Legal

29. Architect professionals has primary legal responsibility for the performance of a building in an earthquake.

Not: Building code official; Structural engineer; Geotechnical consultant

Steel

Steel roof joists are manufactured with camber to compensate for deflection.
Not: Provide positive roof drainage; support a variety or roof deck systems; increase lateral stability

A balcony is hung from steel roof framing over a hotel atrium. 33 percent is the minimum code required increase in live load due to impact.
Not: 0 percent; 25 percent; 50 percent

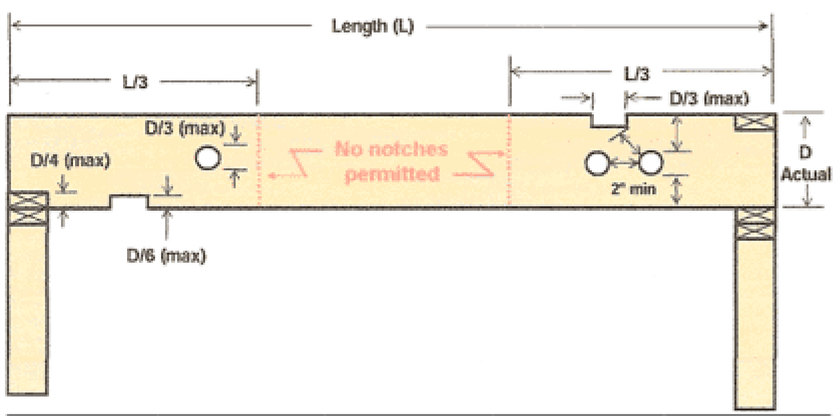
ASCE 4.7.2. It states that balconies loads shall be increased 33% for impact. IBC section 1602 also mentions impact loads.

ASCE 7-02 Section 4.7 does address impact loads. The code does not specifically address a solid steel ball dropping from a certain elevation. For example: Elevator loads shall be increased by 100% for impact, and the structural supports shall be designed within the limits of deflection prescribed by Refs 4-1 and 4-2. For your example, it would seem as if it is similar to a crane load. This is found in section 4.10 of the ASCE7-02.

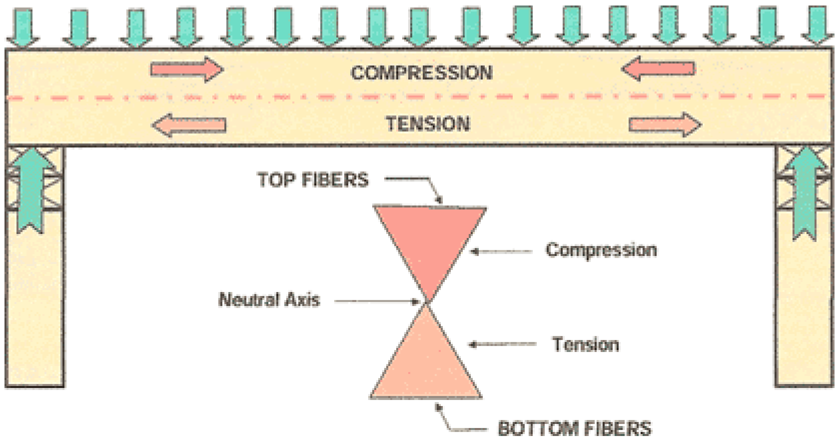
Wood:

In a renovation of an existing residential building, in which piping of conduit needs to be run through a 2 x 12 [50 x 300 mm] (actual) wood floor joist, 2.0 in [50 mm] is the minimum dimension required by the IBC [NBC] from the top or bottom of the joist to the bored hole.
Not: 1.0 in [25 mm]; 1.5 in [38 mm]; 2.5 in [63 mm]

- Notches in floor joists may occur in the top or bottom of the member but may not be located in the middle third of the span.
- A notch may not exceed one-sixth of the depth of the joist except at the very end where it may be one-fourth of the joist depth.
- The length of joist notches cannot exceed one-third of the depth of the member.
- Holes bored in joists must not be larger than one-third the depth of the joists.
- Holes cannot be located within two inches of the top or bottom edge of the member, or to any other hole located in the member.
- Holes cannot be located within 2" of any notch.



Joist Size	Max Hole	Max Notch Depth	Max End Notch	Max Notch Length
2x4	NONE	NONE	NONE	NONE
2x6	1 1/2	7/8	1 3/8	1 1/2
2x8	2 3/8	1 1/4	1 7/8	2 3/8
2x10	3	1 1/2	2 3/8	3
2x12	3 3/4	1 7/8	2 7/8	3 3/4



Gypsum shaft wall is generally the most economical material for the hoist-way wall of an elevator in a wood frame, two-story apartment building.
Not: Reinforced concrete; Pre-fabricated concrete; Concrete blocks

Timber

An 18th century farmhouse on the National Historic Register with exposed timber framing is to be restored and opened for tours. Limit the number of visitors in spaces to the available live load is the most historically correct method of addressing the lack of live load capacity of the floor framing.

Not: Replace the undersized framing with new adequately sized members; Sister the existing joists and beams; Reduce the span of the floor framing.

Concrete

Portland Cement

Raw ingredients of Portland cement: iron ore, lime, alumina and silica, which are used in various proportions depending upon the type of cement being made. These are ground up and fired in a kiln to produce a clinker. After cooling, the clinker is very finery ground (to about the texture of talcum powder) and a small amount of gypsum is added to retard the initial setting time.

- **Type I** - General purpose (least expensive, the majority of concrete)
- **Type II** - Sulfate resisting, concrete in contact with high sulfate soils (gains strength faster than Type I)
- **Type III** - High early strength, which gains strength faster than Type I, enabling forms to be removed sooner
- **Type IV** - Low heat of hydration, for use in massive construction
- **Type V** - Severe sulfate resisting

Aggregates

- Fine aggregate (sand) particles which can pass through a 3/8 in sieve;
- Coarse aggregates are larger than 3/8 inch in size.
- Clean, hard, and well-graded, without natural cleavage planes(i.e. slate or shale)
- Quality of aggregates: important since 6 to 75% of the volume
- Impossible to make good concrete with poor aggregates.
- Grading of both fine and coarse aggregate is very significant because having a full range of sizes reduces the amount of cement paste needed.
- Well-graded aggregates tend to make the mix more workable as well.
- Normal concrete is made using sand and stones (~150 pcf)
- Lightweight concrete: industrial by-products: expanded slag or clay (90 to 125 pcf)
- High strengths are more difficult to achieve with weaker aggregates.
- Light Weight Concrete: savings of building self-weight, may be important when building on certain types of soil.
- Insulating concrete is made using perlite and vermiculite, it weighs only about 15 to 40 pcf and has no structural value.

3.1 Properties of Concrete

Concrete is an artificial conglomerate stone made essentially of Portland cement, water, and aggregates. When first mixed the water and cement constitute a paste which surrounds all the individual pieces of aggregate to make a plastic mixture. A chemical reaction called hydration takes place between the water and cement, and concrete normally changes from a plastic to a solid state in about 2 hours. Thereafter the concrete continues to gain strength as it cures. A typical strength-gain curve is shown in Figure 1. The industry has adopted the 28-day strength as a reference point, and specifications often refer to compression tests of cylinders of concrete which are crushed 28 days after they are made. The resulting strength is given the designation f'c

Concrete should reach its design compressive strength in 28 days

Not: 3, 7, 32

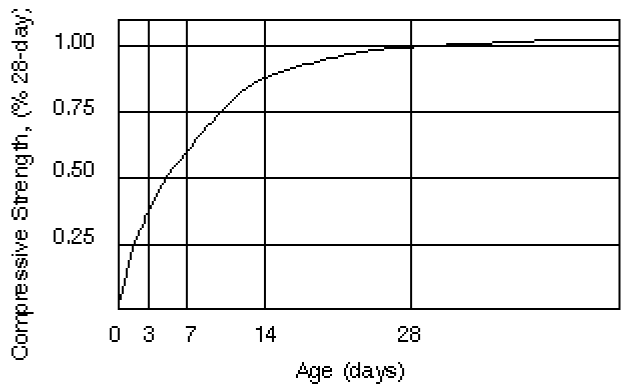


Figure 1. Typical strength-gain curve.

During the first week to 10 days of curing it is important that the concrete not be permitted to freeze or dry out because either of these, occurrences would be very detrimental to the strength development of the concrete. Theoretically, if kept in a moist environment, concrete will gain strength forever, however, in practical terms, about 90% of its strength is gained in the first 28 days.

Concrete has almost no tensile strength (usually measured to be about 10 to 15% of its compressive strength), and for this reason it is almost never used without some form of reinforcing. Its compressive strength depends upon many factors, including the quality and proportions of the ingredients and the curing environment. The single most important indicator of strength is the ratio of the water used compared to the amount of cement. Basically, the lower this ratio is, the higher the final concrete strength will be.

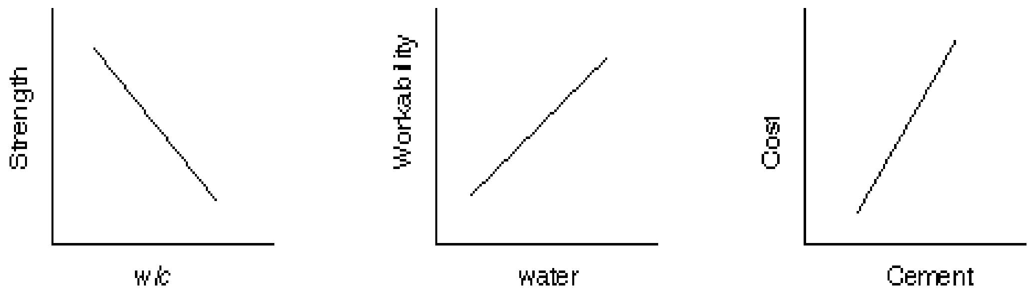


Figure 3. Mix Proportion relationships.

Since larger aggregate sizes have relatively smaller surface areas (for the cement paste to coat) and since less water means less cement, it is often said that one should use the largest practical aggregate size and the stiffest practical mix. (Most building elements are constructed with a maximum aggregate size of 3/4 to 1 in, larger sizes being prohibited by the closeness of the reinforcing bars.)

A good indication of the water content of a mix land thus the workability) can be had from a standard slump test. In this test a metal cone 12 in tall is filled with fresh concrete in a specified manner. When the cone is lifted, the mass of concrete "slumps" downward (Figure 4) and the vertical drop is referred to as the slump. Most concrete mixes have slumps in the 2- to 5-in range.

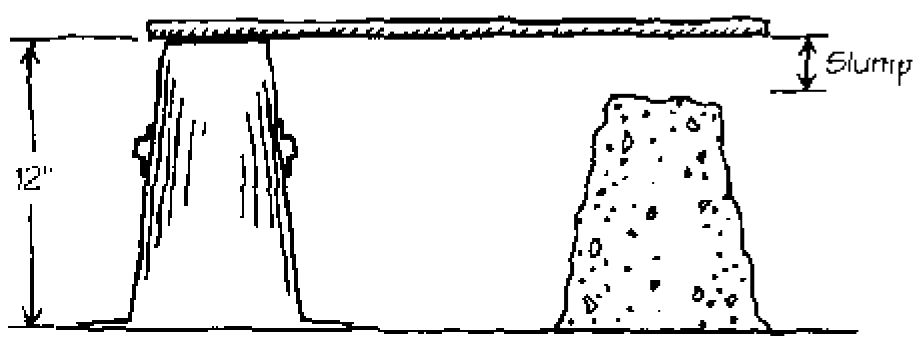


Figure 4. Slum p Test..

The Basic Mix:

The physical properties of density and strength of concrete are volume proportional mixture of water, cement, and aggregate. Mix the dry ingredients and slowly add water until the concrete is workable. This mixture may need to be modified depending on the aggregate used to provide a concrete of the right workability. The mix should not be too stiff or too sloppy. It is difficult to form good test specimens if it is too stiff. If it is too sloppy, water may separate (bleed) from the mixture.

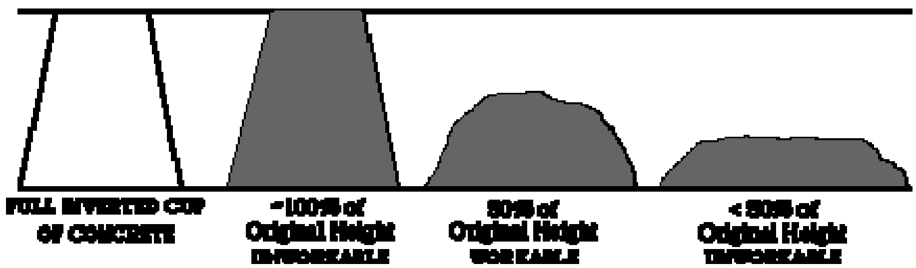
Remember that water is the key ingredient. Too much water results in weak concrete. Too little water results in a concrete that is unworkable.

Suggestions:

1. If predetermined quantities are used, the method used to make concrete is to dry blend solids and then slowly add water (with admixtures, if used).
2. It is usual to dissolve admixtures in the mix water before adding it to the concrete. Super plasticizer is an exception.
3. Forms can be made from many materials. Cylindrical forms can be plastic or paper tubes, pipe insulation, cups, etc. The concrete needs to be easily removed from the forms. Pipe insulation from a hardware store was used for lab trials. This foam-like material was easy to work with and is reusable with the addition of tape. The bottom of the forms can be taped, corked, set on glass plates, etc. Small plastic weighing trays or Dairy Queen banana split dishes can be used as forms for boats or canoes.
4. If compression tests are done, it may be of interest to spread universal indicator over the broken face and note any color changes from inside to outside. You may see a yellowish surface due to carbonation from CO_2 in the atmosphere. The inside may be blue due to calcium hydroxide.
5. To answer the proverbial question, "Is this right?" a slump test may be performed. A slump test involves filling an inverted, bottomless cone with the concrete mixture. A Styrofoam or paper cup with the bottom removed makes a good bottomless cone. Make sure to pack the concrete several times while filling the cone. Carefully remove the cone by lifting it straight upward. Place the cone beside the pile of concrete. The pile should be about 1/2 to 3/4 the height of the cone for a concrete mixture with good workability.

A slump cone is used primarily to provide an Strength and workability characteristics of concrete.

Not: Durability and finish; Air entrainment and chemical resistance; Appearance and color



6. To strengthen samples and to promote hydration, soak concrete in water (after it is set).
7. Wet sand may carry considerable water, so the amount of mix water should be reduced to compensate.
8. Air bubbles in the molds will become weak points during strength tests. They can be eliminated by:
    - i. packing the concrete.
    - ii. Tapping the sides of the mold while filling the mold.
    - iii. "rodding" the concrete inside the mold with a thin spatula.
9. Special chemicals called "water reducing agents" are used to improve workability at low water to cement ratios and thus produce higher strengths. Most ready-mix companies use these chemicals, which are known commercially as super plasticizers. They will probably be willing to give you some at no charge.

A bag contains 94 lb. (40kg) of cement.

The ingredients of concrete can be proportioned by weight or volume. The goal is to provide the desired strength and workability at minimum expense. Sometimes there are special requirements such as abrasion resistance, durability in harsh climates, or water impermeability, but these properties are usually related to strength. Sometimes concretes of higher strength are specified even though a lower f'c value would have met all structural requirements.

A low water-to-cement ratio is needed to achieve strong concrete. It would seem therefore that by merely keeping the cement content high one could use enough water for good workability and still have a low w/c ratio.

The most important factor affecting the strength of concrete is the water-to-cement ratio

Not: weather conditions during curing; volume of the mixture;

$$E = 57{,}000\sqrt{f'_c}$$

E values thus computed have proven to be acceptable amount of vibration of the mix

CONCRETE:

TYPICAL CONCRETE COMPRESSIVE STRENGTHS		
CONCRETE	MINIMUM 28 DAY COMPRESSIVE STRENGTH	SLUMP AT PLACEMENT
UNLESS NOTED OTHERWISE, ALL CONCRETE SHALL BE	3,000 PSI	4 1/2" MAXIMUM
CONCRETE OVER STEEL DECK	3,000 PSI	4" MAXIMUM
SLABS ON GRADE	3,500 PSI	4" MAXIMUM
FOOTINGS AND STEM WALLS	3,000 PSI	4" MAXIMUM

All footings are 3000 PSI. Now refer back to the Typical Reinforcing Bar Splice Detail. Now the grade of rebar needs to be found. Referring back to S-01 the following is found.

Creep In Concrete

When concrete is held under sustained stress, the strain will continue to increase with time. Creep defines this time-dependent phenomenon.

Not: Shrinkage; Temperature expansion; Contraction

Concrete creep is defined as: deformation of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending.

Creep does not necessarily cause concrete to fail or break apart. Creep is factored in when concrete structures are designed.

Factors Affecting Creep

1. Aggregate
2. Mix Proportions
3. Age of concrete

1. Influence of Aggregate

Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep. The modulus of elasticity of aggregate is one of the important factors influencing creep.

It can be easily imagined that the higher the modulus of elasticity the less is the creep. Light weight aggregate shows substantially higher creep than normal weight aggregate.

2. Influence of Mix Proportions:

The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio. In other words, it can also be said that creep is inversely proportional to the strength of concrete. Broadly speaking, all other factors which are affecting the water/cement ratio are also affecting the creep.

3. Influence of Age:

Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more. What is said above is not a very accurate statement because of the fact that the moisture content of the concrete being different at different age also influences the magnitude of creep.

Effects of Creep on Concrete and Reinforced Concrete

- In reinforced concrete beams, creep increases the deflection with time and may be a
critical consideration in design.
- In eccentrically loaded columns, creep increases the deflection and can load to buckling.
- In case of statically indeterminate structures and column and beam junctions creep may relieve the stress concentration induced by shrinkage, temperatures changes or movement of support. Creep property of concrete will be useful in all concrete structures to reduce the internal stresses due to non-uniform load or restrained shrinkage.
- In mass concrete structures such as dams, on account of differential temperature conditions at the interior and surface, creep is harmful and by itself may be a cause of cracking in the interior of dams. Therefore, all precautions and steps must be taken to see that increase in temperature does not take place in the interior of mass concrete structure.
- Loss of prestress due to creep of concrete in prestressed concrete structure.

Design thin shell

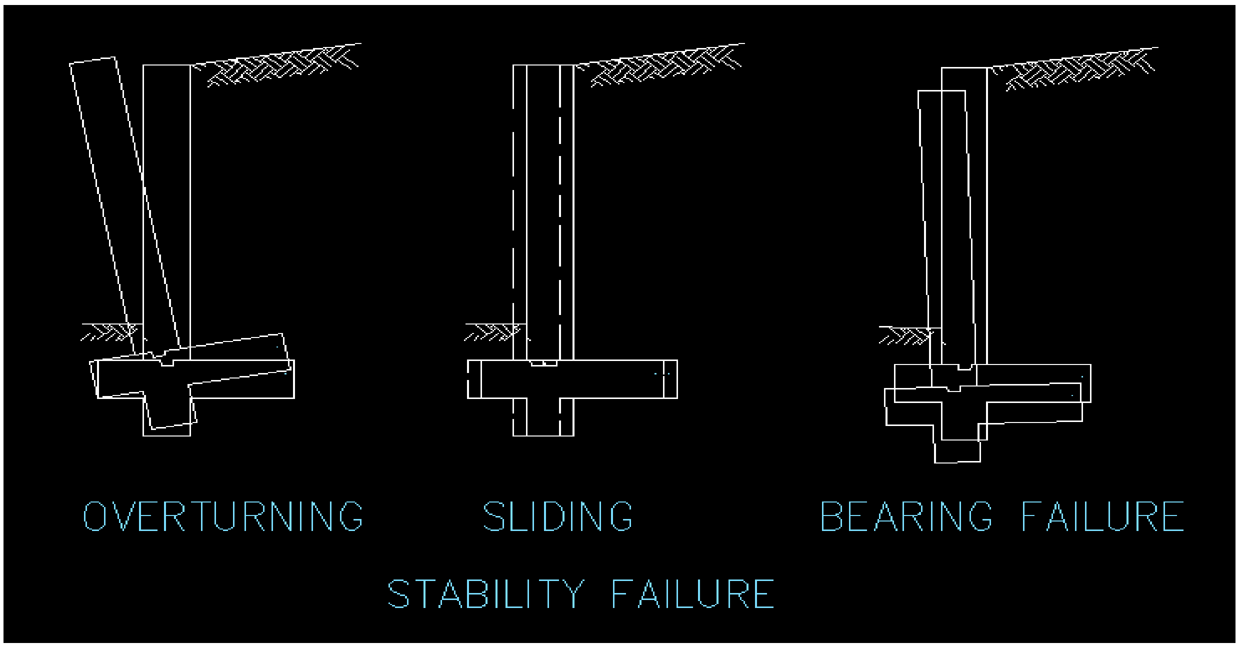
Since the 1960's, thin-shell concrete roof structures have seldom been utilized in the United States and Canada primarily because formwork is prohibitively expensive.
Not: Building codes often make it difficult to obtain approval for their use; design fees are substantially greater than for more conventional structures; materials (concrete and steel) are too costly

Design of concrete cantilever retaining wall

Common failure of retaining wall:

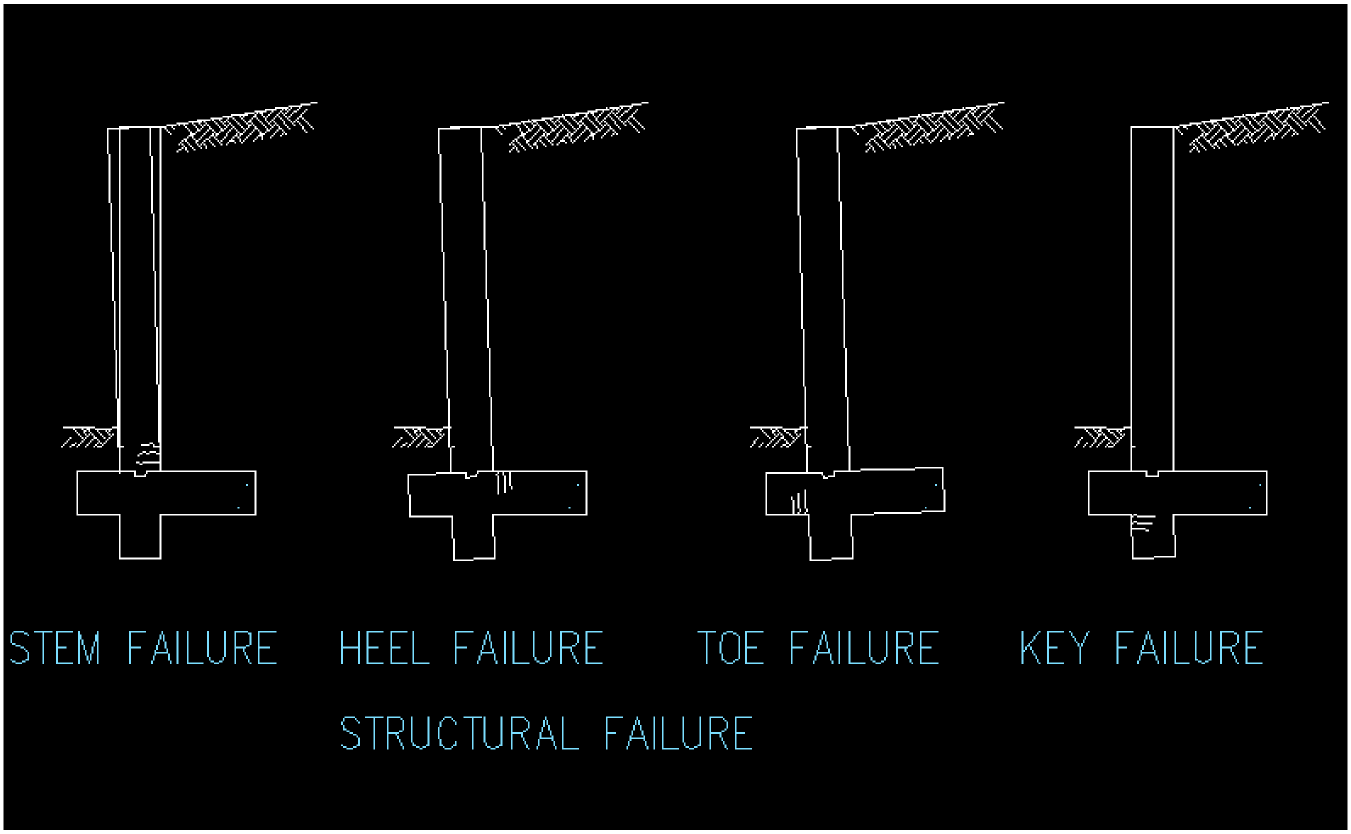
Stability failure

1. Overturning.
2. Sliding.
3. Bearing capacity.



Structural failure

4. Bending or shear failure of stem.
5. Bending or shear failure of heel.
6. Bending or shear failure of toe.
7. Bending or shear failure of key.



All items above should be considered in designing a retaining wall.
There is also a rotational stability failure that is not normally checked except when a retaining wall is located on a slope.

Design procedure for cantilever retaining wall:

Stability analysis

1. Check factor of safety against overturning.
2. Check soil bearing pressure.
3. Check factor of safety against sliding.

Reinforced concrete design

1. Check thickness of stem for shear stress.
2. Design stem reinforcement for bending.
3. Check thickness of heel for shear stress.
4. Design heel reinforcement.
5. Check shear stress for toe when the toe is long.
6. Design toe reinforcement for bending.
7. Check shear stress in key when key is deep and narrow.
8. Design key reinforcement for bending.

Factor of Safety

Foundatation Analysis by Bowels has good recommendations for safety factors. He evaluates uncertainties and assigns a factor of safety by taking into account the following:

1. Magnitude of damages (loss of life and property damage)
2. Relative cost of increasing or decreasing the factor of safety
3. Relative change in probability of failure by changing the factor of safety
4. Reliability of soil data
5. Construction tolerances
6. Changes in soil properties due to construction operations
7. Accuracy (or approximations used) in developing design/ analysis methods

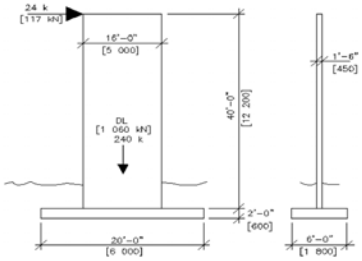
Typical values of customary safety factors, **F.S.**, as presented by Bowels.

Failure Mode	**Foundation Type**	**F.S.**
Shear	Earthwork for Dams, Fills, etc.	1.2 - 1.6
Shear	Retaining Walls	1.5 - 2.0
Shear	Sheet piling, Cofferdams	1.2 - 1.6
Shear	Braced Excavations (Temporary)	1.2 - 1.5
Shear	Spread Footings	2 - 3
Shear	Mat Footings	1.7 - 2.5
Shear	Uplift for Footings	1.7 - 2.5
Seepage	Uplift, heaving	1.5 - 2.5
Seepage	Piping	3 - 5

Other customary factors of safety, **F.S.**, used are:

1.5 for retaining walls overturning with granular backfill
2.0 for retaining walls overturning with cohesive backfill
1.5 for retaining walls sliding with active earth pressures
2.0 for retaining walls sliding with passive earth pressures

4.2 is the factor of safety against overturning for the concrete shear wall shown if resisted only by gravity forces. Assume the weight of concrete equals 150 lb/ft 3 [23.5 kN/m3], and the dead load equals 240 kips [1060 kN]. Ignore the weight of the soil over the footing.
Not: 1.5; 2.0; 3.7


24 k
[117 kN]
16'-0"
[5 000]
DL
[1 060 kN]
240 k
40'-0"
[12 200]
2'-0"
[600]
20'-0"
[6 000]
1'-6"
[450]
6'-0"
[1 800]

Rebar Earth cover

TYPICAL CLEAR CONCRETE COVERAGES		
CONCRETE CAST AGAINST AND PERMANENTLY EXPOSED TO EARTH		3"
FORMED CONCRETE EXPOSED TO EARTH OR WEATHER	#6 AND LARGER	2"
	#5 AND SMALLER	1 1/2"
FORMED CONCRETE NOT EXPOSED TO WEATHER OR IN CONTACT WITH GROUND :		
SLABS, WALLS, OR JOISTS	#14 AND LARGER	1 1/2"
	#11 AND SMALLER	3/4"
BEAMS, COLUMNS (TO PRIMARY REINFORCEMENT, TIES, OR STIRRUPS)		1 1/2"
ALL OTHERS PER LATEST EDITION OF ACI 318.		

OR

MAINTAIN THE FOLLOWING CONCRETE COVERAGE'S FOR CONCRETE REINFORCING:

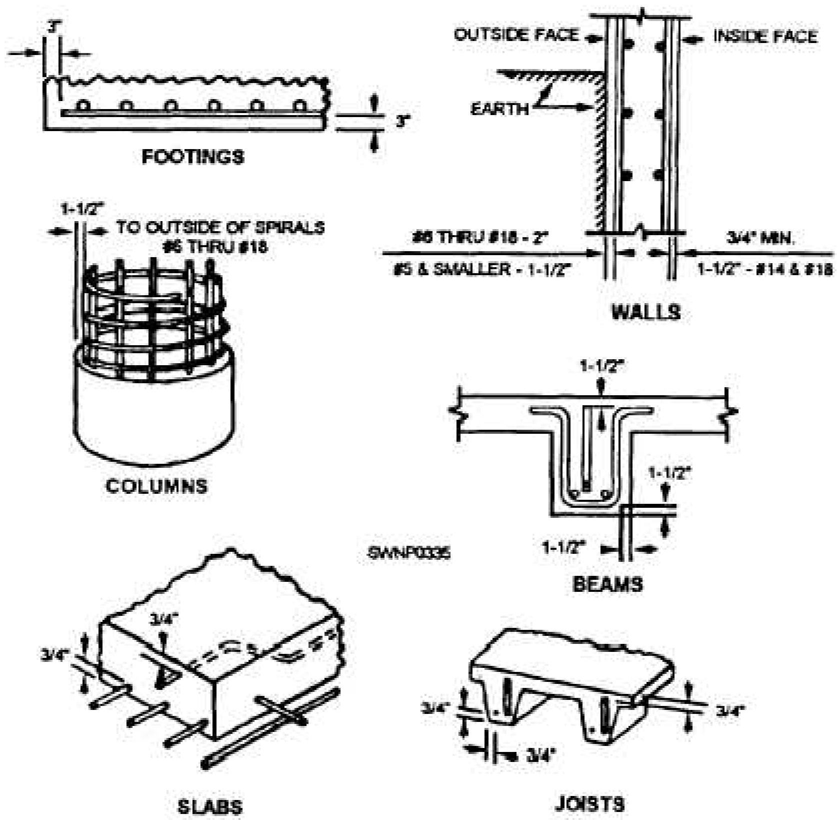
UNFORMED SURFACES IN CONTACT WITH EARTH	3"
FORMED SURFACES IN CONTACT WITH EARTH	2"
FORMED SURFACES EXPOSED TO OUTSIDE WEATHER	1 1/2"
SLABS AND WALLS NOT EXPOSED TO WEATHER	0 3/4"
CLEAR DISTANCE BETWEEN BARS	2"

Condition 1: The top condition vertical component of the dowel is essentially a formed surface Exposed to outside weather requiring 1 1/2" of concrete coverage.
Condition 2: The bottom condition of the vertical component of the dowel is an unformed surface in contact with the earth so it requiring 3" of concrete coverage.
Condition 3: The horizontal end component of the dowel is a formed surface in contact with the earth requiring 2" of concrete coverage.

Cast in Place

Cast-in-place concrete beams and columns with No. 11 [35M] rebar or smaller reinforcing bars that are not exposed to weather or in contact with the ground should have a minimum coverage of concrete over the bars of 1 1/2 in [37 mm].

Not: 3/4 in [19 mm]; 1 in [25 mm]; 1/2 in [12 mm]



Slabs

Slab Types

Slab on Grade (SOG)
Slab on Metal Deck (SOMD)
Suspended Slabs (SS)
Reinforcing
Rebar [All]
Mesh [All]
Fiber Mesh [more typical SOG]
PT Cable [SS]
Forming

One Way Slab
A one-way slab is used typically in Parking **types of buildings.**
Not: Museum; Library; Warehouse

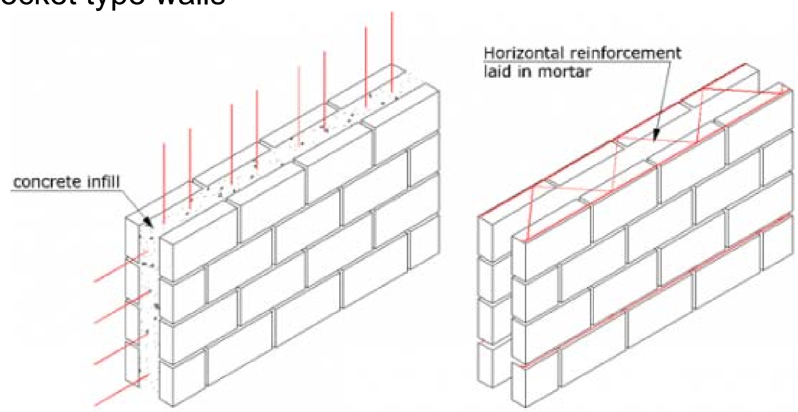
Concrete Masonry Unit

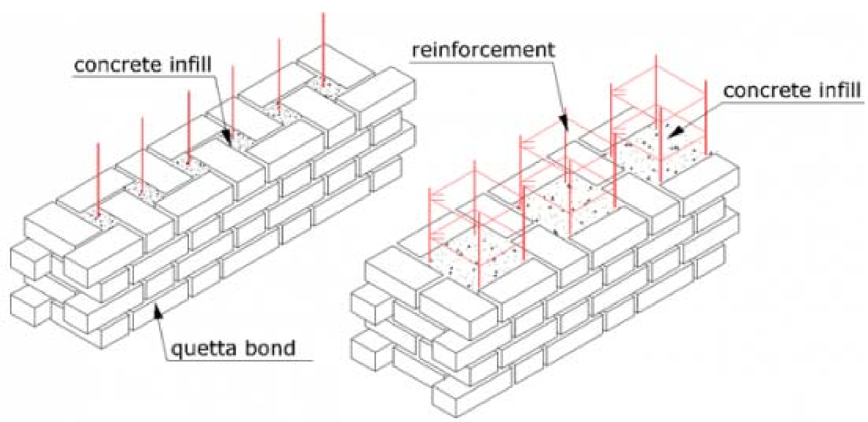
Each unit laid in and bound by mortar: brick, stone, concrete block, and tile.

It provide great compressive strength

- **Tensile Strength**- it is weak in tensile strength (twisting or stretching) unless reinforced
- **Reinforcement**- A construction system where steel reinforcement is embedded in the mortar joints of masonry or placed in holes and after filled with concrete or grout is called Reinforced masonry. Typical reinforced masonry can be classified into three types:

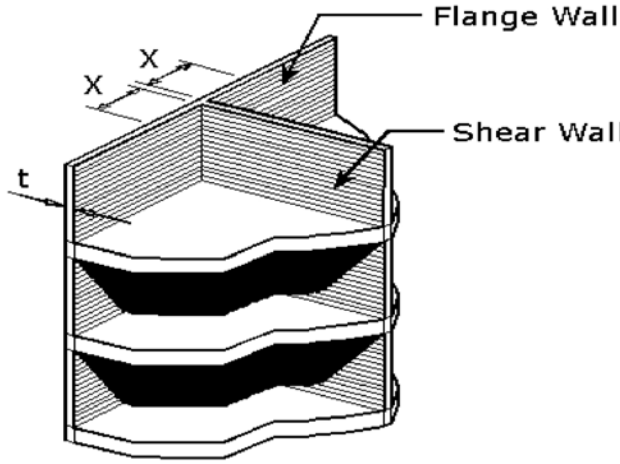
1. Reinforced hollow unit masonry
2. Reinforced grouted cavity masonry
3. Reinforced pocket type walls





A primary cause of failure of concrete masonry walls during hurricanes is a lack of vertical reinforcement. Not: Poorly filled mortar joints; improper base and sill flashing; an inadequate number of wall anchors

In the CMU stem-flanged shear wall arrangement shown, the minimum dimension X recommended to achieve shear transfer is 6t.
Not: 3t, 9t, 12t



According to model codes; Connection of masonry web shear walls to masonry flange walls must be accomplished using Running bond, Bond beams, and Metal plate strap anchors.

Not: Stacked bond; Steel dowels, High-strength mortar

NCARB 4.0 MC questions:
http://www.ncarb.org/are/StudyAids/SS-40.pdf

#24. In the CMU stem-flanged shear wall arrangement shown, the minimum dimension X recommended to achieve shear transfer is:
3t
6t
9t
12t

#35. According to model codes; Connection of masonry web shear walls to masonry flange walls must be accomplished using which of the following details? Check the three that apply.
A. Running bond
B. Bond Beams
C. Stacked bond
D. Steel Dowels
E. high-Strength mortar
F. Metal plate strap anchors

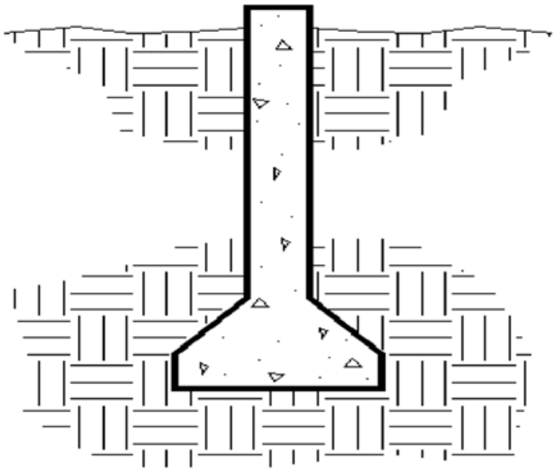
It seems like they both deal with the same concept (masonry web shear wall attachment to flange wall) that somehow I don't know anything about, your help would be much appreciated.

NCARB 3.1, General Structure:

#22. For the block shown (it shows a block that weighs 50 lb and there is a lateral force of 10 lb), what is the factor against sliding if the coefficient of friction is 0.5?
2.5
5
25
50

Footings

The drilled pier (caisson) shown above is belled in order to increase the bearing area
Not: prevent water infiltration; prevent caving; increase frictional resistance



The most frequently used footing type at the exterior wall for load-bearing wall support systems is continuous wall footings.
Not: mat footings; pile footings; isolated pad footings

Soil

A loss of soil shear strength resulting in the movement of the surficial soil layers of a building site in a direction parallel to the ground surface under earthquake conditions is most likely caused by liquefiable soils.
Not: a low bearing capacity; a gently sloping site;

If the soil bearing capacity is 3000 psf [143 500 N/m2] and the applied load is 48,000 lbs [212 kN], 16 sf [1.5 m2] is the area for the footing.

48/3= 16 sqft or 4x4 footing

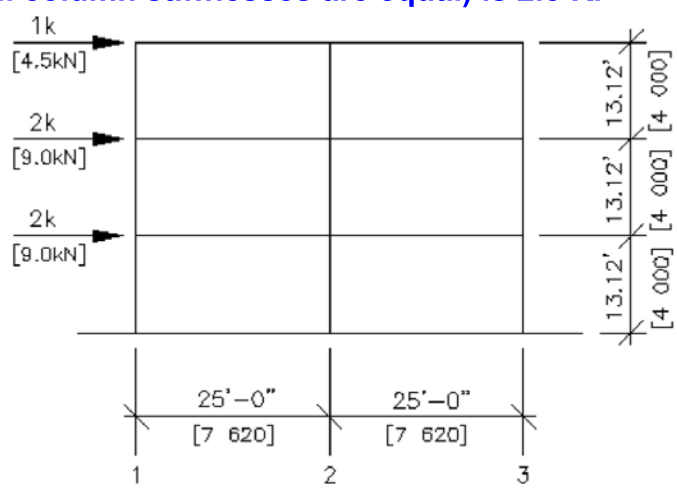
Seismic forces

33. The earthquake regulations of model codes are intended to provide resistance to Ground shaking.
Not: Earth slides; Ground rupture in fault zones; Settlement

34. A structure will have a better chance of surviving an earthquake if The structure has redundancy .
Not: Principal members change section abruptly; The load-bearing members are not equally loaded; All columns and walls are discontinuous.

