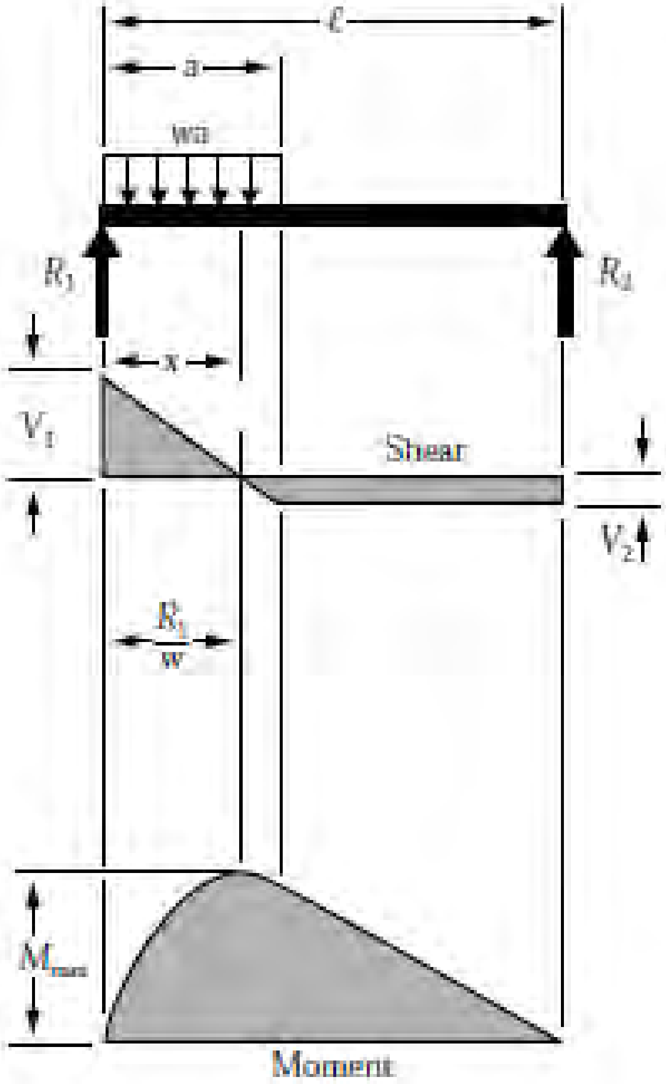
$$M_{max} \left(\text{at } x = a + \frac{R_1}{w}\right) \quad \ldots\ldots \quad = R_1\left(a + \frac{R_1}{2w}\right)$$

$$M_x \text{ (when } x < a) \quad \ldots\ldots\ldots\ldots \quad = R_1 x$$

$$M_x \left(\text{when } x > a \text{ and } < (a + b)\right) \quad \ldots \quad = R_1 x - \frac{w}{2}(x - a)^2$$

$$M_x \left(\text{when } x > (a + b)\right) \quad \ldots\ldots \quad = R_2(\ell - x)$$

Figure 3 Simple Beam – Uniform Load Partially Distributed at One End



$$R_1 = V_1 \quad \ldots\ldots \quad = \frac{wa}{2\ell}(2\ell - a)$$

$$R_2 = V_2 \quad \ldots\ldots \quad = \frac{wa^2}{2\ell}$$

$$V_x \ (\text{when } x < a) \quad \ldots\ldots \quad = R_1 - wx$$

$$M_{max}\left(\text{at } x = \frac{R_1}{w}\right) \quad \ldots\ldots \quad = \frac{R_1^2}{2w}$$

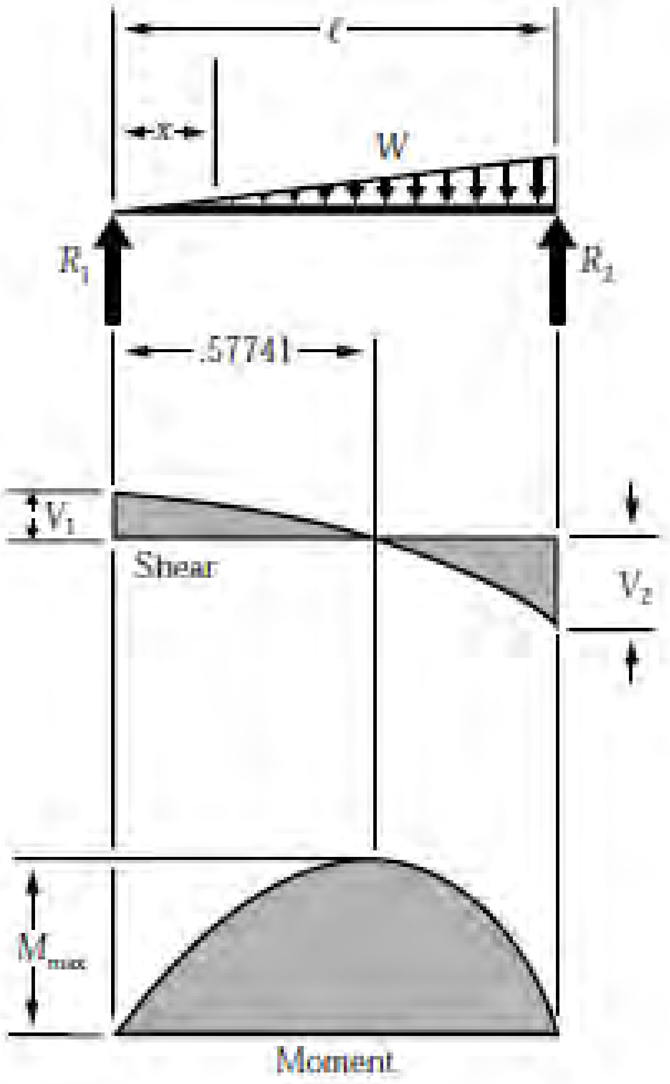
$$M_x \ (\text{when } x < a) \quad \ldots\ldots \quad = R_1 x - \frac{wx^2}{2}$$

$$M_x \ (\text{when } x > a) \quad \ldots\ldots \quad = R_2(\ell - x)$$

$$\Delta_x \ (\text{when } x < a) \quad \ldots\ldots \quad = \frac{wx}{24\,EI\ell}\left(a^2(2\ell - a)^2 - 2ax^2(2\ell - a) + \ell x^3\right)$$

$$\Delta_x \ (\text{when } x > a) \quad \ldots\ldots \quad = \frac{wa^2(\ell - x)}{24\,EI\ell}(4x\ell - 2x^2 - a^2)$$

Figure 5 Simple Beam – Load Increasing Uniformly to One End



$$R_1 = V_1 \ldots\ldots = \frac{W}{3}$$

$$R_2 = V_2 \ldots\ldots = \frac{2W}{3}$$

$$V_x \ldots\ldots = \frac{W}{3} - \frac{Wx^2}{\ell^2}$$

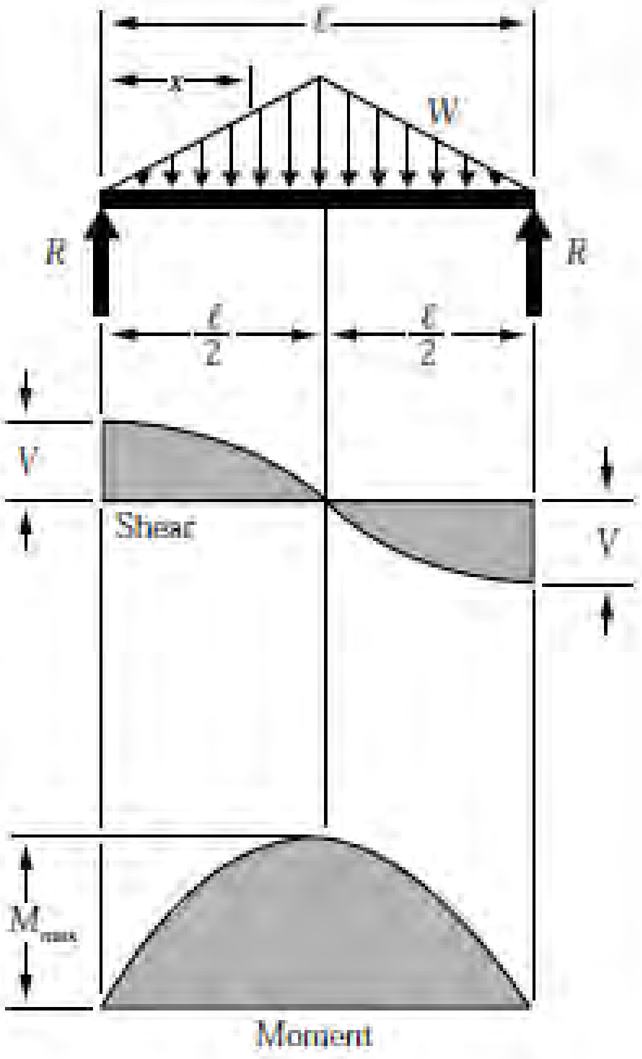
$$M_{max}\left(\text{at } x = \frac{\ell}{\sqrt{3}} = .5774\ell\right) \ldots = \frac{2W\ell}{9\sqrt{3}} = .1283W\ell$$

$$M_x \ldots\ldots = \frac{Wx}{3\ell^2}(\ell^2 - x^2)$$

$$\Delta_{max}\left(\text{at } x = \ell\sqrt{1-\sqrt{\frac{8}{15}}} = .5193\ell\right) . = .01304\frac{W\ell^3}{EI}$$

$$\Delta_x \ldots\ldots = \frac{Wx}{180EI\ell^2}(3x^4 - 10\ell^2x^2 + 7\ell^4)$$

Figure 6 Simple Beam – Load Increasing Uniformly to Center



$$R = V \quad \cdots\cdots\cdots \quad = \frac{W}{2}$$

$$V_x \left(\text{when } x < \frac{\ell}{2}\right) \quad \cdots\cdots\cdots \quad = \frac{W}{2\ell^2}(\ell^2 - 4x^2)$$