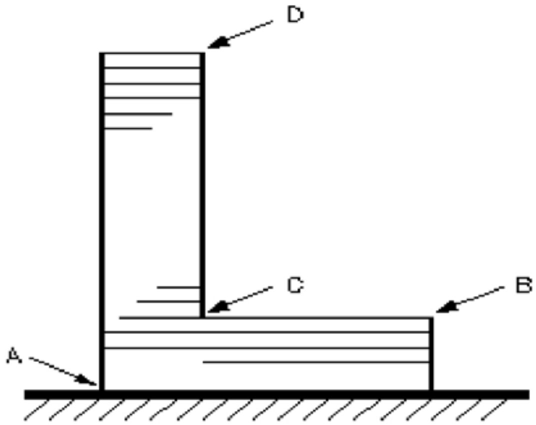
19. A building with a symmetrical square plan would be most appropriate for a high-rise building in a high-risk seismic zone.
Not: A building on stilts; A building with an L-shaped plan; A building with a symmetrical T-shaped plan

For the rigid frame structure shown, the approximate horizontal shear at the base of column 2 (assuming all column stiffnesses are equal) is 2.5 K.



Seismic Forces are: 1k+2K+3K = 5 K
They react with three columns: column 1,2, and 3. The tributary forces on 2 carry more than the other two 1 and 3. If building is uniform weight, the weight ratio for 2 is twice the 1 and 3, therefore, Column2: 5/2= 2.5 k shear force.

37. In the elevation of a multi-storied building subject to earthquake forces shown above, at at position C is stress concentration most likely to be a problem.



Shear walls, Braced frames, and Moment-resisting frames are primary structural system that is employed to resist lateral loads.
Not: Hinged frames

All of the following are criteria for base isolation systems:

- The system must allow lateral movement.
- The system must control the movement between ground and structure.
- Energy must be dissipated in the isolators.

Not: The system must amplify ground accelerations.

An eccentrically braced frame (EBF) utilized to resist lateral seismic forces in a building is a frame in which diagonal members are connected to a beam a short distance from the column joint
Not: Frame in which members are subjected primarily to axial forces; frame in which members and joints are capable of resisting forces by flexure as well as along the axis of the member; braced frame whose plan location results in torsion

Base isolation in an office building is most effective for four story building heights, assuming that the areas per floor are the same
Not: One-story; Twenty-story; Forty-story

38. A building form that is ideal for resistance to earthquake forces would be characterized by Symmetrical in plan and Heavier at the base than at the top
Not: Symmetrical about a reentrant corner; Asymmetrical in plan; Long linear plan; Asymmetrical in elevation

Column

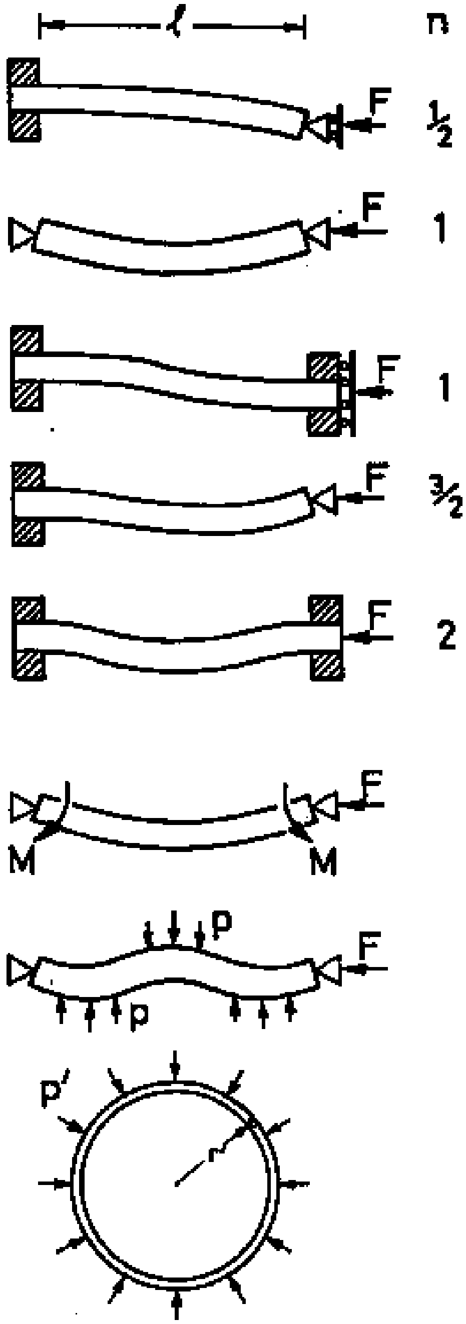
Column: **Buckling of Columns, Panels and Shafts**

If sufficiently slender, an elastic column, loaded in compression, fails by elastic buckling at a critical load, F_{crit}. This load is determined by the end constraints, of which four extreme cases are illustrated on Fig. A4: an end may be constrained in a position and direction; it may be free to rotate but not translate (or 'sway'); it may sway without rotation; and it may both sway and rotate. Pairs of these constraints applied to the ends of column lead to the five cases shown. Each is characterized by a value of the constant n which is equal to the number of half-wavelengths of the buckled shape.

The addition of the bending moment M reduces the buckling load by the amount shown in the second box. A negative value of F_{crit} means that a tensile force is necessary to prevent buckling.

An elastic foundation is one that exerts a lateral restoring pressure, p, proportional to the deflection ($p = ky$ where k is the foundation stiffness per unit depth and y the local lateral deflection). Its effect is to increase F_{crit}, by the amount shown in the third box.

A thin-walled elastic tube will buckle inwards under an external pressure p', given in the last box. Here I refers to the second moment of area of a section of the tube wall cut parallel to the tube axis.



$$F_{crit} = \frac{n^2\pi^2 EI}{\ell^2} \quad \text{or} \quad \frac{F_{crit}}{A} = \frac{n^2\pi^2 E}{(\ell/r)^2}$$

F = force (N)

M = moment (Nm)

E = Young's Modulus (N/m^2)

ℓ = Length (m)

A = Section area (m^2)

I = See Fig. A1

r = Gyration rad $\left(\frac{I}{A}\right)^{\frac{1}{2}}$ (m)

k = Foundation stiffness (N/m^2)

n = Half-wavelengths in buckled shape

p′ = pressure (N/m^2)

$$F_{crit} = \frac{\pi^2 EI}{\ell^2} - \frac{M^2}{4EI}$$

$$F_{crit} = \frac{n^2\pi^2 EI}{\ell^2} + \frac{k\ell^2}{n^2}$$

$$P'_{crit} = \frac{3EI}{(r')^3}$$

Figure A2 Buckling of Columns

Buckling of a column can be reduced by (a) Increasing the size of the member, (b) Bracing the column (c) Changing the type of end restraints; (D) Reducing the length of the column
Not: Reducing the radius of gyration, Rotating the column

26. Buckling of a column can be reduced by: A. Increasing the size of the member; C. Bracing the column; D. Changing the type of end restraints; E. Reducing the length of the column.
Not: Rotating the column

28. The recommended deflection criteria due to wind loading on a brick veneer wall utilizing a metal stud back-up system is L/600.
Not: L/360; L/400; L/720

Building Code requirements for Masonry Structures ACI 530-05 limits the deflection of beams and lintels to l/600 (.3in.) to prevent cracking. The deflection of the brick veneer with stud backup isn't specified. But the commentary from ACI 530 says "The Brick Industry Association has held that an appropriate deflection limit should be in the range of stud span length divided by 600 to 720."

Another way to look at the question is that L/360 is a max deflection for wood member carrying live load.

L/400 is recommended for formwork.

L/720 is recommended for soft stone tile/marble.

Basically you want less deflection for more delicate connections/materials.

Deflection Limit State

In the absence of more specific criteria, criteria for structures with brittle finishes (as found in code documents for years) is frequently used. This simplistic criteria puts a limit of the span divided by 360 on the incremental deflection due to live (or transient) load only and a limit of the span divided by 240 on deflection under total load. These limit states are mathematic expressed as:

$$\Delta_{LL} \leq L/360$$

$$\Delta_{TL} \leq L/240$$

These limits were originally developed for members with "brittle" finishes, such as plaster. Plaster is not commonly used as a finishing material anymore. The goal of the limits was to minimize the possibility of damage to the finish and provide reasonable comfort for the building occupants. The criteria has persisted in practice.

Other criteria has been used that more explicitly addresses the use of the beam under consideration. For example, the Timber Construction Manual [ref. 12], page 66 suggests the values given in Table 8.4.2.1 and 8.4.2.2. Other references give different, but similar, criteria.

Table 8.4.2.1
AITC Recommended Deflection Limits
Used with Permission

Use Classification	Applied Load Only	Applied Load + Dead Load
Roof Beams		
- Industrial	L/180	L/120
- Commercial and institutional		
- Without plaster ceiling	L/240	L/180
- With plaster ceiling	L/360	L/240
Floor Beams		
- Ordinary usage[a]	L/360	L/240
Highway bridge stringers	L/200 to L/300	
Railway bridge stringers	L/300 to L/400	

[a]Ordinary usage classification for floors is intended for construction in which walking comfort and minimized plaster cracking are the main considerations. These recommended deflection limits may not eliminate all objections to vibrations such as in long spans approaching the maximum limits or for some office and institutional applications where increased floor stiffness is desired. For these usages, the deflections limits of table 8.4.2.2 have been found to provide additional stiffness.

Table 8.4.2.2
AITC Deflection Limits for Uses Where Increased Floor Stiffness is Desired
Used with Permission

Use Classification	Applied Load Only	Applied Load + Dead Load[a]

Floor Beams		
- Commercial, Office & Institutional		
- Floor Joists, spans to 26 ft[b]		
- LL ≤ 60 psf	L/480	L/360
- 60 psf < LL < 80 psf	L/480	L/360
- LL ≥ 80 psf	L/420	L/300
- Girders, spans to 36 ft[b]		
- LL ≤ 60 psf	L/480	L/360
- 60 psf < LL < 80 psf	L/420	L/300
- LL ≥ 80 psf	L/360	L/240

[a]The AITC includes a modifier on DL depending on whether or not the timber is seasoned.
[b]For girder spans greater than 36 ft and joist spans greater than 26 ft, special design considerations may be required such as more restrictive deflection limits and vibration considerations that include the total mass of the floor.

Live Load Reduction

IBC Sections 1607.9 (floors) and 1607.11 (roofs) allow live loads set forth in IBC Table 1607.1 to be reduced. Live loads are permitted to be reduced because, for the most part, the likelihood that the entirety of a given floor or roof area will be fully loaded with the design live loads is low. There are many rules set forth in the code for when, and by how much, live loads may be reduced. See the table below to clearly understand these rules and why they are necessary.

Rule	Reduction of Floor Live Loads		Reduction of Roof Live Loads	Reason
	Section 1607.9.1 Based on Influence Area	Section 1607.9.2 (ALTERNATE) Based on Tributary Area	Section 1607.11.2 Based on Tributary Area	
1	(KLL)(AT) needs to be greater than 400 square feet.	Tributary area A needs to be greater than 150 square feet.	For flat roofs, AT needs to be greater than 200 square feet.	A minimum area is necessary before it can be assumed that an entire area will not be fully loaded with the design live loads.
2	Reduction cannot exceed 50 percent for elements that support loads of a single floor.	Reduction cannot exceed 40 percent or 23.1 (1 + D/L0) percent for horizontal members.	20 psf of roof live load may not be reduced to less than 12 psf.	This ensures that a horizontal structural member, such as a beam or a slab, will be designed for a minimum live load.
3	Reduction cannot be more than 60 percent for elements that support loads of two or more floors. for vertical members.	Reduction cannot exceed 60 percent or 23.1 (1 + D/L0) percent	20 psf of roof live load may not be reduced to less than 12 psf.	This ensures that a vertical structural member, such as a column or wall, will be designed for a minimum live load.
4	AT for one-way slabs, for use in reduction calculation, cannot exceed the slab span times a width of 1.5 times the slab span.	Tributary area A for one-way slabs, for use in reduction calculation, cannot exceed the slab span times 0.5 times the slab span.	No rule	This takes into account the lower redundancy of (possibility of load redistribution in) one-way slabs compared to two-way slabs.
5	Live loads greater than 100 psf cannot be reduced, except that live loads for members supporting two or more floors may be reduced by as much as 20 percent (plus one more exception).			In storage-type applications with heavier live loads, several adjacent floor panels may be fully loaded.
6	Live loads in passenger vehicle garages cannot be reduced, except that live loads for members supporting two or more floors may be reduced by as much as 20 percent.			Passenger vehicle garage decks often are fully loaded.
7	Live loads of 100 psf, or on areas where fixed seats are located, cannot be reduced in Group A occupancies.	Live loads cannot be reduced in Group A occupancies.	Live loads of 100 psf or more on areas of roofs classified as Group A occupancies shall not be reduced.	Because of large concentrations of people in Group A occupancies, it is likely that the entire area under consideration will be fully loaded.

There are changes in the live load reduction provisions between the 2006 IBC and the 2009 IBC, the most significant of which can be summarized as follows:

Table 1607.9.1 Live load element factor, K_{LL} — the live load reduction provisions are revised to align with similar provisions in ASCE 7-05 Section 4.8. “One-way slabs” is added to IBC Table 1607.9.1 to make it consistent with Table 4-2 of ASCE 7-05. In the 2006 IBC, Section 1607.9.1.4 prohibited live load reduction on one-way slabs, except for certain heavy live load scenarios. The 2009 IBC permits the reduction of live loads on one-way slabs using Equation 16-24 with a K_{LL} value of 1. However, new 2009 IBC Section 1607.9.1.1 imposes a restriction on the value of the tributary area, A_T, of a one-way slab that can be used in Equation 16-24. The restriction is the same as that found in ASCE 7-05 Section 4.8.5.

Section 1607.9.1.4 Group A Occupancies — 2009 IBC Section 1607.9.1.4 now refers to Group A occupancies instead of assembly occupancies, as was done in 2006 IBC Section 1607.9.1.3, in order to clearly define the scope of the provision. Because there are public assembly uses with occupant loads less than 50 and categorized as Group B that do not warrant the prohibition, specifying Group A occupancy unambiguously applies the provision only where it is applicable. The scope of this provision now is restricted even further by applying it to live loads of 100 pounds per square foot (psf) only, instead of the 2006 IBC requirement of 100 psf *or less*. The only exception to this is an area where fixed seats are located. Even though the live load for fixed seats in an assembly area is 60 psf (Item 4 in Table 1607.1), it was judged that the areas with fixed seats also warrant this prohibition.

Section 1607.9.2 Alternate floor live load reductions — a new exception is added to make the alternate floor live load reduction applicable to live loads exceeding 100 psf where the usage is not storage and a registered design professional approves such a reduction through a rational approach. This revision makes Section 1607.9.2 consistent with Section 1607.9.1.2 (2006 IBC Section 1607.9.1.1).

Section 1607.11.2.1 Flat, pitched, and curved roofs — awnings and canopies other than those of fabric construction supported by a lightweight rigid skeleton structure are now specifically included within the scope of live load reduction provision of this section. The language in Item 29 in Table 1607.1 implies that reduction is permitted for these kinds of roofs, but no clear indication was given in the 2006 IBC regarding how to carry out the reduction. It has always been the intent of the code to apply the provisions of Section 1607.11.2.1 to the above mentioned roof category. However, since "awnings and canopies" are distinctly separate from "ordinary flat, pitched, and curved roofs" in Item 29 of Table 1607.1, this intent was not automatically conveyed. This oversight now is fixed.

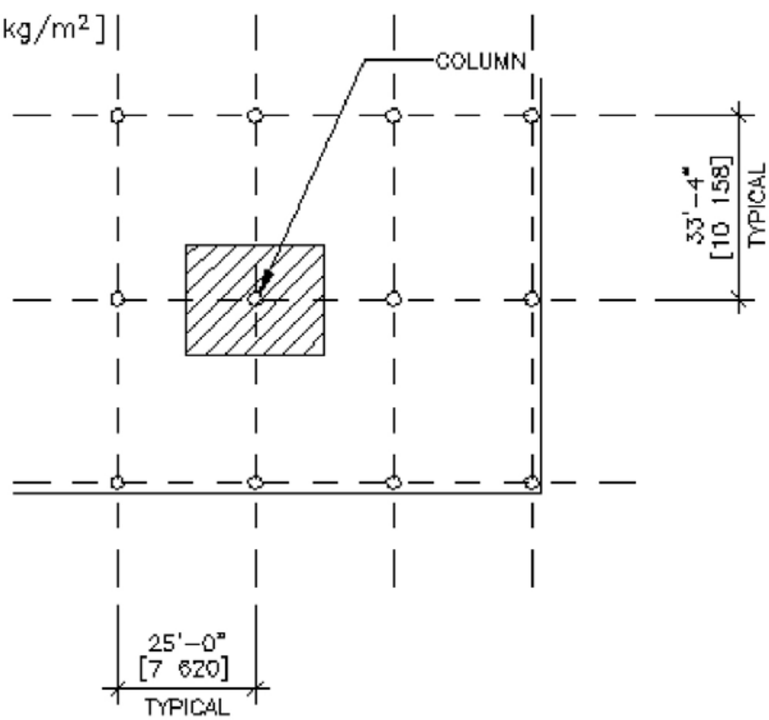
A change in the language also clearly specifies that greenhouses are just one example of the type of structures that use special scaffolding for maintenance and repair purposes. Thus, the requirement of using a minimum live load of 12 psf is not specific to greenhouses, but to all such structures.

Live Load = 80 psf [390 kg/m²]

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

K_{LL} Beam = 2.0

K_{LL} Column = 4.0



Area= (25*33'4") *80= 66,6667 lb

When considering permitted live load reductions for the column shown above, 67 kips [30 390 kg] the live load for the floor supported by the column.

Not applicable: L= 80 (0.25 +15/sqrt(4.0*25*33.3))= 80(0.25+0.259)= 33.33 kips. Possibly the problem is for public assembly.
Not applicable when:
(a) In Public assemblies (any?) Live load for assembly is 100 psf, non-reducible. Due to higher probability of people congregated in one area, think about exiting after a concert

(b) Where the Lo is < or = 100psf (any application?) Live load 100 psf or less is reducible. So, a 101 psf live load is non-reducible.

(c) Ballast mentions something about Parking garages .... when? Live load reduction is not allowed for horizontal members. 20% reduction allowed for columns.Typical parking stall is 9'-0" x 18'-0" times 40 psf (code required live load for garages) equals 6,480 lbs. Some hummers weigh more than this. In older codes the live load was 50 psf.

(d) any member supporting more than 150 SF Members supporting more than 150 sf CAN have their live load reduced. Members with area less than 150 psf are not allowed a live load reduction.

1. water-to-cement ratio
2. increase the bearing area
3. Strength and workability
4. formwork is prohibitively expensive
5. continuous wall footings
6. 57.3 in^3 [cm^3]
7. 67 kips [30 390 kg]
8. 16 sf [1.5 m^2]
9. Bending forces in the vertical members
10. 28
11. Creep
12. compensate for deflection
13. 2.0 in [50 mm]
14. Limit the number of visitors in spaces to the available live load.
15. 1 1/2 in [37 mm]
16. 33 percent
17. Gypsum shaft wall
18. Parking
19. A building with a symmetrical square plan
20. Hinged frames
21. The system must amplify ground accelerations.
22. frame in which diagonal members are connected to a beam a short distance from the column joint
23. 2.50 k [11.25 kN]
24. Four-story
25. 6t
26. A, C, D, E
27. liquefiable soils
28. L/600
29. Architect
30. Steel, reinforced concrete, reinforced masonry, wood
31. 4.2
32. a lack of vertical reinforcement
33. Ground shaking
34. The structure has redundancy.
35. Wind forces
36. A, B, F
37. C
38. B, C

Concrete Lecture

Even though the CSI codes do not breakdown concrete work any further into footing/foundation/slabs etc, we will break it down further for the assignement.

Rebar

- #3 = .376 lb/lf
- #4 = .668 lb/lf
- #5 = 1.043 lb/lf
- #6 = 1.502 lb/lf
- #7 = 2.044 lb/lf
- #8 = 2.670 lb/lf
- #9 = 3.400 lb/lf

Rebar Diameter in inches = Rebar Size /8 (For bar sizes 8 and smaller. For larger bars reference a table for the exact diameter.)
IE #4 Bar / 8 = 1/2" diameter

Lap

Suppose that you have 100' of footings with 2 runs of #4 rebar. The overlap is 30 bar diameter and the rebar comes in 20'pieces. What is the total LBs of rebar for this footing?
First draw a picture of what the problem looks like that you are trying to solve.

_____ _____ _____
------ ----- ---

The general formula to calculate lbs of rebar is :
(Total LF + Laps)* # of runs of Rebar * conversion factor to lbs

<u>Laps</u>
To find out how much the laps add, take the <u>number of laps</u> * <u>length of a lap</u>.

The <u>number of laps</u>= total LF / length of the rebar pieces. 100'/20' = 5 laps

The <u>length of the lap</u> = Bar Diameter lap * (Rebar Size/8) /12 =
30 * (4/8) /12 = 1.25'

LBS of rebar = (100 + (5 *1.25)) * 2 * .668 = 141.95 lbs

The length of the lap is often given in the Structural Notes. Sometimes, you may need to dig for the lap length. The following is an example of how to find the lap length when it is not given easily in the structural notes.

First, in the Structual Notes on S-01 the following is given under Rebar Lap.

LAP SPLICES IN CONCRETE:

UNLESS NOTED OTHERWISE, LAP SPLICES IN CONCRETE SHALL BE PER TYPICAL REINFORCING BAR SPLICE DETAIL. LAPS IN WELDED WIRE FABRIC SHALL BE MADE SO THAT THE OVERLAP MEASURED BETWEEN OUTERMOST CROSS WIRES OF EACH FABRIC SHEET IS NOT LESS THAN THE SPACING OF CROSS WIRES PLUS 2 INCHES.

Now the Typical Reinforcing Bar Splice Detail needs to be found. It is found on Sheet S-03, which is still part of the Structural Notes pages.

TENSION BARS f'c = 2,500 PSI, NORMAL WEIGHT

BAR SIZE	TOP BARS GR 40 NOTE 1	TOP BARS GR 40 NOTE 2	TOP BARS GR 60 NOTE 1	TOP BARS GR 60 NOTE 2	OTHER BARS GR 40 NOTE 1	OTHER BARS GR 40 NOTE 2	OTHER BARS GR 60 NOTE 1	OTHER BARS GR 60 NOTE 2
#3	20	20	23	23	16	16	18	18
#4	22	20	33	31	17	16	25	24
#5	34	27	51	41	26	21	39	31
#6	47	39	72	58	36	30	55	44

TENSION BARS f'c ≥ 3,000 PSI, NORMAL WEIGHT

BAR SIZE	TOP BARS GR 40 NOTE 1	TOP BARS GR 40 NOTE 2	TOP BARS GR 60 NOTE 1	TOP BARS GR 60 NOTE 2	OTHER BARS GR 40 NOTE 1	OTHER BARS GR 40 NOTE 2	OTHER BARS GR 60 NOTE 1	OTHER BARS GR 60 NOTE 2
#3	20	20	21	21	16	16	16	16
#4	20	20	30	28	16	16	23	22
#5	31	25	46	37	24	19	36	29
#6	43	35	65	52	33	27	50	40

COMPRESSION BARS f'c = ALL

BAR SIZE	OPEN	ENCLOSED WITH TIES
#3	12	12
#4	15	13
#5	19	16
#6	23	19

NOTES:

1. CENTER-TO-CENTER SPACING OF REINFORCING = < 3db.
2. CENTER-TO-CENTER SPACING OF REINFORCING = > 3db.
3. TOP BARS ARE HORIZONTAL BARS WITH MORE THAN 12 INCHES OF CONCRETE CAST BELOW THE BARS.
4. UNLESS NOTED OTHERWISE, LAP SPLICE IN CONCRETE BEAMS, SLABS, WALLS, STEM WALLS AND FOOTINGS SHALL BE TENSION LAP SPLICES AND LAP SPLICES IN CONCRETE COLUMNS SHALL BE COMPRESSION LAP SPLIC
5. LAP SPLICES SHOWN IN SCHEDULE ARE IN INCHES.
6. db = NOMINAL BAR DIAMETER.
7. < MEANS LESS THAN, < MEANS LESS THAN OR EQUAL TO, > MEANS GREATER THAN, > MEANS GREATER THAN OR EQUAL TO.
8. CONCRETE COLUMN DOWEL EMBEDMENT SHALL BE A STANDARD COMPRESSION DOWEL EMBEDMENT LENGTH ACCORDING TO THE LATEST EDITION OF ACI 318.

CONVE

21 MINIMUM REINFORCING BAR SPLICE LENGTHS IN CONCRETE

FILE: 103-01A TYPICAL DETAIL

From the above tables, first analyze are the bars in Tension or Compression. Footings are in Tension. Then, what is the PSI of concrete being used.

To find the PSI of concrete, refer back to sheet S-01, and the following is found.

STEEL REINFORCING:

TYPICAL REINFORCING BAR STRENGTHS	
#4 OR LARGER	ASTM A615 (GR60) DEFORMED
#3 OR SMALLER	ASTM A615 (GR40) DEFORMED
REINFORCING TO BE WELDED	ASTM A706 (GR60) LOW ALLOY, DEFORMED
WELDED WIRE FABRIC	ASTM A185, WIRE PER ASTM A82

Since the rebar is larger than #4, grade 60 rebar is to be used. Now refer back to the Typical Reinforcing Bar Splice Detail and use the Notes in the detail to determine the length of the lap.

Footings

Types of footings
Spread / Spot
Continuous
Grade Beams
Mat / Raft
Forming (SFCA)
Forming materials

- 2 x Lumber
- Plywood
- Symons
- Gang
- Slip

IBC Sections 1607.9 (floors) and 1607.11 (roofs) allow live loads set forth in IBC Table 1607.1 to be reduced. Live loads are permitted to be reduced because, for the most part, the likelihood that the entirety of a given floor or roof area will be fully loaded with the design live loads is low. There are many rules set forth in the code for when, and by how much, live loads may be reduced. See the table below to clearly understand these rules and why they are necessary.

Rule	Reduction of Floor Live Loads		Reduction of Roof Live Loads	Reason
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3	Reduction cannot be more than 60 percent for elements that support loads of two or more floors. for vertical members.	Reduction cannot exceed 60 percent or 23.1 (1 + D/L0) percent	20 psf of roof live load may not be reduced to less than 12 psf.	This ensures that a vertical structural member, such as a column or wall, will be designed for a minimum live load.
4	AT for one-way slabs, for use in reduction calculation, cannot exceed the slab span times a width of 1.5 times the slab span.	Tributary area A for one-way slabs, for use in reduction calculation, cannot exceed the slab span times 0.5 times the slab span.	No rule	This takes into account the lower redundancy of (possibility of load redistribution in) one-way slabs compared to two-way slabs.
5	Live loads greater than 100 psf cannot be reduced, except that live loads for members supporting two or more floors may be reduced by as much as 20 percent (plus one more exception).			In storage-type applications with heavier live loads, several adjacent floor panels may be fully loaded.
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7	Live loads of 100 psf, or on areas where fixed seats are located, cannot be reduced in Group A occupancies.	Live loads cannot be reduced in Group A occupancies.	Live loads of 100 psf or more on areas of roofs classified as Group A occupancies shall not be reduced.	Because of large concentrations of people in Group A occupancies, it is likely that the entire area under consideration will be fully loaded.

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Section 1607.9.1.4 Group A Occupancies — 2009 IBC Section 1607.9.1.4 now refers to Group A occupancies instead of assembly occupancies, as was done in 2006 IBC Section 1607.9.1.3, in order to clearly define the scope of the provision. Because there are public assembly uses with occupant loads less than 50 and categorized as Group B that do not warrant the prohibition, specifying Group A occupancy unambiguously applies the provision only where it is applicable. The scope of this provision now is restricted even further by applying it to live loads of 100 pounds per square foot (psf) only, instead of the 2006 IBC requirement of 100 psf *or less*. The only exception to this is an area where fixed seats are located. Even though the live load for fixed seats in an assembly area is 60 psf (Item 4 in Table 1607.1), it was judged that the areas with fixed seats also warrant this prohibition.

Section 1607.9.2 Alternate floor live load reductions — a new exception is added to make the alternate floor live load reduction applicable to live loads exceeding 100 psf where the usage is not storage and a registered design professional approves such a reduction through a rational approach. This revision makes Section 1607.9.2 consistent with Section 1607.9.1.2 (2006 IBC Section 1607.9.1.1).

Section 1607.11.2.1 Flat, pitched, and curved roofs — awnings and canopies other than those of fabric construction supported by a lightweight rigid skeleton structure are now specifically included within the scope of live load reduction provision of this section. The language in Item 29 in Table 1607.1 implies that reduction is permitted for these kinds of roofs, but no clear indication was given in the 2006 IBC regarding how to carry out the reduction. It has always been the intent of the code to apply the provisions of Section 1607.11.2.1 to the above mentioned roof category. However, since “awnings and canopies” are distinctly separate from “ordinary flat, pitched, and curved roofs” in Item 29 of Table 1607.1, this intent was not automatically conveyed. This oversight now is fixed.

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TRANSFER FORMULA

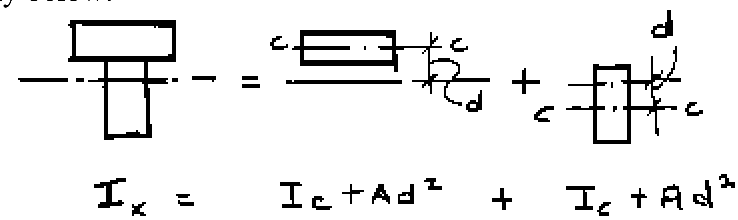
There are many built-up sections in which the component parts are not symmetrically distributed about the centroidal axis. The easiest way to determine the moment of inertia of such a section is to find the moment of inertia of the component parts about their own centroidal axis and then apply the transfer formula. The **transfer formula** transfers the moment of inertia of a section or area from its own centroidal axis to another parallel axis. It is known from calculus to be:

$$\mathbf{I_x = I_c + (A)d^2}$$

Where:

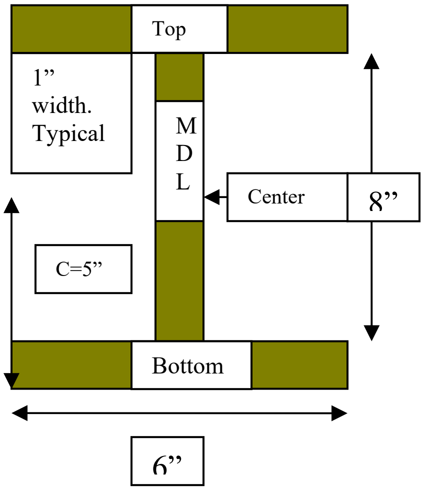
- $\mathbf{I_x}$ = moment of inertia about axis x-x (in^4)
- $\mathbf{I_c}$ = moment of inertia about the centroidal axis c-c parallel to x-x (in^4)
- **A** = area of the section (in^2)
- **d** = perpendicular distance between the parallel axes x-x and c-c (in)

Finding the moment of inertia of an asymmetric built-up cross-section is simplified to the procedure shown diagrammatically below:



57.3 in3 [cm3] the section modulus for the geometric section illustrated above.

$$S = I/c$$



$I = bd^3/12$, y= distance from Centroid

Section	b	d	I	y	Area
Top	6	1	0.5	4.5	6
Middle	1	8	42.7	0.0	8
Bottom	6	1	0.5	4.5	6

$I = \Sigma I_{effective} = I_{Top} + I_{Bottom} + I_{Middle}$

$I_{effective} = I + Ay^2$

Section	I	Ay^2	$I_{effective}$
Top	0.5	121.5	122
Middle	42.7	0.0	42.7
Bottom	0.5	121.5	<u>122</u>

$I = \Sigma I_{effective} = 286.7$ $inch^4$

S=I/C= 286.75= 57.4 $inch^3$

Section modulus is a geometric property for a given cross-section used in the design of beams or flexural members. Other geometric properties used in design include area for tension, radius of gyration for compression, and moment of inertia for stiffness. Any relationship between these properties is highly dependant on the shape in question. Equations for the section moduli of common shapes are given below. There are two types of section moduli, the elastic section modulus (S) and the plastic section modulus (Z).

. SEISMIC FORCES

%28-%32 percent of scored

33. The earthquake regulations of model codes are intended to provide resistance to Ground shaking.
Not: Earth slides; Ground rupture in fault zones; Settlement

34. A structure will have a better chance of surviving an earthquake if The structure has redundancy .
Not: Principal members change section abruptly; The load-bearing members are not equally loaded; All columns and walls are discontinuous.

19. A building with a symmetrical square plan would be most appropriate for a high-rise building in a high-risk seismic zone.
Not: A building on stilts; A building with an L-shaped plan; A building with a symmetrical T-shaped plan

37. In the elevation of a multi-storied building subject to earthquake forces shown above, at which location is stress concentration most likely to be a problem?
- A
- B
- **C**
- D

26. A, C, D, E
36. A, B, F
37. C

38. B, C

Shear:

For the rigid frame structure shown, the approximate horizontal shear at the base of column 2 (assuming all column stiffnesses are equal) is 2.50 k [11.25 kN]

Base Shear - International Building Code (IBC)

The IBC addresses the probability of significant seismic ground motion by using maps of spectral response accelerations (**S_s** and **S_1**) for various geographic locations (see IBC Figures 1615(1) through 1615(10)). These mapped spectral response accelerations are combined with soil conditions and building occupancy classifications to determine Seismic Design Categories A through F for various structures. Seismic Design Category A indicates a structure that is expected to experience very minor (if any) seismic activity. Seismic Design Category F indicates a structure with very high probability of experiencing significant seismic activity.

The *equivalent static force procedure* in the International Building Code (IBC 1617.4) specifies the following formula for calculating base shear **(V)**:

Shear walls, Braced frames, and Moment-resisting frames are primary structural system that is employed to resist lateral loads.
Not: Hinged frames

Architect has primary legal responsibility for the performance of a building in an earthquake.
Not: Building code official; Structural engineer; Geotechnical consultant

All of the following are criteria for base isolation systems:

- **The system must allow lateral movement.**
- **The system must control the movement between ground and structure.**
- **Energy must be dissipated in the isolators.**

Not: The system must amplify ground accelerations.

An eccentrically braced frame (EBF) utilized to resist lateral seismic forces in a building is a frame in which diagonal members are connected to a beam a short distance from the column joint
Not: Frame in which members are subjected primarily to axial forces; frame in which members and joints are capable of resisting forces by flexure as well as along the axis of the member; braced frame whose plan location results in torsion

Base isolation in an office building is most effective for four story building heights, assuming that the areas per floor are the same
Not: One-story; Twenty-story; Forty-story

P-Δ or P-Delta

Bending forces in the vertical members best defines the P-delta effect.

Not: Lateral forces on the foundations; Horizontal forces in the roof sections; Moment forces at the joint

P delta is the result of both lateral and vertical forces acting together. Imagine a force acting on a column, it presses down and the column reacts up..

In structural engineering, the **P-Δ** or **P-Delta** effect refers to the abrupt changes in ground shear, overturning moment, and/or the axial force distribution at the base of a sufficiently tall structure or structural component when it is subject to a critical lateral displacement.

The P-Delta effect is a destabilizing moment equal to the force of gravity multiplied by the horizontal displacement a structure undergoes as a result of a lateral displacement.

To illustrate the effect, take the example of a typical statics case: in a perfectly rigid body subject only to small displacements, the effect of a gravitational or concentrated vertical load at the top of the structure is usually neglected in the computation of ground reactions. However, structures in real life are flexible and can exhibit large lateral displacements in unusual circumstances. The lateral displacements can be caused by wind or seismically induced inertial forces. Given the side displacement, the vertical loads present in the structure can adversely perturb the ground reactions. This is known as the P-Δ effect.

In some sense, the P-Delta effect is similar to the buckling load of an elastic, small-scale solid column given the boundary conditions of a free end on top and a completely restrained end at the bottom, with the exception that there may exist an invariant vertical load at the top of the column. A rod planted firmly into the ground, given a constant cross-section, can only extend so far up before it buckles under its own weight; in this case the lateral displacement for the solid is an infinitesimal quantity governed by Euler buckling.

Ductility

Steel, reinforced concrete, reinforced masonry, wood material lists provides ductility in building construction in the order of highest to lowest.
Not: Steel, reinforced masonry, reinforced concrete, wood; Wood, steel, reinforced masonry, reinforced concrete; Reinforced masonry, reinforced concrete, wood, steel

Ductility is the characteristic of a metal or another material that allows it to be drawn or rolled to be made longer without the material breaking. To get a little more technical, it is the ability of a material to undergo plastic deformation without failure. It is one of the physical properties of a material.

The ductility of steel for concrete reinforcement can be defined as an ability to achieve significant deformations without marked increase of stresses beyond the yield strength of steel. This term applies to the behavior of a construction in the conditions of nonlinear deformations, in which ductility plays an important role.

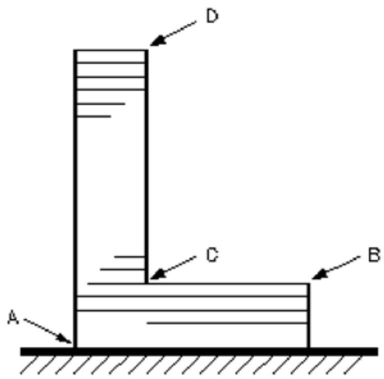
For many years there have been observed large differences between the actual durability of statically indeterminable elements of a construction and the values determined according to the principles of linear - elastic theory.

24. Base isolation in an office building is most effective for Four Story building heights, assuming that the areas per floor are the same.
Not: One-story; Twenty-story; Forty-story

33. The earthquake regulations of model codes are intended to provide resistance to Ground shaking
Not: Earth slides; Ground rupture in fault zones; Settlement

34. A structure will have a better chance of surviving an earthquake if The structure has redundancy.
Not: Principal members change section abruptly; The load-bearing members are not equally loaded; All columns and walls are discontinuous.

37. In the elevation of a multi-storied building subject to earthquake forces shown above, at "C" location is stress concentration most likely to be a problem. Not: Base A, Not Corners on building B, or D



38. A building form that is ideal for resistance to earthquake forces would be characterized by a) Symmetrical in plan and b) Heavier at the base than at the top.
Not: Symmetrical about a reentrant corner; Asymmetrical in plan; Long linear plan; Asymmetrical in elevation

30. Steel, reinforced concrete, reinforced masonry, wood material lists provides ductility in building construction in the order of highest to lowest.
Not: a) Steel, reinforced masonry, reinforced concrete, wood; b) Wood, steel, reinforced masonry, reinforced concrete; c) Reinforced masonry, reinforced concrete, wood, steel

1Stiff systems like shear walls are good because they transfer the seismic loads to the base and don't deflect as much as more flexible systems like braced frames and MRF. Deflection is tough on building materials and occupants. We do not care about building materials in seismic design. It is a given that after a code level seismic event the building gets torn down.see below

Ductility is desireable because in a ductile system energy is dissipated by the permanent distortions of the materials. Steel will deform quite considerably before it fails altogether which has the benefit of absorbing energy and warning of failure.

Also, you should be comfortable with the idea that ductility is different from flexibility.

3. WIND FORCES
%14-%17 percent of scored

A. Principles
Apply lateral force principles into the design and construction of buildings to resist wind.

1. Building Design
Analyze behavior of building structural systems when subjected to wind load, including load path, loading effects and building response, nature of wind loads on structures, and causes and characteristics of wind.

2. Building Systems and their Integration
Consider wind force resisting systems and elements including braced frames, shear walls, rigid frames, flexible and rigid membranes, and foundations to integrate into the design.

3. Implications of Design Decisions
Examine impact of design for wind forces considering cost, building configuration, building function, historic preservation, and construction schedule.

B. Materials & Technology

Analyze the impact of design decisions on the selection of systems, materials, and construction details related to wind forces.

1. Construction Details and Constructability
Examine construction details and non-structural elements pertaining to resistance to wind.