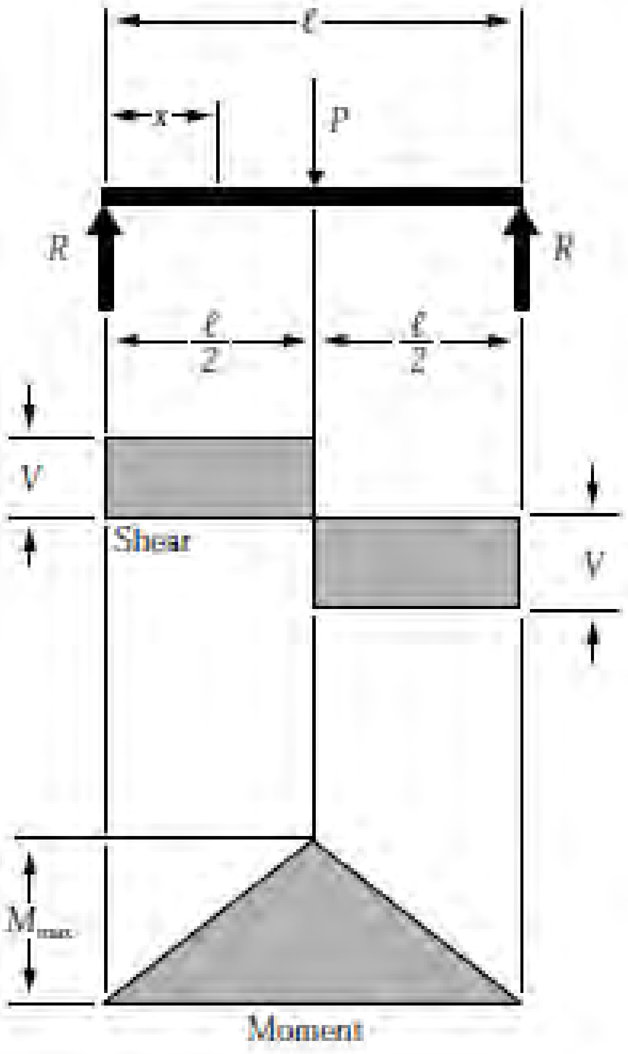
$$M_{max} \text{ (at center)} \quad \cdots\cdots\cdots \quad = \frac{W\ell}{6}$$

$$M_x \left(\text{when } x < \frac{\ell}{2}\right) \quad \cdots\cdots\cdots \quad = Wx\left(\frac{1}{2} - \frac{2x^2}{3\ell^2}\right)$$

$$\Delta_{max} \text{ (at center)} \quad \cdots\cdots\cdots \quad = \frac{W\ell^3}{60EI}$$

$$\Delta_x \quad \cdots\cdots\cdots \quad = \frac{Wx}{480EI\ell^2}(5\ell^2 - 4x^2)^2$$

Figure 7 Simple Beam – Concentrated Load at Center



$$R = V \quad \ldots\ldots\ldots\ldots \quad = \frac{P}{2}$$

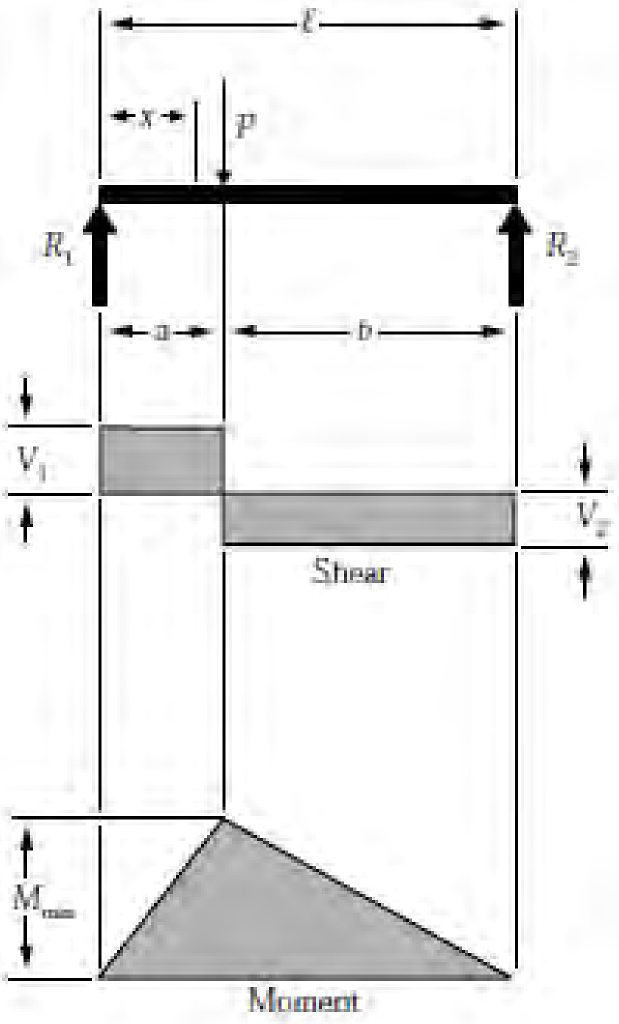
$$M_{max} \text{ (at point of load)} \quad \ldots\ldots \quad = \frac{P\ell}{4}$$

$$M_x \left(\text{when } x < \frac{\ell}{2}\right) \quad \ldots\ldots \quad = \frac{Px}{2}$$

$$\Delta_{max} \text{ (at point of load)} \quad \ldots\ldots \quad = \frac{P\ell^3}{48EI}$$

$$\Delta_x \left(\text{when } x < \frac{\ell}{2}\right) \quad \ldots\ldots \quad = \frac{Px}{48EI}(3\ell^2 - 4x^2)$$

Figure 8 Simple Beam – Concentrated Load at Any Point



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

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

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

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

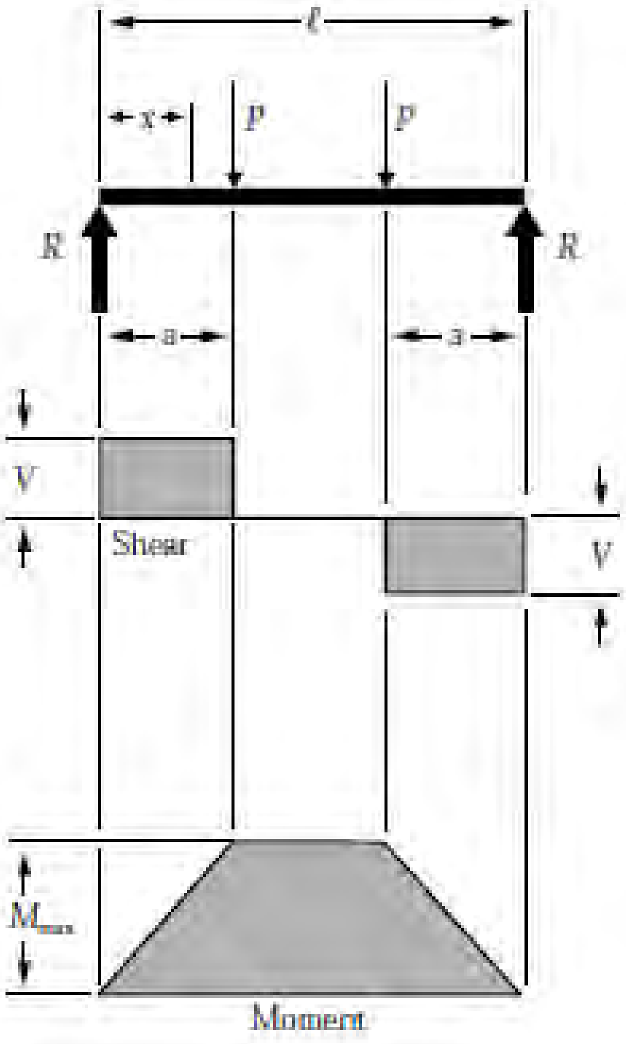
$$\Delta_{max} \left(\text{at } x = \sqrt{\frac{a(a+2b)}{3}} \text{ when } a > b\right) \ldots = \frac{Pab(a+2b)\sqrt{3a(a+2b)}}{27EI\ell}$$

$$\Delta_a \text{ (at point of load)} \ldots\ldots = \frac{Pa^2b^2}{3EI\ell}$$

$$\Delta_x \text{ (when } x < a) \ldots\ldots = \frac{Pbx}{6EI\ell}(\ell^2 - b^2 - x^2)$$

$$\Delta_x \text{ (when } x > a) \ldots\ldots = \frac{Pa(\ell - x)}{6EI\ell}(2\ell x - x^2 - a^2)$$