2. Construction Materials
Ascertain construction materials pertaining to resistance to wind.

C. Codes & Regulations
Incorporate building codes and other regulatory requirements related to wind forces.

1. Government and Regulatory Requirements and Permit Processes
Incorporate building and life safety codes and regulations for inclusion in design of structures for resistance to wind.

Wind

35. Wind forces **considerations in structural design are based on probability as a result of historical analysis.**
Not: Water pressures; Dead loads; Soil pressures

Wind forces in structural design are based on probability as a result of historical analysis/
Not: Water pressures; Dead loads; Soil pressures

Recommended deflection criteria due to wind loading on a brick veneer wall utilizing a metal stud back-up system is L/600
Not: L/360; L/400; L/720

4. LATERAL FORCES

%13-%16 percent of scored

A. Principles

Apply lateral forces principles to the design and construction of buildings.

1. Building Design

Analyze behavior of building structural systems when subjected to lateral loads, including load path, loading effects and building response, lateral load resisting systems, and nature of lateral loads on structures.

2. Building Systems and their Integration

Consider lateral load resisting systems and elements including braced frames, shear walls, rigid frames, flexible and rigid membranes, foundations, and retaining walls to integrate into the design.

3. Implications of Design Decisions

Assess impact of lateral loads design decisions such as cost, building configuration, building function, and construction sequencing and schedule.

B. Materials & Technology

Apply lateral forces principles to the design and construction of buildings.

1. Construction Details and Constructability

Examine construction details and non-structural elements pertaining to lateral forces.

2. Construction Materials

Select construction materials that resist lateral forces.

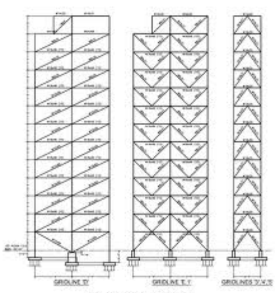
Lateral Forces

19. A building with a symmetrical square plan would be most appropriate for a high-rise building in a high-risk seismic zone.
Not: A building on stilts; A building with an L-shaped plan; A building with a symmetrical T-shaped plan

20. Hinged frames is NOT a primary structural system that is employed to resist lateral loads.
Not: Shear walls; Braced frames; Moment-resisting frames

21. All of the following a) The system must allow lateral movement; b) The system must control the movement between ground and structure; c) Energy must be dissipated in the isolators are criteria for base isolation systems EXCEPT: The system must amplify ground accelerations.

22. An eccentrically braced frame (EBF) utilized to resist lateral seismic forces in a building is a frame in which diagonal members are connected to a beam a short distance from the column joint.
Not: frame in which members are subjected primarily to axial forces; frame in which members and joints are capable of resisting forces by flexure as well as along the axis of the member; braced frame whose plan location results in torsion


BRACED BAY ELEVATIONS

Basis of Strength of Materials: Stress, strain, strength,

Stresses

Stress is the same as pressure in compression or normal (pushing perpendicular, σ), tension (pulling perpendicular, σ), or shear (parallel or tangential, τ (tau),). The force applied on surface area. The stress on an object:

$$\sigma = \frac{F}{A}$$

σ : tensile stress,

F : force on object

A: cross-sectional area of the object

$$\tau = \frac{F}{A}$$

τ = the shear stress

Strain

When the object is pulled or pushed, the object is under strain. In case of pulling, the object elongates. The level of deformation and displacement is known by strain. Strain is the change in distance of elongation by the original distance.

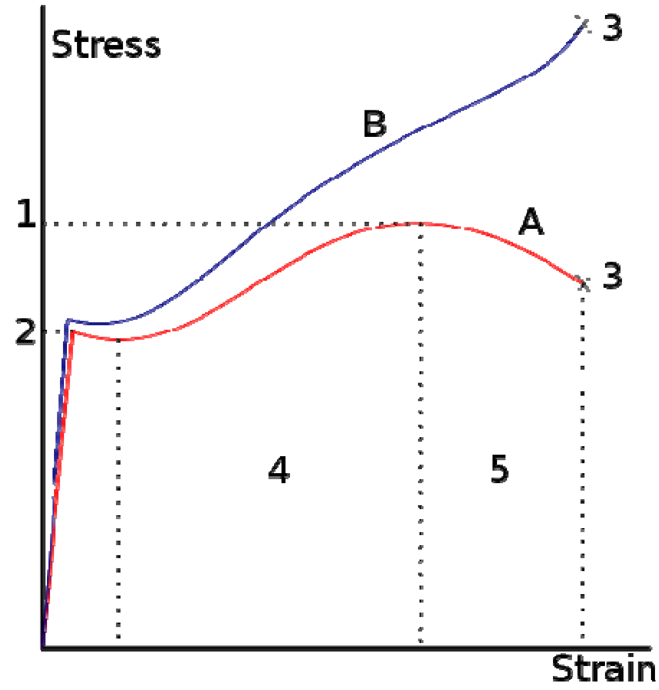
Hooke's Law- Hooke's law of elasticity is an approximation that states that the extension of a spring is in direct proportion with the load added to it as long as this load does not exceed the elastic limit, Linear elasticity.

Young's Modulus- material property that describes the stiffness of a elastic material.

$$E \equiv \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{\sigma}{\varepsilon} = \frac{F/A_0}{\Delta L/L_0} = \frac{FL_0}{A_0 \Delta L}$$

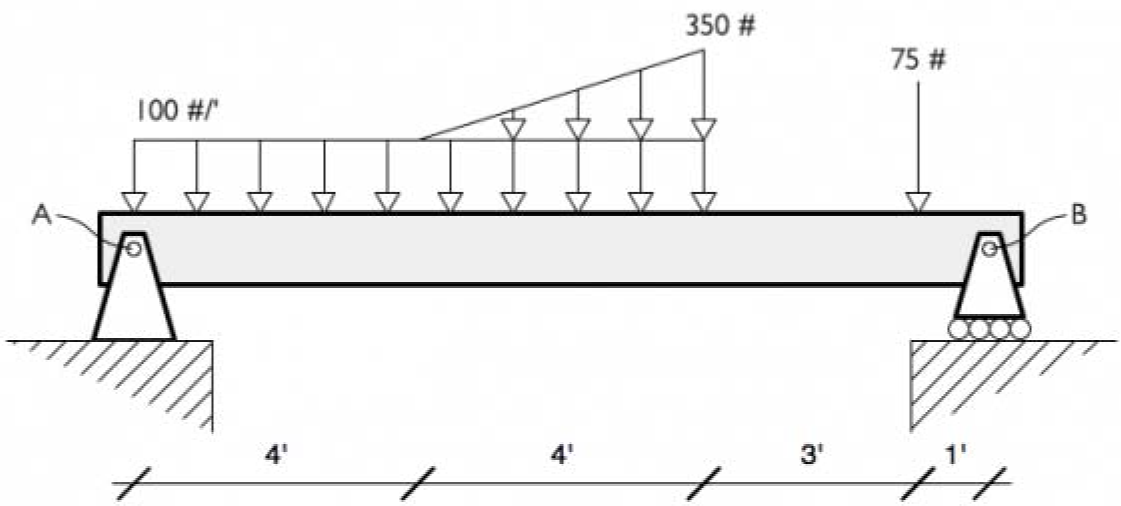
E is the Young's modulus (modulus of elasticity)
F is the force applied to the object;
A_0 is the original cross-sectional area through which the force is applied;
ΔL is the amount by which the length of the object changes;

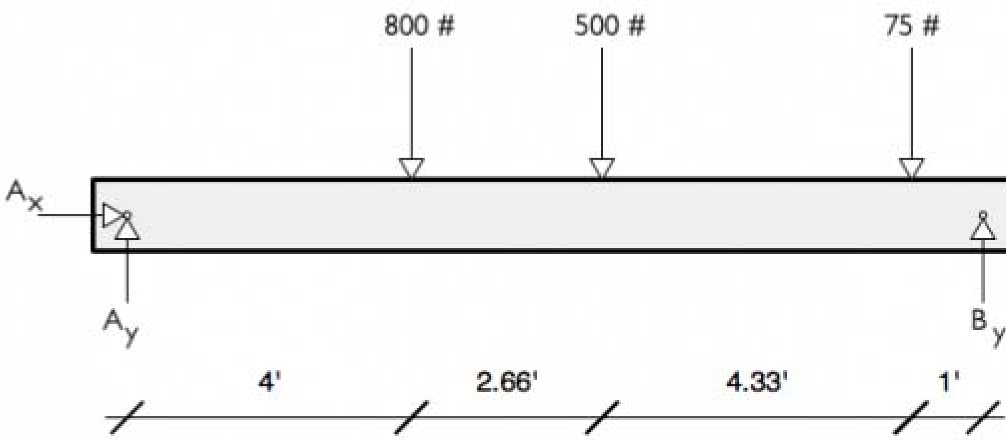
L_0 is the original length of the object.



Stress vs. Strain curve typical of structural steel
1. Ultimate Strength: The maximum stress a material can withstand when subjected to tension, compression or shearing. It is the maximum stress on the stress-strain curve.
2. Yield strength: The stress at which material strain changes from elastic deformation to plastic deformation, causing it to deform permanently.
3. Rupture
4. Strain hardening region
5. Necking region.
A: Apparent (engineering) stress- Academic
B: Actual (true) stress

Breaking strength- The stress coordinate on the stress-strain curve at the point of rupture.


350 #
75 #
100 #/'
A
B
4'
4'
3'
1'


800 #
500 #
75 #
A_x
A_y
B_y
4'
2.66'
4.33'
1'

step 1

100 #/' x 8' = 800#

1/2 (250#/' x 4') = 500#

step 2

Σ Ma= 0
By (12') - 800 (4') - 500 (6.66') - 75 (11') =0
By = 338.2

step 3

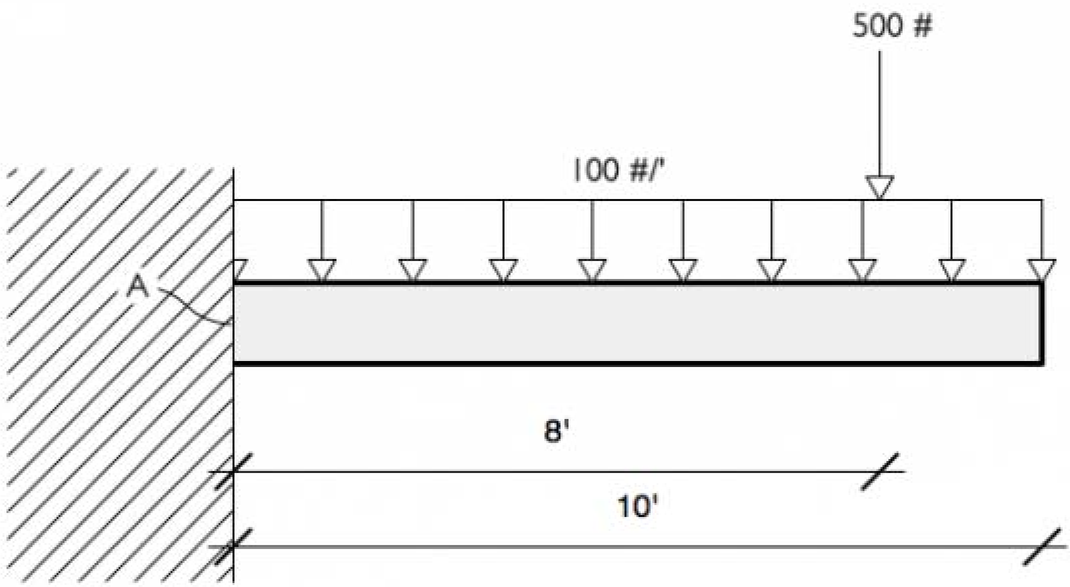
Σ Fy= 0
Ay + By - 800# - 500# -75# = 0
Ay =1037 #

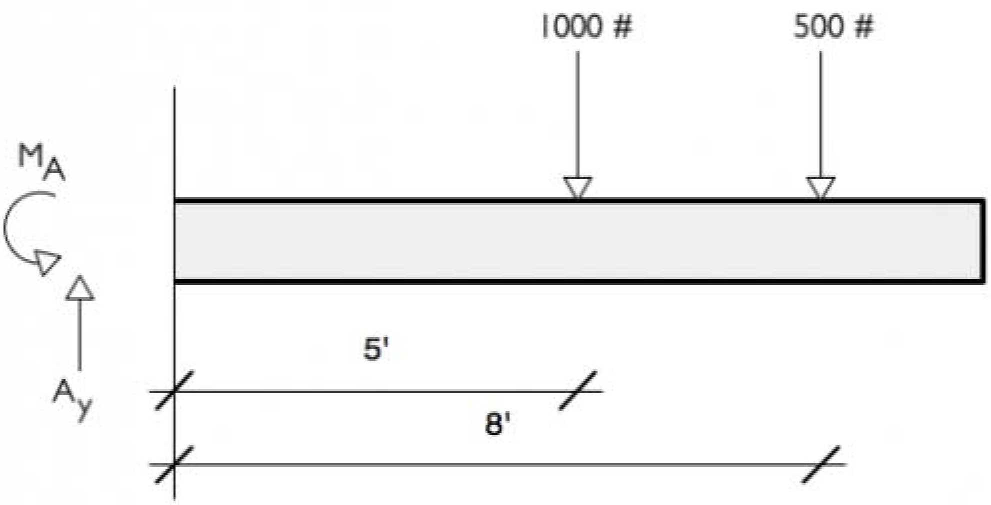
step 4

Σ Fx= 0
Ax = 0

Example Problem:

Find forces at point A on beam.


500 #
100 #/'
A
8'
10'


1000 #
500 #
M_A
A_y
5'
8'

step 1

$\sum Fy = 0$

Ay - 1000# -500# =0

Ay = 1500#

step 2

$\sum M = 0$

- Ma + (1000# x 5') + (500# x 8') = 0

Ma = 9000 #'

Statically Determinate vs. Indeterminate- Any problem with more than 3 unknown forces will be indeterminate (some thing to keep in the back of your mind when drawing your free body diagrams)

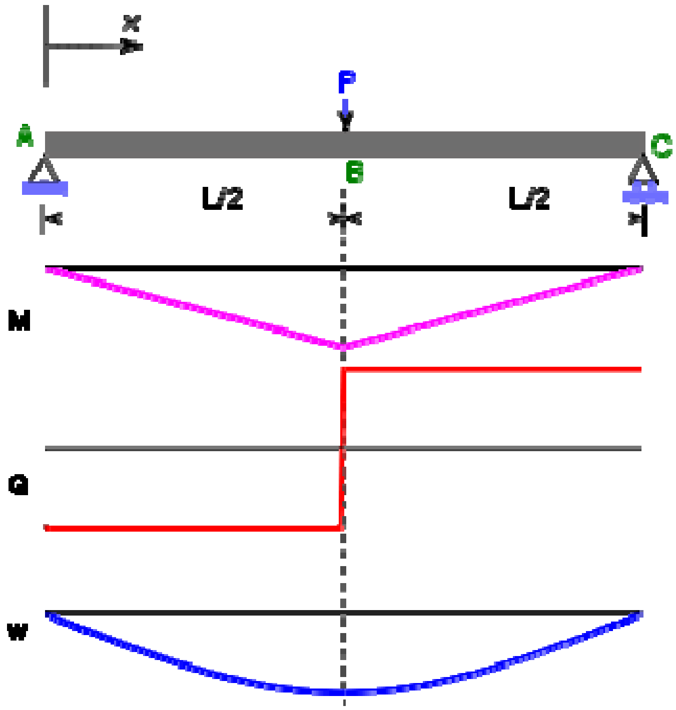
<u>Shear and Moment Diagram</u>

Graphically presenting the value of shear force and bending moment at a given point of an element.

- **Process**- There are three steps to constructing the shear and moment diagrams. The first is to construct a loading diagram, the second is to calculate the shear force and the bending moment as a function of the position of the beam, and the third is to draw the shear and moment diagrams.

1. **Loading Diagram**- shows all loads applied to the beam
2. **Calculating Shear and Moment**- to find the value of the shear force and moment at any given point along the element
3. **Draw the Shear and Moment Diagram**- shear diagram is drawn directly below the loading diagram with the moment diagram drawn directly beneath the shear diagram. This is to show particular points on the shear and moment diagrams line up with the different loadings that the member is subjected to.

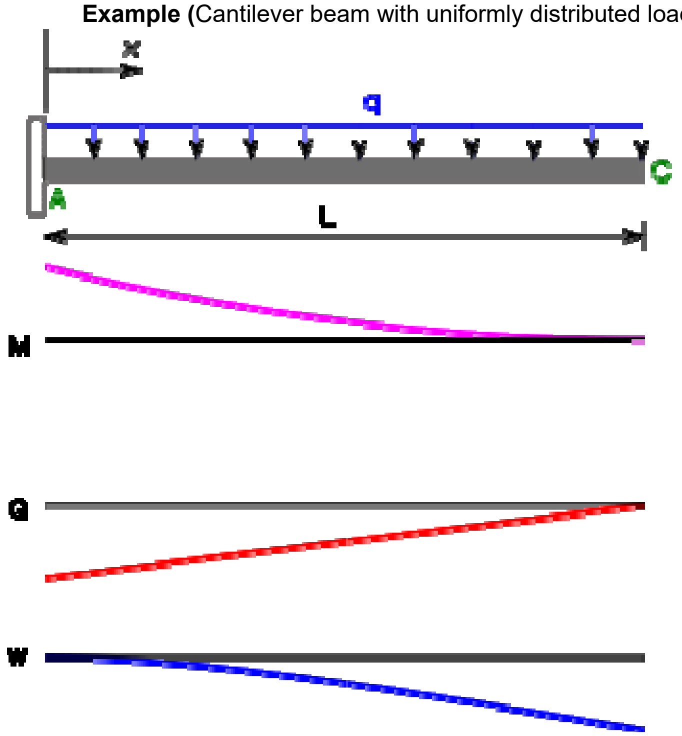
- **Example** (Simply supported beam with central load). M as moment, Q as shear, and W depicting deflection.



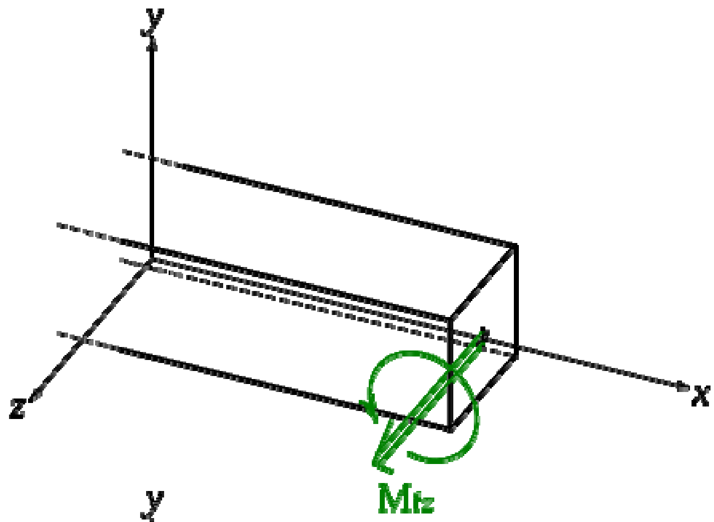
- **Misc Tips on Diagram**

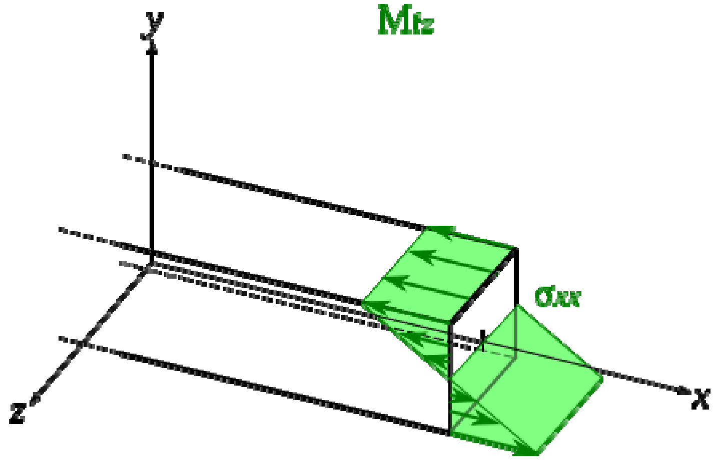
1. Uniform loads create a straight line (uniform slope) in Shear
2. The same Uniform load then creates a curve in Moment
3. Shear stress always peaks at support locations, this in turn is also where Moment is at its minimum
4. When Shear stress is at zero, Moment is at its peak

- **Example (**Cantilever beam with uniformly distributed load)



Bending Stress





The formula for determining the bending stress (flexure) in a beam under simple bending is

$$\sigma = \frac{M\,y}{I_x}$$

σ is the bending stress

M – the moment about the neutral axis

y – the perpendicular distance to the neutral axis

Ix – the second moment of area about the neutral axis x

b – the width of the section being analyzed

h – the depth of the section being analyzed

Column

is a vertical structural element that transmits, through compression, the weight of the structure above to other structural elements below.

Support- Similar to beam, typical examples use pin, roller and fixed supports. See Beam Supports (abv) for conditions of supports

Deformation via Axial Load- Compression or Elongation of column

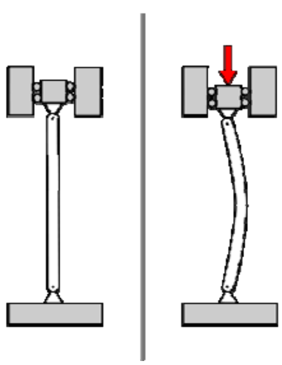
$$\Delta L = \frac{PL}{AE}$$

ΔL – deformation, changes in Length (in) caused by Axial Load (P)
P – Axial Load (#,k)
L – Initial Length (in.)
A – Cross Sectional Area (in sq)
E – Modulus of Elasticity (Psi, Ksi)

Unit Strain- For tensile strain, the elongation per unit length. For compressive strain, the shortening per unit length.

$$\text{Unit Strain} = \frac{\Delta L}{L}$$

Buckling- is a failure mode characterized by a sudden failure of a structural member subjected to high compressive stresses, where the actual compressive stress at the point of failure is less than the ultimate compressive stresses that the material is capable of withstanding.

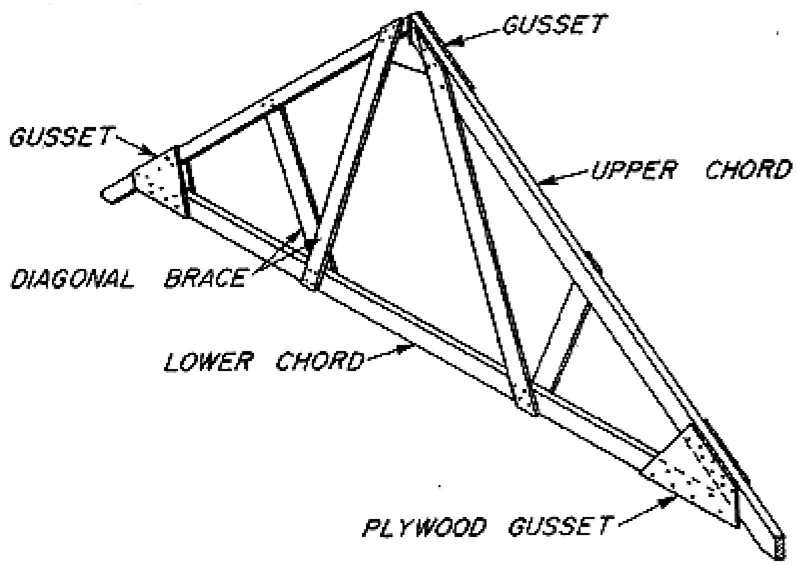


Walls

Load Bearing Wall- wall structure that carries the load of the roof towards the foundation. Without this wall, the roof collapses. The forces are transmitted from roof to foundation. The wall is under continuous gravity load. Any modification must be engineering.
Non Load Bearing Wall- Curtain wall or a partition or sound wall is only to partition rooms and create the space as required. The wall is still carries its own weight, possible other elements, and must be engineering for seismic or other environmental issues.
Shear Wall- These walls are intended to support against lateral forces based on wind and earthquake. California being the worst earthquake and Florida with hurricanes become such candidates. The footings as well as 1/2 of the tributary walls and roof and all equipment on roof are subjects to these forces. ASCE 05 is the primary documentation addressing these issues.

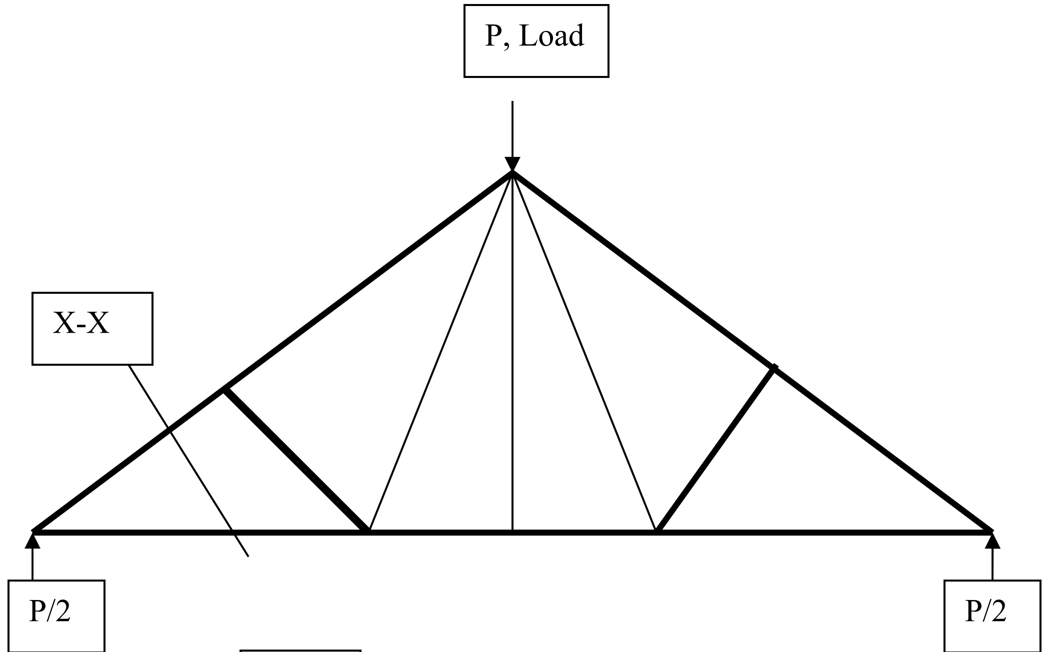
Trusses

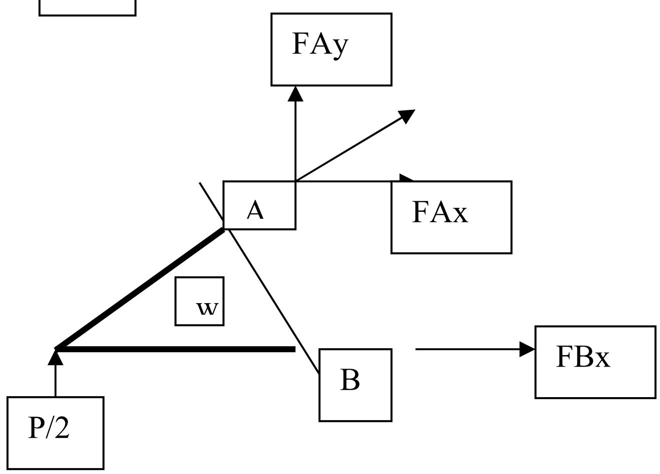
Trusses are used commonly in Steel buildings and bridges. All straight members, connected together with pin joints, connected only at the ends of the members and all external forces (loads & reactions) must be applied only at the joints. A truss is a structure that consists of every member of a truss is a 2 force member and assumed to be of negligible weight (compared to loads they carry.)



Gussets provide very strong connection details for large amount of force exerted, the upper and lower chords carry the tension and compression of the frames, the diagonal braces breakdown the forces into smaller force transmissions, hence, the light weight of the truss.

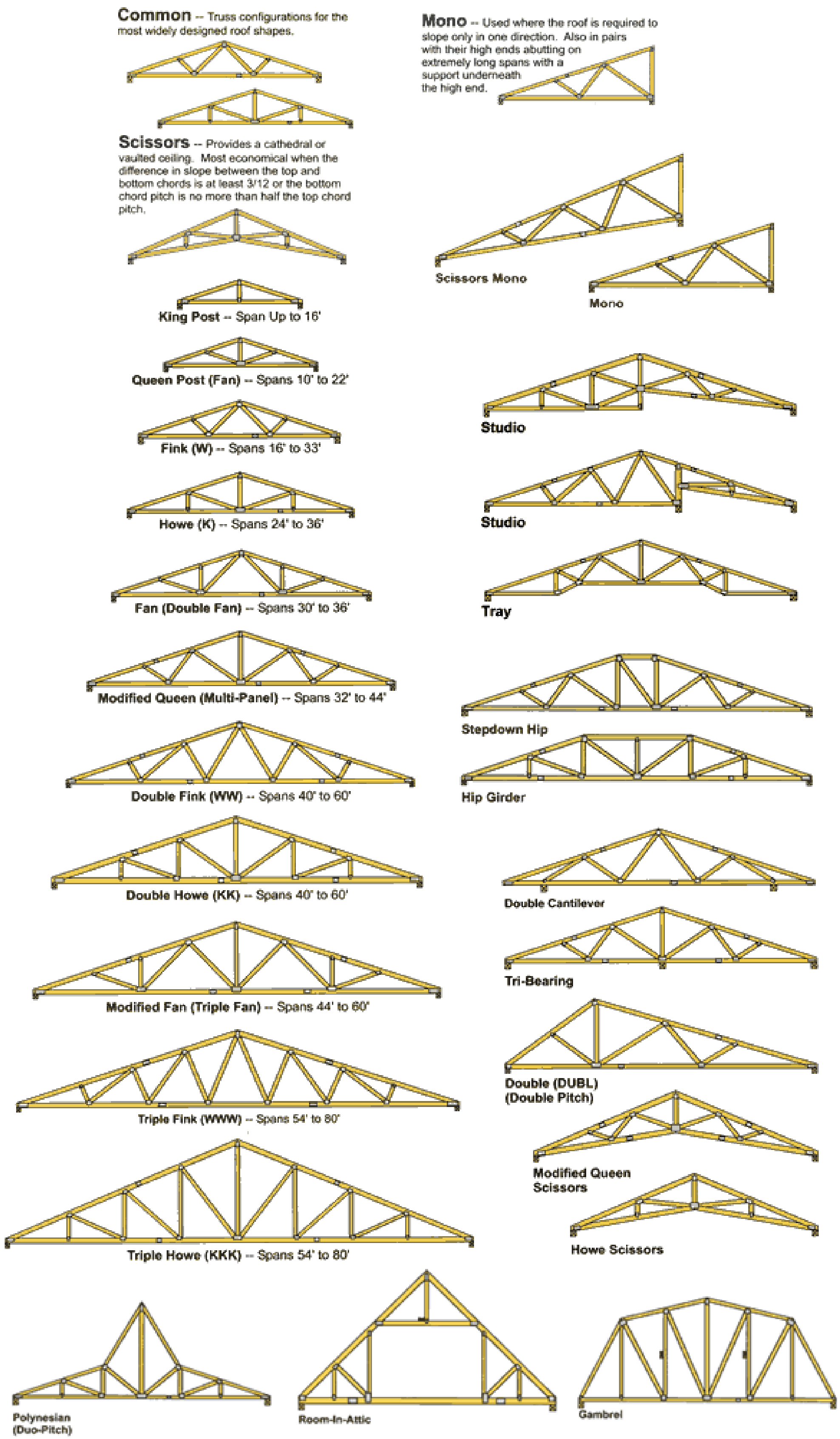
Truss Calculations is a series of vector equations that stem from the equilibrium equations. Vector sum of all forces and moment equations become foundations of finding all forces on each linkage. Of course complex trusses would become a computer driven equations. Each force on linkage determines the strength required on that member and the connections required to satisfy the stability of the bridge.





P/2 = FAy= FA sin w
FA= (P/2) sin w
FBy=0; FBx=FB
FB+FAx= FB+FA cos w=0
FB +(P/2)sin w (cos w) = 0

FB= P (sin w)(cos w)/2=0
FA=P (sin w)/2


Common -- Truss configurations for the most widely designed roof shapes.
Mono -- Used where the roof is required to slope only in one direction. Also in pairs with their high ends abutting on extremely long spans with a support underneath the high end.
Scissors -- Provides a cathedral or vaulted ceiling. Most economical when the difference in slope between the top and bottom chords is at least 3/12 or the bottom chord pitch is no more than half the top chord pitch.
Scissors Mono
Mono
King Post -- Span Up to 16'
Queen Post (Fan) -- Spans 10' to 22'
Studio
Fink (W) -- Spans 16' to 33'
Studio
Howe (K) -- Spans 24' to 36'
Fan (Double Fan) -- Spans 30' to 36'
Tray
Modified Queen (Multi-Panel) -- Spans 32' to 44'
Stepdown Hip
Double Fink (WW) -- Spans 40' to 60'
Hip Girder
Double Howe (KK) -- Spans 40' to 60'
Double Cantilever
Tri-Bearing
Modified Fan (Triple Fan) -- Spans 44' to 60'
Double (DUBL) (Double Pitch)
Triple Fink (WWW) -- Spans 54' to 80'
Modified Queen Scissors
Howe Scissors
Triple Howe (KKK) -- Spans 54' to 80'
Polynesian (Duo-Pitch)
Room-In-Attic
Gambrel

Definitions and Terms in Trusses

ADHESIVE

A substance capable of holding materials together by (sticky) surface attachment. In roof and floor Trusses the term includes cements, mucilage, and chemical and natural glues.

ALLOWABLE STRESS INCREASE

The calculated percentage increase in the stress permitted in a member, based on the length of time that the load causing the calculated stress acts on that member or assembly. The shorter the duration of the load, the higher the percent increase in allowable stress.

ANCHOR (ANCHORING)

The "tying" of a roof or wall component or system down or together to resist racking or lift. Walls can be "anchored" using foundation bolts, straps, and brackets; trusses using brackets, hangers and buckets.

APEX/PEAK

The high point on the Truss where the sloped chords meet. Same as PEAK.

ATTIC SCUTTLE

Framed in the field opening, most often with removable cover, providing access up into the attic.

AXIAL FORCE

The internal force compression or tension, acting along the length of each member. Axial Force is normally expressed in pounds or similar metric equivalent.

BALLOON FRAMING

A continuously framed gable wall where studs form one continuous piece from the floor to the roof. In the balloon method, the gable and the wall are framed all in one piece. Most houses have a rafter set on top of the wall to form the gable, and this is not a preferred method for wind resistance.

BEARING

Structural support, usually a wall, girder or beam, that is specified by the building designer to transmit Truss reaction loads downward to the building foundation. Point of Bearing, normally occurs at the top and/or bottom chord of the Truss.

BEARING AREA

The area, normally expressed in square inches, of the Truss member that is resting on the support.

BENDING MOMENT

The measure of the bending effect on a structural member due to forces acting perpendicular to the length of that member. The bending moment at a given point along a member equals the sum of all perpendicular forces, to either side of that point, times their corresponding distances from the point..

BOB-TAIL

A term used to describe a gable shaped Truss that is clipped at the end.

BOTTOM CHORD UPSET

Same as BUTT CUT

BOTTOM CHORD

A horizontal or inclined (scissors Truss) member that establishes the bottom edge of a Truss, usually carrying combined tension and bending stresses.

BOTTOM CHORD BEARING

Term used to describe the bearing condition of a parallel chord Truss that bears on its bottom chord.

BRIDGING

Wood or metal members that are fastened between Trusses and/or joists in an angled position, usually from the top on one to bottom of the next in a crisscross format, intended to spread and even the loading.

BIRDSMOUTH CUT

An angular notch on the bottom side at the end of a member to allow for an overhang past the outside of the wall onto which it is bearing.

BUILDING DESIGNER

Registered architect or registered engineer who is responsible for the technical design of the building.

BUILT-UP BEAM

A single unit composed of two wooden members having the same thickness, but not necessarily the same depth, which is designed to provide greater load-carrying capability as well as lower deflection.

BUILT-UP ROOF

Roofing composed of three to five layers of asphalt (normally installed on a level or near level roof.)

BUTT CUT

Slight vertical cut at outside edge of Truss bottom chord to ensure uniform nominal span and tight joints.

BUTT JOINT

The interface at which the ends of two members or other members meet in a square cut joint.

CAD

Computer **A**ided **D**esign and drafting.

CAMBER

An upward curvature built into a Truss to compensate for deflection due to future loading conditions.

CANTILEVER

The part of a Truss that extends beyond its point of bearing/support, exclusive of overhang.

CENTER LINE SPAN

Theoretical span sometimes used to design Trusses.

CLEAR SPAN

Indicates the inside (interior) support/bearing-to-support/bearing dimensions. The unsupported horizontal distance between the inside edges of any two adjacent Truss supports. Not to be confused with SPAN.

CLINCHED NAIL

A nail selected and applied to be abnormally longer than the member that it is driven through and which is then bent back into the dimension of its excess length to strengthen the point of fastening.

CLIPPED (Clipped End)

Same as STUB or STUBBED TRUSS.

COLLAR BEAM

Wooden member connecting opposite roof rafters, often to resist lateral separation forces.

COLLAR TIE

A horizontal member placed between two rafters at a specific vertical distance above the very top plate line for the purpose of limiting outward thrust of the rafters.

COMMON TRUSS

An engineered component shaped so as to have a near equal pitch on both sides of a center peak. See the definition for TRUSS and FLOOR/FLAT TRUSS and click HERE for a detailed drawing of a common Truss.

COMPOSITE LUMBER (Structural, wood composites)

A family of materials that contain wood in whole and/or fiber form that is bound together with an adhesive as a substitute for dimension lumber.

COMPOUND CUT

A double cut made across the member width.

COMPRESSION

The force within a Truss member that has the effect of tending to apply shortening or compressing pressure that Truss member.

CONNECTOR

A mechanical device for securing two or more Trusses, components, pieces, parts, or members together, including anchors, buckets, straps, wall ties, and fasteners.

CONTRACT DOCUMENTS

Architectural and/or engineering drawings (plans), specifications, etc., used to produce a structure.

CONVENTIONAL FRAMING (Common Framing)

Framing with conventional joists, rafters and wall studs.

CREEP

Time and humidity and temperature caused deformation of a structural member(s) under constant load.

CRICKET

A ridge or drainage flume structure designed to divert roof framing. Generally found on the high sloped end of a chimney or the transition from one roof area to another.

CUTTING SHEETS (Cut Sheet)

A diagram and listing of lumber lengths and angles of cut for Truss web members and chords.

CUTTING BILL

See CUTTING SHEETS

DIRECT NAIL

To nail perpendicular to the member being nailed.

DROP TRUSS

A Truss designed to carry the same loading as other similar Trusses in a given structure, that is built to a given dimension shorter in overall height than the other Trusses in that run, designed to facilitate a double layer of roofing or other covering on the roof, while maintaining the same roof height throughout.

DRYWALL

Interior finish material sheet manufactured with gypsum (gypsum board).

FASCIA

The flat surface located at the outer end of a roof overhang or cantilever end

FEATHER CUT

A heel cut which has been made with a zero butt cut (a sawn member with a feathered edge).

FIREPLACE TRUSS

A Truss fabricated with a modified shape to allow clearance for the penetration of a chimney through the roof, whose loads are supported by a master (girder) Truss. (requires special engineering)

FLOOR/FLAT TRUSS

An engineered component shaped so as to be nearly rectangular. See the definition for TRUSS and ROOF TRUSS and click HERE for a detailed drawing of a flat Truss.

GABLE END FRAME TRUSS

A component manufactured to the profile of the mating Truss having vertical "in-plane" members fastened to the chords instead of diagonal web members. It is not a structural Truss and requires continuous support by a bearing wall or other load bearing element such as a beam along the bottom chord.

GABLE

The portion of the roof above the eave line of a double sloped (triangle shaped) roof.

GAMBREL

A roof having two slopes on each side, the lower slope usually steeper than the upper.

GIRDER

A beam of wood or steel used as the principal support of concentrated loads at points along its span.

GIRDER TRUSS

A Truss designed and engineered to carry heavy loads transmitted from other structural members bearing upon it. Often a multiple ply Truss.

HARDWARE

A computer and its peripherals (printer, plotter, etc.) other than the software.

HEADER

A conventionally framed wood girder located between stud, jack, tee, joist, rafter, or Truss openings.

HEEL JOINT

The point on a Truss where the top and bottom chords intersect.

HIP MASTER

Hip girder Truss designed to carry prefabricated roof jacks or common framing and hip corners.

HIP TRUSS

A component of a hip roof system of roof Trusses affording symmetry of architectural appearance. The eave line extends to the same level around all sides of the building eliminating the use of gable ends. Normally the off site manufacture of hip Truss parts aids in speed and quality of field construction.

HURRICANE STRAP or CLIP

Galvanized steel or stainless steel brackets, or thin metal strips used to strengthen “wood to wood” or “wood to concrete” connections. These straps may also be referred to as “hurricane clips.”

HYDRAULIC PRESS

A press consisting of a "C" clamp hydraulic cylinder; or an l-beam platen, or flat upper pressing platen, powered by hydraulic cylinders which are used to embed Truss connector plates into the wood.

INTERIOR BEARING

Term used to describe supports which are interior to two exterior supports.

JIG

The fixture which holds the Truss pieces in position until they are rigidly fastened with connectors.

JOINT

See PANEL POINT.

JOIST

A horizontal roof or floor framing member.

KICKER

Alternate expression for a Truss web member cantilever strut.

KNEE BRACE

A brace positioned between a column and Truss panel bearing points when Trusses are supported by columns lacking transverse bracing.

LADDER PANEL

Prefabricated wall panel fastened to the roof eave to create a sloped overhang.

LATERAL BRACING

Members placed and connected at right angles to a chord or web member of a Truss.

LET [the] TAILS RUN

When lumber making up the top chord of a roof Truss is not cut off to a specified length during manufacture, but rather is allowed to retain the random length of the piece of lumber used to fabricate that roof Truss. (Used for the purpose of meeting unspecified roof overhang requirements in the field.)

LEVEL RETURN

A Lumber filler placed horizontally from the end of an overhang tail returning back to the outside wall, to form a soffit that is level with the ground.

LSL - Laminated **S**trand **L**umber

LSL uses timber from logs that are not large, strong, or straight enough to be of structural value in conventional wood products and is most often made from Aspen or Yellow Poplar. 75% of the tree is used. This engineered timber product marketed under the trade name TimberStrand®, this Laminated Strand Lumber (LSL) product, can be up to 60 feet long, 8 feet wide and over 6 inches thick. Beams, headers, decking are the most popular structural applications. As a substitute for traditional framing materials, costs may be higher than dimension lumber. We have, in our opinion only, some question as to its durability and its performance when exposed to moisture. Another possible disadvantage is that it is heavier than an equivalent amount of pine. For instance, in our testing, a 2 x 6, 16 feet in length, weighed approximately 29 pounds. An LSL functional equivalent weighed approximately 43 Pounds.

LVL – Laminated **V**eneer **L**umber

An engineered wood product created by layering selected dried and graded wood veneers with waterproof adhesive into blocks of material known as billets. This product is manufactured to disperse wood's natural defects, such as knots, thus minimizing their effect on performance and stability. Before bonding, the grain of the component wood pieces making up each layer is placed at right angles to the grain of each other successive layer, adding strength and helping to prevent warpage in the finished product. These blocks are then sawn into popular lumber sizes. Marketed under the trade name Microllam®, LVL can be made with wood from smaller, faster-growing trees. Microllam products are typically available in various thicknesses and widths that can be wider in dimension that native grown lumber. LVL is also known as Structural Composite Lumber (SCL).

MEMBER

A load/stress carrying component of a roof Truss or floor (flat) Truss assembly.

MITER CUT

A single cut made at an angle to the length of a member.

MOE - Modulus **o**f **E**lasticity

An index of the stiffness of a the wood used to manufacture the Truss, applicable to the bending of a beam. Derived by measuring the elastic deformation of the wood as it is placed under stress, and then dividing the stress by the deformation..

MOMENT

A force that produces rotation of a member and commensurate bending stresses.

MPCWT - **M**etal **P**late **C**onnected **W**ood **T**russ

One of the methods used to fasten one or more members of of a Truss to others.

MSR – Machine **S**tress **R**ated

Lumber that is graded for strength by testing equipment as opposed to visually inspected and rated.

NAIL-ON PLATE

Light-gauge steel Truss connector plates with or without pre-punched holes, through which nails are driven by hand or pneumatic means into the lumber.

NAILER (Scab)

A member fastened to another member by nails for reinforcement.

NATIONAL DESIGN SPECIFICATION (NDS) FOR WOOD CONSTRUCTION

A publication of the American Forest & Paper Association (AFPA) providing an appendix of lumber sizes, grades, species and allowable stresses for each.

NATIONAL DESIGN STANDARD FOR METAL PLATE CONNECTED WOOD TRUSS CONSTRUCTION

A publication of the Truss Plate Institute (TPI), outlining design and performance standards for Trusses to be designated as an ANSI/TPI approved standard product.

NET FREE VENTILATED AREA

Area required by building codes to allow for proper ventilation in enclosed constructed spaces.

NOMINAL SPAN

Horizontal distance between outside edges of the outermost supports.

NOTCH

A vertical and crosswise horizontal cut at the end of the chord, joist or rafter. See BIRDSMOUTH CUT.

ON CENTER (O. C.)

The measurement of spacing for structural members like Trusses, studs, rafters and joists in a building, from the center of one member to the center of the next.

ON EDGE

Vertical placement of a member's wider edge.

ON THE FLAT

Horizontal placement of a member's wide edge.

OUT-TO-OUT SPAN

Same as OVERALL SPAN

OUTRIGGER

A wood member nailed to a Truss to form a roof or balcony overhang beyond the wall line.

OVERALL SPAN

Outside of frame dimensions (not outside of veneer dimensions).

OVERHANG

The extension of the top chord of a Truss beyond the outside of the bearing support.

PCT

Parallel **C**hord **T**russes such as a floor Truss. See example HERE.

P. E.

Designation abbreviation acronym for Licensed Registered **P**rofessional **E**ngineer. See typical engineered roof Truss drawing HERE.

PANEL POINT

A point at which one or more web members intersect the top and/or bottom chord.

PANEL

The chord segment defined by two adjacent joints.

PANEL LENGTH

The distance between joints measured along the center line of the chord. See COMMON TRUSS DETAILS.

PEAK/APEX

The high point on the Truss where the sloped chords meet.

PENNY

Common nail length. Originally, nails were sold by "penny weight", or price per hundred.

PIGGYBACK TRUSS

A Truss fabricated in two pieces, often consisting of a hip-profile Truss with a triangular cap fastened to be fastened to it in the field. This Truss design is mandated when shipping, manufacturing and/or architectural requirements or limitations are affected by overall Truss height.

PITCH

The incline angle of the roof/roof Truss and/or the ratio of the total rise of the roof to the total width of a given Truss system. For example, a 10 foot rise and a 30 foot total width yields a roof pitch of one third or 3 in one. Roof pitch is also known as the angle that the top chord makes with the lower chord such as a 20 pitch or a 45 pitch.

PLACING DRAWING/LAYOUT

Line drawing used to locate assumed placement positions of roof and floor Trusses by Truss fabricator.

PLUMB CUT

The end of the top chord is cut to to provide for a vertical (plumb) installation of fascia and rain gutter. The other common option is for the Truss tails to be SQUARE CUT.

PLY

The term given to one component Truss layer of a multiple-layer girder Truss.

PPSA - **P**urdue **P**lane **S**tructures **A**nalyzer

A wood structures computer program developed at Purdue University.

PRESS

A term used to describe the device used to embed Truss connector plates using compression.

PRESS-ON PLATE

A Truss connector manufactured with pre-formed teeth that are embedded by compression into the lumber, usually by an air, roller or hydraulic press.

PROFILE DRAWING

Sketches of Truss profiles used by mechanical engineer to determine where mechanical ducts, piping, etc., are to be located when installed in the finished construction.

PSL - **P**arallel **S**trand **L**umber (PSL)

Also known by the trade name Parallam®, this product is made from the fiber on the outermost edges of the log which is often wasted or used in lesser-grade wood products. This patented process produces an engineered product that can be longer, thicker and stronger than timber cut from old growth native forests. PSL lumber is suitable for beams, columns, posts.

PURLIN

A horizontal member attached perpendicular to the Truss top chord for support of the roofing (i.e., corrugated roofing or plywood and shingles).

RACKING

A misshaping of a system, component or frame caused when horizontal loads applied to vertical members displace the frame from the designed triangular of rectangular configuration.

RAFTER

A sloping or pitched member in roof framing.

RAKE

The edge of a roof at the intersection of the gable.

RAKE OVERHANG PANEL

Prefabricated overhang panel that extends over the edge of the roof and is fastened to the gable end Truss, usually in the field.

REVIEWING ENGINEER

The term used to define the Truss engineer who checks and certifies the computer generated designs (CAD) of the Truss fabricator. The reviewing engineer may be an employee experienced in the design and testing of Trusses, and assigned this responsibility by a Truss plate manufacturer. He or she may also be an independent consultant experienced in the design, testing and performance of metal plate connected Trusses, and contracted by the Truss fabricator to perform such services.

RIDGE

The horizontal roof line made by the top surfaces of two sloping roof surfaces

RIDGE VENT

A prefabricated and formed metal strip placed along the apex of the roof to allow exhaust ventilation in combination with intake soffit or gable end ventilation.

RISE

The vertical distance from the bottom of the bottom chord to bottom side of the top chord.

ROLLER PRESS

A press that embeds connector plates by forcing them through the pressure two opposing rollers.

ROOF ASSEMBLY

A system designed to provide weather protection and resistance to design loads. The system consists of a roof covering and roof deck, or a single component serving as both the roof covering and roof deck. The roof assembly includes Trusses, or roof joists, the roof deck (often plywood,) a vapor 'barrier,' a thermal barrier, insulation and roof covering to keep out the heat or cold, rain and sun.

ROOF SCUTTLE

Framed opening in commercial roofs surrounded by a hinged door used for access to a commercial roof.

ROOF SHEATHING

Most commonly, the boards or sheet material fastened to the roof Trusses of roof rafters onto which the shingle or other roof covering, weather repelling material is laid.

ROOF TRUSS

The basic components of a roof Truss are the top and bottom chords and the web members. The top chords serve as roof rafters. The bottom chords act as ceiling joists. The web members run between the top and bottom chords. The Truss parts are usually made of 2 by 4 inch or 2 by 6 inch material and are fastened together with special metal connector/nail plates.

Roof Trusses are common and are designed and produced in a variety of shapes and sizes. The most commonly used roof Trusses, are in light-frame construction and are the king-post, the W-type, and the scissors Trusses. The most simple type of Truss used in frame construction is the king-post Truss. It is mainly used for spans up to 22 feet. The most widely used Truss in light-frame construction is the W-type Truss. The W-type Truss can be placed over spans up to 50 feet. The scissors, or cathedral Truss is used for buildings with sloping ceilings. Generally, the slope of the bottom chord equals one-half the slope of the top chord. It can be placed over spans up to 50 feet. see TRUSS.

SCUPPER

Provision for roof drainage pipe or duct.

SCL - Structural **C**omposite **L**umber

See LVL, above.

SET BACK

The distance from the outside edge of a bearing wall, exclusive of any wall veneer or non-structural covering, to the face of a hip master (girder) Truss.

SHEATHING

The material, most often plywood, covering the frame, walls and roof Trusses, on the exterior.

SHOP DRAWING

A drawing of roof Trusses prepared by a Truss fabricator from stock Truss engineering drawings, used to specify and fabricate Trusses. See typical engineered roof Truss drawing HERE.

SHOULDER JOINT

Same as BREAK POINT JOINT.

SISTER TRUSS (Joist)

Sistering is the popular term for the reinforcement of a Truss or joist by bolting, nailing, or otherwise attaching alongside the existing Truss or joist, another Truss or joist or reinforcing member. The second member is referred to as the 'SISTER' component.

SLIDER

Nominal two inch dimension lumber inserted between the top and bottom chords at the heel joint in the plane of the Truss to reinforce the top or bottom chord.

SLOPE

The incline angle of the roof described in inches of rise per foot of run (e.g., 4/12).

SLOPED SOFFIT

Any sloped overhang as compared to a level soffit return .

SOFFIT VENTS

Prefabricated soffit material with perforated or slotted openings created for the purpose of providing and enhancing intake roof ventilation.

SOFFIT

The underside of a roof overhang or Truss cantilever end. A soffit is normally ventilated.

SOFT STORY

A habitable room or rooms above a living, working or storage area such as garage, carport, or other area, that was not engineered to transmit shear and lateral forces appropriately. [If supporting walls and roof systems are not designed to handle loading forces, the entire structure may fail.]

SOFTWARE

Computer programs used to create management and engineering information, etc.

SPAN

The term generally used to communicate outside-to-outside or overall span of a Truss design. Also sometimes indicates the center line to centerline of bearing.

SPLICE POINT

The point at which two chord members are joined together to form a single member. It may occur at a panel point or between panel points.

SQUARE CUT

The tail end of the top chord that is cut so as to be perpendicular to the slope of the member at 90 degrees to the length of that member (most economical construction; see PLUMB CUT.)

STACKED CHORDS

The term most often used for agricultural Trusses when two members are positioned on top of each other to create a bottom chord.

STRINGER

Lumber industry terminology for lumber graded with respect to its strength in bending when loaded on the narrow dimension face. Used for cross members in floors or ceilings.

STRONGBACK

A nominal two inch thick framing member attached in the perpendicular to floor or roof Trusses; placed vertically against the vertical Truss web.

STUB TRUSS

Same as BOB TAILED TRUSS

STUDDED GABLE

Terminology for a gable end Truss built as a wall and resembling a stud wall built in the shape of a triangle. These chords are usually on the flat.

SUBSTRATE

The surface upon which the roofing membrane is placed.

SUPPORT (TRUSS SUPPORT)

The device, fixture or area designed to receive, hold and support the weight. live load and dead load, of each of the Truss members in the system.

T-BRACE

A brace consisting of nominal two inch dimension lumber nailed directly to the member requiring a brace, and with the width of the member perpendicular to the width of the brace.

THRUST

The term used to describe outward horizontal force.

TOE NAIL

A nail driven at an angle to fasten one member to another.

TOP CHORD BEARING

The bearing condition of a parallel or sloping chord Truss that bears on its top chord extension.

TOP PLATE

Framing consisting of two members on the flat that form the top of the exterior wood bearing walls of platform frame construction. Also, a single member on the flat in non-bearing wall construction.

TOP CHORD

An inclined or horizontal member that establishes the top surface member of a Truss.

TRIMMER

A conventionally framed wall member usually consisting of fastened multiple studs in a framed wall opening, used to carry header load reaction. The trimmer is the shorter member of the fabricated unit.

TRUSS (see Roof Truss)

An engineered pre-built component, designed to carry its own weight and added superimposed design loads, that most often functions as a structural support member. A Truss, most often made of wood, employs one or more triangles in its construction. Made from dimension lumber of various sizes, the chords and webs are most often connected together by the use of toothed connector plates which transfer the tensile and shear forces. Metal connector plates are stamped from galvanized steel sheet metal of varying grades and gauge thicknesses to provide different grip values. See COMMON TRUSS DETAILS.

TRUSS CLIP

A metal component designed to provide the structural connection of roof or floor Trusses to wall plates in order to facilitate resistance to wind uplift forces.

TRUSS FRAME (Truss-Frame)

The product of the structural connection of an upper Truss to a lower Truss by its integral wall members. View a technical drawing of a typical Truss-Frame component, HERE.

TRUSS LAYOUT

A technical drawing, produced by the Truss engineer, illustrating the precise inter-relation of Truss components and their final placement location on the final structural assembly. View sample HERE.

TRUSS SYSTEM

An assemblage of floor and/or roof Trusses, and/or Truss Frame components and Truss girders, together with all bracing, connections, and other structural elements and all spatial and locational criteria, that, in combination, function to support the dead, live and wind loads applicable to the roof of a structure, with respect to a Truss system for the roof, and/or the floor of a structure with respect to a Truss system for the floor. A Truss System does not include foundations, or any other structural support system.

UPLIFT

Wind, increased in speed, moving over a structure causing negative wind pressure (suction) to be placed inside an enclosed structure, creating uplift forces (upward pull) capable of blowing off the roof. Roofs are designed to resist only certain uplift caused when high winds travel over and across the roof.

WEBS/WEBBING

The term often given to the shorter members that join the top and bottom chords of a roof or floor Truss, which form triangular patterns in that Truss, usually carrying. transmitting tension or compression stresses, and are designed to prevent bending and/or flexing.

• Steel

Steel: an alloy (combination of materials into a base metal) ; iron and minute carbon content between 0.2% and 2.1%.

Material Properties

physical properties: high strength, easy to mold and shape, does not corrode easily with water/moisture, high dimensional stability due to age and environment, low weight, durability, high strength to weight ratio, flexibility and corrosive resistance.

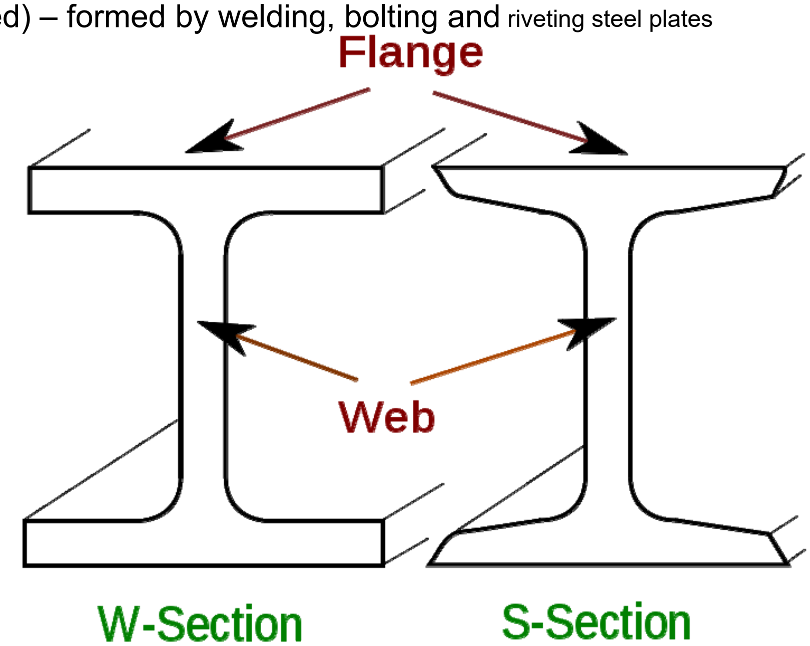
In fire with rising heat, steel lose their strength and cause failure. Encasing in fire resistive material is required.

Highly recyclable and sustainable.

Structural Uses

Beam - I-beams are widely used and are available in a variety of standard sizes. I-beams can be used both as beams (bending loads) and as columns (axial loads). It often used in combination of other material, typically concrete. There are two standard I-beam forms:

1. Rolled – formed by hot rolling, cold rolling, or extrusion. rolling is a metal forming process in which metal stock is passed through a pair of rolls
2. Plate (welded) – formed by welding, bolting and riveting steel plates



- **Beam Design –** I-Beams are excellent for unidirectional bending in a plane parallel to the web, not well in bidirectional bending. It provides little resistance to twisting and undergo sectional warping under torsional loading.

1. There are currently two types of design methodology. The oldest is the Allowable Strength Design (ASD) which is a permissible stress design method. The second, and more recent, is the Load and Resistance Factor Design (LRFD) method.

2. Beams are specified using the depth and weight of the beam. For example, a “W12x28″ beam is approximately 12 inches in depth and weighs approximately 28 lb/ft.

- **Cellular beams -**the web of which is first divided/cut into custom shapes and then re-welded which results in a beam 40-60% deeper than its parent section. The finished depth, cell diameter and cell spacing are able to be adapted to specific needs. A cellular beam could be 2.5 times stronger than its parent section. Cellular Beams requires less material while providing superior strength.

Column

Square and round tubular sections of steel can also be used, often filled with concrete. Steel Columns are still subject to buckling. Buckling is characterized by a sudden failure of a structural member subjected to high compressive stress.

• Wood

Wood: naturally grown material, many variations due to genetics and environment, cellulose fibers bound in lignin along a common axis. Because of these fibers, the mechanical properties of wood vary: grain orientation, imperfections such as knots, cracks, and pitch pocket.

Two Categories of Wood:
Softwood – construction framing: conifers, USA: Southern Yellow Pine and Douglas fir
Hardwood – deciduous and broad-leaved trees, harder use in construction, i.e. cabinetry, flooring and furniture

Defects

There are numerous influence to the deterioration of wood buildings: **Exposure** - Sunlight with surface erosion or photodegradation (sun breaks down the wood cell wall). **Moisture and Heat Cycles (weathering)** – Weathering leads to various types of degradation, including checking and splitting of wood as well as separation at the glueline of bonded wood products. **Insects and Fungi** – Insects will consume and also inhabit the wood, causing structural degradation. Fungi will cause wood to decay and breakdown again resulting in structural failure

Wood

Light-Frame Construction (balloon framing and platform framing), is a building technique based around structural members, usually called studs, which provide a stable frame to which interior and exterior wall coverings are attached, and covered by a roof comprising horizontal ceiling joists and sloping rafters. Use of minimal structural materials allows builders to enclose a large area with minimal cost.

1. **Dimensional lumber-** is a term used for lumber that is finished/planed and cut to standardized width and depth specified
2. **Composite Strength**- light-frame structures usually gain lateral stability from rigid panels (plywood and other composites such as oriented strand board (OSB) used in concert with the stud wall
3. **Stud**- vertical member within the wall framing

Lumber

or timber is the term used for wood used as structural material for construction.

- **Finished lumber –** Also known as Dimensional lumber is lumber that is finished/planed and cut to standardized width and depth specified in inches.

1. **Sizes** – Lumber is typically called out by the width and depth. Such as: 2×2, 2×6, and 4×4. This denoted the nominal dimensions <u>not</u> the actual dimensions. The length is specified separately.

example:

2×2 piece of lumber is actually 1 ½ in × 1 ½ in

- **Stress Grades** – Lumber of similar mechanical properties are placed in categories called stress grades. Indicated on boards as Grade Stamps. Lumber is either visually graded (noting knots, grain, checks, heartwood, etc) or machine graded (using a nondestructive test followed by visual grading). **example:**

Quality Standard Used – "WWPA", certification mark

Mill – "12″, Firm name, brand, or assigned mill number

Grade – "STAND", Grade name, number or abbreviation. Common produced grades are Selects, Commons and Factory lumber

Species – "D-FIR", Indicates individual species or species combinations

Seasoning – "S-DRY", Indicates condition of seasoning at time of surfacing. It is seasoned in temperature and humidity-controlled dry kilns or stacked and air-dried until the moisture content reaches the desired level, from 12 to 19 percent

Engineered Lumber

also known as composite wood, man-made wood, or manufactured board; includes a range of derivative wood products which are manufactured by binding the strands, particles, fibers, or veneers of wood, together with adhesives, to form composite materials. These products are engineered to precise design specifications which are tested to meet national or international standards

Typical Categories

- Laminated Veneer Lumber – Uses multiple layers of thin wood assembled with adhesives. They function as beams to provide support over large spans.
- Wood I-Joists – Consist of a top and bottom chord/flange made from dimensional lumber with a webbing in-between made from oriented strand board (OSB). Extremely efficient in its strength to weight and size
- Glu-lam Beams – Composed of several layers of dimensioned timber glued together. By laminating several smaller pieces of timber, a single large, strong, structural member is manufactured from smaller pieces. This eliminates the need to harvest larger, more expensive trees for larger sized beams
- Manufactured Trusses – Pre-fabricated replacement for roof rafters and ceiling joists.

Sizing a Beam

1. **to find the resisting moment of a beam -** The maximum bending moment for a beam experiencing a uniformly distributed load is $WL^2/8$.

2. **to select a beam -** Section Modulus S = M / Fb to select a beam. Find Fb from table siting species and grade
3. **use beam table** – use standardized beam table to match needs, such as American Wood Council (AWC) or National Design Standard for Wood Construction (NDSWC)

example

Wood beam with a uniformed load of 200 lb/ft with required span of 18 ft. Given Fb = 1,000 psi. Find the section modulus (area) to spec beam with.

M = WL2/8

M = 200 x (18 x 18) / 8

M = 8,100

S = M / Fb

S = 8,100 x 12 / 1,000

S = 97.2 in cubed

Wood

The strength of connections is a function of: the strength of the timber; the type and stiffness of the fastener; and the geometry of the connection (the orientation of fastener forces with respect to the grain direction).

Grain- When the fastener is driven into the **side grain** of the timber, the shear forces on the timber are either parallel to the strong direction of the wood grain or causing bending of individual wood fibers. This connection is stronger than that where the fastener is driven into the**end grain** of the timber.

Geometry of Connection

- **Thickness of components** - to ensure that there is sufficient depth
- **Spacing of fasteners** - to control the splitting forces generated by driving nails or screws into the wood
- **Edge distances** - to ensure that there is enough wood fiber adjacent to the nail or screw to prevent it from breaking out of the timber

note: Don't ever apply tension perpendicular to the grain

Fasteners and Connectors- a hardware device that mechanically joins or affixes two or more objects together.

- **Nail**- a pin-shaped, sharp object of hard metal. Nails driven into the timber spread the fibers apart. The timber fibers are not cut, so the strength of the member is not compromised. The tensile strength of the timber member therefore remains unaffected by the nailed connection. Its strength in shear is comparable to screws. In tension type connection it is far inferior

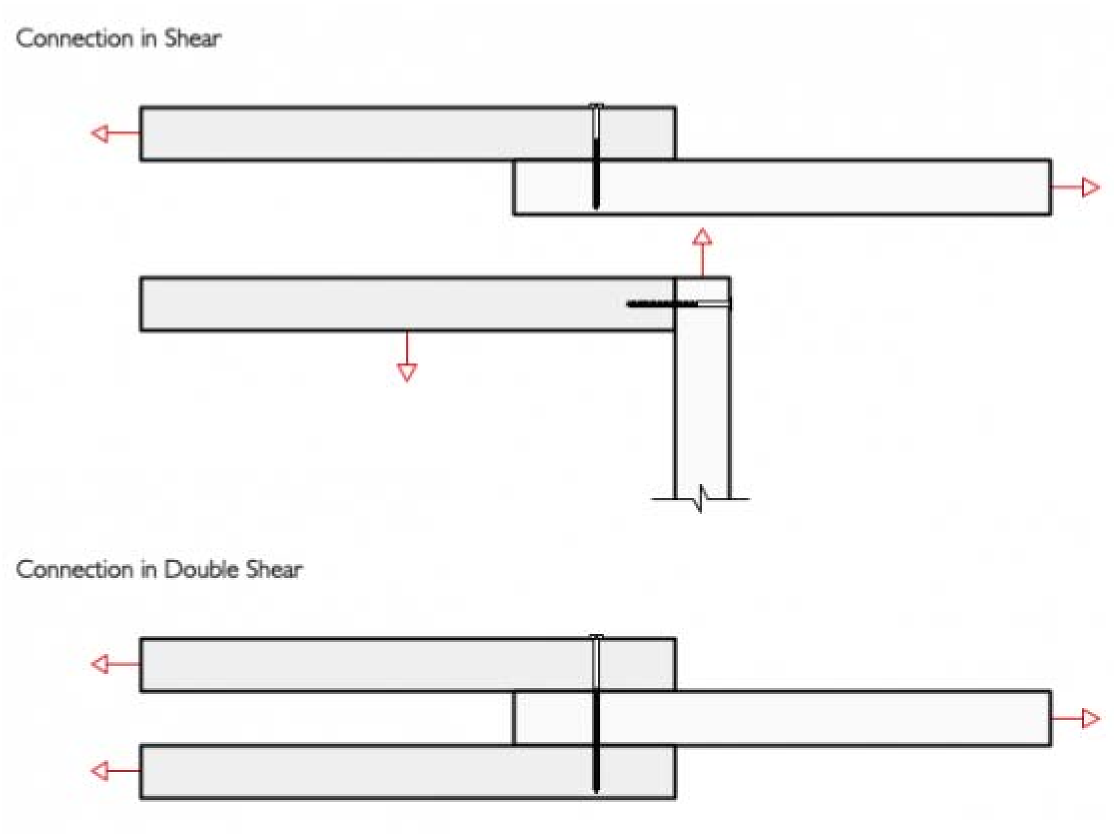
- **Screw**- fastener know by its helical ridge, thread, wrapped around a cylinder. Screws have a head, which is a specially formed section on one end of the screw that allows it to be turned, or driven. The thread cuts into the fiber structure and forms a mechanical bond with the wood. Similar to nails in shear strength, able to resist tension through connection via thread
- **Bolt**- a threaded fastener designed for insertion through holes, and is intended to be tightened or released by torquing a nut. Washers spread any axial load over a reasonable area of timber. The nut holds the connected elements together and the bolt shank gives a bearing surface to timber

• Detailing Considerations

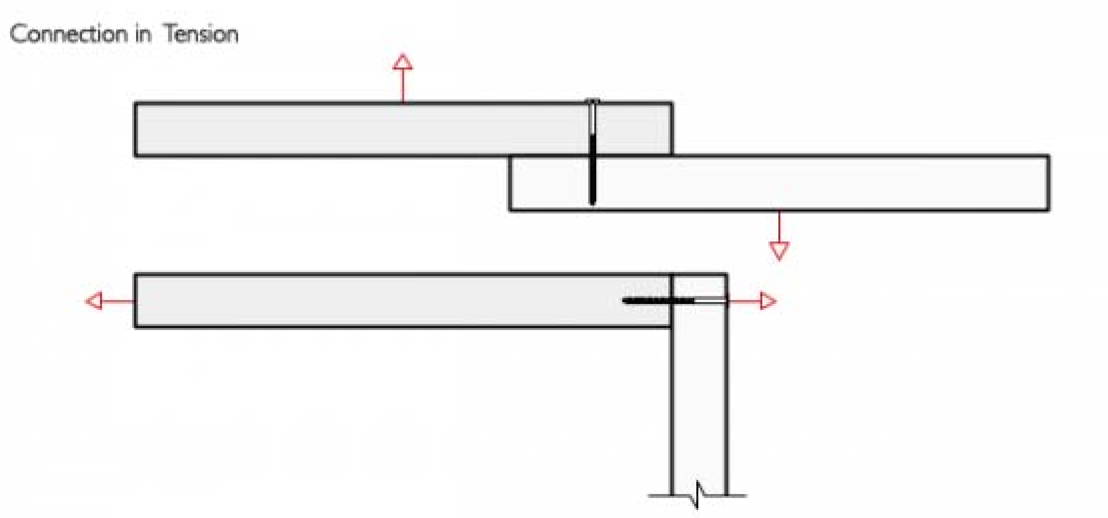
Joints or connections transfer loads within the structure from one member to another, and eventually to the foundation.

Connection Types

Connections are typically designed to resist two stress scenarios, **shear** and **tension**

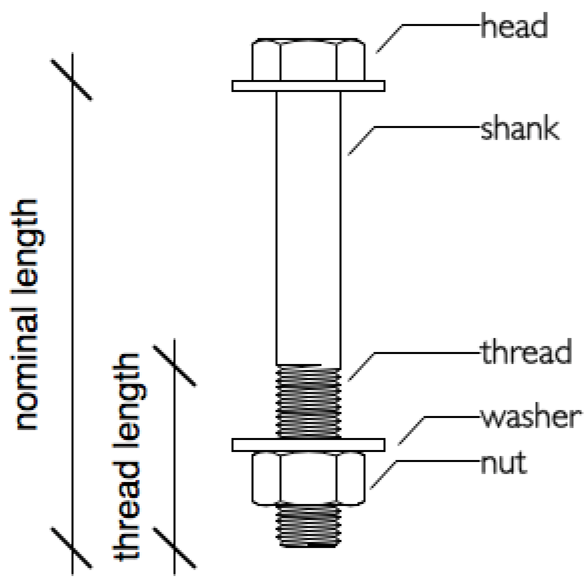


note: nails or screws in double shear will have twice the capacity of the same fasteners in single



shear

Typical Bolt

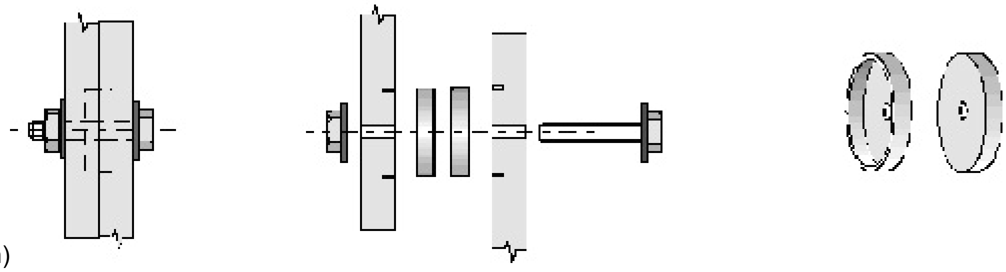


Nailed Connections	Bolted Connections
Nails part fibers - there is no discontinuity in the timber fibers	Bolts are installed into pre-drilled holes, so timber fibers are broken.
Nails are small diameter fasteners, allowing flexibility in the connection.	Bolts are large diameter fasteners and quite rigid.
The force transfer is by bearing and friction in a nailed connection.	In a bolted connection, the force transfer is by bearing only.
Nailed connections employ many small fasteners, so there is a low load per unit area.	Bolted connections use only a relatively few large fasteners, so there is a high load per unit area.
There is little stress concentration in nailed connections as the forces are distributed over a large area.	The stress concentration is higher in bolted connections as the bolts cover only a small area.

- **Specialized Hardware**

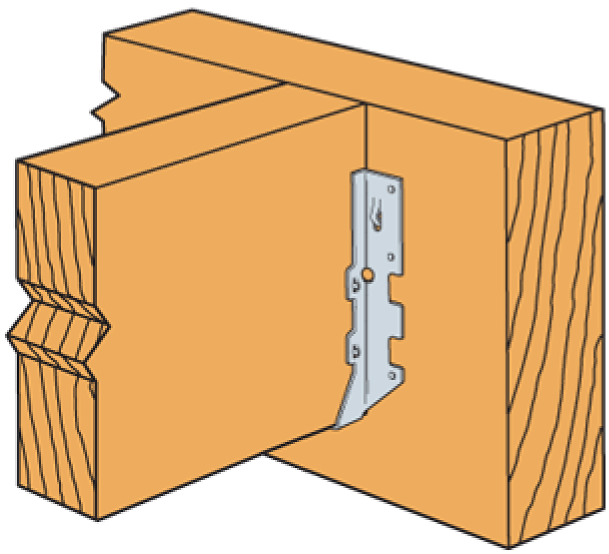
1. **Nail Plates**- are used to connect timber of the same thickness in the same plane. They are pressed into the side of the timber using special hydraulic tools (because of this specialized assembly it is not often used on site) . As the plate is pressed in, the nails are all “driven” simultaneously and the compression between adjacent nails reduces the tendency to split

2. **Split Ring**- A circular slot is made in the two contact faces of the members. A steel ring is fitted into this slot and the members are held in contact by a small bolt through the center of the ring (illustration from Australian



Timber Education)

3. **Hangers, Ties, Anchors and Straps**- Stamped steel connectors used in concert with nails(illustration from Simpson



Strong Tie)

Concrete

Conctrete:6% Air; 11% Cement; 41% Gravel or crushed stone (coarse aggregate); 26% Sand (Fine Aggregate); 16% Water

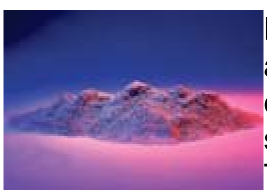
In its simplest form, concrete is a mixture of paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete.

Within this process lies the key to a remarkable trait of concrete: it's plastic and malleable when newly mixed, strong and durable when hardened. These qualities explain why one material, concrete, can build skyscrapers, bridges, sidewalks and superhighways, houses and dams.

Proportioning

The key to achieving a strong, durable concrete rests in the careful proportioning and mixing of the ingredients. A concrete mixture that does not have enough paste to fill all the voids between the aggregates will be difficult to place and will produce rough, honeycombed surfaces and porous concrete. A mixture with an excess of cement paste will be easy to place and will produce a smooth surface; however, the resulting concrete is likely to shrink more and be uneconomical.

A properly designed concrete mixture will possess the desired workability for the fresh concrete and the required durability and strength for the hardened concrete. Typically, a mix is about 10 to 15 percent cement, 60 to 75 percent aggregate and 15 to 20 percent water. Entrained air in many concrete mixes may also take up another 5 to 8 percent.



Portland cement's chemistry comes to life in the presence of water. Cement and water form a paste that coats each particle of stone and sand. Through a chemical reaction called hydration, the cement paste hardens and gains strength. The character of the concrete is determined by quality of the paste. The strength of the paste, in turn, depends on the ratio of water to cement. The water-cement ratio is the weight of the mixing water divided by the weight of the cement. High-quality concrete is produced by lowering the water-cement ratio as much as possible without sacrificing the workability of fresh concrete. Generally, using less water produces a higher quality concrete provided the concrete is properly placed, consolidated, and cured.

Other Ingredients

Although most drinking water is suitable for use in concrete, aggregates are chosen carefully. Aggregates comprise 60 to 75 percent of the total volume of concrete. The type and size of the aggregate mixture depends on the thickness and purpose of the final concrete product. Almost any natural water that is drinkable and has no pronounced taste or odor may be used as mixing water for concrete. However, some waters that are not fit for drinking may be suitable for concrete.

Excessive impurities in mixing water not only may affect setting time and concrete strength, but also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability. Specifications usually set limits on chlorides, sulfates, alkalis, and solids in mixing water unless tests can be performed to determine the effect the impurity has on various properties. Relatively thin building sections call for small coarse aggregate, though aggregates up to six inches (150 mm) in diameter have been used in large dams. A continuous gradation of particle sizes is desirable for efficient use of the paste. In addition, aggregates should be clean and free from any matter that might affect the quality of the concrete.

Hydration Begins

Soon after the aggregates, water, and the cement are combined, the mixture starts to harden. All Portland cements are hydraulic cements that set and harden through a chemical reaction with water. During this reaction, called hydration, a node forms on the surface of each cement particle. The node grows and expands until it links up with nodes from other cement particles or adheres to adjacent aggregates.

The building up process results in progressive stiffening, hardening, and strength development. Once the concrete is thoroughly mixed and workable it should be placed in forms before the mixture becomes too stiff.

During placement, the concrete is consolidated to compact it within the forms and to eliminate potential flaws, such as honeycombs and air pockets. For slabs, concrete is left to stand until the surface moisture film disappears. After the film disappears from the surface, a wood or metal handfloat is used to smooth off the concrete. Floating produces a relatively even, but slightly rough, texture that has good slip resistance and is frequently used as a final finish for exterior slabs. If a smooth, hard, dense surface is required, floating is followed by steel troweling.

Curing begins after the exposed surfaces of the concrete have hardened sufficiently to resist marring. Curing ensures the continued hydration of the cement and the strength gain of the concrete. Concrete surfaces are cured by sprinkling with water fog, or by using moisture-retaining fabrics such as burlap or cotton mats. Other curing methods prevent evaporation of the water by sealing the surface with plastic or special sprays (curing compounds).

Special techniques are used for curing concrete during extremely cold or hot weather to protect the concrete. The longer the concrete is kept moist, the stronger and more durable it will become. The rate of hardening depends upon the composition and fineness of the cement, the mix proportions, and the moisture and temperature conditions. Most of the hydration and strength gain take place within the first month of concrete's life cycle, but hydration continues at a slower rate for many years. Concrete continues to get stronger as it gets older.

The Forms of Concrete

Concrete is produced in four basic forms, each with unique applications and properties.

Ready-mixed concrete, by far the most common form, accounts for nearly three-fourths of all concrete. It's batched at local plants for delivery in the familiar trucks with revolving drums.

Precast concrete products are cast in a factory setting. These products benefit from tight quality control achievable at a production plant. Precast products range from concrete bricks and paving stones to bridge girders, structural components, and panels for cladding.