Figure 9 Simple Beam – Two Equal Concentrated Loads Symmetrically Placed



$R = V$ . . . . $= P$

M_{max} (between loads) . . . . $= Pa$

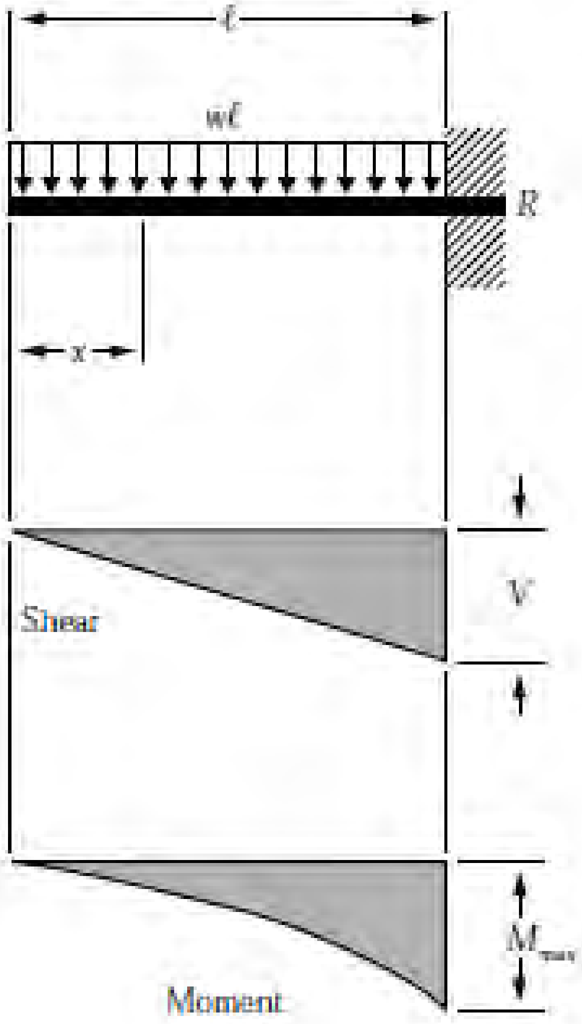
M_x (when $x < a$) . . . . $= Px$

Δ_{max} (at center) . . . . $= \frac{Pa}{24EI}(3\ell^2 - 4a^2)$

Δ_x (when $x < a$) . . . . $= \frac{Px}{6EI}(3\ell a - 3a^2 - x^2)$

Δ_x (when $x > a$ and $< (\ell - a)$) . . . . $= \frac{Pa}{6EI}(3\ell x - 3x^2 - a^2)$

Figure 12 Cantilever Beam – Uniformly Distributed Load



$R = V$ . . . . $= w\ell$

V_x . . . . $= wx$

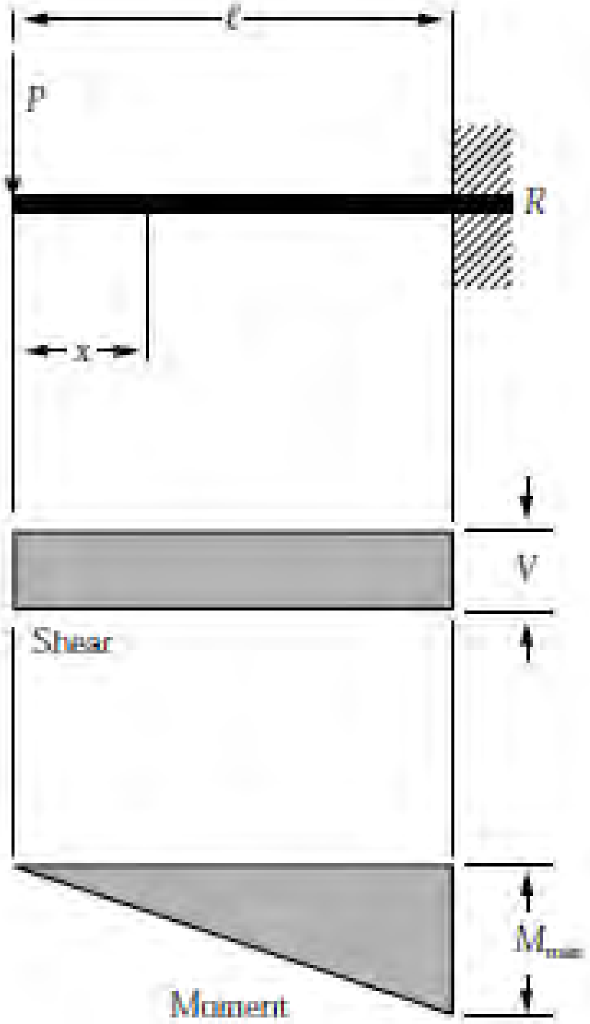
M_{max} (at fixed end) . . . . $= \dfrac{w\ell^2}{2}$

M_x . . . . $= \dfrac{wx^2}{2}$

Δ_{max} (at free end) . . . . $= \dfrac{w\ell^4}{8EI}$

Δ_x . . . . $= \dfrac{w}{24EI}(x^4 - 4\ell^3 x + 3\ell^4)$

Figure 13 Cantilever Beam – Concentrated Load at Free End



$R = V$ . . . . $= P$

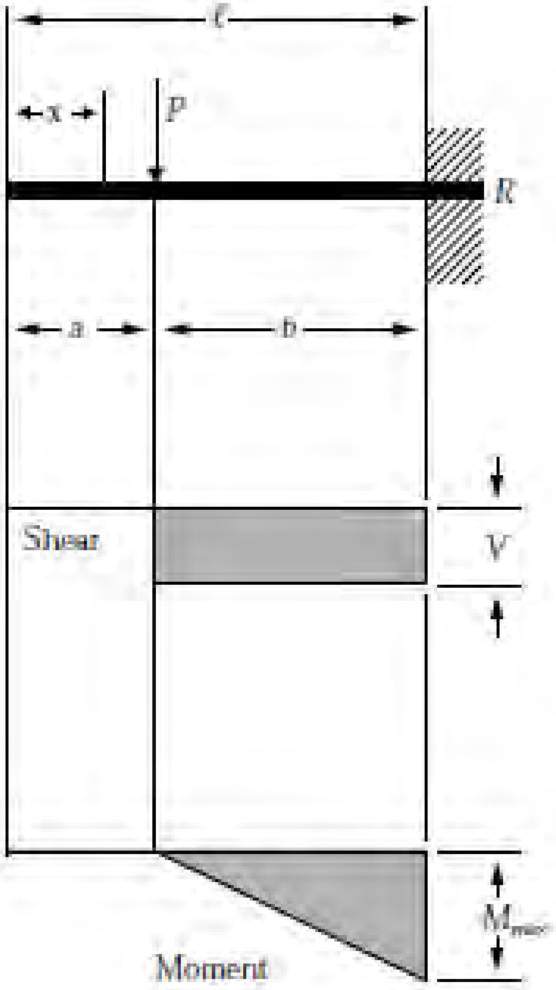
M_{max} (at fixed end) . . . . $= P\ell$

M_x . . . . $= Px$

Δ_{max} (at free end) . . . . $= \frac{P\ell^3}{3EI}$

Δ_x . . . . $= \frac{P}{6EI}(2\ell^3 - 3\ell^2 x + x^3)$

Figure 14 Cantilever Beam – Concentrated Load at Any Point



$R = V$ . . . . $= P$

M_{max} (at fixed end) . . . . $= Pb$

M_x (when $x > a$) . . . . $= P(x - a)$

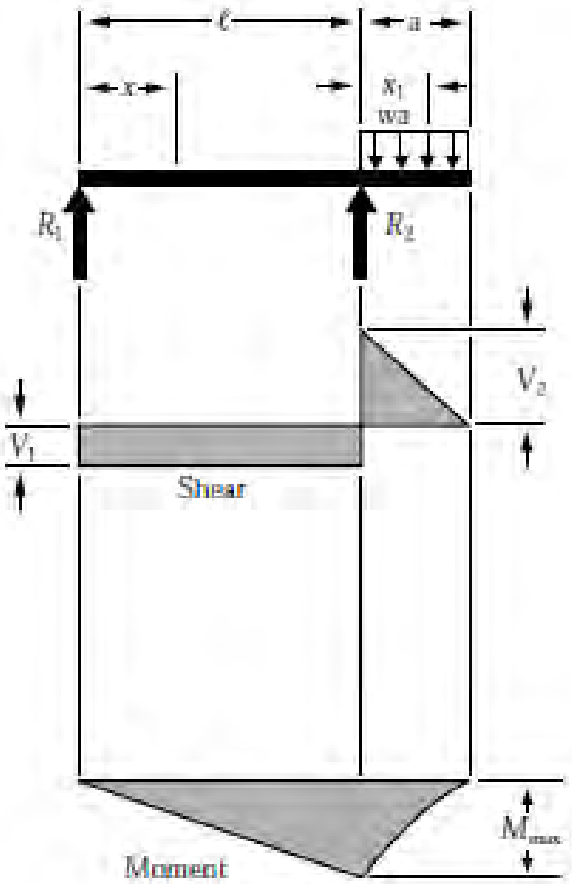
Δ_{max} (at free end) . . . . $= \dfrac{Pb^2}{6EI}(3\ell - b)$