Concrete masonry, another type of manufactured concrete, may be best known for its conventional 8 x 8 x 16-inch block. Today's masonry units can be molded into a wealth of shapes, configurations, colors, and textures to serve an infinite spectrum of building applications and architectural needs. Cement-based materials represent products that defy the label of "concrete," yet share many of its qualities. Conventional materials in this category include mortar, grout, and terrazzo. Soil-cement and roller-compacted concrete—"cousins" of concrete-are used for pavements and dams. Other products in this category include flowable fill and cement-treated bases. A new generation of advanced products incorporates fibers and special aggregate to create roofing tiles, shake shingles, lap siding, and countertops. And an emerging market is the use of cement to treat and stabilize waste. Properties of Concrete

3.1 Properties of Concrete

3. 1920s and is in worldwide use today.) A minimum w/c ratio (water-to-cement ratio) of about 0.3 by weight is necessary to ensure that the water comes into contact with all cement particles (thus assuring complete hydration). In practical terms, typical values are in the 0.4 to 0.6 range in order to achieve a workable consistency so that fresh concrete can be placed in the forms and around closely spaced reinforcing bars.

$$E = 33w^{1.5}\sqrt{f'_c}$$

Typical stress-strain curves for various concrete strengths are shown in Figure 2. Most structural concretes have f'c values in the 3000 to 5000 psi range. However, lower-story columns of high-rise buildings will sometimes utilize concretes of 12,000 or 15,000 psi to reduce the column dimensions which would otherwise be inordinately large. Even though Figure 2 indicates that the maximum strain that concrete can sustain before it crushes varies inversely with strength, a value of 0.003 is usually taken (as a simplifying measure) for use in the development of design equations.

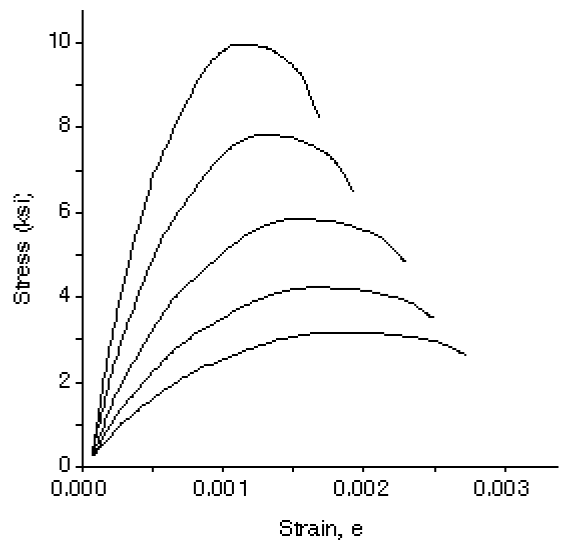


Figure 2.. Stress versus Strain curves.

Because concrete has no linear portion to its stress-strain curve, it is difficult to measure a proper modulus of elasticity value. For concretes up to about 6000 psi it can be approximated as

(1)

where *w* is the unit weight (pcf), *f'c* is the cylinder strength (psi). (It is important that the units of f'c be expressed in psi and not ksi whenever the square root is taken). The weight density of reinforced concrete using normal sand and stone aggregates is about 150 pcf. If 5 pcf of this is allowed for the steel and w is taken as 145 in Equation (1), then

for use in deflection calculations.

As concrete cures it shrinks because the water not used for hydration gradually evaporates from the hardened mix. For large continuous elements such shrinkage can result in the development of excess tensile stress, particularly if a high water content brings about a large shrinkage. Concrete, like all materials, also undergoes volume changes due to thermal effects, and in hot weather the heat from the exothermic hydration process adds to this problem. Since concrete is weak in tension, it will often develop cracks due to such shrinkage and temperature changes. For example, when a freshly placed concrete slab-on-grade expands due to temperature change, it develops internal compressive stresses as it overcomes the friction between it and the ground surface. Later when the concrete cools land shrinks as it hardens) and tries to contract, it is not strong enough in tension to resist the same frictional forces. For this reason contraction joints are often used to control the location of cracks that inevitably occur and so-called temperature and shrinkage reinforcement is placed in directions where reinforcing has not already been specified for other reasons. The purpose of this reinforcing is to accommodate the resulting tensile stresses and to minimize the width of cracks that do develop.

In addition to strains caused by shrinkage and thermal effects, concrete also deforms due to creep. Creep is Increasing deformation that takes place when a material sustains a high stress level over a long time period. Whenever constantly applied loads (such as dead loads) cause significant compressive stresses to occur, creep will result. In a beam, for example, the additional longterm deflection due to creep can be as much as two times the initial elastic deflection The way to avoid this increased deformation is to keep the stresses due to sustained loads at a low level. This is usually done by adding compression steel.

3.2 Mix Proportions

The ingredients of concrete can be proportioned by weight or volume. The goal is to provide the desired strength and workability at minimum expense. Sometimes there are special requirements such as abrasion resistance, durability in harsh climates, or water impermeability, but these properties are usually related to strength. Sometimes concretes of higher strength are specified even though a lower f'c value would have met all structural requirements.

As mentioned previously, a low water-to-cement ratio is needed to achieve strong concrete. It would seem therefore that by merely keeping the cement content high one could use enough water for good workability and still have a low w/c ratio. The problem is that cement is the most costly of the basic ingredients.

The most important factor affecting the strength of concrete is the water-to-cement ratio

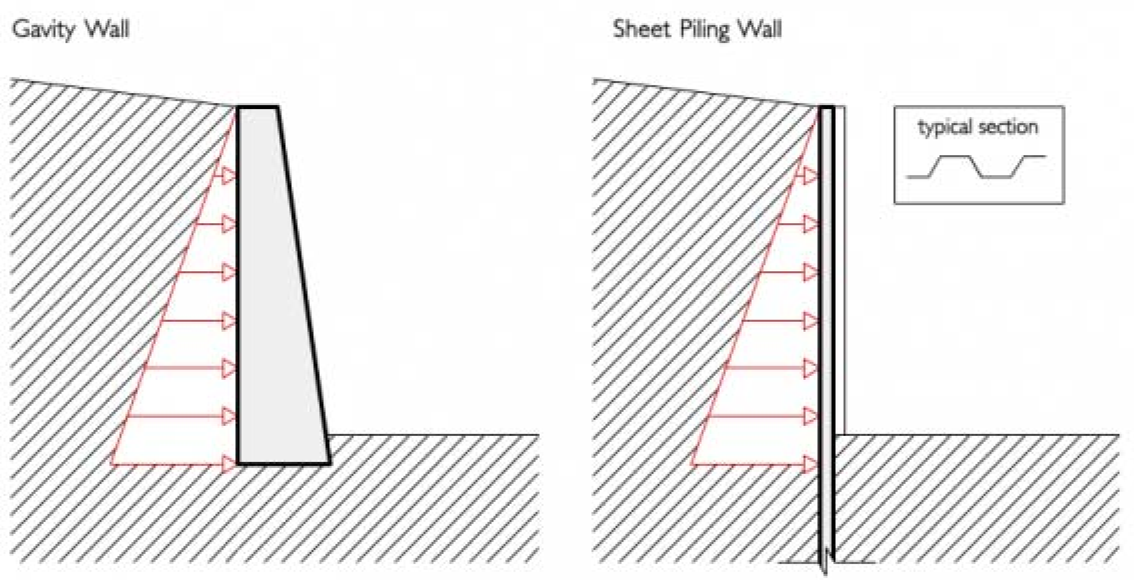
Not: weather conditions during curing; volume of the mixture;

Concrete (Reinforced)

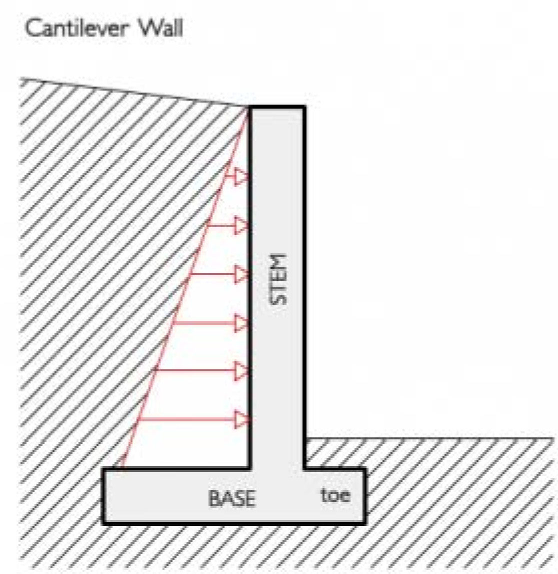
concrete in which reinforcement bars (rebars), reinforcement grids, plates or fibers have been incorporated to strengthen the concrete in tension. Other materials used to reinforce concrete can be organic and inorganic fibres as well as composites in different forms. Concrete is strong in compression, but weak in tension, thus adding reinforcement increases the strength in tension.

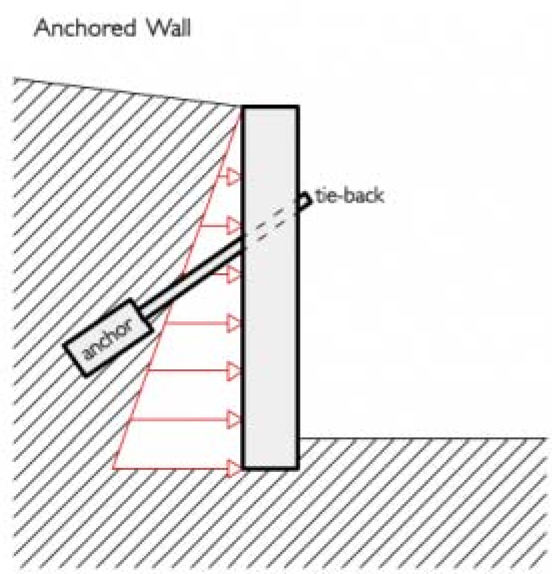
- **Tilt up**- is a type of building, and a construction technique using concrete. The process resembles barn raising. It is cost-effective for low buildings. In this method building elements are formed on a concrete slab, usually the building floor. After the concrete has cured, the elements are tilted from horizontal to vertical with a crane and braced into position until the remaining building structural components are secured.
  Retaining Wall is a structure designed and constructed to resist the lateral pressure of soil to serve a desired change in ground elevation.

- **Gravity**- Gravity walls depend on the weight of their mass to resist pressures from behind and will sometimes have an increased footprint, to improve stability.
- **Sheet pile**- are made out of steel, vinyl or wood planks which are driven into the ground. Made for tight confines and soft soils.



- **Cantilever**- Cantilevered retaining walls are made from an internal stem of steel-reinforced, cast-in-place concrete or mortared masonry typically in the shape of an inverted T
- **Anchored**- An anchored retaining wall can be constructed in any of the aforementioned styles but also includes additional strength using cables or other stays anchored in the rock or soil behind it


Cantilever Wall
STEM
BASE
toe


Anchored Wall
tie-back
anchor

• Foundations

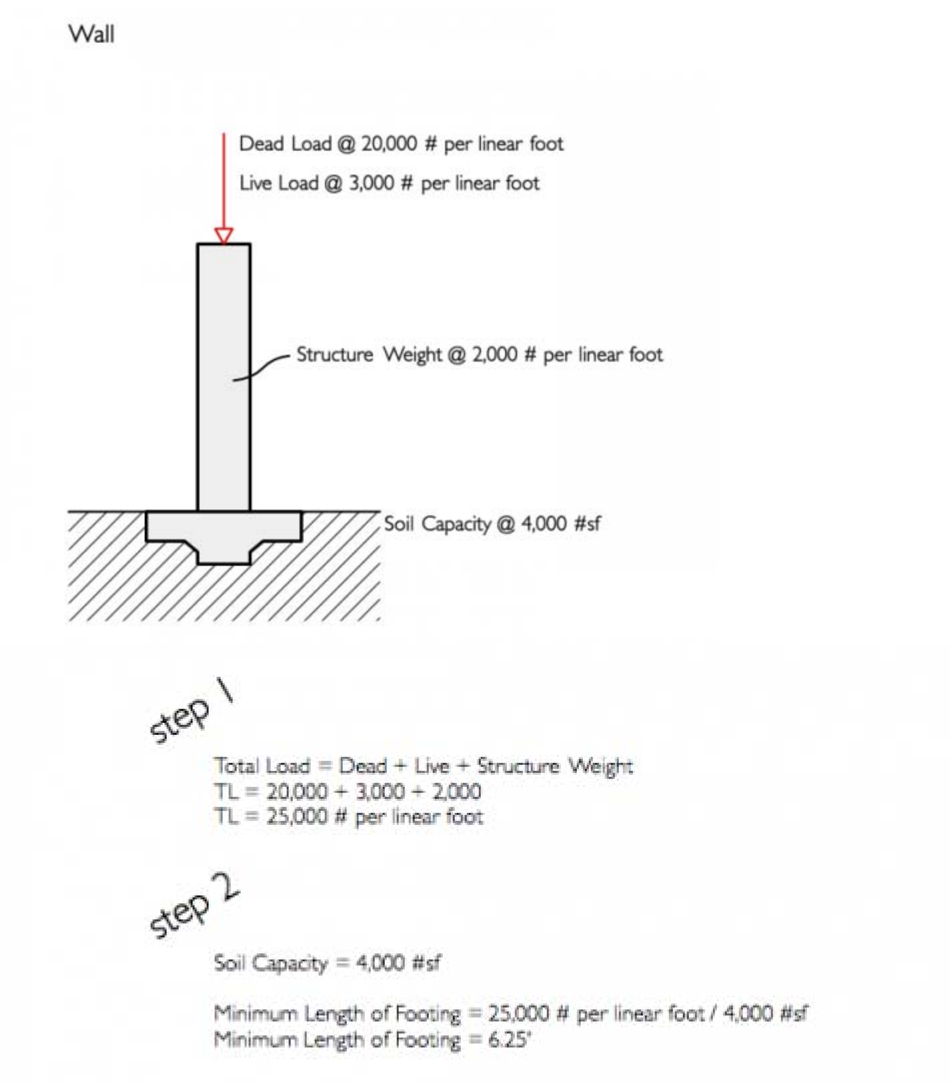
Foundation

The structure that transfers loads to the ground. Roughly categorized into two footing types: shallow and deep.

Shallow Footing

Foundation transfers building loads to the earth very near the surface, within 1′-10′. Shallow foundations includes: spread footing foundations, slab-on-grade foundations, and rubble trench foundations.

Example Problem:



Deep Footing

Foundation which are set to a far more depth into the ground. This is to match certain condition or requirements, such as: very large design loads, a poor soil conditions, or site constraints. Different terms used to describe types of deep foundations: piles, drilled shafts, caissons and piers. Deep foundations are typically made out of timber, steel, reinforced concrete or pre-tensioned concrete.

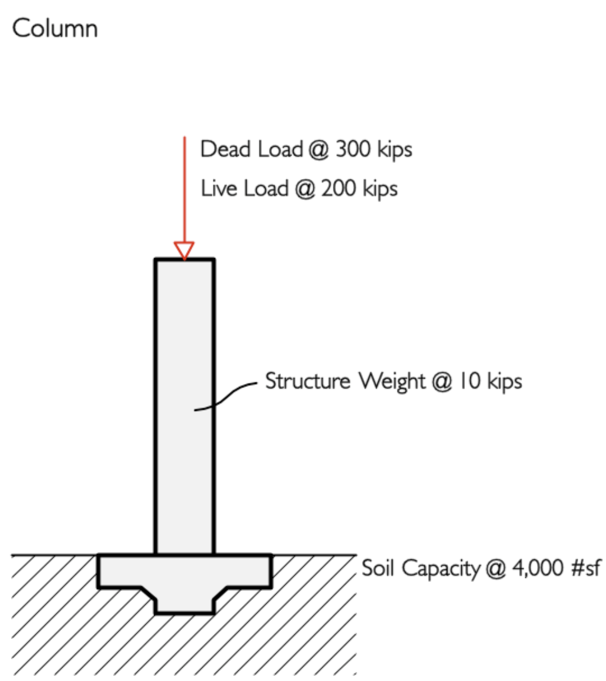
Design

Footings are designed by the structure engineer to balance load capacity of the soil and the load required (dictated by the weight of the structure). Settlement, the consolidation of soil under the pressure of the foundation, must be considered. Too much settlement can cause significant structure issues.

- **Bearing Capacity** – The capacity of soil to support the loads applied to the ground. *Ultimate bearing capacity* is the theoretical maximum pressure which can be supported without failure; *allowable bearing capacity* is the ultimate bearing capacity divided by a factor of safety

1. **Testing** – Soil Analysis is performed by drilling boring, bringing up sample of soil at various depths. Load test can also be performed at the site.
2. **Soil Types** – In descending order of bearing capacity: Rock; gravel and sand; slit and clay; and organic soils.

Example Problem: Find the necessary footing dimensions given: Bearing capacity, and Loads.



step 1

Total Load = Dead + Live + Structure Weight
TL = 300 + 200 + 10
TL = 510 kips

step 2

Soil Capacity = 4,000 #sf

Minimum Area of Footing = 510 kips / 4,000 #sf
Minimum Area of Footing = 127.5 sf

step 3

11.5' x11.5' = 132.5 sf
132.5 sf > 127.5 sf
A footing of 11'-6"x11'-6" is acceptable

- **Settlement/Consolidation** - When constant stress is applied to a soil that causes the soil particles to pack together more tightly, thereby reducing its volume.
  1. **Differential Settlement** – When one part of a foundation settles more than another part.
- **Climate Influences**
  1. **Frost Heave** – Results from ice forming beneath the surface of soil during freezing conditions. The ice grows in the direction of heat loss (vertically toward the surface) starting at the freezing boundary, frost line, in the soil. The foundation is set below the frost line to counteract frost heave
  2. **Expansive Soil** – Changes in soil moisture will influence soil volume. Clay soil are especially sensitive to moisture. Piles can be set below the seasonal soil change.
  3. **Groundwater** – Foundations below the groundwater line with have to be design to counteract hydrostatic pressure

Footing Types

Shallow

- **Spread Footing –** Strips or pads of concrete which transfer the loads from walls and columns to the soil. Common in residential construction. Relatively simple system considered a shallow foundation system
- **Slab on Grade –** Concrete slab is poured into a mold (consisting of trenches and wood forms) that is created on site. There is no cavity between the existing earth and concrete. This type of construction is more typically found in warmer climate with out the issues of frost heave
- **Rubble Trench –** Type of foundation that uses loose stone or rubble to minimize the use of concrete and improve drainage. Consisting of a rubble trench and layer which the concrete slab is then poured over.

Deep

Driven, Drilled Foundations

- **Driven Piles -** Prefabricated piles that are driven into the ground by a pile driver. The act of driving the pile causes increased friction, caused by the compression of soil around the pile

1. **Pile Cap** – Concrete block into which the heads of the piles are embedded

- **Drilled Piles –** Also known as caissons and CIDH piles. A cavity is bored to the designed depth then a reinforcing cage is introduced, concrete is poured in the bore.

Base Isolation Systems

Designed to deal with seismic forces. It is a collection of structural elements which decouples a superstructure from its substructure in an event of an earthquake. Its goal is to dampen the extreme forces with decoupling isolation units. Some examples are spring-damper systems (similar to an automotive suspension) and sliding units.

Example:

- **Structural Vignette Overview**
- **Lateral Forces (Wind and Seismic)**

*A more in-depth Structural load

Program

The preliminary floor plan for an urban mini-mall has been completed and approved, and you are now required to develop a roof framing layout for the building or portion of the building shown on the work screen. The layout must accommodate the conditions and requirements given below.

Site/Foundation

1. The site has no seismic activity and wind pressures are negligible.
2. The soils and foundation system should be assumed adequate for all standard and normal loads.
3. The distribution of concentrated or special loads need not be considered.

Construction/Materials

1. Structural steel/open web steel joist construction has been chosen for the roof structure type.
2. Steel beam sections are to be rolled or built-up.
3. The metal roof deck is capable of carrying the design loads on spans up to and including 4 ft.
4. Joists are sized to carry roof loads only.

General Requirements

1. All portions of the roof framing are flat.
2. Cantilevers are prohibited.
3. Structural members must not extend beyond the building envelope, except to frame a designated covered entry.
4. Columns may be located within walls, including the window wall and the clerestory window wall.
5. Walls shown on the background floor plan may be designated as bearing walls. Additional bearing walls are not allowed.
6. Lintels are required to be shown in bearing walls only. Other lintels shall not be indicated.
7. The opening located between the common area and the seating area must be unobstructed and column-free.
8. The common area must be column-free.
9. The window wall and the clerestory window extend to the underside of the structure above. All other openings have a head height of 7 ft above finish floor.
10. The roof over the high ceiling space must be higher than the roof over the low ceiling spaces.
  _ The common area requires a high ceiling with a top of structure height of 18 ft.
  _ The remaining spaces require a low ceiling with a top of structure height of 12 ft.
11. The structure must accommodate a clerestory window to be located along the full length of the north wall of the common area.

1. GENERAL STRUCTURES
%38-%42 percent of scored

A. Principles
Apply general structural principles to building design and construction.

1. Building Design

Achieve required building design by

- applying principles,
- theory, and
- calculations needed to analyze and
- design structural systems and components,
- calculating forces on members
    1. loads,
    2. shear,
    3. moments,
    4. reactions, and
    5. truss analysis), and

applying basic engineering principles including but not limited to:

- moment of inertia,
- section modulus, and
- deflection.

2. Building Systems and their Integration

Apply principles, theory, and calculations related to a building's structural system and its individual components by selecting a structural system or component that is appropriate for its application including but not limited to: post and beam, frames, trusses, arches, shells, plates, and skins.

3. Implications of Design Decisions

Assess the impact of structural design decisions on cost, schedule, and building systems including: material, span, height, use, historic preservation, architectural form, acoustical properties, sustainability, vibration susceptibility, MEP considerations, etc.

B. Materials & Technology

Consider impact of design decisions on the selection of systems, materials, and construction details on general structural design.

1. Construction Details and Constructability

Apply principles, theory, and calculations related to the design of connections of the various elements of the structure, including connections, fasteners, hangers, and plates. Assess the impact of structural decisions on the construction process: including underpinning, shoring, temporary structures, stabilization, and construction methods.

2. Construction Materials

Understand properties of materials that may affect the structural characteristics including section modulus, moment of inertia, thermal movement, fatigue, creep, and information gathered from material test reports, or manuals and apply the knowledge to the design.

C. Codes & Regulations

Incorporate building codes, specialty codes, and other regulatory requirements in the design of general structural systems

1. Government and Regulatory Requirements and Permit Processes

Examine building and fire codes and other regulations affecting structural systems. Apply conditions, Constraints, and the permit approval process to structural issues, including: life safety, testing, inspections, loads, connections, allowable stresses, erection, and safety factors.

Design:

Calculating the section modulus, and moment of Intertia

To calculate the section modulus, the following formula applies:

$Z = \frac{I}{y}$ where *I* = moment of inertia, y = distance from centroid to top or bottom edge of the rectangle $\left(\frac{d}{2}\right)$

For symmetrical sections the value of **Z** is the same above or below the centroid.

For asymmetrical sections, two values are found: **Z** max and **Z** min.

To calculate the value of **Z** for a simple symmetrical shape such as a rectangle:

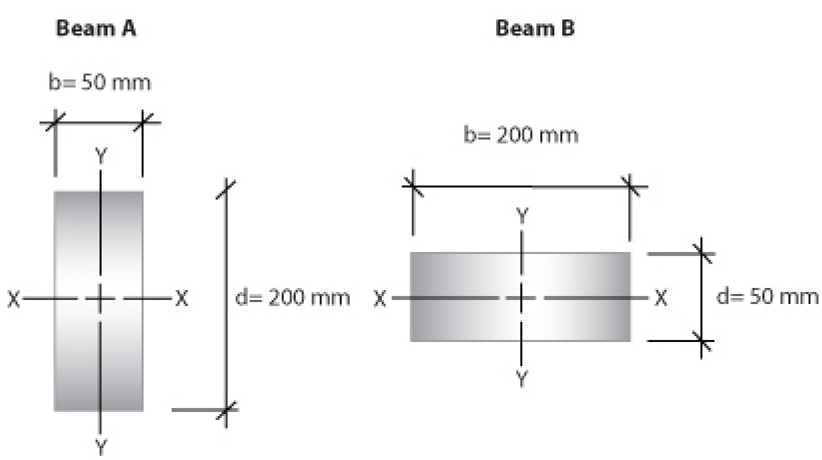
$Z_{xx} = \frac{Ixx}{y}$ where $I_{xx} = \frac{bd^3}{12}\ mm^4$

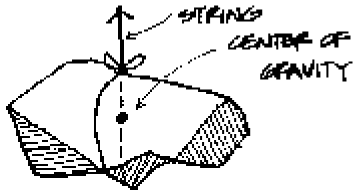
and y = $\frac{1}{2}$ depth or $\frac{d}{2}$ mm

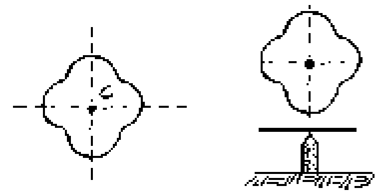
This gives the formula for **Z** as: $Z = \frac{bd^2}{6}\ mm^3$

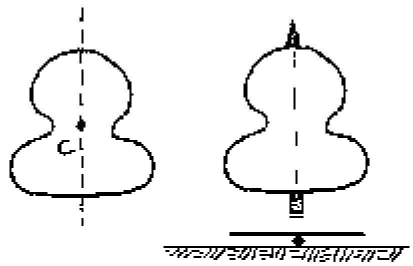
Note: The standard form of writing the value of **Z** is to write it as a number x $10^3\ mm^3$, eg a value of 2,086 is written as 2.086 x 10^3.

Calculating Z









Centroids &Moment of Inertia

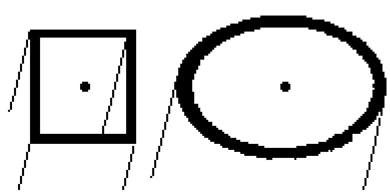
The **centroid**, or center of gravity, of any object is the point within that object from which the force of gravity appears to act. An object will remain at rest if it is balanced on any point along a vertical line passing through its center of gravity. In terms of moments, the center of gravity of any object is the point around which the moments of the gravitational forces completely cancel one another.

The center of gravity of a rock (or any other three dimensional object) can be found by hanging it from a string. The line of action of the string will always pass through the center of gravity of the rock. The precise location of the center of gravity could be determined if one would tie the string around the rock a number of times and note each time the line of action of the string. Since a rock is a three dimensional object, the point of intersection would most likely lie somewhere within the rock and out of sight.

The centroid of a two dimensional surface (such as the cross-section of a structural shape) is a point that corresponds to the center of gravity of a very thin homogeneous plate of the same area and shape. The planar surface (or figure) may represent an actual area (like a tributary floor area or the cross-section of a beam) or a figurative diagram (like a load or a bending moment diagram). It is often useful for the centroid of the area to be determined in either case.

Symmetry can be very useful to help determine the location of the centroid of an area. If the area (or section or body) has one line of symmetry, the centroid will lie somewhere along the line of symmetry. This means that if it were required to balance the area (or body or section) in a horizontal position by placing a pencil or edge underneath it, the pencil would be best laid directly under the line of symmetry.

If a body (or area or section) has two (or more) lines of symmetry, the centroid must lie somewhere along each of the lines. Thus, the centroid is at the point where the lines



intersect. This means that if it were required to balance the area (or body or section) in a horizontal position by placing a nail underneath it, the point of the nail would best be placed directly below the point where the lines of symmetry meet. This might seem obvious, but the concept of the centroid is very important to understand both graphically and numerically. The position of the center of gravity for some simple shapes is easily determined by inspection. One knows that the centroid of a circle is at its center and that of a square is at the intersection of two lines drawn connecting the midpoints of the parallel sides. The circle has an infinite number of lines of symmetry and the square has four. (Two were described above - what are the other two lines of symmetry?)

The centroid of a section is not always within the area or material of the section. Hollow pipes, L shaped and some irregular shaped sections all have thir centroid located outside of the material of the section. This is not a problem since the centroid is really only used as a reference point from which one measures distances. The exact location of the centroid can be determined as described above, with graphic statics, or numerically.

The centroid of any area can be found by taking moments of identifiable areas (such as rectangles or triangles) about any axis. This is done in the same way that the center of gravity can be found by taking moments of weights. The moment of an large area about any axis is equal to the algebraic sum of the moments of its component areas. This is expressed by the following equation:

$$\textbf{Sum } M_{Atotal} = M_{A1} + M_{A2} + M_{A3} + \ldots$$

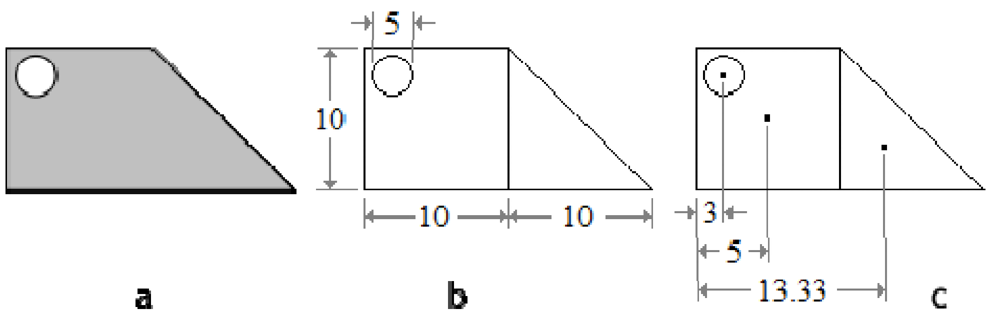
The moment of any area is defined as the product of the area and the perpendicular distance from the centroid of the area to the moment axis. By means of this principle, we may locate the centroid of any simple or composite area.

Centroid- the geometric center of the object’s shape, the center of mass and center of gravity.

- **Geometric Decomposition Method-** The centroid of a plane figure *X* can be solved by dividing it into a finite number of simpler figures $X_1, X_2, \ldots, X_n$, finding the centroid C_i and area A_i of each part, and then solving the equation (diagram below)

$$C = \frac{\sum C_i A_i}{\sum A_i}.$$

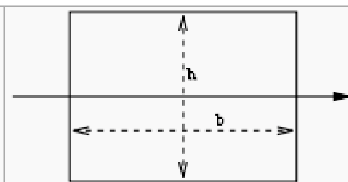
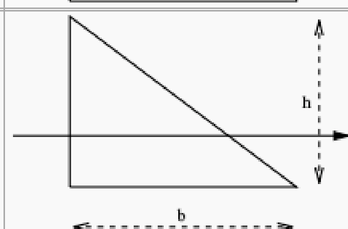
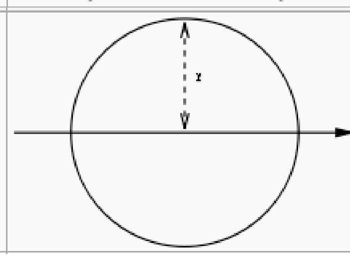
Example Problem: Holes in the figure *X*, overlaps between the parts, or parts that extend outside the figure can all be handled using negative areas A_i. Namely, the measuresA_i should be taken with positive and negative signs in such a way that the sum of the signs of $A_i$for all parts that enclose a given point *p* is 1 if *p* belongs to *X*, and 0 otherwise.
For example, the figure below (a) is easily divided into a square and a triangle, both with positive area; and a circular hole, with negative area (b).



The centroid of each part can be found in any list of centroids of simple shapes (c).Then the centroid of the figure is the weighted average of the three points. The horizontal position of the centroid, from the left edge of the figure is

$$x = \frac{5 \times 10^2 + 13.33 \times \frac{1}{2}10^2 - 3 \times \pi 2.5^2}{10^2 + \frac{1}{2}10^2 - \pi 2.5^2} \approx 8.5\text{units}$$

(modified from en.wikipedia)

a filled rectangular area with a base width of *b* and height *h*		$I_0 = \frac{bh^3}{12}$
a filled triangular area with a base width of *b* and height *h* with respect to an axis through the centroid		$I_0 = \frac{bh^3}{36}$
a filled circular area of radius *r*		$I_0 = \frac{\pi r^4}{4}$

Center of Gravity

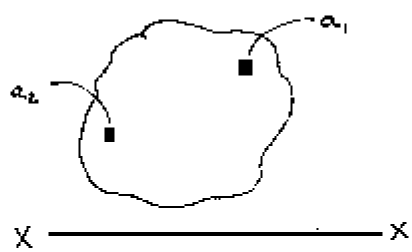
The **Moment of Inertia (I)** is a term used to describe the capacity of a cross-section to resist bending. It is always considered with respect to a reference axis such as X-X or Y-Y. It is a mathematical property of a section concerned with a surface area and how that area is distributed about the reference axis. The reference axis is usually a centroidal axis.

The moment of inertia is also known as the **Second Moment of the Area** and is expressed mathematically as:

$$I_{xx} = \text{Sum } (A)(y^2)$$

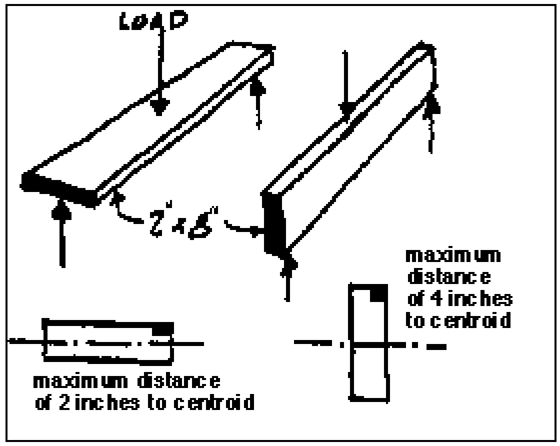
In which:

I_{xx} = the moment of inertia around the x axis
A = the area of the plane of the object
y = the distance between the centroid of the object and the x axis



The Moment of Inertia is an important value which is used to determine the state of stress in a section, to calculate the resistance to buckling, and to determine the amount of deflection in a beam. For example, if a designer is given a certain set of constraints on a structural problem (i.e. loads, spans and end conditions) a "required" value of the moment of inertia can be determined. Then, any structural element which has at least that specific moment of inertia will be able to be utilized in the design. Another example could be in the inverse were true: a specific element is given in a design. Then the load bearing capacity of the element could be determined.

Let us look at two boards to intuitively determine which will deflect more and why. If two boards with actual dimensions of 2 inches by 8 inches were laid side by side - one on the two inch side and the other on the eight inch side, the board which is supported on its 2" edge is considerably stiffer than that supported along its 8" edge. Both boards have the same cross-sectional area, but the area is distributed differently about the horizontal centroidal axis.



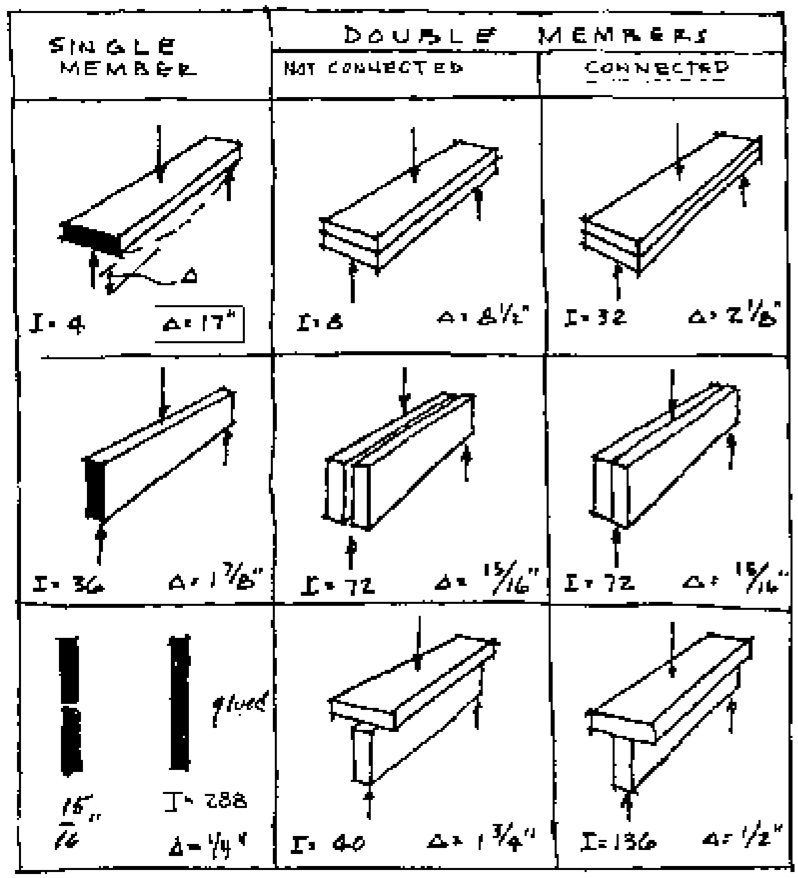
Calculus is ordinarily used to find the moment of inertia of an irregular section. However, a simple formula has been derived for a rectangular section which will be the most important section for this course.

$$\mathbf{I_{xx} = (^1/_{12})(b)(h^3)}$$

In which the value **b** is **alway**s taken to be the side parallel to the reference axis and **h** the height of the section. This is very important to note! If the wrong value is assumed for the value of **b**, the calculations will be totally wrong.

Moment of Inertia

The importance of the distribution of the area around its centroidal axis becomes clear when comparing the values of the moment of inertia of a number of typical beam configurations. All of the members shown below are 2" x 6"; in cross section, equal in length and equally loaded.



BUILT-UP SECTIONS

It is often advantageous to combine a number of smaller members in order to create a beam or column of greater strength. The moment of inertia of such a built-up section is found by adding the moments of inertia of the component parts. This can be done< B> if and only if the moments of inertia of each component area are taken about a common axis and **if and only if** the resulting section acts as one unit.

UNDER NO OTHER CONDITION CAN THEY BE ADDED!

Two examples of built-up sections are seen below. In each case the components of the whole have a common axis and act as one unit.

Built-Up Sections

TRANSFER FORMULA

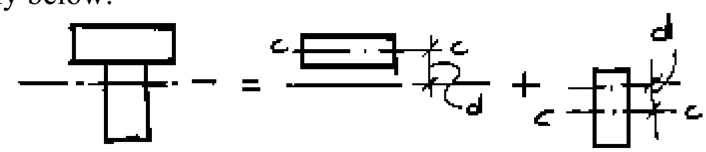
There are many built-up sections in which the component parts are not symmetrically distributed about the centroidal axis. The easiest way to determine the moment of inertia of such a section is to find the moment of inertia of the component parts about their own centroidal axis and then apply the transfer formula. The **transfer formula** transfers the moment of inertia of a section or area from its own centroidal axis to another parallel axis. It is known from calculus to be:

$$\mathbf{I_x = I_c + (A)d^2}$$

Where:

I_x = moment of inertia about axis x-x (in^4)
I_c = moment of inertia about the centroidal axis c-c parallel to x-x (in^4)
A = area of the section (in^2)
d = perpendicular distance between the parallel axes x-x and c-c (in)

Finding the moment of inertia of an asymmetric built-up cross-section is simplified to the procedure shown diagrammatically below:



$$I_x = I_c + Ad^2 + I_c + Ad^2$$

57.3 in3 [cm3] the section modulus for the geometric section illustrated above.

$$S = I/c$$

Section modulus is a geometric property for a given cross-section used in the design of beams or flexural members. Other geometric properties used in design include area for tension, radius of gyration for compression, and moment of inertia for stiffness. Any relationship between these properties is highly dependant on the shape in question. Equations for the section moduli of common shapes are given below. There are two types of section moduli, the elastic section modulus (S) and the plastic section modulus (Z).

Notation

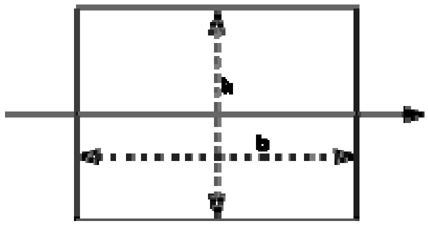
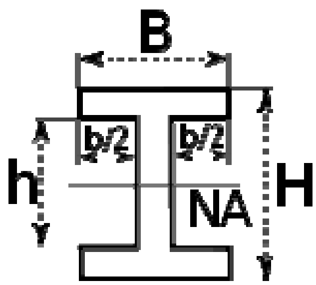
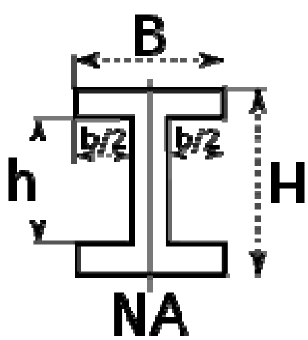
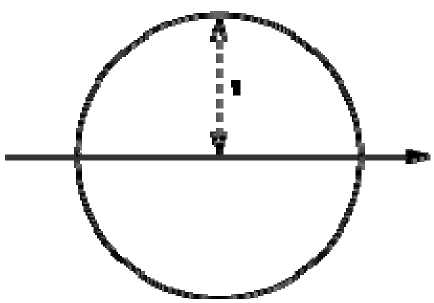
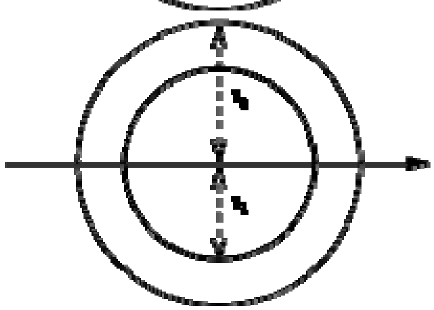
North American and British/Australian convention reverse the usage of S & Z. Elastic modulus is S in North America,[1] but Z in Britain/Australia[2], and vice versa for the plastic modulus. Eurocode 3 (EN 1993 - Steel Design) resolves this by using W for both, but distinguishes between them by the use of subscripts - W_{el} and W_{pl}.

Elastic section modulus

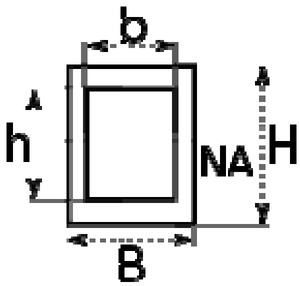
For general design, the elastic section modulus is used, applying up to the yield point for most metals and other common materials.

The elastic section modulus is defined as S = I / y, where I is the second moment of area (or moment of inertia) and y is the distance from the neutral axis to any given fibre.[3]. It is often reported using y = c, where c is the distance from the neutral axis to the most extreme compression fibre, as seen in the table below. It is also often used to determine the yield moment (M_y) such that $M_y = S \times \sigma_y$, where σ_y is the yield strength of the material.[3]

Section modulus equations[4]

Cross-sectional shape	Figure	Equation	Comment
Rectangle		$S = \frac{bh^2}{6}$	Solid arrow represents neutral axis
doubly symmetric I-section (strong axis)		$S = \frac{BH^2}{6} - \frac{bh^3}{6H}$	NA indicates neutral axis
doubly symmetric I-section (weak axis)		$S = \frac{B^2(H-h)}{6} + \frac{(B-b)^3 h}{6B}$	NA indicates neutral axis
Circle		$S = \frac{\pi r^3}{4} = \frac{\pi d^3}{32}$ [4]	Solid arrow represents neutral axis
Circular tube		$S = \frac{\pi\left(r_2^4 - r_1^4\right)}{4r_2} = \frac{\pi\left(d_2^4 - d_1^4\right)}{32d_2}$	Solid arrow represents neutral axis

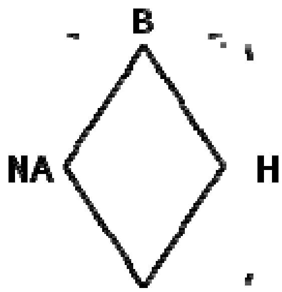
Rectangular tube



$$S = \frac{BH^2}{6} - \frac{bh^3}{6H}$$

NA indicates neutral axis

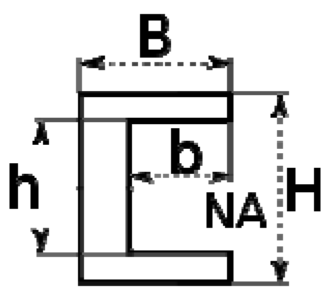
Diamond



$$S = \frac{BH^2}{24}$$

NA indicates neutral axis

C-channel



$$S = \frac{BH^2}{6} - \frac{bh^3}{6H}$$

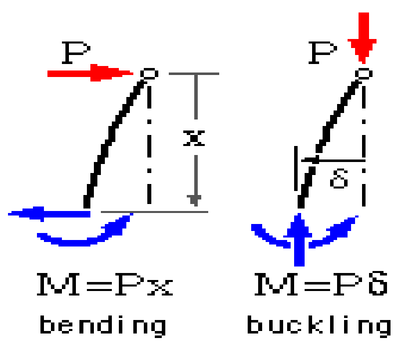
NA indicates neutral axis

1.

BUCKLING

When a structure (subjected usually to compression) undergoes visibly large displacements transverse to the load then it is said to ***buckle.*** Buckling may be demonstrated by pressing the opposite edges of a flat sheet of cardboard towards one another. For small loads the process is elastic since buckling displacements disappear when the load is removed.
Local buckling of plates or shells is indicated by the growth of bulges, waves or ripples, and is commonly encountered in the component plates of thin structural members.

Buckling proceeds in manner which may be either :



stable - in which case displacements increase in a controlled fashion as loads are increased, ie. the structure's ability to sustain loads is maintained, or
unstable -in which case deformations increase instantaneously, the load carrying capacity nose- dives and the structure collapses catastrophically.

Neutral equilibrium is also a theoretical possibility during buckling - this is characterised by deformation increase without change in load.
Buckling and bending are similar in that they both involve bending moments. In bending these moments are substantially independent of the resulting deflections, whereas in buckling the moments and deflections are mutually **inter-dependent** - so moments, deflections and stresses are **not** proportional to loads.
If buckling deflections become too large then the structure fails - this is a **geometric** consideration, completely divorced from any material **strength** consideration. If a component

or part thereof is prone to buckling then its design must satisfy both strength and buckling safety constraints - that is why we now examine the subject of buckling.

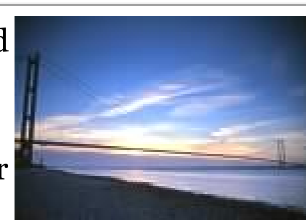
Buckling has become more of a problem in recent years since the use of high strength material requires less material for load support - structures and components have become generally more slender and buckle- prone. This trend has continued throughout technological history, as is demonstrated by bridges in the following sequence :

The Pont du Gard in Provence was completed by the Romans in the first century AD as part of a 50km aqueduct to convey water from a spring at Uzès to the garrison town of Nemausus (Nimes). The bridge is constructed from limestone blocks fitted together without mortar and secured with iron clamps. The three tiered structure avoids the need for long compressive members. (source Art images for College Teaching)

The Royal Border Bridge, Berwick upon Tweed, was built by Robert Stephenson whose father George built the Stockton and Darlington Railway (the first public railway) in 1825. Opened in 1850, the bridge continues today as an important link in the busy King's Cross (London) - Edinburgh line. The increased slenderness of the columns compared to the Pont du Gard reflect technological improvements over many centuries. (source FreeFoto.com)

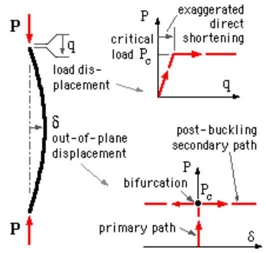
The Crymlyn Viaduct over the Ebbw Alley opened in 1857 as Welsh coal mining expanded. It was constructed of wrought and cast iron, and remained the highest railway viaduct in the UK until its closure in 1964 due to increased locomotive weights (1908 photo). The advance from masonary to the slender metal compressive members which make up each column requires substantial bracing to prevent buckling (source John Croeso)

The Humber road bridge, opened in 1981, comprises a continuously welded closed box road deck suspended from catenary cables supported on reinforced concrete towers. Suspension bridges eliminate the need for struts other than the two towers, however avoiding buckles in other slender components becomes an issue (source FreeFoto.com)

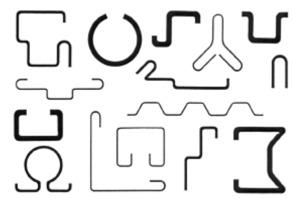


The dangers associated with over-slender build were tragically driven home by the collapse of the Tacoma Narrows road bridge over the Puget Sound in 1940. Although this failure was apparently due to wind- structure aerodynamic coupling rather than buckling as such, this film clip demonstrates graphically the ability of large structures to undergo significant elastic deflections. *(MoviePlayer or similar is required to view this .mov video)* (source CamGuys.com)

Buckling of thin-walled structures



A ***thin-walled*** structure is made from a material whose thickness is much less than other structural dimensions. Into this category fall plate assemblies, common hot- and cold- formed structural sections, tubes and cylinders, and many bridge and aeroplane structures.



Cold- formed sections such as those illustrated are increasingly supplanting traditional hot- rolled I-beams and channels. They are particularly prone to buckling and in general must be designed against several different types of buckling.

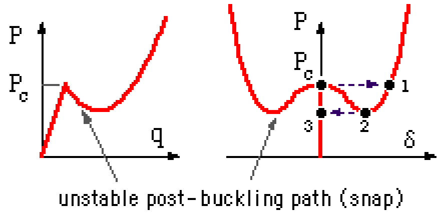
It is not difficult to visualise what can happen if a beam is made from such a cold- rolled channel section. One flange is in substantial compression and may therefore buckle locally at a low stress (ie. much less than yield) thus reducing the load capacity of the beam as a whole. Buckling rather than strength considerations thus dictate the beam's performance.

Let us now look at typical examples of buckling.

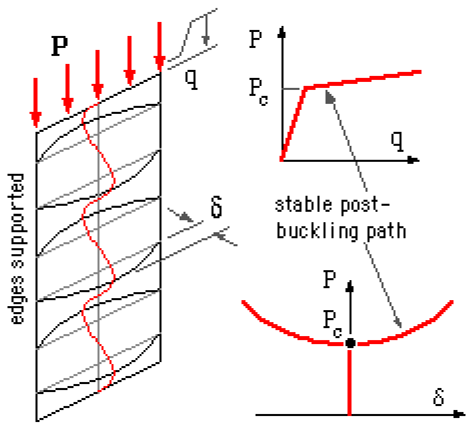
The slender elastic pin-ended ***column*** is the protoype for most buckling studies. It was examined first by Euler in the 18th century. The model assumes perfection - the column is perfectly straight prior to loading, and the load when applied is perfectly coaxial with the column.

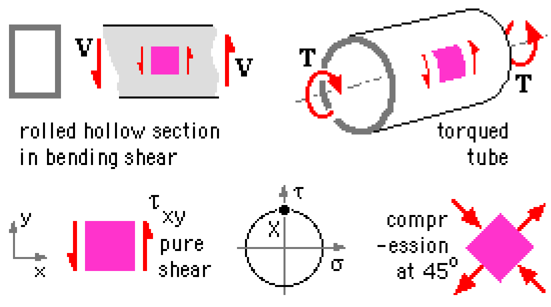
The behaviour of a buckling system is reflected in the shape of its load- displacement curve - referred to as the ***equilibrium path***. The lateral or 'out-of-plane' displacement, δ, is preferred to the load displacement, q, in this context since it is more descriptive of buckling.

Nothing is visible when the load on a perfect column first increases from zero - the column is stable, there is no buckling, and no out- of- plane displacement. The P-δ equilibrium path is thus characterised by a vertical segment - the ***primary path*** - which lasts until the increasing load reaches the critical ***Euler load*** $P_c = \pi^2 EI_{min}/L^2$ a constant characteristic of the column *(for a derivation of this, see below or Timoshenko & Gere op cit. for example).*

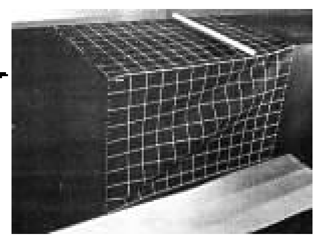


When the load reaches the Euler load, buckling suddenly takes place without any further load increase, and lateral deflections δ grow instanteously in either equally probable direction. After buckling therefore, the equilibrium path bifurcates into two symmetric ***secondary paths*** as illustrated. Clearly the critical Euler load limits the column's safe load capacity.





Local buckling of an edge-supported thin ***plate*** does not necessarily lead to total collapse as in the case of columns, since plates can generally withstand loads greater than critical. However the P-q curve illustrates plates' greatly reduced stiffness after buckling, so plates cannot be used in the post- buckling region unless the behaviour in that region is known with confidence.



It should be emphasised that the knee in the P-q curve is unrelated to any elastic- plastic yield transition; the systems being discussed are totally elastic. The knee is an effect of overall geometric rather than material instability.

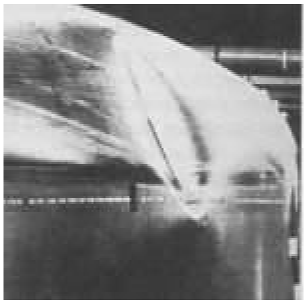
This photograph illustrates local buckling of a model box girder constructed from thin plates, not unlike the road deck of the Humber bridge above.

Inclined striations are caused by shear loading in the web of a beam or in a torqued tube giving rise to compressive buckling stresses at 45° to the longitudinal direction as predicted by Mohr's circle.

The behaviour of a compressed ***shell*** after buckling is quite different to that of a plate; in this case an unstable (negative) stiffness is accompanied by a sudden reduction of load capacity.

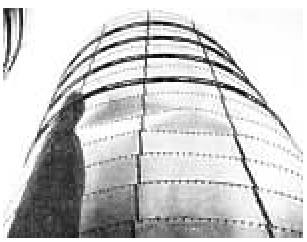
Since the displacements are uncontrolled in most practical systems, shells behave in a snap- buckling mode - ie. as an increasing load reaches the bifurcation point, the cylinder must undergo an instantaneous increase in deflection *("snap")* to the point **1** in order to accomodate the increasing load. A subsequent decrease in load is accomodated by a corresponding decrease in buckling deflection until the point **2** is reached whereupon the structure again snaps instantaneously - this time back to the point **3** on the primary path.

Clearly this behaviour makes it imperative in design to apply large safety factors to the theoretical buckling loads of compressed cylinders.



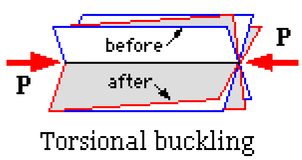
It has been noted that a pressure vessel ***head*** is subjected to a **compressive hoop stress** at its junction with the cylinder.

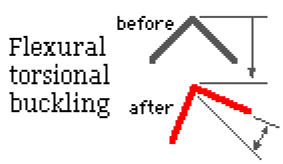
The two photographs here *(from Ramm op cit)* show both inward and outward buckles arising from this compression in the torispherical heads of internally pressurised 3 m diameter stainless steel vessels.

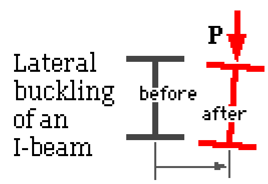


Longitudinal stresses in a vertical cylinder may also promote buckling as these two photographs illustrate *(from Rhodes & Walker op cit)*.
Warning of impending failure of the 7.3 m diameter vitreous enamelled silo on the left is provided by the visible buckles.
Grain pours out of the buckled bin on the right - the ladder gives an idea of the bin size.

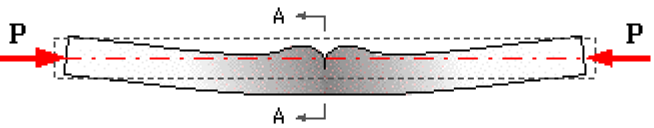
Torsional buckling of columns can arise when a section under compression is very weak in torsion, and leads to the column rotating about the force axis.



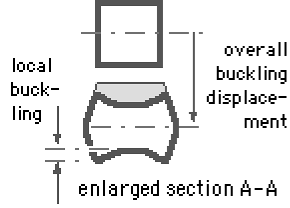




More commonly, where the section does not possess two axes of symmetry as in the case of an angle section, this rotation is accompanied by bending and is known as ***flexural torsional buckling.***
Lateral buckling of beams is possible when a beam is stiff in the bending plane but weak in the transverse plane and in torsion, as is the I-beam of the sketch.

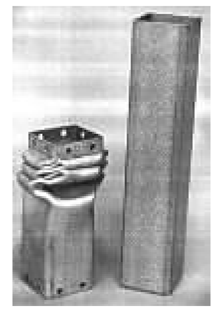


Local and overall buckling interaction in a hollow box column



It often happens that a system is prone to buckling in various modes. These usually interact to reduce the load capacity of the system compared to that under the buckling modes individually. An example of mode interaction is the thin box section which develops local buckles at an early stage of loading, as shown greatly exaggerated here.
The behaviour of the column is influenced by these local buckles, and gross column buckle will occur at a load much less than the ideal Euler load. The Steel Structures Code, AS 1250 *op cit.* sets out rules for the avoidance of mode interaction in large components, and its guidelines should be followed in design.

Buckling has mixed blessings in automotive applications. The photograph on the left illustrates how local buckling of a car's thin-walled A-pillar dramatically reduces passenger cell integrity in the event of roll-over.
Conversely, the energy absorbed by plastic buckling can reduce significantly the injuries suffered by a vehicle's occupants in the event of a crash. The energy absorption capability of thin- walled sections is demonstrated clearly by the experiment photographed on the right. *(from Murray op cit)*



The detailed analysis of most practical buckle-prone structures is too complex mathematically to attempt here. We therefore examine instead some mechanisms which demonstrate (un)stable behaviour similar to that of structures. The mechanisms allow us to appreciate buckling behaviour and the tools used to analyse it, and to introduce the concept of imperfections which must occur in practical components and which have a relatively large effect on buckling behaviour and safety.
This work leads to the derivation of a design equation for practical columns, in which the twin failure modes of strength and geometric instability invariably interact. This interaction is apparent also in the behaviour of cracks - the subject of a later chapter.
Prediction of the plastic collapse of sub-sea pipelines is also addressed.

Shear:

For the rigid frame structure shown, the approximate horizontal shear at the base of column 2 (assuming all column stiffnesses are equal) is 2.50 k [11.25 kN]

Base Shear - International Building Code (IBC)

The IBC addresses the probability of significant seismic ground motion by using maps of spectral response accelerations (**S_s** and **S_1**) for various geographic locations (see IBC Figures 1615(1) through 1615(10)). These mapped spectral response accelerations are combined with soil conditions and building occupancy classifications to determine Seismic Design Categories A through F for various structures. Seismic Design Category A indicates a structure that is expected to experience very minor (if any) seismic activity. Seismic Design Category F indicates a structure with very high probability of experiencing significant seismic activity.

The *equivalent static force procedure* in the International Building Code (IBC 1617.4) specifies the following formula for calculating base shear **(V)**:

$$\mathbf{V = C_s W} \quad \text{(IBC Equation 16-34)}$$

where the seismic response coefficient, **C_s**, is defined as:

$$\mathbf{C_s = (2/3)\, F_v S_1 I_E / R\, T} \quad \text{(IBC equations 16-36, 16-17, and 16-19)}$$

The IBC specifies the following upper and lower bounds for **C_s**:

Upper bound: $\mathbf{C_s < (2/3)\, F_a\, S_s\, I_E / R}$ (IBC Equations 16-35, 16-16, and 16-18)

Lower bound: $\mathbf{C_s > (0.044)\,(2/3)\, F_a\, S_s\, I_E}$ (IBC Equations 16-37, 16-16, and 16-18)

An additional lower bound applies for structures in Seismic Design Categories E and F, or structures with a large spectral response acceleration for one-second period of vibration, **S_1** > 0.6g:

$$\mathbf{C_s > 0.5\, S_1\, I_E / R} \quad \text{(IBC Equation 16-38)}$$

The upper bound value for $\mathbf{C_s}$ tends to govern for relatively stiff structures that exhibit a small (short) fundamental period of vibration (**T**). The lower bound values for $\mathbf{C_s}$ tend to govern for relatively flexible structures that exhibit a large (long) fundamental period of vibration (**T**).

The terms used to calculate base shear (**V**) in IBC Equations 16-34 through 16-38 are defined as follows:

W = effective seismic weight of the structure (dead loads plus applicable portions of some storage loads and snow loads, as specified in IBC 1617.4.1)

$\mathbf{I_E}$ = seismic importance factor (see IBC Table 1604.5)

The importance factor is essentially an extra safety adjustment used to increase the calculated load on a structure based on its occupancy and/or function. Essential facilities (such as hospitals, fire and police stations, etc.) have the highest seismic importance factors ($\mathbf{I_E}$= 1.5), while buildings where people congregate (such as schools, auditoriums, etc.) also have relatively high seismic importance factors ($\mathbf{I_E}$ = 1.25). Other structures have a seismic importance factor of unity ($\mathbf{I_E}$ = 1.0). Higher importance factors are intended to insure that structural integrity is not compromised and important facilities remain operational during emergencies and natural disasters. Based on typical occupancy classifications for most wood structures, wood buildings are frequently designed using an importance factor of unity ($\mathbf{I_E}$ = 1.0).

Designers should note that the seismic importance factor ($\mathbf{I_E}$) is not identical to the importance factor for wind ($\mathbf{I_w}$) nor the importance factor for snow ($\mathbf{I_s}$).

T = fundamental (natural) period of vibration for a structure
The IBC provides the following simplified method for estimating **T** based on the height of the structure ($\mathbf{h_n}$):

$$\mathbf{T = C_t (h_n)^{3/4}} \qquad \text{(IBC Equation 16-39)}$$

where $\mathbf{C_t}$ = 0.02 for wood structures
$\mathbf{h_n}$ = height of the top level of a structure (ft)

For structures with flat roofs, $\mathbf{h_n}$ is the distance from the ground to the roof/ceiling system. For structures with sloped (pitched) roofs, $\mathbf{h_n}$may be taken as either the height of the ceiling system above the ground or as the mean roof height.

R= structural response modification factor (see IBC Table 1617.6)

The **R** factor is intended to account for inelastic structural behavior and the ability of a structure to displace/deform and dissipate energy without failing. Since all **R** factors specified in IBC Table 1617.6 are greater than unity (**R** > 1.0), the **R** factor effectively reduces the calculated base shear (**V**) by varying amounts depending on the ductility of a structure. In general, ductile structural systems should have higher **R** factors than brittle structural systems. A typical value of **R** for many low-rise wood structures is:

- **R = 6** for light frame wood buildings with shear walls that support gravity loads and *simultaneously* resist lateral loads

The following additional **R** factor also applies to wood structures, but is associated with less commonly used structural systems:

- **R = 6.5** for light frame wood buildings in which the frame system supports gravity loads *independently* of the shear panels that resist lateral loads

$\mathbf{S_s}$ and $\mathbf{S_1}$ are maximum spectral response accelerations for short (0.2 second) periods of vibration and for longer (1.0 second) periods of vibration, respectively. Values for $\mathbf{S_s}$ and $\mathbf{S_1}$ are provided as contour lines superimposed on maps of the United States (see IBC Figures 1615(1) through 1615(10)), in units of percent acceleration due to gravity (%g).

$\mathbf{F_v}$ and $\mathbf{F_a}$ are seismic coefficients associated with structural sensitivity to the velocity and acceleration (respectively) of seismic ground motion. $\mathbf{F_v}$ and $\mathbf{F_a}$are based on the spectral response accelerations ($\mathbf{S_s}$ and$\mathbf{S_1}$) associated with the geographic location of the structure and soil conditions at the site. Values for $\mathbf{F_v}$ and $\mathbf{F_a}$ are specified in IBC Tables 1615.1.2(1) and 1615.1.2(2).

Lateral forces that counteract the base shear, **V**, are assumed to act at each story level of the structure. The magnitude of each story force,$\mathbf{F_x}$, is determined from the following formula:

$$F_x = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} V$$

(IBC Equations 16-41 and 16-42)

where:

$\mathbf{h_x}$ is the height from the base of the structure to level *x*

w_x is the portion of the building weight assumed to be ìlumpedî at level **x**. w_x typically includes the total weight of the floor or ceiling/roof system at level **x**, plus half the weight of the vertical elements (walls; columns) located immediately below level **x** and half the weight of the vertical elements located immediately above level **x**.

k is an exponent that affects the distribution of lateral forces to various story levels. The magnitude of **k** is determined based on the natural (fundamental) period of vibration of the structure, **T**:

$\mathbf{k} = 1$	when $\mathbf{T} < 0.5$s
$1 < \mathbf{k} < 2$	when $0.5\text{ s} < \mathbf{T} < 2.5\text{ s}$
$\mathbf{k} = 2$	when $\mathbf{T} > 2.5$s

When $\mathbf{k} = 1$ the equivalent lateral story forces ($\mathbf{F_x}$) vary linearly with height. When $\mathbf{k} > 1$ the equivalent lateral story forces vary nonlinearly with height to approximate the effects of higher modes of structural vibration. Since $\mathbf{k} = 1$ when$\mathbf{T} < 0.5$s, it is apparent from IBC Equation 16-39 that $\mathbf{k} = 1$ for buildings less than 73.1 ft tall. Thus, $\mathbf{k} = 1$ for most wood buildings.

EXCEPTION: In regions of low seismic activity (Seismic Design Category A) it is not necessary to calculate the base shear, **V**. Furthermore, lateral story forces ($\mathbf{F_x}$) are simply assumed to be 1% of the ìlumped weightî at level **x**:

$\mathbf{F_x} = 0.01\, w_x$ (IBC Equation 16-27)

IBC Simplified Lateral Forces

An alternate (simplified) procedure can be used to determine the base shear, **V**, and story forces, $\mathbf{F_x}$, for low-rise, ìstandard occupancyî light frame wood structures that are 3 stories or less in height (see IBC 1616.6.1, 1617.5, and Table 1604.5):

$\mathbf{V = (1.2)\,(2/3)\,F_aS_s\,W/\,R}$ (IBC Equations 16-49, 16-16, and 16-18)

$\mathbf{F_x = (1.2)\,(2/3)\,F_a\,S_s}\,w_x\,\mathbf{/\,R}$ (IBC Equations 16-50, 16-16, and 16-18)

This simplified procedure eliminates explicit consideration of the natural (fundamental) period of structural vibration, **T**, and the height to each floor level, h_x, when calculating base shear, **V**, and story forces, F_x.

IBC Comparison

In order to provide a comparison between the *equivalent lateral force method* and the *simplified lateral force method*, consider a 3-story wood-frame structure with:

- Building weight distributed in equal proportions to the 1st level, 2nd level, and 3rd (roof) level of the structure ($w_1 = w_2 = w_3 = W/3$), and
- Equal distance (height) between each level of the structure ($h_1 = h$; $h_2 = 2h$; $h_3 = h_n = 3h$).

Since the total height ($h_n = 3h$) of a 3-story wood structure will be less than 73.1 ft, this means that $k = 1$. As illustrated below, solving IBC Equation 16-41 and 16-42 for the *equivalent lateral force* at each level results in lateral force magnitudes of:

- 50% of the base shear at the top (roof) level ($F_3 = F_n = V/2$)
- 33% of the base shear at the 2nd level of the structure ($F_2 = V/3$)
- 17% of the base shear at the 1st level of the structure ($F_1 = V/6$)

Alternatively, solving IBC Equation 16-50, 16-16 and 16-18 for the *simplified lateral force* at each level results in:

$$F_1 = F_2 = F_3 = V/3$$

IBC Diaphragm Forces

The seismic lateral force applied to the perimeter of floor or roof/ceiling diaphragms at each level of a structure is determined as follows (IBC 1620.3.3):

$$F_{px} = \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} (w_{px})$$

(IBC Equation 16-65)

The IBC also specifies the following lower and upper bounds for $\mathbf{F_{px}}$:

Lower bound: $\mathbf{F_{px} > (0.15)\,(2/3)\,F_aS_s\,I_E\,\boldsymbol{w}_{px}}$

Upper bound: $\mathbf{F_{px} < (0.30)\,(2/3)\,F_aS_s\,I_E\,\boldsymbol{w}_{px}}$

where $\boldsymbol{w}_{\mathbf{px}}$ is the portion of the building weight assumed to be "lumped" with the diaphragm at level $\boldsymbol{x}$.

$\boldsymbol{w}_{\mathbf{px}}$ is similar to $\boldsymbol{w}_{\mathbf{x}}$ used to calculate equivalent lateral story forces, $\mathbf{F_x}$, but does not include the weight of the shear walls that are aligned in the direction of the lateral diaphragm force, $\mathbf{F_{px}}$, under consideration.

The diaphragm force, $\mathbf{F_{px}}$, can be divided by the diaphragm length, **L**, perpendicular to the direction of $\mathbf{F_{px}}$ in order to determine an equivalent uniformly distributed lateral diaphragm load applied to the edge (perimeter) of the diaphragm.

Concrete

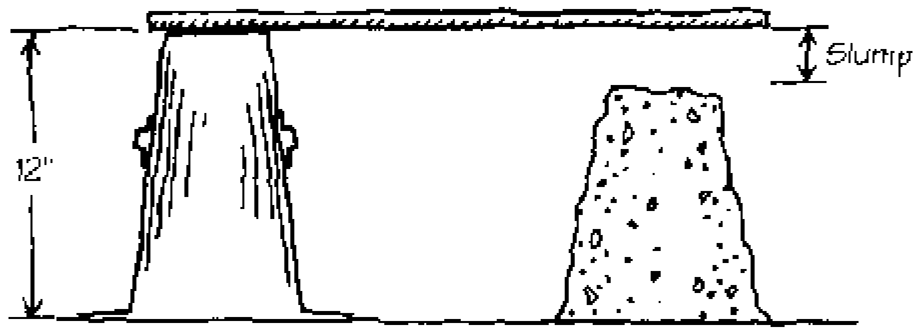


Figure 4. Slump Test..

3.3 Portland Cement

The raw ingredients of Portland cement are iron ore, lime, alumina and silica, which are used in various proportions depending upon the type of cement being made. These are ground up and fired in a kiln to produce a clinker. After cooling, the clinker is very finery ground (to about the texture of talcum powder) and a small amount of gypsum is added to retard the initial setting time. There are five basic types of Portland cement in use today:

- **Type I** - General purpose
- **Type II** - Sulfate resisting, concrete in contact with high sulfate soils
- **Type III** - High early strength, which gains strength faster than Type I, enabling forms to be removed sooner
- **Type IV** - Low heat of hydration, for use in massive construction
- **Type V** - Severe sulfate resisting

Type I is the least expensive and is used for the majority of concrete structures. Type III is also frequently employed because it enables forms to be reused quickly, allowing construction time to be reduced. It is important to note that while Type II gains strength faster than Type I, it does not take its initial set any sooner).

3.4 Aggregates

Fine aggregate (sand) is made up of particles which can pass through a 3/8 in sieve; coarse aggregates are larger than 3/8 inch in size. Aggregates should be clean, hard, and well-graded, without natural cleavage planes such as those that occur in slate or shale. The quality of aggregates is very important since they make up about 60 to 75% of the volume of the concrete; it is impossible to make good concrete with poor aggregates. The grading of both fine and coarse aggregate is very significant because having a full range of sizes reduces the amount of cement paste needed. Well-graded aggregates tend to make the mix more workable as well.

Normal concrete is made using sand and stones, but lightweight concrete can be made using industrial by-products such as expanded slag or clay as lightweight aggregates. This concrete weighs only 90 to 125 pcf and high strengths are more difficult to achieve because of the weaker aggregates. However, considerable savings can be realized in terms of the building self-weight, which may be very important when building on certain types of soil. Insulating concrete is made using perlite and vermiculite, it weighs only about 15 to 40 pcf and has no structural value. promote the safe and efficient design and construction of concrete structures. The ACI has numerous publications to assist designers and builders; the most important one in terms of building structures is entitled Building Code Requirements for Reinforced Concrete and Commentary. It is produced by Committee 318 of the American Concrete Institute and contains the basic guidelines for building code officials, architects, engineers, and builders regarding the use of reinforced concrete for building structures. Information is presented concerning materials and construction practices, standard tests, analysis and design, and structural systems. This document has been adopted by most building code authorities in the United States as a standard reference. It provides all rules regarding reinforcing sizes, fabrication, and placement and is an invaluable resource for both the designer and the detailer.

Periodic updates occur (1956, 1963, 1971, 1977, 1983, and 1989), and this text makes constant reference to the 1989 edition, calling it the ACI Code or merely the Code. Documents and officials also refer to it by its numerical designation, ACI 318-89.

3.7 References

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Mainstone, R, J. (1975). Developments in Structural Form, The MIT Press, Cambridge.

3.5 Admixtures

Admixtures are chemicals which are added to the mix to achieve special purposes or to meet certain construction conditions. There are basically four types: air-entraining agents, workability agents, retarding agents, and accelerating agents.

In climates where the concrete will be exposed to freeze-thaw cycles air is deliberately mixed in with the concrete in the form of billions of tiny air bubbles about 0.004 in in diameter. The bubbles provide interconnected pathways so that water near the surface can escape as it expands due to freezing temperatures. Without air-entraining, the surface of concrete will almost always spall off when subjected to repeated freezing and thawing. (Air-entraining also has the very beneficial side effect of increasing workability without an increase in the water content.) Entrained air is not to be confused with entrapped air, which creates much larger voids and is caused by improper placement and consolidation of the concrete. Entrapped air, unlike entrained air, is never beneficial.

Workability agents, which include water-reducing agents and plasticizers, serve to reduce the tendency of cement particles to bind together in flocs and thus escape complete hydration. Fly ash, a by-product of the burning of coal that has some cementitious properties, is often used to accomplish a similar purpose. Superplasticizers are relatively new admixtures which when added to a mixture serve to increase the slump greatly, making the mixture very soupy for a short time and enabling a low-water-content or otherwise very stiff) concrete to be easily placed. Superplasticizers are responsible for the recent development of very high strength concretes, some in excess of 15,000 psi because they greatly reduce the need for excess water for workability.

Retarders are used to slow the set of concrete when large masses must be placed and the concrete must remain plastic for a long period of time to prevent the formation of "cold joints" between one batch of concrete and the next batch. Accelerators serve to increase the rate of strength gain and to decrease the initial setting time. This can be beneficial when concrete must be placed on a steep slope with a single form or when it is desirable to reduce the time period in which concrete must be protected from freezing. The best known accelerator is calcium chloride, which acts to increase the heat of hydration, thereby causing the concrete to set up faster.

Other types of chemical additives are available for a wide range of purposes. Some of these can have deleterious side effects on strength gain, shrinkage, and other characteristics of concrete, and test batches are advisable if there is any doubt concerning the use of a particular admixture.

3.6 The ACI Code

The American Concrete Institute (ACI), based in Detroit, Michigan, is an organization of design professionals, researchers, producers, and constructors. One of its functions is to

Concrete Mixture

4. LATERAL FORCES

%13-%16 percent of scored

A. Principles

Apply lateral forces principles to the design and construction of buildings.

1. Building Design

Analyze behavior of building structural systems when subjected to lateral loads, including load path, loading effects and building response, lateral load resisting systems, and nature of lateral loads on structures.

2. Building Systems and their Integration

Consider lateral load resisting systems and elements including braced frames, shear walls, rigid frames, flexible and rigid membranes, foundations, and retaining walls to integrate into the design.

3. Implications of Design Decisions

Assess impact of lateral loads design decisions such as cost, building configuration, building function, and construction sequencing and schedule.

B. Materials & Technology

Apply lateral forces principles to the design and construction of buildings.

1. Construction Details and Constructability

Examine construction details and non-structural elements pertaining to lateral forces.

2. Construction Materials

Select construction materials that resist lateral forces.

STRUCTURAL SYSTEMS REFERENCE INDEX

The following is a list of formulas and references that will be available to all candidates during their Structural System Exam, with the permission of the *American Institute of Steel Construction*, the *Canadian Institute of Steel Construction*, the *International Code Council*, and the *National Research Council Canada*. NCARB does not have copyright permission to reproduce these references *except* in testing centers. In order to help candidates properly prepare for the test, sources for each reference are listed.

Reference

International System of Units in Structural Engineering *See Attached*
Bean Diagrams and Formula - Nomenclature **A:** *pg.* 2-293 & 2-294
Simple Beam Formulas - Conditions 1-3 **A:** *pg.* 2-296 or **E:** *pg.* 3-211
Simple Beam Formulas - Conditions 4-6 **A:** *pg.* 2-297 or **E:** *pg.* 3-212
Simple Beam Formulas - Conditions 7-9 **A:** *pg.* 2-298 or **E:** *pg.* 3-213
Beam Fixed at Both Ends Formulas - Conditions 15-17 **A:** *pg.* 2-301 or **E:** *pg.* 3-216
Beam Overhanging One Support Formulas - Conditions 24-28 **A:** *pg.* 2-304 & 2-305 or **E:** *pg.* 3-219 & 3-220

Dimensions and Properties of US Members

W 44 thru 27 - Dimensions and Properties **A:** *pg.* 1-10 thru 1-16 or **E:** *pg.* 1-10 thru 1-15
W 24 thru W14x145 - Dimensions and Properties **A:** *pg.* 1-18 thru 1-25 or **E:** *pg.* 1-16 thru 1-21
W 14x132 thru W4 - Dimensions and Properties **A:** *pg.* 1-26 thru 1-32 or **E:** *pg.* 1-22 thru 1-27
C - Dimensions and Properties **A:** *pg.* 1-40 thru 1-41 or **E:** *pg.* 1-34 thru 1-35
Angles Properties **A:** *pg.* 1-46 thru 1-52 or **E:** *pg.* 1-40 thru 1-47
Rectangular HSS Dimensions and Properties **A:** *pg.* 1-97 thru 1-103 or **E:** *pg.* 1-72 thru 1-89
Square HSS Dimensions and Properties **A:** *pg.* 1-94 thru 1-96 or **E:** *pg.* 1-90 thru 1-93
Round HSS Dimensions and Properties **E:** *pg.* 1-94 thru 1-98
Bolts Threaded Parts, and Rivets Loads in Tension and Shear **A:** *pg.* 4-3 & 4-5

Dimensions and Properties of Canadian Members

W1100 thru W610 - Properties, Dimensions and Surface Areas **B:** *pg.* 6-40 thru 6-45
W530 thru W360x216 - Properties, Dimensions and Surface Areas **B:** *pg.* 6-46 thru 6-49
W360x196 thru W100 - Properties, Dimensions and Surface Areas **B:** *pg.* 6-50 thru 6-55
C - Shapes **B:** *pg.* 6-66 thru 6-67
MC - Shapes **B:** *pg.* 6-68 thru 6-71
Angles Properties About Geometric Axis, Dimension & Properties
About Principal Axis **B:** *pg.* 6-72 thru 6-81
Rectangular Hollow Structural Sections Properties and Dimensions **B:** *pg.* 6-106 thru 6-107
Square Hollow Structural Sections Properties and Dimensions **B:** *pg.* 6-108 thru 6-109
Round Hollow Structural Sections Properties and Dimensions **B:** *pg.* 6-110 thru 6-111
Canadian Bolt Slip Resistance **B:** *pg.* 3-8 & 3-15

Live and Concentrated Loads

Uniform and Concentrated Loads IBC table 1607.1 **C:** *pg.* 285 & 286
Canada: Live loads on Area of Floor or Roof **D:** *Division B*, 4-8 thru 4-10
Sources:

A. United States. American Institute of Steel Construction, Inc. Manual of Steel Construction: Allowable Stress Design; 9th Edition. Chicago, Illinois, 1989.

B. Canada. Canadian Institute of Steel Construction. Handbook of Steel Construction; 9th Edition. Toronto, Ontario, 2006.
C. United States. International Code Council, Inc. 2006 International Building Code. Country Club Hills, Illinois, 2006.
D. Canada. Institute for Research in Construction, National Research Council Canada. National Building Code of Canada 2005, Volume 1. Ottawa, Ontario, 2005.
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Second moment of area

From Wikipedia, the free encyclopedia
Jump to: navigation, search
This article is about the moment of inertia as related to the ***bending of a beam****. For the moment of inertia dealing with the kinetics of a rotating object, see Moment of inertia.*

The **second moment of area**, also known as "moment of inertia of plane area", "polar moment of inertia","area moment of inertia", or "second area moment", is a property of a cross-section that can be used to predict the resistance of a beam to bending and deflection around an axis that lies in the cross-sectional plane. The stress in, and deflection of, a beam under load depends not only on the load but also on the geometry of the beam's cross-section: larger values of second moment cause smaller values of stress and deflection. This is why beams with larger second moments of area, such as I-beams, are used in building construction in preference to other beams with the same cross-sectional area.