Δ_a (at point of load) . . . . $= \dfrac{Pb^3}{3EI}$

Δ_x (when $x < a$) . . . . $= \dfrac{Pb^2}{6EI}(3\ell - 3x - b)$

Δ_x (when $x > a$) . . . . $= \dfrac{P(\ell - x)^2}{6EI}(3b - \ell + x)$

Figure 19 Beam Overhanging One Support – Uniformly Distributed Load on Overhang



$R_1 = V_1 \ldots\ldots\ldots\ldots = \dfrac{wa^2}{2\ell}$

$R_2 = V_1 + V_2 \ldots\ldots\ldots\ldots = \dfrac{wa}{2\ell}(2\ell + a)$

$V_2 \ldots\ldots\ldots\ldots = wa$

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

M_{max} (at R_2) $\ldots\ldots\ldots\ldots = \dfrac{wa^2}{2}$

M_x (between supports) $\ldots\ldots\ldots\ldots = \dfrac{wa^2 x}{2\ell}$

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

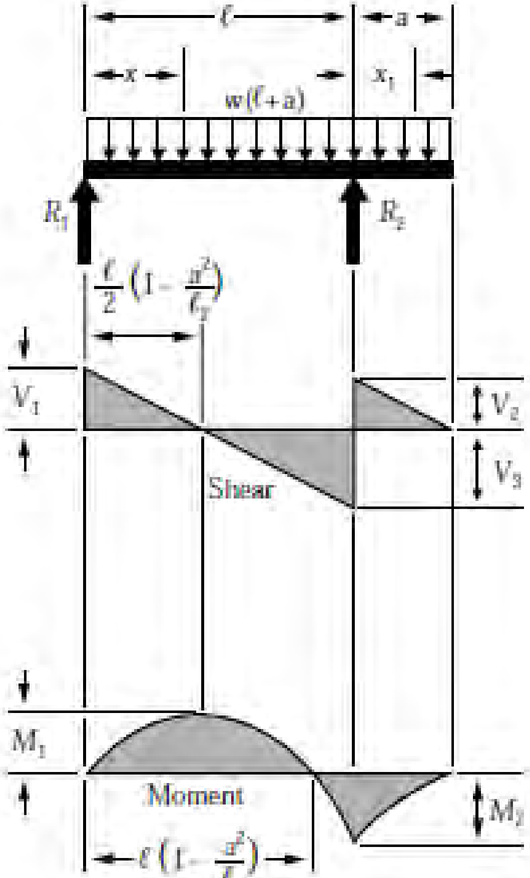
$\Delta_{max}\left(\text{between supports at } x = \dfrac{\ell}{\sqrt{3}}\right) = \dfrac{wa^2\ell^2}{18\sqrt{3}EI} = .03208\,\dfrac{wa^2\ell^2}{EI}$

Δ_{max} (for overhang at $x_1 = a$) $\ldots\ldots = \dfrac{wa^3}{24EI}(4\ell + 3a)$

Δ_x (between supports) $\ldots\ldots\ldots\ldots = \dfrac{wa^2 x}{12EI\ell}(\ell^2 - x^2)$

Δ_{x_1} (for overhang) $\ldots\ldots\ldots\ldots = \dfrac{wx_1}{24EI}(4a^2\ell + 6a^2 x_1 - 4ax_1^2 + x_1^3)$

Figure 18 Beam Overhanging One Support – Uniformly Distributed Load



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

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

V_2 . . . . $= wa$

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

V_x (between supports) . . . . . $= R_1 - wx$

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

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

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

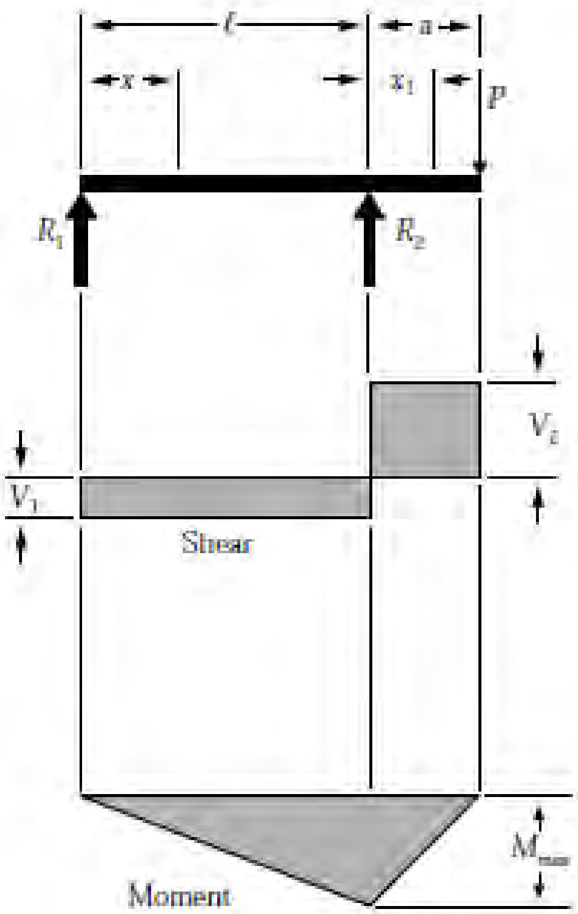
M_x (between supports) . . . . . $= \frac{wx}{2\ell}(\ell^2 - a^2 - x\ell)$

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

Δ_x (between supports) . . . . . $= \frac{wx}{24EI\ell}(\ell^4 - 2\ell^2x^2 + \ell x^3 - 2a^2\ell^2 + 2a^2x^2)$

Δ_{x_1} (for overhang) . . . . . . $= \frac{wx_1}{24EI}(4a^2\ell - \ell^3 + 6a^2x_1 - 4ax_1^2 + x_1^3)$

Figure 20 Beam Overhanging One Support – Concentrated Load at End of Overhang



$R_1 = V_1 \dots = \frac{Pa}{\ell}$

$R_2 = V_1 + V_2 \dots = \frac{P}{\ell}(\ell + a)$

$V_2 \dots = P$

M_{max} (at R_2) $\dots = Pa$

M_x (between supports) $\dots = \frac{Pax}{\ell}$

M_{x_1} (for overhang) $\dots = P(a - x_1)$

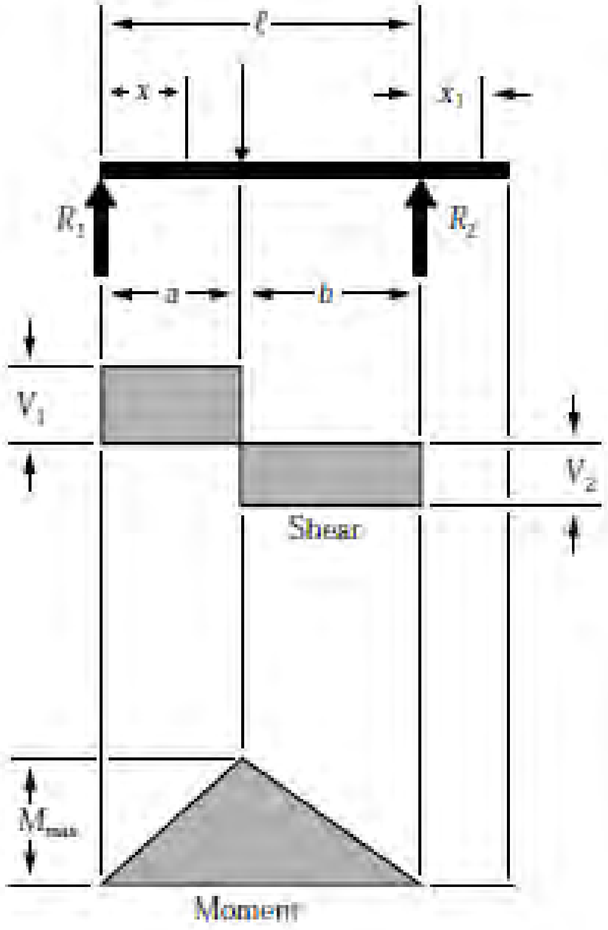
Δ_{max} $\left(\text{between supports at } x = \frac{\ell}{\sqrt{3}}\right) = \frac{Pa\ell^2}{9\sqrt{3}EI} = .06415\frac{Pa\ell^2}{EI}$

Δ_{max} (for overhang at $x_1 = a$) $\dots = \frac{Pa^2}{3EI}(\ell + a)$

Δ_x (between supports) $\dots = \frac{Pax}{6EI\ell}(\ell^2 - x^2)$

Δ_{x_1} (for overhang) $\dots = \frac{Px_1}{6EI}(2a\ell + 3ax_1 - x_1^2)$

Figure 21 Beam Overhanging One Support – Concentrated Load at Any Point Between Supports



$R_1 = V_1$ (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 $x < a$) . . . . $= \frac{Pbx}{\ell}$

Δ_{max} $\left(\text{at } x = \sqrt{\frac{a(a+2b)}{3}} \text{ when } a > b\right)$. $= \frac{Pab(a+2b)\sqrt{3a(a+2b)}}{27EI\ell}$