Contents

[hide]

[edit] Nomenclature and units

When the second moment of area is referred to as area moment of inertia, confusion with the mass moment of inertia can arise. Often, each of these is referred to simply as "moment of inertia". Use of the symbol J for the second moment of area marks it as distinct from the mass moment of inertia, often given the symbol *I*. Which 'inertia' is meant (bending, twisting, or kinetic) is also usually clear from the context, and from the units: moments of area have units of length to the fourth power [L^4], whereas the mass moment of inertia has units of mass times length squared [$M*L^2$].

See also: moment (physics)

[edit] Intuition

Consider the problem of determining the deflection of a beam of uniform material and uniform cross section, for example, a cantilevered I-beam with a weight on the end. If the beam is long, the dominant deflection mode is bending rather than shear. Thinking of the beam as made of elements along its length, like sliced bread, consider the load on one of these slices. The load is a bending moment. The top is in tension and the bottom is in compression. Points on a horizontal line in the centre of the slice experience no load: this line is known as the neutral axis. We wish to describe the effects on beam stiffness due to the cross-sectional shape of the beam as a single number; this is the second moment of area.

Assuming linear elasticity, the stress at any point in the beam is proportional to the strain it experiences. (This particular stress-strain relationship is described by Hooke's law). The strain in the beam is greatest at the top, decreases linearly to zero at the neutral axis, and continues to decrease linearly to the bottom. The energy is proportional to the square of the strain. Thus, the energy stored in a cross-sectional slice of the beam bent by some amount is proportional to the sum of the square of the distance to the neutral axis. This strain-energy storage is described well by the Minimum total potential energy principle.

Let the beam lie along the *z* axis with *y* pointing up. The bending moment is around the *x* axis. Considering only the factor due to the cross-sectional shape of the beam gives the second moment of area:

$$J_{xx} = \int_A y^2 \, dA$$

[edit] Definition

Let *A* be a beam cross section perpendicular to the beam's axis. That is, *A* is a plane region of a particular shape. Let *i* and *j* be straight lines in the plane (by definition, perpendicular to the axis of the beam). Then the second moment of area of the region *A* about the two lines *i* and *j* is:

$$J_{ij} = \int_A nm \, \mathrm{d}A$$

where

- J_{ij} = the second moment of area about the lines *i* and *j*, defined here with positive sign following common practice adopted in structural analysis (see e.g., Pilkey 2002, p. 15).
- d*A* is an elemental area
- *n*, *m* are the perpendicular distances respectively from the line *i* and *j* to the element d*A*

Keeping track of the second moments of area is confusing and tedious. A holistic approach is to note that the second moment of area is fundamentally a tensor — an object that provides deflection direction and magnitude, or elastic energy, as a function of loading direction. Much like the mass tensor of inertia, the area tensor of inertia is

$$J_{ij} = \int (r^2\delta_{ij} - r_i r_j)\,\mathrm{d}A$$

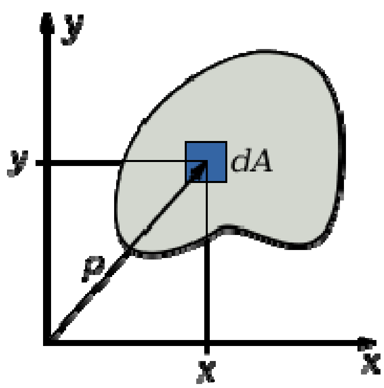
where δ_{ij} is the Kronecker delta.

The reason for the $r^2\delta_{ij} - r_i r_j$ as opposed to just the outer product, $r_i r_j$, is that the tensor operates on moments. That is, we would like the expression

$$\tau^{\mathsf{T}} J \tau$$

to be proportional to the energy for a given torque, τ. See Moment of inertia#Comparison with covariance matrix for details. The unit for second moment of area is length to the fourth power (typically mm^4, in^4, etc.)

[edit] Second moments and product moments



A schematic showing how the **second moment of area** is calculated for an arbitrary shape. ρ is the radial distance to the element dA, with projection x and y on axis.

When the lines i and j are, for example, both the x axis, and the bending force is parallel to the y axis, the second moment of area can be computed as

$$J_{xx} = \iint_A y^2\,\mathrm{d}x\,\mathrm{d}y$$

For calculating the stresses of bending, the above can only be used on its own when sections are symmetrical about the x-axis. When this is not the case, the product moment of area, J_{xy} (see below), is also required.

Then the J_{zz}, where z is normal to the area, which is commonly referred to as the *polar moment of inertia* is by the perpendicular axis theorem[1]:

$$J_{zz} = J_{xx} + J_{yy}$$

It is a quantity used to predict an object's ability to resist torsion, in objects (or segments of objects) with an invariant circular cross section and no significant warping or out-of-plane deformation.[2] It is used to calculate the angular displacement of an object subjected to a torque. Some authors use J_x instead of J_{xx} and J_y rather than J_{yy}.

While the second moment of area about an axis describes a beam's resistance to bending along that axis, some beams will deflect in a direction other than the direction they are loaded. For example, imagine a leaf spring running along the *x* axis but oriented so that its surface normal is in the (0,1,1) direction. If you push down on it (0,0,−1), that will result in a bending moment in the (0,1,0) direction. However, although it will move down, it will primarily deflect in the (0,−1,−1) direction. This behavior is captured by the **product moment of area**, J_{xy} (sometimes known as the area product of inertia). This is defined as

$$J_{xy} = \iint_A xy \, \mathrm{d}x \, \mathrm{d}y$$

- x = the perpendicular distance to the element dA from the axis y
- y = the perpendicular distance to the element dA from the axis x

  Note that J_{xy} is defined here with positive sign following common practice adopted in structural analysis (see e.g., Pilkey 2002, p. 15).

The product moment of area is significant for determining the bending stress in an asymmetric cross section. Unlike the second moment of area, the product moment of area may give both negative and positive values. A coordinate system in which the product moment is zero is referred to as a set of principal axes, and the second moments of area calculated with respect to the principal axes will assume their maxima and minima. This is a direct result of the spectral theorem applied to the moment tensor, described below, because it is symmetric positive semi-definite.

[edit] Coordinate transformations

When calculating moments of the section it is often practical to compute them in one coordinate system (typically bound to the section shape) and then transform to another one using co-ordinate transformations. As an outer product of vectors, this tensor transforms as a type (0,2) tensor.

[edit] Parallel axis theorem

Main article: parallel axis theorem

The parallel axis theorem can be used to determine the moment of an object about any axis, given the second moment of area of the object about the parallel axis through the object's center of mass (or centroid) and the perpendicular distance between the axes.

$$J_{xx} = (J_{xx})_{CG} + Ad^2$$

- J_{xx} = the second moment of area with respect to the x-axis
- J_{xxCG} = the second moment of area with respect to an axis parallel to x and passing through the centroid of the shape (coincides with the neutral axis)
- A = area of the shape
- d = the distance between the x-axis and the centroidal axis

[edit] Axis rotation in the xy plane

The following formulae can be used to calculate moments of the section in a co-ordinate system rotated in the xy plane relative to the original co-ordinate system:

$$J_{xx}{}^* = \frac{J_{xx} + J_{yy}}{2} + \frac{J_{xx} - J_{yy}}{2}\cos(2\phi) - J_{xy}\sin(2\phi)$$
$$J_{yy}{}^* = \frac{J_{xx} + J_{yy}}{2} - \frac{J_{xx} - J_{yy}}{2}\cos(2\phi) + J_{xy}\sin(2\phi)$$
$$J_{xy}{}^* = \frac{J_{xx} - J_{yy}}{2}\sin(2\phi) + J_{xy}\cos(2\phi)$$

- ϕ= the angle of rotation (anticlockwise sense):

$$x^* = x\cos\phi + y\sin\phi$$
$$y^* = -x\sin\phi + y\cos\phi$$

- J_{xx}, J_{yy} and J_{xy} = the second moments and the product moment of area in the original coordinate system
- $J_{xx}{}^*$, $J_{yy}{}^*$ and $J_{xy}{}^*$ = the second moments and the product moment of area in the rotated coordinate system.

The value of the angle ϕ, which will give a product moment of area of zero, is equal to:

$$\phi = -\frac{1}{2}\arctan\frac{2J_{xy}}{J_{xx} - J_{yy}}$$

This angle is the angle between the axes of the original coordinate system and the principal axes of the cross section.

[edit] Stress in a beam

The general form of the classic bending formula for a beam in co-ordinate system having origin located at the neutral axis of the beam is (Pilkey 2002, p. 17):

$$\sigma = -\frac{M_y J_{xx} + M_x J_{xy}}{J_{xx} J_{yy} - J_{xy}^2} x + \frac{M_x J_{yy} + M_y J_{xy}}{J_{xx} J_{yy} - J_{xy}^2} y$$

- σ is the normal stress in the beam due to bending
- x = the perpendicular distance to the centroidal y-axis
- y = the perpendicular distance to the centroidal x-axis
- M_y = the bending moment about the y-axis
- M_x = the bending moment about the x-axis
- J_{xx} = the second moment of area about x-axis
- J_{yy} = the second moment of area about y-axis
- J_{xy} = the product moment of area

If the coordinate system is chosen to give a product moment of area equal to zero, the formula simplifies to:

$$\sigma = -\frac{M_y}{J_{yy}} x + \frac{M_x}{J_{xx}} y$$

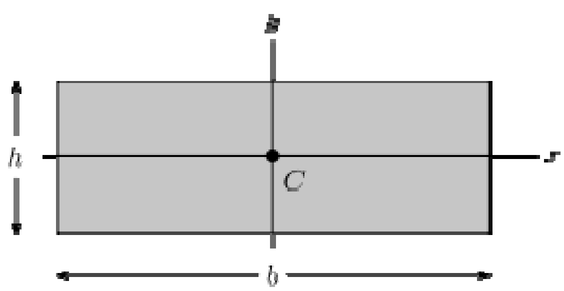
If additionally the beam is only subjected to bending about one axis, the formula simplifies further:

$$\sigma = \frac{M}{J_{xx}} y$$

[edit] Second moment of area for various cross sections

See list of area moments of inertia for other cross sections.

[edit] Rectangular cross section



$$J_{xx} = \frac{bh^3}{12}$$

$$J_{yy} = \frac{hb^3}{12}$$

- b = width (x-dimension),
- h = height (y-dimension)

[edit] Circular cross section

$$J_{xx} = J_{yy} = \frac{\pi d^4}{64} = \frac{\pi r^4}{4}$$
$$J_{zz} = \frac{\pi d^4}{32} = \frac{\pi r^4}{2}$$

- d = diameter
- r = radius

[edit] Hollow Cylindrical Cross Section

$$J_{xx} = J_{yy} = \frac{\pi}{64}({D_O}^4 - {D_I}^4) = \frac{\pi}{4}({r_O}^4 - {r_I}^4)$$
$$J_{zz} = \frac{\pi}{32}({D_O}^4 - {D_I}^4) = \frac{\pi}{2}({r_O}^4 - {r_I}^4)$$

- D_O= outside diameter
- D_I= inside diameter
- r_O= outside radius
- r_I= inside radius

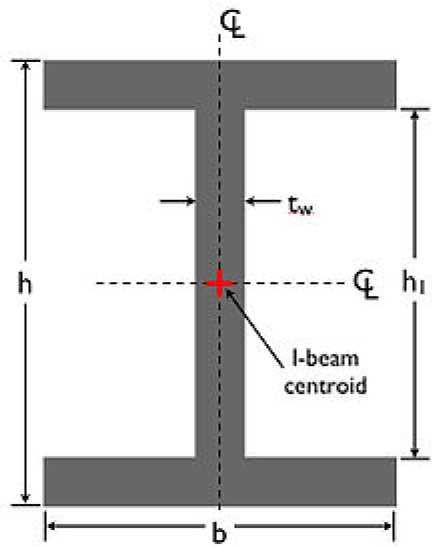
[edit] Composite cross section

When it is easier to compute the moment for an item as a combination of pieces, the second moment of area is calculated by applying the parallel axis theorem to each piece and adding the terms:

$$J_{xx} = \sum \left(J_{\text{local}} + y^2 A\right)$$
$$J_{yy} = \sum \left(J_{\text{local}} + x^2 A\right)$$

- y = distance from x-axis
- x = distance from y-axis
- A = surface area of part
- I_{local} is the second moment of area for that part of the composite, in the appropriate direction (i.e. J_{xx} or J_{yy} respectively).

[edit] "I-beam" cross section

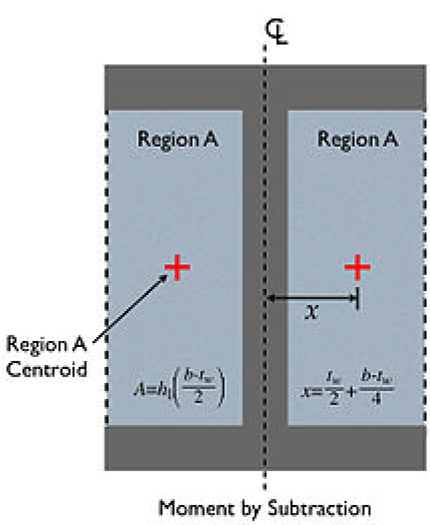


I-beam

The I-beam can be analyzed as either three pieces added together or as a large piece with two pieces removed from it. Either of these methods will require use of the formula for composite cross section. This section only covers *doubly symmetric* I-beams, meaning the shape has two planes of symmetry.

- b = width (x-dimension),
- h = height (y-dimension)
- t_w = width of central webbing
- h_1 = inside distance between flanges (usually referred to as h_w, the height of the web)

This formula uses the method of a block with two pieces removed. (While this may not be the easiest way to do this calculation, it is instructive in demonstrating how to subtract moments).



I-beam diagram, moment by subtraction

Since the I-beam is symmetrical with respect to the y-axis the J_{xx} has no component for the centroid of the blocks removed being offset above or below the x axis.

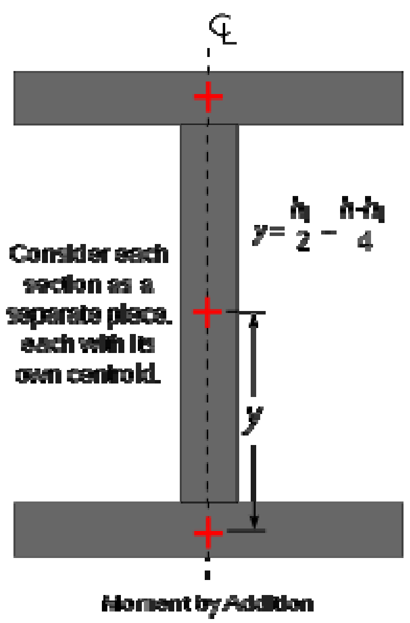
$$J_{xx} = \frac{bh^3 - 2\left(\frac{b-t_w}{2}\right)h_1^{\,3}}{12}$$

When computing J_{yy} it is necessary to allow for the fact that the pieces being removed are offset from the Y axis, this results in the Ax^2 term.

$$J_{yy} = \frac{hb^3}{12} - 2\left(\frac{h_1\left(\frac{b-t_w}{2}\right)^3}{12} + Ax^2\right)$$

- A = Area contained within the middle of one of the 'C' shapes of created by two flanges and the webbing on one side of the cross section = $h_1\left(\frac{b-t_w}{2}\right)$
- x = distance of the centroid of the area contained in the 'C' shape from the y-axis of the beam = $\frac{b+t_w}{4}$

Doing the same calculation by combining three pieces, the center webbing plus identical contributions for the top and bottom piece:



I-beam diagram, moment by addition

Since the centroids of all three pieces are on the y-axis J_{yy} can be computed just by adding the moments together.

$$J_{yy} = \frac{h_1 t_w^3}{12} + 2\frac{\left(\frac{h-h_1}{2}\right) b^3}{12}$$

However, this time the law for composition with offsets must be used for J_{xx} because the centroids of the top and bottom are offset from the centroid of the whole I-beam.

- A = Area of the top or bottom piece = $b\left(\frac{h-h_1}{2}\right)$
- y = offset of the centroid of the top or bottom piece from the centroid of the whole I-beam = $\frac{h+h_1}{4}$

$$J_{xx} = \frac{t_w h_1^3}{12} + 2\left(\frac{b\left(\frac{h-h_1}{2}\right)^3}{12} + Ay^2\right) = \frac{t_w h_1^3}{12} + 2\left(\frac{b\left(\frac{h-h_1}{2}\right)^3}{12} + b\left(\frac{h-h_1}{2}\right)\left(\frac{h}{}\right.\right.$$

[edit] Any cross section defined as polygon

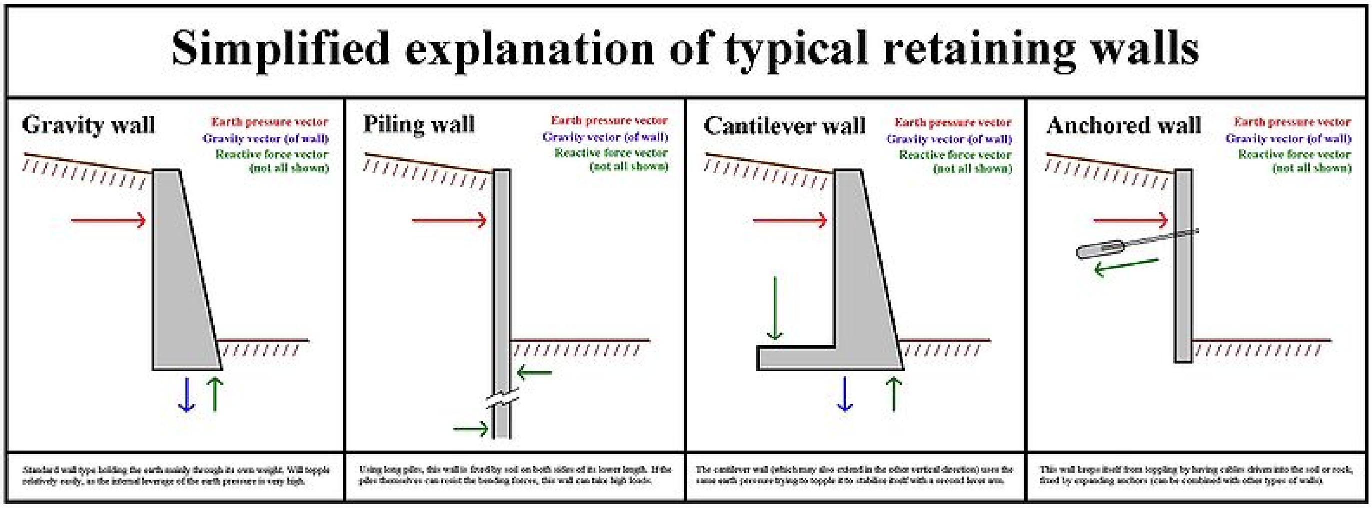
The second moments of area for any cross section defined as a simple polygon on XY plane can be computed in a generic way by summing contributions from each segment of a polygon.

For each segment defined by two consecutive points of the polygon, consider a triangle with two corners at these points and third corner at the origin of the coordinates. Integration by the area of that triangle and summing by the polygon segments yields:

$$J_{xx} = \frac{1}{12}\sum_{i=1}^{n-1}(y_i^2 + y_i y_{i+1} + y_{i+1}^2)a_i$$
$$J_{yy} = \frac{1}{12}\sum_{i=1}^{n-1}(x_i^2 + x_i x_{i+1} + x_{i+1}^2)a_i$$
$$J_{xy} = \frac{1}{24}\sum_{i=1}^{n-1}(x_i y_{i+1} + 2x_i y_i + 2x_{i+1} y_{i+1} + x_{i+1} y_i)a_i$$

- $a_i = x_i y_{i+1} - x_{i+1} y_i$ is twice the (signed) area of the elementary triangle,
- index i passes over all n points in the polygon, which is considered closed, i.e. point n is point 1

These formulae imply that points defining the polygon are ordered in anticlockwise manner; for clockwisely defined polygons it will give negative values. See polygon area for calculating area and centroid of the section using similar formulae.


Simplified explanation of typical retaining walls
Gravity wall
Earth pressure vector
Gravity vector (of wall)
Reactive force vector
(not all shown)
Standard wall type holding the earth mainly through its own weight. Will topple relatively easily, as the internal leverage of the earth pressure is very high.
Piling wall
Earth pressure vector
Gravity vector (of wall)
Reactive force vector
(not all shown)
Using long piles, this wall is fixed by soil on both sides of its lower length. If the piles themselves can resist the bending forces, this wall can take high loads.
Cantilever wall
Earth pressure vector
Gravity vector (of wall)
Reactive force vector
(not all shown)
The cantilever wall (which may also extend in the other vertical direction) uses the same earth pressure trying to topple it to stabilise itself with a second lever arm.
Anchored wall
Earth pressure vector
Gravity vector (of wall)
Reactive force vector
(not all shown)
This wall keeps itself from toppling by having cables driven into the soil or rock, fixed by expanding anchors (can be combined with other types of walls).

Questions

Concrete Mix

1. The most important factor affecting the strength of concrete is the water-to-cement ratio
Not: weather conditions during curing; volume of the mixture; amount of vibration of the mix

1**0.** Concrete should reach its design compressive strength in 28 days.
Not: 3; 7; 32

11. When concrete is held under sustained stress, the strain will continue to increase with time. Creep defines this time-dependent phenomenon.
Not: Shrinkage; Temperature expansion; Contraction

3. A slump cone is used primarily to provide an indication of Strength and workability characteristics of concrete.
Not: Durability and finish; Air entrainment and chemical resistance; Appearance and color

Concrete is an artificial conglomerate stone made essentially of Portland cement, water, and aggregates. When first mixed the water and cement constitute a paste which surrounds all the individual pieces of aggregate to make a plastic mixture. A chemical reaction called hydration takes place between the water and cement, and concrete normally changes from a plastic to a solid state in about 2 hours. Thereafter the concrete continues to gain strength as it cures. A typical strength-gain curve is shown in Figure 1. The industry has adopted the 28-day strength as a reference point, and specifications often refer to compression tests of cylinders of concrete which are crushed 28 days after they are made. The resulting strength is given the designation f'c

Concrete should reach its design compressive strength in 28 days

Not: 3, 7, 32

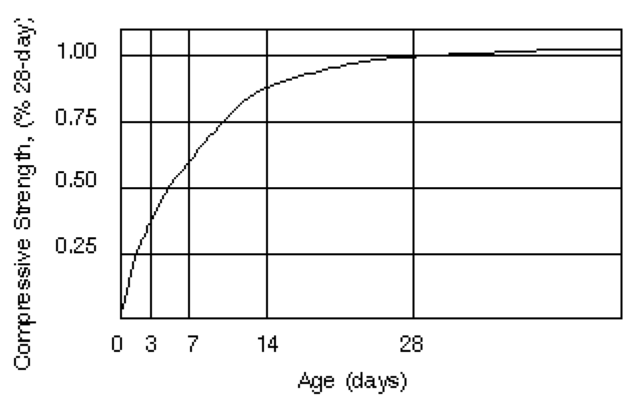


Figure 1. Typical strength-gain curve.

During the first week to 10 days of curing it is important that the concrete not be permitted to freeze or dry out because either of these, occurrences would be very detrimental to the strength development of the concrete. Theoretically, if kept in a moist environment, concrete will gain strength forever, however, in practical terms, about 90% of its strength is gained in the first 28 days.

Concrete has almost no tensile strength (usually measured to be about 10 to 15% of its compressive strength), and for this reason it is almost never used without some form of reinforcing. Its compressive strength depends upon many factors, including the quality and proportions of the ingredients and the curing environment. The single most important indicator of strength is the ratio of the water used compared to the amount of cement. Basically, the lower this ratio is, the higher the final concrete strength will be. (This concept was developed by Duff Abrams of The Portland Cement Association in the early .

$$E = 57{,}000\sqrt{f'_c} \quad (2)$$

E values thus computed have proven to be acceptable amount of vibration of the mix

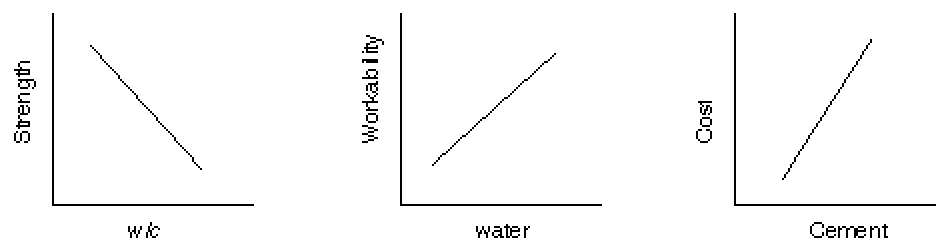


Figure 3. Mix Proportion relationships.

Since larger aggregate sizes have relatively smaller surface areas (for the cement paste to coat) and since less water means less cement, it is often said that one should use the largest practical aggregate size and the stiffest practical mix. (Most building elements are constructed with a maximum aggregate size of 3/4 to 1 in, larger sizes being prohibited by the closeness of the reinforcing bars.)

A good indication of the water content of a mix land thus the workability) can be had from a standard slump test. In this test a metal cone 12 in tall is filled with fresh concrete in a specified manner. When the cone is lifted, the mass of concrete "slumps" downward (Figure 4) and the vertical drop is referred to as the slump. Most concrete mixes have slumps in the 2- to 5-in range.

A slump cone is used primarily to provide an Strength and workability characteristics of concrete.

Not: Durability and finish; Air entrainment and chemical resistance; Appearance and color

The Basic Mix:

A general guide for concrete preparation

The physical properties of density and strength of concrete are determined, in part, by the proportions of the three key ingredients, water, cement, and aggregate. You have your choice of proportioning ingredients by volume or by weight. Proportioning by volume is less accurate, however due to the time constraints of a class time period this may be the preferred method.

A basic mixture of mortar can be made using the volume proportions of 1 water : 2 cement : 3 sand. Most of the student activities can be conducted using this basic mixture. Another "old rule of thumb" for mixing concrete is 1 cement : 2 sand : 3 gravel by volume. Mix the dry ingredients and slowly add water until the concrete is workable. This mixture may need to be modified depending on the aggregate used to provide a concrete of the right workability. The mix should not be too stiff or too sloppy. It is difficult to form good test specimens if it is too stiff. If it is too sloppy, water may separate (bleed) from the mixture.

Remember that water is the key ingredient. Too much water results in weak concrete. Too little water results in a concrete that is unworkable.

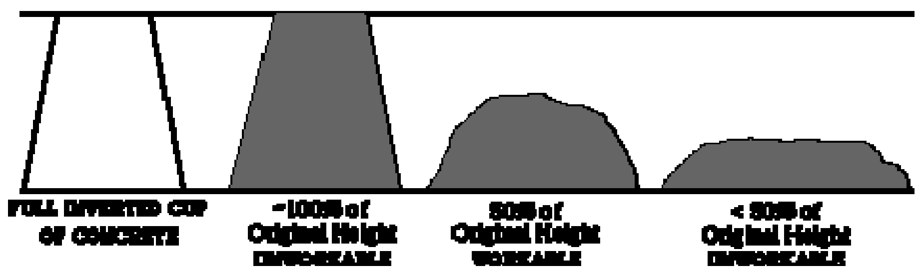
Suggestions:

10. If predetermined quantities are used, the method used to make concrete is to dry blend solids and then slowly add water (with admixtures, if used).
11. It is usual to dissolve admixtures in the mix water before adding it to the concrete. Super plasticizer is an exception.
12. Forms can be made from many materials. Cylindrical forms can be plastic or paper tubes, pipe insulation, cups, etc. The concrete needs to be easily removed from the forms. Pipe insulation from a hardware store was used for lab trials. This foam-like material was easy to work with and is reusable with the addition of tape. The bottom of the forms can be taped, corked, set on glass plates, etc. Small plastic weighing trays or Dairy Queen banana split dishes can be used as forms for boats or canoes.
13. If compression tests are done, it may be of interest to spread universal indicator over the broken face and note any color changes from inside to outside. You may see a yellowish surface due to carbonation from CO_2 in the atmosphere. The inside may be blue due to calcium hydroxide.
14. To answer the proverbial question, "Is this right?" a slump test may be performed. A slump test involves filling an inverted, bottomless cone with the concrete mixture. A Styrofoam or paper cup with the bottom removed makes a good bottomless cone. Make sure to pack the concrete several times while filling the cone. Carefully remove the

cone by lifting it straight upward. Place the cone beside the pile of concrete. The pile should be about 1/2 to 3/4 the height of the cone for a concrete mixture with good workability.

A slump cone is used primarily to provide an Strength and workability characteristics of concrete.

Not: Durability and finish; Air entrainment and chemical resistance; Appearance and color



15. To strengthen samples and to promote hydration, soak concrete in water (after it is set).
16. Wet sand may carry considerable water, so the amount of mix water should be reduced to compensate.
17. Air bubbles in the molds will become weak points during strength tests. They can be eliminated by:
    - i. packing the concrete.
    - ii. Tapping the sides of the mold while filling the mold.
    - iii. "rodding" the concrete inside the mold with a thin spatula.
18. Special chemicals called "water reducing agents" are used to improve workability at low water to cement ratios and thus produce higher strengths. Most ready-mix companies use these chemicals, which are known commercially as superplasticizers. They will probably be willing to give you some at no charge.
19. You can buy a bag of cement from your local hardware store. A bag contains 94 lb. (40kg) of cement. Once the bag has been opened, place it inside a garbage bag (or two) that is well sealed from air. This will keep the cement fresh during the semester. An open bag will pick up moisture and the resulting concrete may be weaker. Once cement develops lumps, it must be discarded. The ready mix company in your area may give you cement free of charge in a plastic pail.

Creep In Concrete

When concrete is held under sustained stress, the strain will continue to increase with time. Creep defines this time-dependent phenomenon.
Not: Shrinkage; Temperature expansion; Contraction

Concrete creep is defined as: deformation of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending.

Creep does not necessarily cause concrete to fail or break apart. Creep is factored in when concrete structures are designed.

Factors Affecting Creep

4. Aggregate
5. Mix Proportions
6. Age of concrete

1. Influence of Aggregate

Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep. The modulus of elasticity of aggregate is one of the important factors influencing creep.

It can be easily imagined that the higher the modulus of elasticity the less is the creep. Light weight aggregate shows substantially higher creep than normal weight aggregate.

2. Influence of Mix Proportions:

The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio. In other words, it can also be said that creep is inversely proportional to the strength of concrete. Broadly speaking, all other factors which are affecting the water/cement ratio are also affecting the creep.

3. Influence of Age:

Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time.

Such gel creeps less, whereas a young gel under load being not so stronger creeps more. What is said above is not a very accurate statement because of the fact that the moisture content of the concrete being different at different age also influences the magnitude of creep.

Effects of Creep on Concrete and Reinforced Concrete

- In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.
- In eccentrically loaded columns, creep increases the deflection and can load to buckling.
- In case of statically indeterminate structures and column and beam junctions creep may relieve the stress concentration induced by shrinkage, temperatures changes or movement of support. Creep property of concrete will be useful in all concrete structures to reduce the internal stresses due to non-uniform load or restrained shrinkage.
- In mass concrete structures such as dams, on account of differential temperature conditions at the interior and surface, creep is harmful and by itself may be a cause of cracking in the interior of dams. Therefore, all precautions and steps must be taken to see that increase in temperature does not take place in the interior of mass concrete structure.
- Loss of prestress due to creep of concrete in prestressed concrete structure.

Design

Since the 1960's, thin-shell concrete roof structures have seldom been utilized in the United States and Canada primarily because formwork is prohibitively expensive.

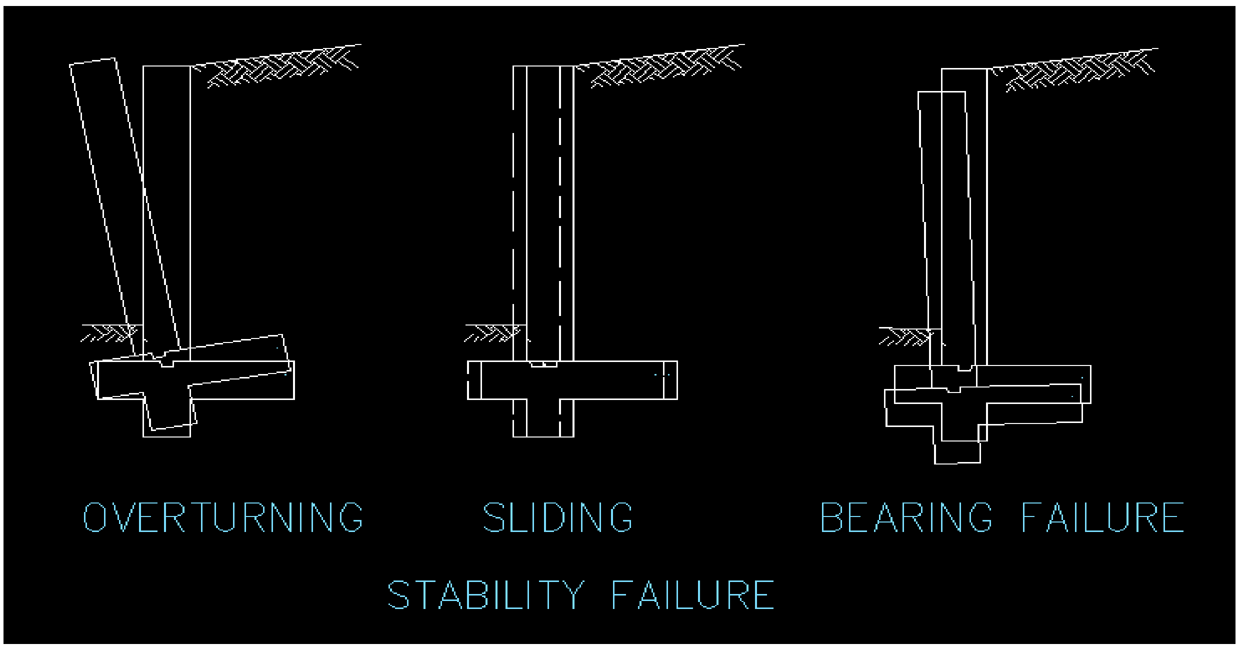
Not: Building codes often make it difficult to obtain approval for their use; design fees are substantially greater than for more conventional structures; materials (concrete and steel) are too costly

Design of concrete cantilever retaining wall

Introduction

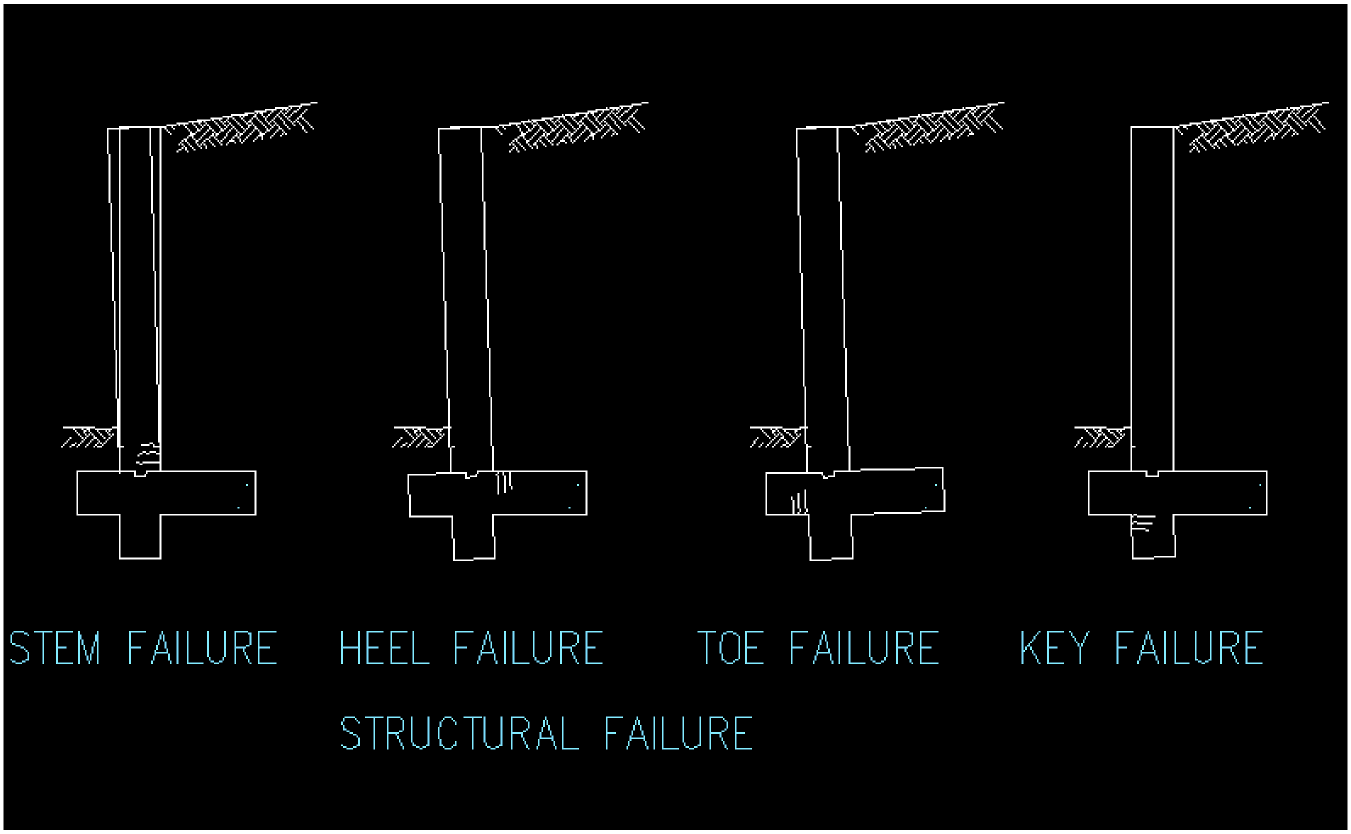
Common failure of retaining wall:

Stability failure
1. Overturning.
2. Sliding.
3. Bearing capacity.



Structural failure

4. Bending or shear failure of stem.
5. Bending or shear failure of heel.
6. Bending or shear failure of toe.
7. Bending or shear failure of key.



All items above should be considered in designing a retaining wall.
There is also a rotational stability failure that is not normally checked except when a retaining wall is located on a slope.

Design procedure for cantilever retaining wall:

Stability analysis

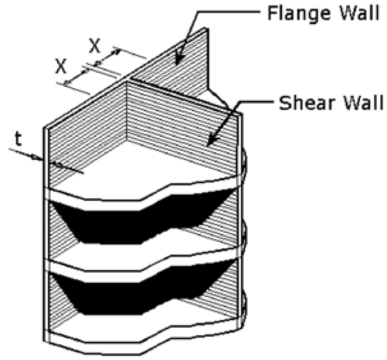
1. Check factor of safety against overturning.
2. Check soil bearing pressure.
3. Check factor of safety against sliding.

Reinforced concrete design

1. Check thickness of stem for shear stress.
2. Design stem reinforcement for bending.
3. Check thickness of heel for shear stress.
4. Design heel reinforcement.
5. Check shear stress for toe when the toe is long.
6. Design toe reinforcement for bending.
7. Check shear stress in key when key is deep and narrow.
8. Design key reinforcement for bending.