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

Δ_x (when $x < a$) . . . . $= \frac{Pbx}{6EI\ell}(\ell^2 - b^2 - x^2)$

Δ_x (when $x > a$) . . . . $= \frac{Pa(\ell - x)}{6EI\ell}(2\ell x - x^2 - a^2)$

Δ_{x_1} . . . . $= \frac{Pabx_1}{6EI\ell}(\ell + a)$

Deflection

TABLE 1604.3
DEFLECTION LIMITS[a, b, c, h, i]

CONSTRUCTION	L or L_r	S or W[f]	$D + L$[d, g]
Roof members:[e]			
Supporting plaster or stucco ceiling	l/360	l/360	l/240
Supporting nonplaster ceiling	l/240	l/240	l/180
Not supporting ceiling	l/180	l/180	l/120
Floor members	l/360	—	l/240
Exterior walls:			
With plaster or stucco finishes	—	l/360	—
With other brittle finishes	—	l/240	—
With flexible finishes	—	l/120	—
Interior partitions:[b]			
With plaster or stucco finishes	l/360	—	—
With other brittle finishes	l/240	—	—
With flexible finishes	l/120	—	—
Farm buildings	—	—	l/180
Greenhouses	—	—	l/120

Superposition

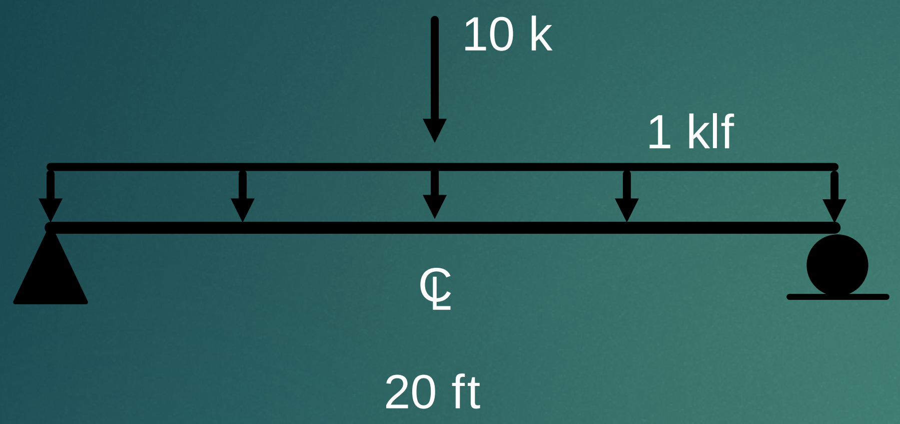
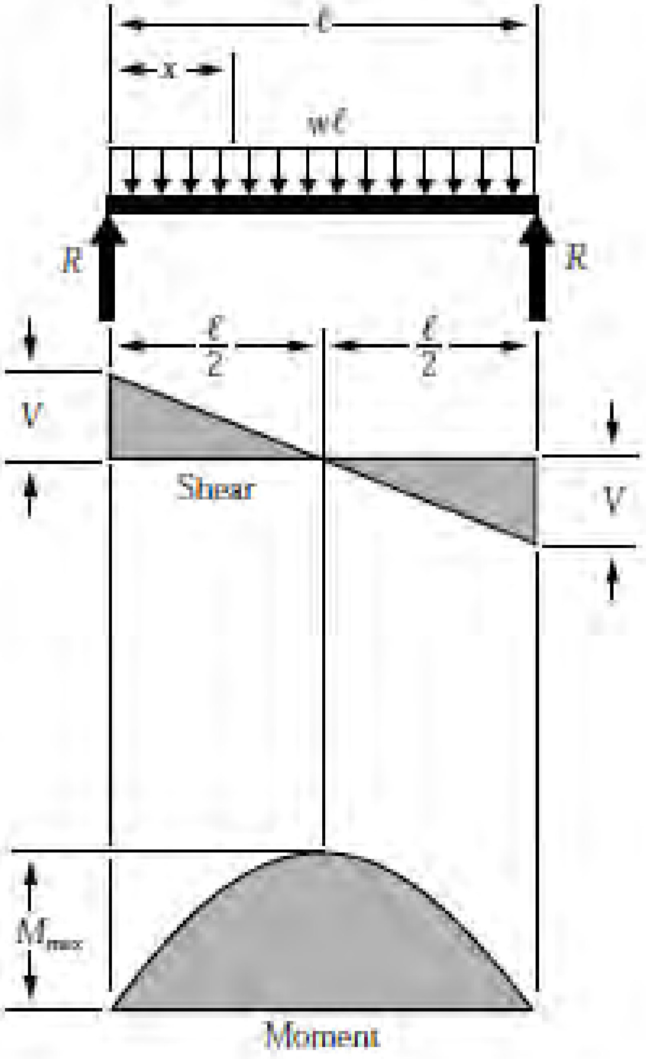


Figure 1 Simple Beam – Uniformly Distributed Load



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

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

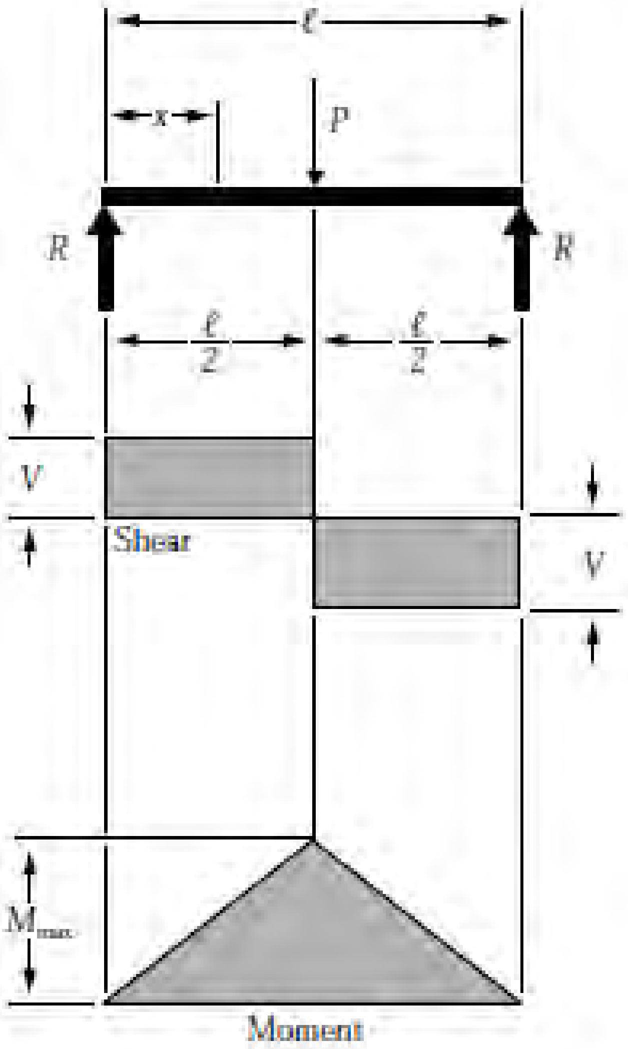
$$M_{max} \text{ (at center)} \quad \ldots\ldots\ldots\ldots \quad = \frac{w\ell^2}{8}$$

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

$$\Delta_{max} \text{ (at center)} \quad \ldots\ldots\ldots\ldots \quad = \frac{5w\ell^4}{384\,EI}$$

$$\Delta_x \quad \ldots\ldots\ldots\ldots \quad = \frac{wx}{24\,EI}(\ell^3 - 2\ell x^2 + x^3)$$

Figure 7 Simple Beam – Concentrated Load at Center



$$R = V \quad \ldots\ldots\ldots\ldots \quad = \frac{P}{2}$$

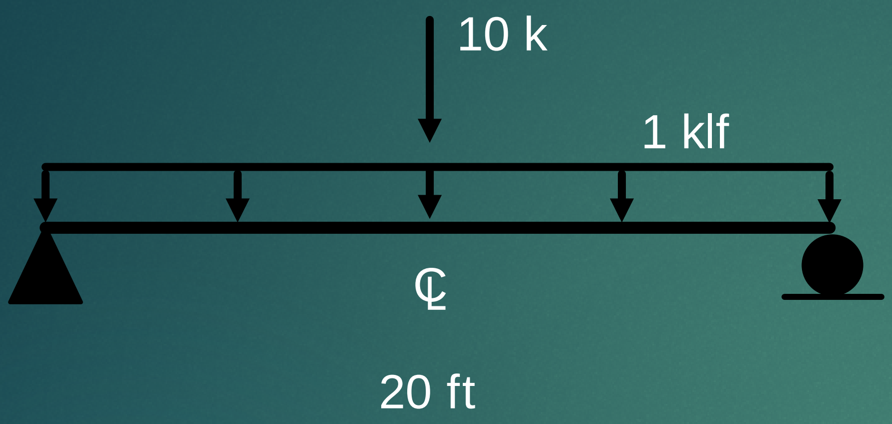
$$M_{max} \text{ (at point of load)} \quad \ldots\ldots \quad = \frac{P\ell}{4}$$

$$M_x \left(\text{when } x < \frac{\ell}{2} \right) \quad \ldots\ldots \quad = \frac{Px}{2}$$

$$\Delta_{max} \text{ (at point of load)} \quad \ldots\ldots \quad = \frac{P\ell^3}{48EI}$$

$$\Delta_x \left(\text{when } x < \frac{\ell}{2} \right) \quad \ldots\ldots \quad = \frac{Px}{48EI}(3\ell^2 - 4x^2)$$

Superposition



$$V_{max} = \frac{Wl}{2} = \frac{(1\ klf)(20\ ft)}{2} = 10k$$

$$V_{max} = \frac{P}{2} = \frac{(10\ k)}{2} = 5k$$

$$V_{max} = 10k + 5k = 15k$$

$$M_{max} = \frac{Wl^2}{8} = \frac{(1\ klf)(20ft)^2}{8} = 50ft\text{-}k$$

$$M_{max} = \frac{Pl}{4} = \frac{(10\ k)(20ft)}{4} = 50ft\text{-}k$$

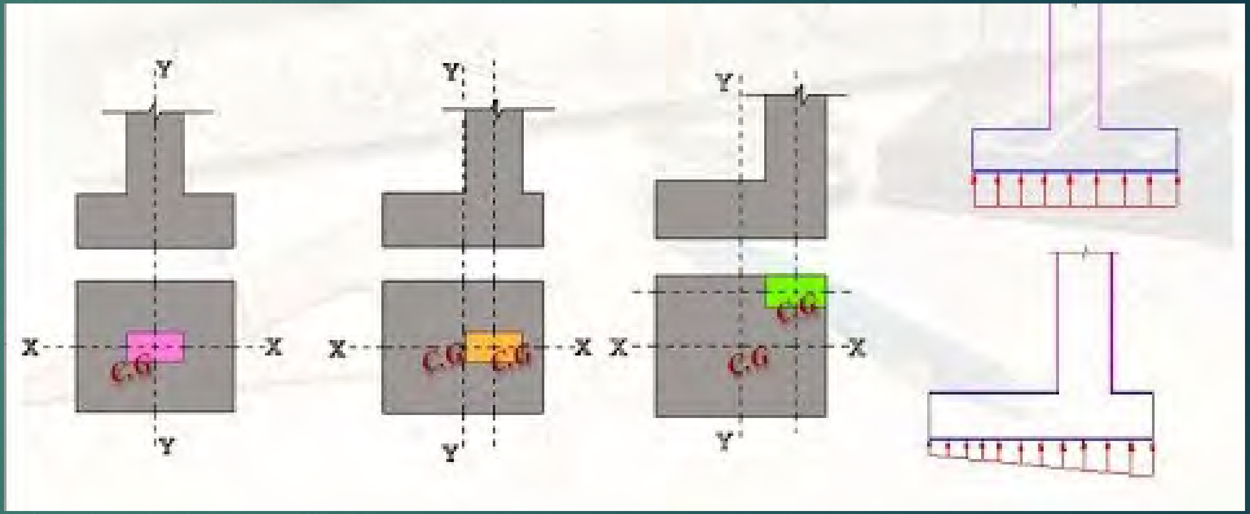
$$M_{max} = 50ft - k + 50ft - k = 100ft - k$$

Loads on Buildings

Concentrated Load v. distributed loads

Concentric v. eccentric Loading

- Concentric loading – the load passes through the center of gravity of the member
- Eccentric Loading – the load passes at some distance (eccentricity) from the center of gravity of the member



Gravity Loads

- Force due the gravitational force (acceleration due to gravity) of the earth, typically acting toward the center of the earth.
- F=MA,
  - M is the mass of the object
  - A is the Acceleration due to gravity 32.2 f/s^2 or 1 g or 9.81 m/s^2

Gravity Loads

- Dead Load - buildings self-weight, permanently attached fixtures and coverings, mechanical equipment, very well known, little change over time
- Live Load - transient in nature, not as well known as dead load, changes over time, people and furniture
- Snow Load - load from frozen precipitation
- Rain Load – load from precipitation

Lateral

- Wind Load – pressure on the building from the movement of air, resulting from differences in atmospheric pressures
- Seismic/Earthquake Load – the response of the building to ground movement and momentum, effected by building mass, soil properties, structural configuration, structural material, acceleration and velocity of the earths movement
- Live load – movement of people, vehicles, etc.

Load Duration

- Static Load – applied slowly and typically present over a long period of time like file storage in an office building
- Dynamic or Impact Load – applied quickly, can have an increased load effect in excess of a factor of two (2) like the effect of a motor vehicle hitting a building

Loads

Forces or other actions that result from the weight of building materials, occupants and their possessions, environmental effects, differential movement and restrained dimensional changes. Permanent loads are those loads in which variations over time are rare or of small magnitude, such as dead loads. All other loads are variable loads (see "Nominal loads").

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.

Table C3.1-1a Minimum Design Dead Loads (psf)[a]

Component	Load (psf)
CEILINGS	
Acoustical fiberboard	1
Gypsum board (per 1/8-in. thickness)	0.55
Mechanical duct allowance	4
Plaster on tile or concrete	5
Plaster on wood lath	8
Suspended steel channel system	2
Suspended metal lath and cement plaster	15
Suspended metal lath and gypsum plaster	10
Wood furring suspension system	2.5
COVERINGS, ROOF, AND WALL	
Asbestos-cement shingles	4
Asphalt shingles	2
Cement tile	16
Clay tile (for mortar add 10 psf)	
Book tile, 2-in.	12
Book tile, 3-in.	20
Ludowici	10
Roman	12
Spanish	19
Composition:	
Three-ply ready roofing	1
Four-ply felt and gravel	5.5
Five-ply felt and gravel	6

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

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.

Live Load

- **1607.2 Loads not specified.** For occupancies or uses not designated in Table 1607.1, the live load shall be determined in accordance with a method approved by the building official.
- **1607.3 Uniform live loads.** The live loads used in the design of buildings and other structures shall be the maximum loads expected by the intended use or occupancy but shall not be less than the minimum uniformly distributed live loads given in Table 1607.1.

Live Load

1607.4 Concentrated live loads. Floors, roofs and other similar surfaces shall be designed to support the uniformly distributed live loads prescribed in Section 1607.3 or the concentrated live loads, given in Table 1607.1, whichever produces the greater load effects. Unless otherwise specified, the indicated concentration shall be assumed to be uniformly distributed over an area of 2-1/2 feet by 2-1/2 feet (762 mm by 762 mm) and shall be located so as to produce the maximum load effects in the structural members.

Live Load

1607.5 Partition loads. In office buildings and in other buildings where partition locations are subject to change, provisions for partition weight shall be made, whether or not partitions are shown on the construction documents, unless the specified live load is 80 psf (3.83 kN/m2) or greater. The partition load shall be not less than a uniformly distributed live load of 15 psf (0.72 kN/m2).

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	50	2,000
Computer use	100	2,000
3. Armories and drill rooms	150[a]	—
4. Assembly areas		—
Fixed seats (fastened to floor)	60[m]	
Follow spot, projections and control rooms	50	
Lobbies	100[m]	
Movable seats	100[m]	
Stage floors	150[a]	
Platforms (assembly)	100[m]	
Other assembly areas	100[m]	
5. Balconies and decks[b]	1.5 times the live load for the area served, not required to exceed 100	—
6. Catwalks	40	300
7. Cornices	60	—

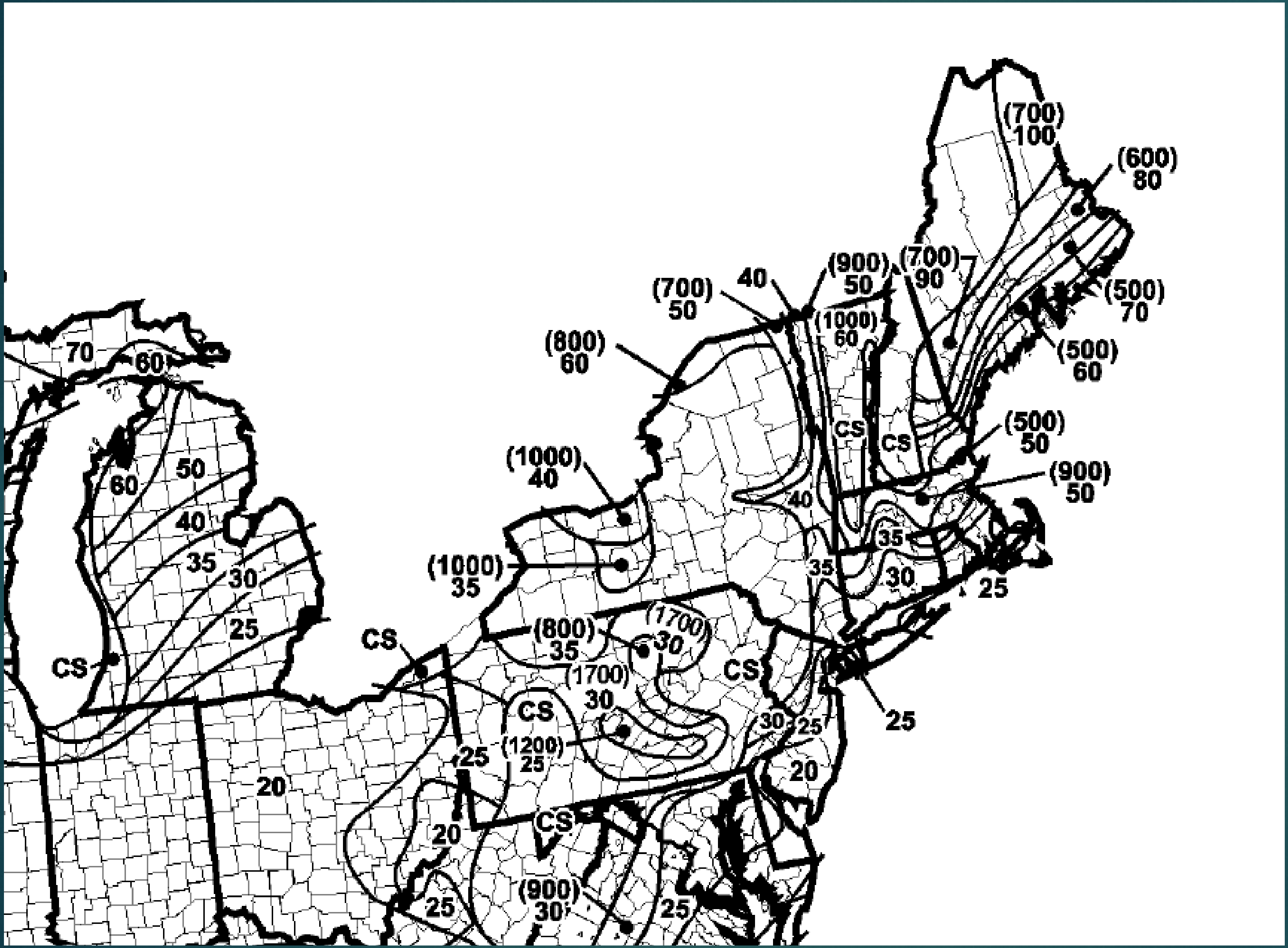
Live Load, Roof

A load on a roof produced:

1. During maintenance by workers, equipment and materials;
2. During the life of the structure by movable objects such as planters or other similar small decorative appurtenances that are not occupancy related; or
3. By the use and occupancy of the roof such as for roof gardens or assembly areas.

Snow Load

- **GROUND SNOW LOAD:** The site-specific weight of the accumulated snow at the ground level used to develop roof snow loads on the structure. It generally has a 50-year mean recurrence interval.
- **MINIMUM SNOW LOAD:** Snow load on low sloped roofs, including the roof snow load immediately after a single snow storm without wind.
- **SLOPED ROOF SNOWLOAD:** Uniform load on horizontal projection of a sloped roof, also known as the balanced load.



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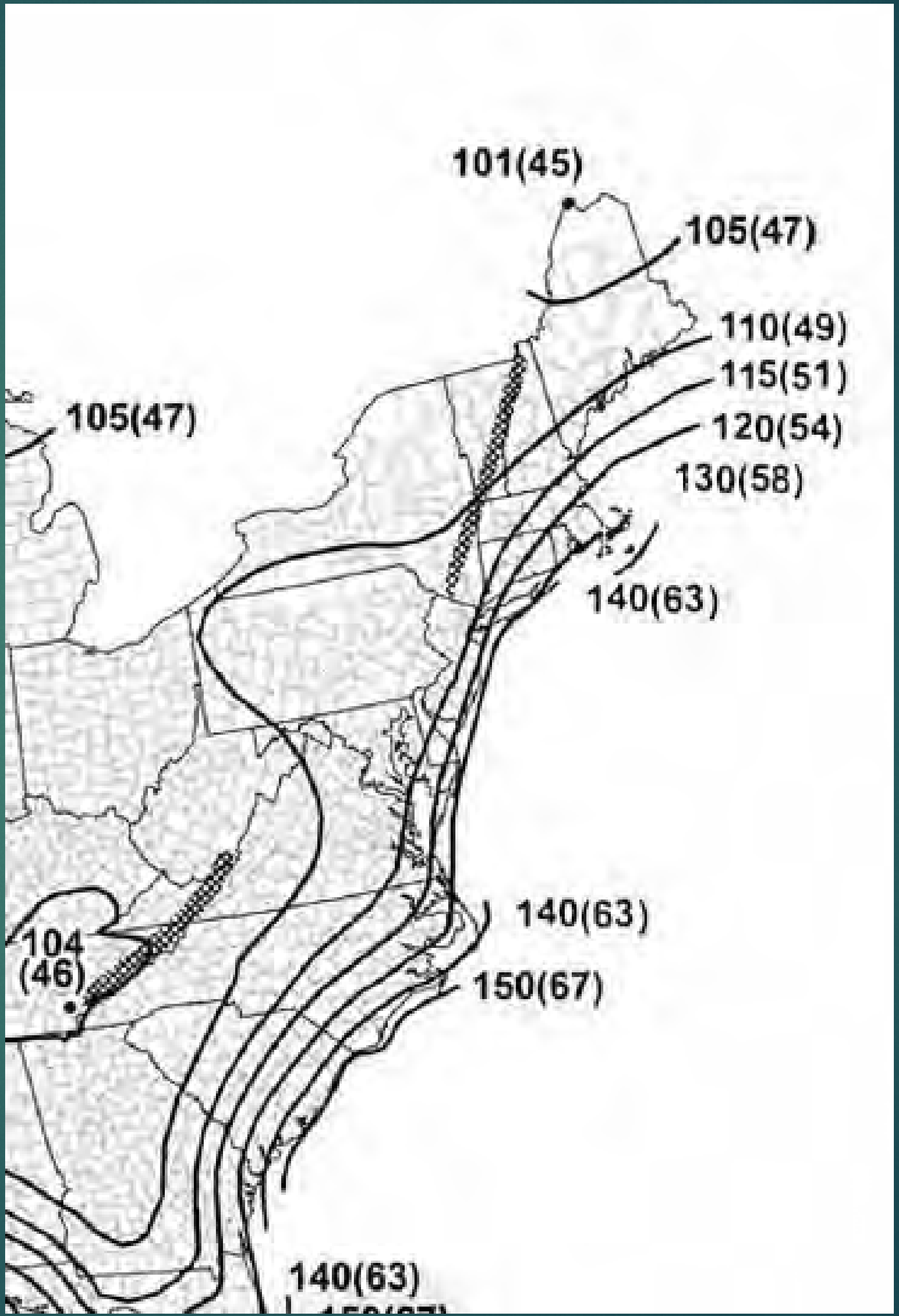
Wind Loads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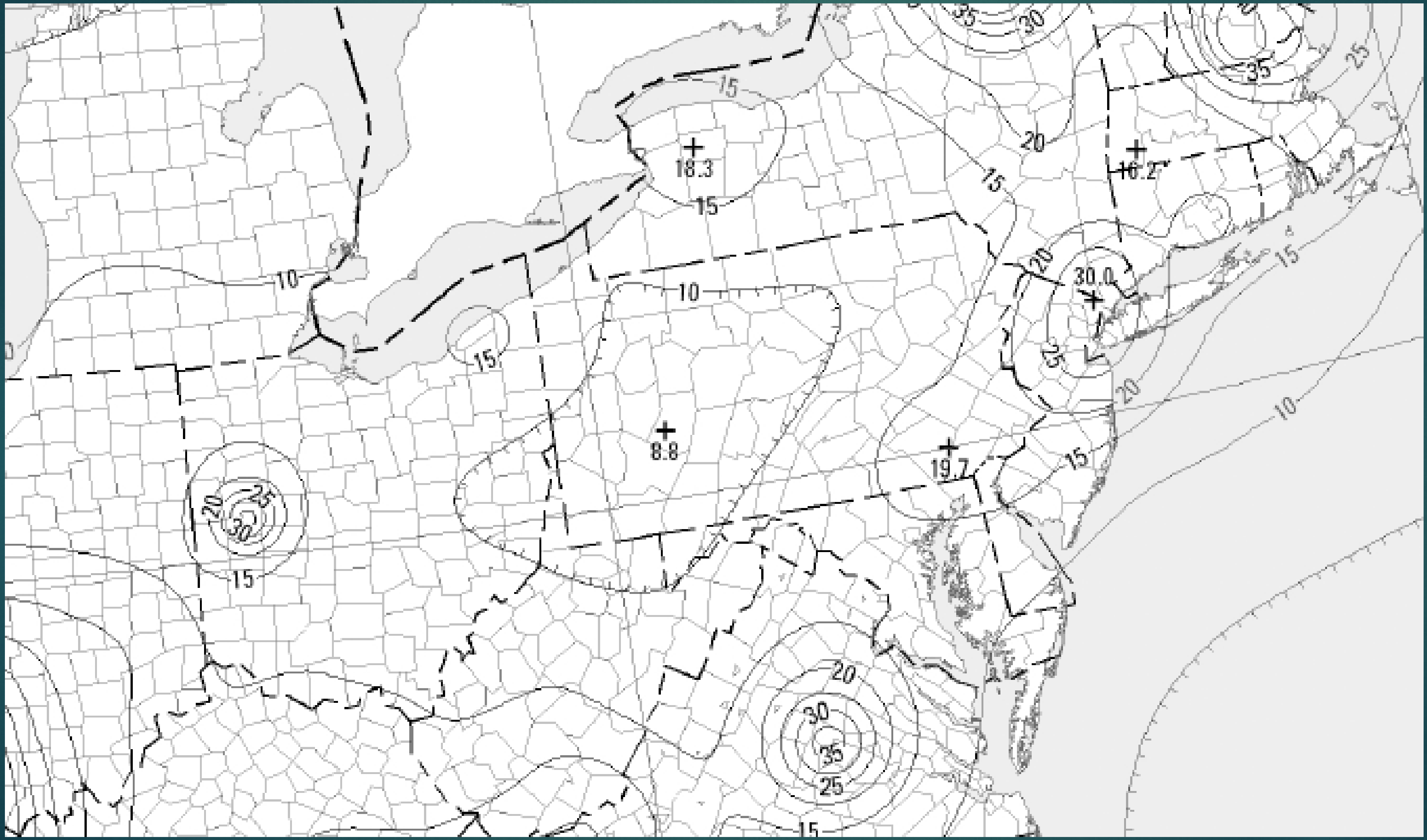
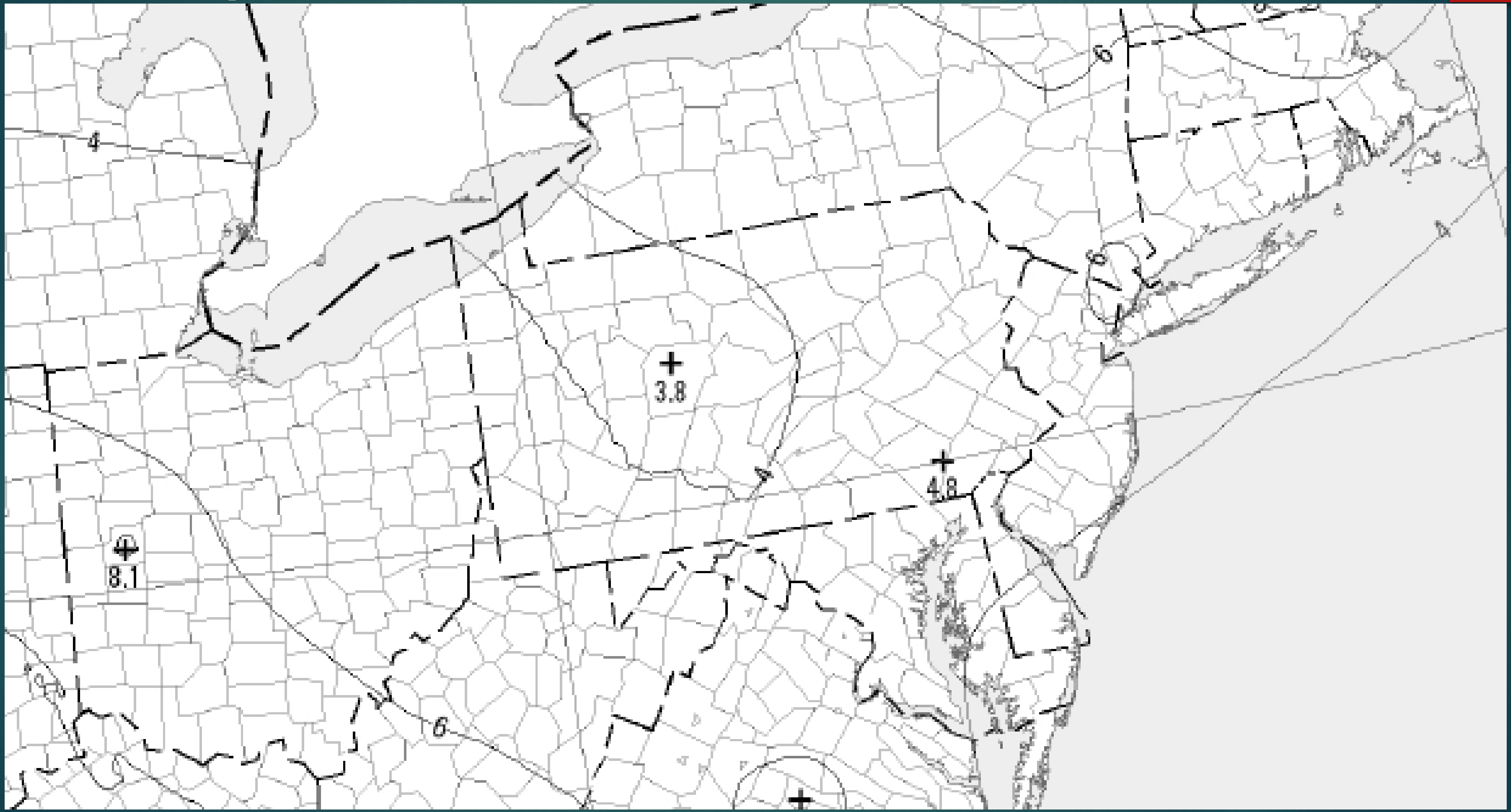
Earthquake Loads



Earthquake Loads



Soil Loads

TABLE 1610.1
LATERAL SOIL LOAD

DESCRIPTION OF BACKFILL MATERIAL[c]	UNIFIED SOIL CLASSIFICATION	DESIGN LATERAL SOIL LOAD[a] (pound per square foot per foot of depth)	
		Active pressure	At-rest pressure
Well-graded, clean gravels; gravel-sand mixes	GW	30	60
Poorly graded clean gravels; gravel-sand mixes	GP	30	60
Silty gravels, poorly graded gravel-sand mixes	GM	40	60
Clayey gravels, poorly graded gravel-and-clay mixes	GC	45	60
Well-graded, clean sands; gravelly sand mixes	SW	30	60
Poorly graded clean sands; sand-gravel mixes	SP	30	60
Silty sands, poorly graded sand-silt mixes	SM	45	60
Sand-silt clay mix with plastic fines	SM-SC	45	100
Clayey sands, poorly graded sand-clay mixes	SC	60	100
Inorganic silts and clayey silts	ML	45	100
Mixture of inorganic silt and clay	ML-CL	60	100
Inorganic clays of low to medium plasticity	CL	60	100
Organic silts and silt clays, low plasticity	OL	Note b	Note b
Inorganic clayey silts, elastic silts	MH	Note b	Note b
Inorganic clays of high plasticity	CH	Note b	Note b
Organic clays and silty clays	OH	Note b	Note b

Load Combinations

Where allowable stress design (working stress design), as permitted by this code, is used, structures and portions thereof shall resist the most critical effects resulting from the following combinations of loads:

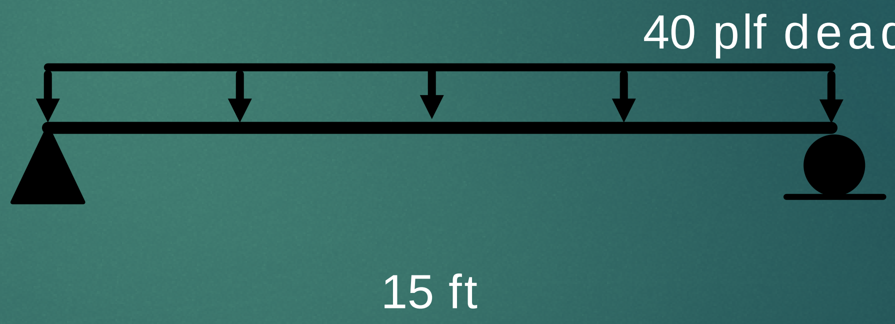
- D + F (Equation 16-8)
- D + H + F + L (Equation 16-9)
- D + H + F + (Lr or S or R) (Equation 16-10)
- D + H + F+ 0.75(L) + 0.75(Lr or S or R) (Equation 16-11)
- D + H + F + (0.6W or 0.7E) (Equation 16-12)
- D + H + F + 0.75(0.6W) + 0.75L + 0.75(Lr or S or R) (Equation 16-13)
- D + H + F + 0.75 (0.7 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)

Stress (rectangular cross-section)

- Axial – $f_a = \frac{P}{A} = \frac{P}{bd}$
- Flexural - $f_b = \frac{M}{S} = \frac{M}{b}\frac{6}{d^2}$
- Shear - $f_v = \frac{3}{2}\frac{V}{A} = \frac{3}{2}\frac{V}{bd}$

Example

- 2x12 No2 DF-L 15 ft long simple beam with 40 plf dead load and 100 plf live load



$$V_{max} = \frac{wl}{2} = \frac{(140plf)(15ft)}{2} = 1050lbs$$

$$M_{max} = \frac{wl^2}{8} = \frac{(140plf)(15ft)^2}{8} = 3937.5ft - lbs$$

$$\delta_{max} = \frac{5wl^4}{384EI} = \frac{5(100plf)(15ft)^4\left(\frac{12in}{ft}\right)^3}{384(1.6E6psi)(178in^4)} = 0.4\text{in}$$

$$\frac{l}{360} = \frac{(15ft)\left(\frac{12in}{ft}\right)}{360} = 0.5in$$

$$f_b = \frac{(3937.5ft - lbs)6\left(\frac{12in}{ft}\right)}{(1.5in)(11.25in)^2} = 1493psi$$

$$f_v = \frac{3}{2}\frac{(1050lbs)}{(1.5in)(11.25in)} = 93.3psi$$

Questions