Concrete Masonry Unit

25. In the CMU stem-flanged shear wall arrangement shown, the minimum dimension X recommended to achieve shear transfer is 6t.
Not: 3t; 9t; 12t

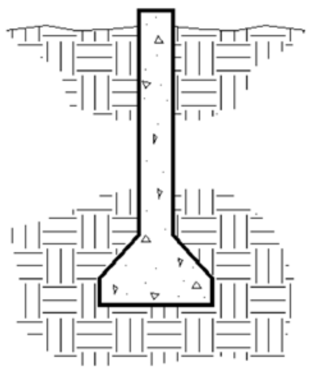


36. According to model codes; Connection of masonry web shear walls to masonry flange walls must be accomplished using which of the following: a) Running bond, b)Bond beams; c) Metal plate strap anchors.
Not: Stacked bond; Steel dowels; High-strength mortar

32. A primary cause of failure of concrete masonry walls during hurricanes is a lack of vertical reinforcement.
Not: poorly filled mortar joints; improper base and sill flashing; an inadequate number of wall anchors

Footing

2. The drilled pier (caisson) shown above is belled in order to increase the bearing area;
Not: prevent water infiltration; prevent caving; increase frictional resistance



5. The most frequently used footing type at the exterior wall for load-bearing wall support systems is continuous wall footings.
Not: mat footings; pile footings; isolated pad footings

Footings

The drilled pier (caisson) shown above is belled in order to increase the bearing area
Not: prevent water infiltration; prevent caving; increase frictional resistance

The most frequently used footing type at the exterior wall for load-bearing wall support systems is continuous wall footings.
Not: mat footings; pile footings; isolated pad footings

Soil

A loss of soil shear strength resulting in the movement of the surficial soil layers of a building site in a direction parallel to the ground surface under earthquake conditions is most likely caused by liquefiable soils.
Not: a low bearing capacity; a gently sloping site;

If the soil bearing capacity is 3000 psf [143 500 N/m_2] and the applied load is 48,000 lbs [212 kN], 16 sf [1.5 m_2] is the area for the footing.

Factor of Safety

Foundatation Analysis by Bowels has good recommendations for safety factors. He evaluates uncertainties and assigns a factor of safety by taking into account the following:

1. Magnitude of damages (loss of life and property damage)
2. Relative cost of increasing or decreasing the factor of safety
3. Relative change in probability of failure by changing the factor of safety
4. Reliability of soil data
5. Construction tolerances
6. Changes in soil properties due to construction operations
7. Accuracy (or approximations used) in developing design/ analysis methods

Typical values of customary safety factors, **F.S.**, as presented by Bowels.

Failure Mode	**Foundation Type**	**F.S.**
Shear	Earthwork for Dams, Fills, etc.	1.2 - 1.6
Shear	Retaining Walls	1.5 - 2.0
Shear	Sheetpiling, Cofferdams	1.2 - 1.6
Shear	Braced Excavations (Temporary)	1.2 - 1.5
Shear	Spread Footings	2 - 3
Shear	Mat Footings	1.7 - 2.5
Shear	Uplift for Footings	1.7 - 2.5
Seepage	Uplift, heaving	1.5 - 2.5
Seepage	Piping	3 - 5

Other customary factors of safety, **F.S.**, used are:

1.5 for retaining walls overturning with granular backfill
2.0 for retaining walls overturning with cohesive backfill
1.5 for retaining walls sliding with active earth pressures
2.0 for retaining walls sliding with passive earth pressures

Other soil and soil related properties are listed below:

Loads

14. An 18th century farmhouse on the National Historic Register with exposed timber framing is to be restored and opened for tours. Limit the number of visitors in spaces to the available live load is the most historically correct method of addressing the lack of live load
Not: capacity of the floor framing; Replace the undersized framing with new adequately sized members; Sister the existing joists and beams; Reduce the span of the floor framing.

16. A balcony is hung from steel roof framing over a hotel atrium. 33% is the minimum code required increase in live load due to impact.
Not: 0 percent; 25 percent; 50 percent

Type of member	Source of Impact	Percent increase
Supporting	Elevators and elevator machinery	100
Supporting	Light machines, shaft, or motor driven	20
Supporting	Reciprocating machines or power-driven units	50
Hangers	Floors or balconies	33

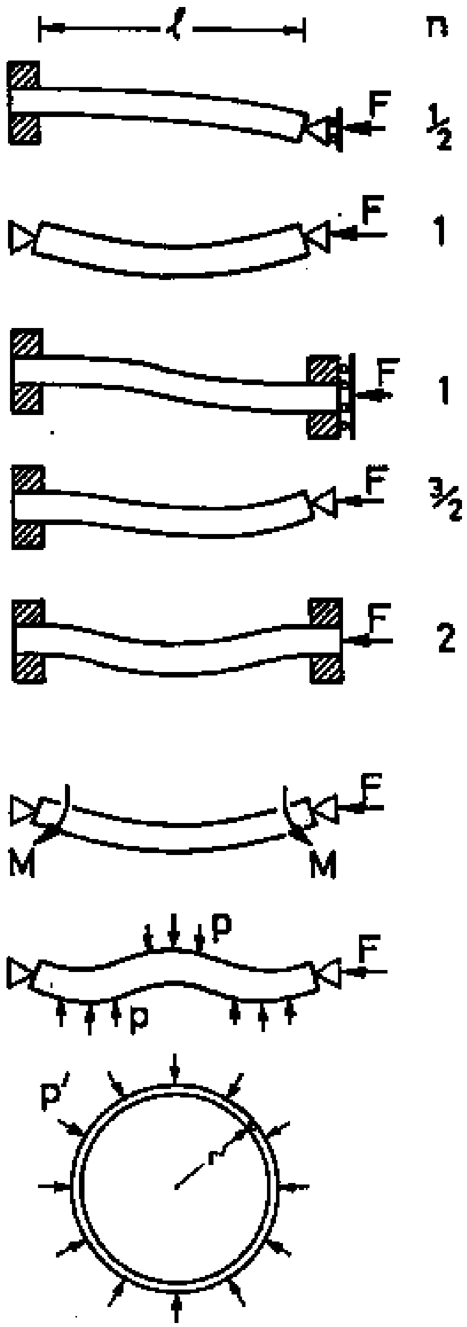
Buckling of Columns, Panels and Shafts

If sufficiently slender, an elastic column, loaded in compression, fails by elastic buckling at a critical load, F_{crit}. This load is determined by the end constraints, of which four extreme cases are illustrated on Fig. A4: an end may be constrained in a position and direction; it may be free to rotate but not translate (or 'sway'); it may sway without rotation; and it may both sway and rotate. Pairs of these constraints applied to the ends of column lead to the five cases shown. Each is characterised by a value of the constant n which is equal to the number of half-wavelengths of the buckled shape.

The addition of the bending moment M reduces the buckling load by the amount shown in the second box. A negative value of F_{crit} means that a tensile force is necessary to prevent buckling.

An elastic foundation is one that exerts a lateral restoring pressure, p, proportional to the deflection (p = ky where k is the foundation stiffness per unit depth and y the local lateral deflection). Its effect is to increase F_{crit}, by the amount shown in the third box.

A thin-walled elastic tube will buckle inwards under an external pressure p', given in the last box. Here I refers to the second moment of area of a section of the tube wall cut parallel to the tube axis.



$$F_{crit} = \frac{n^2 \pi^2 E I}{\ell^2} \quad \text{or} \quad \frac{F_{crit}}{A} = \frac{n^2 \pi^2 E}{(\ell / r)^2}$$

F = force (N)

M = moment (Nm)

E = Young's Modulus (N/m^2)

ℓ = Length (m)

A = Section area (m^2)

I = See Fig. A1

r = Gyration rad $\left(\frac{I}{A}\right)^{\frac{1}{2}}$ (m)

k = Foundation stiffness (N/m^2)

n = Half-wavelengths in buckled shape

p′ = pressure (N/m^2)

$$F_{crit} = \frac{\pi^2 E I}{\ell^2} - \frac{M^2}{4EI}$$

$$F_{crit} = \frac{n^2 \pi^2 E I}{\ell^2} + \frac{k \ell^2}{n^2}$$

$$P'_{crit} = \frac{3EI}{(r')^3}$$

Figure A2 Buckling of Columns

Buckling of a column can be reduced by (a) Increasing the size of the member, (b) Bracing the column (c) Changing the type of end restraints; (D) Reducing the length of the column

Not: Reducing the radius of gyration, Rotating the column

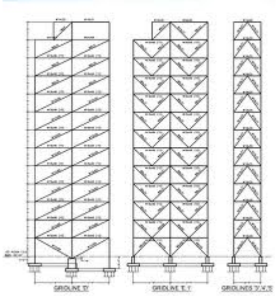
Lateral Forces

19. A building with a symmetrical square plan would be most appropriate for a high-rise building in a high-risk seismic zone.
Not: A building on stilts; A building with an L-shaped plan; A building with a symmetrical T-shaped plan

20. Hinged frames is NOT a primary structural system that is employed to resist lateral loads.
Not: Shear walls; Braced frames; Moment-resisting frames

21. All of the following a) The system must allow lateral movement; b) The system must control the movement between ground and structure; c) Energy must be dissipated in the isolators are criteria for base isolation systems EXCEPT: The system must amplify ground accelerations.

22. An eccentrically braced frame (EBF) utilized to resist lateral seismic forces in a building is a frame in which diagonal members are connected to a beam a short distance from the column joint.
Not: frame in which members are subjected primarily to axial forces; frame in which members and joints are capable of resisting forces by flexure as well as along the axis of the member; braced frame whose plan location results in torsion



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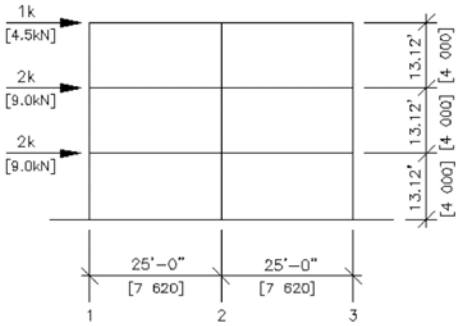
23. For the rigid frame structure shown, the approximate horizontal shear at the base of column 2 (assuming all column stiff nesses are equal) is 2.5 k [kN]



1617.4.3 Vertical distribution of seismic forces.

The lateral force, F_x (kip or kN), induced at any level shall be determined from the following equations:

$F_x = C_{vx}V$ **(Equation 16-41)**

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$

(Equation 16-42)

where:

C_{vx}= Vertical distribution factor.

k = A distribution exponent related to the building period as follows:
For buildings having a period of 0.5 second or less, k = 1.
For buildings having a period of 2.5 seconds or more, k = 2.
For buildings having a period between 0.5 and 2.5 seconds, k shall be 2 or shall be determined by linear interpolation between 1 and 2.

h_i and h_x= The height (feet or m) from the base to Level i or x.

V = Total design lateral force or shear at the base of the building (kip or kN).

w_i and w_x= The portion of the total gravity load of the building, W, located or assigned to Level i or x.

Steel, reinforced concrete, reinforced masonry, wood material lists provides ductility in building construction in the order of highest to lowest.
Not: Steel, reinforced masonry, reinforced concrete, wood; Wood, steel, reinforced masonry, reinforced concrete; Reinforced masonry, reinforced concrete, wood, steel

Ductility is the characteristic of a metal or another material that allows it to be drawn or rolled to be made longer without the material breaking. To get a little more technical, it is the ability of a material to undergo plastic deformation without failure. It is one of the physical properties of a material.

Some nice, soft taffy can be pulled and will "string out" without breaking. But if that taffy is cold and not completely processed, pulling on it will result in a little stretching and a quick break. The metals copper, which is drawn into wire for use as an electrical conductor, and aluminium, which is rolled repeatedly until it is turned into foil which we use in the kitchen, are both metals with high ductility. Their ductility and some other physical characteristics make them ideal choices for the common applications mentioned. A link can be found below.

The ductility of steel for concrete reinforcement can be defined as an ability to achieve significant deformations without marked increase of stresses beyond the yield strength of steel. This term applies to the behavior of a construction in the conditions of nonlinear deformations, in which ductility plays an important role.

For many years there have been observed large differences between the actual durability of statically indeterminable elements of a construction and the values determined according to the principles of linear - elastic theory.

The next phenomenon observed was the behavior of a construction at the load close to the destructive load, when there followed a considerable increase of deformations in the presence of a small increase of stresses.

More recently, it has become more and more popular to apply the plasticity theory to the construction calculation. It is related to the developed knowledge in this area, the greater power of computer calculations as well as to the introduction of the simplified computational method, taking the plasticity condition under consideration, which relies on the assumption of redistribution of bending moments in a calculation carried out with the linear elastic method.

The need for ductility

Yield strength is a property of steel used for calculation of reinforced concrete constructions. Regarding the stretch of steel, the standards (e.g. PN-B-03264:2002) determine two parameters of reinforcing steel: the yield strength for a given grade of steel and the tensile strength.

WHAT CHARACTERIZES GOOD REINFORCING STEEL?

'''1. GOOD RESISTANCE PROPERTIES'''

""2. GOOD PLASTICITY""

High resistance of reinforcing steel is very desirable, but is not sufficient to ensure the proper behaviour of reinforced concrete constructions, for ductility is another important parameter. Concrete, as it is widely known, is a brittle material and without reinforcement cannot be used in the parts of construction exposed to stretch.

The need for ductility in construction, which cannot be ensured by concrete, is met entirely by steel. For this reason, steel should have appropriate ductility, in order to ensure the possibility of a turn of a bending cross-section and enable redistribution of bending moments in constructions statically indeterminable.

'''**Concrete has always been considered the only factor lowering plasticity of a construction due to its brittleness. Reinforcing steel however has ductility at such level that it doesn't disturb the process of plastification in a construction.**'''

This way of thinking is understandable seeing that in the past steel had lower resistance/durability and thus higher ductility (e.g. steel A-I or A-0). The development of reinforcing steel led to the growth of resistance/durability. It was achieved by increasing carbon content in steel or by squeeze in cold rolling. This happened at the cost of ductility of steel.

'''Tens of research studies on the behaviour of reinforced concrete structures proved the impact of the level of ductility of steel on the possibility of a turn of a bending cross-section in places of formation of plastic joins in the construction. As a result of comparative researches of elements of constructions, it turned out that the limitation of lenghtening of steel suggested by the standards - EUK > 2.5% - is insufficient, because the steel close to this upper limit of lenghtening of steel considerably lowers the plasticity of the construction. '''

'''Talking about the plastification of a construction it is worth to mention that one of the important factors of the plastification process of a construction is the appropriate adhesion of steel to concrete, which enables a certain/specified glide, so that scratches and cracking take place in the way set up during the design.'''

'''Ductility of steel is its ability to achieve significant deformations at stresses beyond the yield strength of steel.'''

'''**Ductility of steel is essential in the case of constructions exposed to specific kinds of influences (seismic, dynamic etc.) as well as in the case of the design method assuming strong redistribution of moments.** '''

In the case of reinforced concrete constructions raised in mining or seismic areas, ductility of steel has large influence on the behaviour of a construction. Similarly, in the case of indefinable influences it is desirable to provide a safety margin, which a plastic construction has, being able to reach larger deformations before it is damaged.

Ductility of steel = Safety

'''
'''A PLASTIC CONSTRUCTION IN A STATE CLOSE TO THE DAMAGE UNDERGOES SIGNIFICANT DEFORMATIONS AND CRACKS.''''''

''''''A BRITTLE CONSTRUCTION IS DAMAGED SUDDENLY WITHOUT PREVIOUS WARNINGS, HAVING UNDERGONE INSIGNIFICANT DEFORMATIONS AND CRACKS. ''''''

''' '''

The ductility of steel for concrete reinforcement can be defined as an ability to achieve significant deformations without marked increase of stresses beyond the yield strength of steel. This term applies to the behavior of a construction in the conditions of nonlinear deformations, in which ductility plays an important role.

For many years there have been observed large differences between the actual durability of statically indeterminable elements of a construction and the values determined according to the principles of linear - elastic theory.

The next phenomenon observed was the behavior of a construction at the load close to the destructive load, when there followed a considerable increase of deformations in the presence of a small increase of stresses.

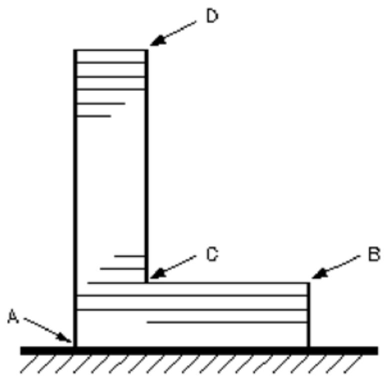
More recently, it has become more and more popular to apply the plasticity theory to the construction calculation. It is related to the developed knowledge in this area, the greater power of computer calculations as well as to the introduction of the simplified computational method, taking the plasticity condition under consideration, which relies on the assumption of redistribution of bending moments in a calculation carried out with the linear elastic method.

24. Base isolation in an office building is most effective for Four Story building heights, assuming that the areas per floor are the same.
Not: One-story; Twenty-story; Forty-story

33. The earthquake regulations of model codes are intended to provide resistance to Ground shaking
Not: Earth slides; Ground rupture in fault zones; Settlement

34. A structure will have a better chance of surviving an earthquake if The structure has redundancy.
Not: Principal members change section abruptly; The load-bearing members are not equally loaded; All columns and walls are discontinuous.

37. In the elevation of a multi-storied building subject to earthquake forces shown above, at "C" location is stress concentration most likely to be a problem. Not: Base A, Not Corners on building B, or D



38. A building form that is ideal for resistance to earthquake forces would be characterized by a) Symmetrical in plan and b) Heavier at the base than at the top.
Not: Symmetrical about a reentrant corner; Asymmetrical in plan; Long linear plan; Asymmetrical in elevation

30. Steel, reinforced concrete, reinforced masonry, wood material lists provides ductility in building construction in the order of highest to lowest.
Not: a) Steel, reinforced masonry, reinforced concrete, wood; b) Wood, steel, reinforced masonry, reinforced concrete; c) Reinforced masonry, reinforced concrete, wood, steel

1Stiff systems like shear walls are good because they transfer the seismic loads to the base and don't deflect as much as more flexible systems like braced frames and MRF. Deflection is tough on building materials and occupants. We do not care about building materials in seismic design. It is a given that after a code level seismic event the building gets torn down.see below

Ductility is desireable because in a ductile system energy is dissipated by the permanent distortions of the materials. Steel will deform quite considerably before it fails altogether which has the benefit of absorbing energy and warning of failure.

Also, you should be comfortable with the idea that ductility is different from flexibility.

Column

26. Buckling of a column can be reduced by: A. Increasing the size of the member; C. Bracing the column; D. Changing the type of end restraints; E. Reducing the length of the column.
Not: Rotating the column

28. The recommended deflection criteria due to wind loading on a brick veneer wall utilizing a metal stud back-up system is L/600.

Not: L/360; L/400; L/720

Building Code requirements for Masonry Structures ACI 530-05 limits the deflection of beams and lintels to l/600 (.3in.) to prevent cracking. The deflection of the brick veneer with stud backup isn't specified. But the commentary from ACI 530 says "The Brick Industry Association has held that an appropriate deflection limit should be in the range of stud span length divided by 600 to 720."

Another way to look at the question is that L/360 is a max deflection for wood member carrying live load.

L/400 is recommended for formwork.

L/720 is recommended for soft stone tile/marble.

Basically you want less deflection for more delicate connections/materials.

Column:

Bending forces in the vertical members best defines the P-delta effect.

Not: Lateral forces on the foundations; Horizontal forces in the roof sections; Moment forces at the joint

P delta is the result of both lateral and vertical forces acting together. Imagine a force acting on a column, it presses down and the column reacts up. Cool. But now imagine the same force acting on the same column at the same time a huge gust of wind has caused the column to displace a bit to the right. Now the vertical force is pushing the column down while the column is bent slightly to the right and there is a compounding of the vertical force. The column will be more likely to buckle because the vertical force is no longer acting along the column's axis.

In structural engineering, the **P-Δ** or **P-Delta** effect refers to the abrupt changes in ground shear, overturning moment, and/or the axial force distribution at the base of a sufficiently tall structure or structural component when it is subject to a critical lateral displacement.

The P-Delta effect is a destabilizing moment equal to the force of gravity multiplied by the horizontal displacement a structure undergoes as a result of a lateral displacement.

To illustrate the effect, take the example of a typical statics case: in a perfectly rigid body subject only to small displacements, the effect of a gravitational or concentrated vertical load at the top of the structure is usually neglected in the computation of ground reactions. However, structures in real life are flexible and can exhibit large lateral displacements in unusual circumstances. The lateral displacements can be caused by wind or seismically induced inertial forces. Given the side displacement, the vertical loads present in the structure can adversely perturb the ground reactions. This is known as the P-Δ effect.

In some sense, the P-Delta effect is similar to the buckling load of an elastic, small-scale solid column given the boundary conditions of a free end on top and a completely restrained end at the bottom, with the exception that there may exist an invariant vertical load at the top of the column. A rod planted firmly into the ground, given a constant cross-section, can only extend so far up before it buckles under its own weight; in this case the lateral displacement for the solid is an infinitesimal quantity governed by Euler buckling.

Deflection Limit State

In the absence of more specific criteria, criteria for structures with brittle finishes (as found in code documents for years) is frequently used. This simplistic criteria puts a limit of the span divided by 360 on the incremental deflection due to live (or transient) load only and a limit of the span divided by 240 on deflection under total load. These limit states are mathematic expressed as:

$$\Delta_{LL} \leq L/360$$

$$\Delta_{TL} \leq L/240$$

These limits were originally developed for members with "brittle" finishes, such as plaster. Plaster is not commonly used as a finishing material anymore. The goal of the limits was to minimize the possibility of damage to the finish and provide reasonable comfort for the building occupants. The criteria has persisted in practice.

Other criteria has been used that more explicitly addresses the use of the beam under consideration. For example, the Timber Construction Manual [ref. 12], page 66 suggests the values given in Table 8.4.2.1 and 8.4.2.2. Other references give different, but similar, criteria.

Table 8.4.2.1
AITC Recommended Deflection Limits
Used with Permission

Use Classification	Applied Load Only	Applied Load + Dead Load
Roof Beams		
- Industrial	L/180	L/120
- Commercial and institutional		
- Without plaster ceiling	L/240	L/180
- With plaster ceiling	L/360	L/240
Floor Beams		
- Ordinary usage[a]	L/360	L/240
Highway	L/200 to L/300	

bridge stringers		
Railway bridge stringers	L/300 to L/400	
[a]Ordinary usage classification for floors is intended for construction in which walking comfort and minimized plaster cracking are the main considerations. These recommended deflection limits may not eliminate all objections to vibrations such as in long spans approaching the maximum limits or for some office and institutional applications where increased floor stiffness is desired. For these usages, the deflections limits of table 8.4.2.2 have been found to provide additional stiffness.		

Table 8.4.2.2
AITC Deflection Limits for Uses Where Increased Floor Stiffness is Desired
Used with Permission

Use Classification	Applied Load Only	Applied Load + Dead Load[a]
Floor Beams		
- Commercial, Office & Institutional		
- Floor Joists, spans to 26 ft[b]		
- LL $\leq$ 60 psf	L/480	L/360
- 60 psf < LL < 80 psf	L/480	L/360
- LL $\geq$ 80 psf	L/420	L/300
- Girders, spans to 36 ft[b]		
- LL $\leq$ 60 psf	L/480	L/360
- 60 psf < LL < 80 psf	L/420	L/300
- LL $\geq$ 80 psf	L/360	L/240
[a]The AITC includes a modifier on DL depending on whether or not the timber is seasoned. [b]For girder spans greater than 36 ft and joist spans greater than 26 ft, special design considerations may be required such as more restrictive deflection limits and vibration considerations that include the total mass of the floor.		

Wind

35. Wind forces considerations in structural design are based on probability as a result of historical analysis.
Not: Water pressures; Dead loads; Soil pressures

1. water-to-cement ratio
2. increase the bearing area
3. Strength and workability
4. formwork is prohibitively expensive
5. continuous wall footings
6. 57.3 in^3 [cm^3]
7. 67 kips [30 390 kg]
8. 16 sf [1.5 m^2]
9. Bending forces in the vertical members
10. 28
11. Creep
12. compensate for deflection
13. 2.0 in [50 mm]
14. Limit the number of visitors in spaces to the available live load.
15. 1 1/2 in [37 mm]
16. 33 percent
17. Gypsum shaft wall
18. Parking
19. A building with a symmetrical square plan
20. Hinged frames
21. The system must amplify ground accelerations.
22. frame in which diagonal members are connected to a beam a short distance from the column joint
23. 2.50 k [11.25 kN]
24. Four-story
25. 6t
26. A, C, D, E
27. liquefiable soils
28. L/600
29. Architect
30. Steel, reinforced concrete, reinforced masonry, wood
31. 4.2
32. a lack of vertical reinforcement
33. Ground shaking
34. The structure has redundancy.
35. Wind forces
36. A, B, F
37. C
38. B, C

Concrete Lecture

Footings Fnd / Slabs / Tilt ups

Ftg's & Fnd's

Modified 02-14-05

CSI Codes
03 20 00 Concrete Reinforcing
03 30 00 Cast in place Concrete

Even though the CSI codes do not breakdown concrete work any further into footing/foundation/slabs etc, we will break it down further for the assignement.

Rebar

- #3 = .376 lb/lf
- #4 = .668 lb/lf
- #5 = 1.043 lb/lf
- #6 = 1.502 lb/lf
- #7 = 2.044 lb/lf
- #8 = 2.670 lb/lf
- #9 = 3.400 lb/lf

Rebar Diameter in inches = Rebar Size /8 (For bar sizes 8 and smaller. For larger bars reference a table for the exact diameter.)
IE #4 Bar / 8 = 1/2" diameter

Lap

Suppose that you have 100' of footings with 2 runs of #4 rebar. The overlap is 30 bar diameter and the rebar comes in 20'pieces. What is the total LBs of rebar for this footing? First draw a picture of what the problem looks like that you are trying to solve.

_____ _____ _____
------ ----- ---

The general formula to calculate lbs of rebar is :
(Total LF + Laps)* # of runs of Rebar * conversion factor to lbs

Laps
To find out how much the laps add, take the number of laps * length of a lap.

The number of laps= total LF / length of the rebar pieces. 100'/20' = 5 laps

The length of the lap = Bar Diameter lap * (Rebar Size/8) /12 =
30 * (4/8) /12 = 1.25'

LBS of rebar = (100 + (5 *1.25)) * 2 * .668 = 141.95 lbs

The length of the lap is often given in the Structural Notes. Sometimes, you may need to dig for the lap length. The following is an example of how to find the lap length when it is not given easily in the structural notes.

First, in the Structural Notes on S-01 the following is given under Rebar Lap.

LAP SPLICES IN CONCRETE:

UNLESS NOTED OTHERWISE, LAP SPLICES IN CONCRETE SHALL BE PER TYPICAL REINFORCING BAR SPLICE DETAIL. LAPS IN WELDED WIRE FABRIC SHALL BE MADE SO THAT THE OVERLAP MEASURED BETWEEN OUTERMOST CROSS WIRES OF EACH FABRIC SHEET IS NOT LESS THAN THE SPACING OF CROSS WIRES PLUS 2 INCHES.

Now the Typical Reinforcing Bar Splice Detail needs to be found. It is found on Sheet S-03, which is still part of the Structural Notes pages.

TENSION BARS f'c = 2,500 PSI, NORMAL WEIGHT								
BAR SIZE	TOP BARS				OTHER BARS			
	GR 40		GR 60		GR 40		GR 60	
	NOTE		NOTE		NOTE		NOTE	
	1	2	1	2	1	2	1	2
#3	20	20	23	23	16	16	18	18
#4	22	20	33	31	17	16	25	24
#5	34	27	51	41	26	21	39	31
#6	47	39	72	58	36	30	55	44

TENSION BARS f'c ≥ 3,000 PSI, NORMAL WEIGHT								
BAR SIZE	TOP BARS				OTHER BARS			
	GR 40		GR 60		GR 40		GR 60	
	NOTE		NOTE		NOTE		NOTE	
	1	2	1	2	1	2	1	2
#3	20	20	21	21	16	16	16	16
#4	20	20	30	28	16	16	23	22
#5	31	25	46	37	24	19	36	29
#6	43	35	65	52	33	27	50	40

COMPRESSION BARS f'c = ALL		
BAR SIZE	OPEN	ENCLOSED WITH TIES
#3	12	12
#4	15	13
#5	19	16
#6	23	19

NOTES:

1. CENTER-TO-CENTER SPACING OF REINFORCING = < 3db.
2. CENTER-TO-CENTER SPACING OF REINFORCING = > 3db.
3. TOP BARS ARE HORIZONTAL BARS WITH MORE THAN 12 INCHES OF CONCRETE CAST BELOW THE BARS.
4. UNLESS NOTED OTHERWISE, LAP SPLICE IN CONCRETE BEAMS, SLABS, WALLS, STEM WALLS AND FOOTINGS SHALL BE TENSION LAP SPLICES AND LAP SPLICES IN CONCRETE COLUMNS SHALL BE COMPRESSION LAP SPLIC
5. LAP SPLICES SHOWN IN SCHEDULE ARE IN INCHES.
6. db = NOMINAL BAR DIAMETER.
7. < MEANS LESS THAN, ≤ MEANS LESS THAN OR EQUAL TO, > MEANS GREATER THAN, ≥ MEANS GREATER THAN OR EQUAL TO.
8. CONCRETE COLUMN DOWEL EMBEDMENT SHALL BE A STANDARD COMPRESSION DOWEL EMBEDMENT LENGTH ACCORDING TO THE LATEST EDITION OF ACI 318.

CONVE

21 MINIMUM REINFORCING BAR SPLICE LENGTHS IN CONCRETE

FILE: 103-01A TYPICAL DETAIL

From the above tables, first analyze are the bars in Tension or Compression. Footings are in Tension. Then, what is the PSI of concrete being used.

To find the PSI of concrete, refer back to sheet S-01, and the following is found.

CONCRETE:

TYPICAL CONCRETE COMPRESSIVE STRENGTHS		
CONCRETE	MINIMUM 28 DAY COMPRESSIVE STRENGTH	SLUMP AT PLACEMENT
UNLESS NOTED OTHERWISE, ALL CONCRETE SHALL BE	3,000 PSI	4 1/2" MAXIMUM
CONCRETE OVER STEEL DECK	3,000 PSI	4" MAXIMUM
SLABS ON GRADE	3,500 PSI	4" MAXIMUM
FOOTINGS AND STEM WALLS	3,000 PSI	4" MAXIMUM

All footings are 3000 PSI. Now refer back to the Typical Reinforcing Bar Splice Detail. Now the grade of rebar needs to be found. Referring back to S-01 the following is found.

STEEL REINFORCING:

TYPICAL REINFORCING BAR STRENGTHS	
#4 OR LARGER	ASTM A615 (GR60) DEFORMED
#3 OR SMALLER	ASTM A615 (GR40) DEFORMED
REINFORCING TO BE WELDED	ASTM A706 (GR60) LOW ALLOY, DEFORMED
WELDED WIRE FABRIC	ASTM A185, WIRE PER ASTM A82

Since the rebar is larger than #4, grade 60 rebar is to be used. Now refer back to the Typical Reinforcing Bar Splice Detail and use the Notes in the detail to determine the length of the lap.

Footings

Types of footings
Spread / Spot
Continuous
Grade Beams
Mat / Raft
Forming (SFCA)
Forming materials

- 2 x Lumber
- Plywood
- Symons
- Gang
- Slip

For this class, both sides of all footings and foundations must be formed.

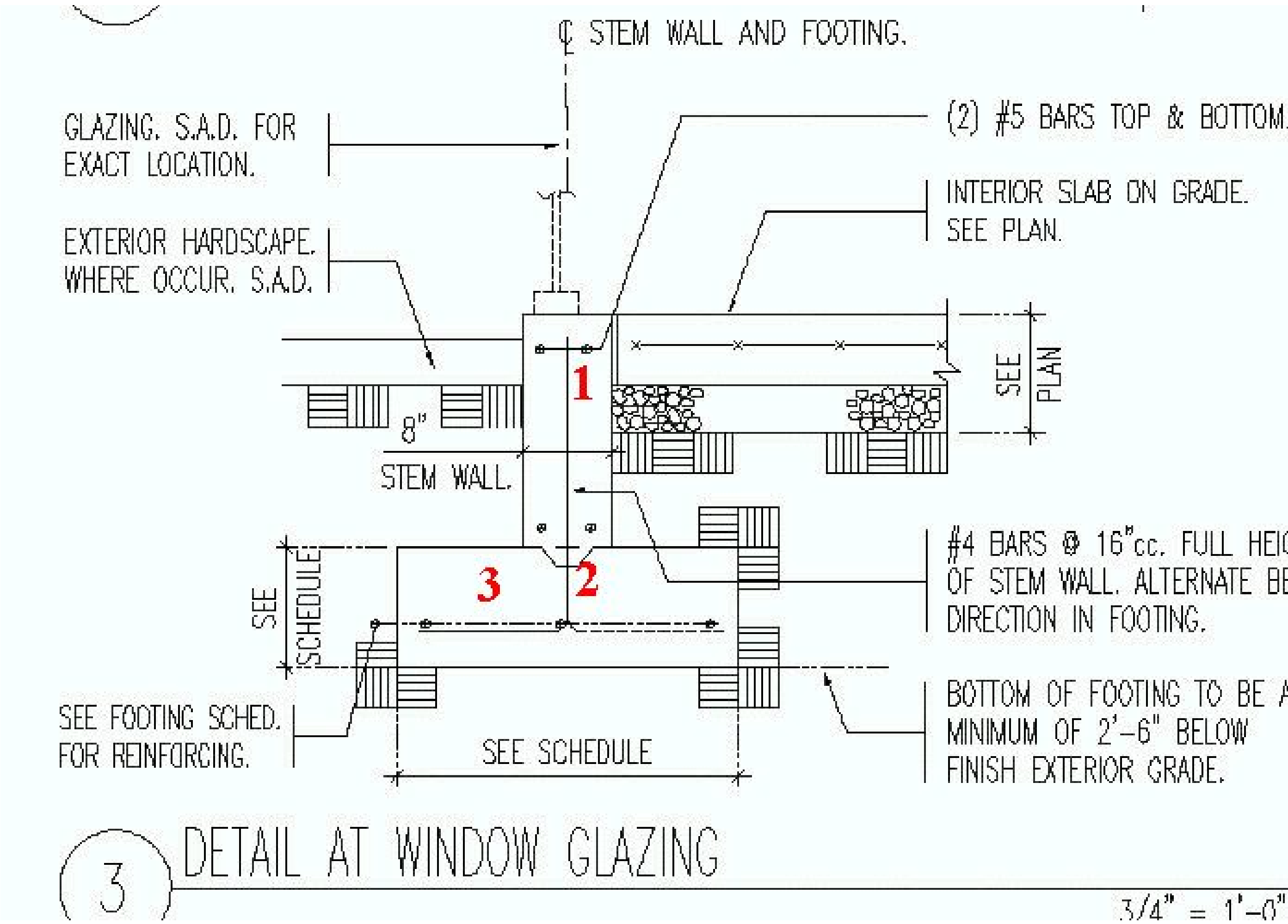
To calculate the SFCA of the continuous footing forms = footing length' * footing height' * 2 sides. Assume the ends of the continuous footings continue on in a footing of a different size.
100' * 12"/12 * 2 = 200 SFCA

To calculate the SFCA of the spread footing forms = ((footing length' + footing width') * 2) footing height'.
((5' + 5') *2) * 12"/12 = 20 SFCA

Placing
Placing costs cover the labor cost of getting the concrete from the truck to the location of placing the concrete. Many times the abbreviation of P/P/F will be used for the description of placing the concrete. P/P/F means prep/pour/finish.
Concrete Material (CY)
To calcuate the CY of concrete = (footing length' * footing height' * footing width' / 27)
(100' * (12"/12("/ft)) * 3') /27 = 11.11 CY
Pumping
When the concrete cannot be placed directly from the truck chute, a concrete pump or some other means may be needed to place the concrete. Other methods of transporting the concrete from the concrete truck would include, a crane and a bucket, or a conveyor systems.

Foundations

Calculating the Dowel Lengths (Vertical rebar)
Given the section below



To calculate the length of the Dowel, find the footing/wall height, then add half the width of the footing. This provides the approximate length of the dowel.
Step 1
Reference the footing schedule to find the width and height of the footing shown in the detail. For this example assume the width to be 30" and the height of 12" for the footing.

Step 2
Calculate the height of the foundation wall. The section states that the footing must be a minimum of 2'6" below exterior finish grade. For this example, assume that the exterior grade is 6" below the finish slab elevation.
Therefore the height of the wall is:
2' 6"
- 1' 0" Height of the footing
+ 0' 6" difference between exterior grade and Top of slab elevation
2' 0" Wall Height.
Notice in the wall section that the dowel does not go to the exterior surface of the concrete, therefore the concrete coverage needs to be subtracted from the height of the

wall. Three varying conditons for concrete coverage exist in this wall. Each condition is labeled with a red number above. The following table taken from the structural notes describes the differing conditions.

TYPICAL CLEAR CONCRETE COVERAGES		
CONCRETE CAST AGAINST AND PERMANENTLY EXPOSED TO EARTH		3"
FORMED CONCRETE EXPOSED TO EARTH OR WEATHER	#6 AND LARGER	2"
	#5 AND SMALLER	1 1/2"
FORMED CONCRETE NOT EXPOSED TO WEATHER OR IN CONTACT WITH GROUND :		
SLABS, WALLS, OR JOISTS	#14 AND LARGER	1 1/2"
	#11 AND SMALLER	3/4"
BEAMS, COLUMNS (TO PRIMARY REINFORCEMENT, TIES, OR STIRRUPS)		1 1/2"
ALL OTHERS PER LATEST EDITION OF ACI 318.		

OR

MAINTAIN THE FOLLOWING CONCRETE COVERAGE'S FOR CONCRETE REINFORCING:

UNFORMED SURFACES IN CONTACT WITH EARTH.	3"
FORMED SURFACES IN CONTACT WITH EARTH.	2"
FORMED SURFACES EXPOSED TO OUTSIDE WEATHER.	1 1/2"
SLABS AND WALLS NOT EXPOSED TO WEATHER.	0 3/4"
CLEAR DISTANCE BETWEEN BARS.	2"

Condition 1
The top condition vertical component of the dowel is essentially a formed surface Exposed to outside weather requiring 1 1/2" of concrete coverage.

Condition 2
The bottom condition of the vertical component of the dowelis an unformed surface in contact with the earth so it requiring 3" of concrete coverage.

Condition 3

The horizontal end component of the dowel is a formed surface in contact with the earth requiring 2" of concrete coverage.
Step 4
The vertical length of the dowel becomes:
24" Wall height coverted to inches
- 1.5" Top concrete coverage
+ 12" Depth of footing
- 3" Bottom concrete coverage
31.5 "

Step 5
The horizontal length of the dowel becomes
30" / 2 = 15" because the dowel leg is only through half the footing.
Then
15"
- 2" of concrete coverage
13"
Step 6
31.5" + 13" = 44.5" or 3.708' Vertical + Horizontal components
Cost Adders
Anything not listed above will add cost to the work. Items to look for are: Waterstop, Keyways, Expoxy Rebar, Chamfer Strips, Blockouts, Haunches, Architectural Finishes, Concrete Additives, Weather Conditions, Access Issues, ETC.

Remember, the prices give above are standard prices that I use. The pricing may go up or down depending on job conditions.

PICTURES

Slabs

The slab takeoff will use crews to determine the pricing of the labor.

Slab Types

Slab on Grade (SOG)
Slab on Metal Deck (SOMD)
Suspended Slabs (SS)
Reinforcing
Rebar [All]
Mesh [All]
Fiber Mesh [more typical SOG]
PT Cable [SS]
Forming

Not all slabs will need to be formed. Often walls are inplace before the slab is poured and can be used to form the perimeter of the slabs.

2x Lumber [SOG, SS, occasionally SOMD]
Angle Iron [SOMD]

Shoring [SS, SOMD]
Placing & Finishing
The size of the slab will affect the pricing. Also, super flat floors will be more expensive.
Concrete Material
Watch for additives into the concrete. Most additives will add to the cost of the material.

Thickened Edges
Thickened Slabs
Pour Strips

Dowels
Column Diamonds
The column diamonds occur at each column in the slab. This allows for the column to be placed after the the slab is poured and also guides cracking to the joints instead of going randomly throughout the slab.
Waste
SOG & SS 3%, SOMD 7%
Pumping
Typically SOMD, SS, often SOG
Costs
Fiber Mesh
Call vendors for pricing information if you need it.
PT Cable
Call vendors for pricing information if you need it.
Shoring
Depending on requirements pricing will vary, starting range would be $3.00/sf to $6.00/sf.

Other Costs, see the Pricing Link.

Tilt up

Process
Casting Process
Forming
Embeds
Hoisting

Pour Strips
Pictures

Seismic Design Principles

by Gabor Lorant, FAIA

Lorant Group, Inc. & Gabor Lorant Architects, Inc.

Last updated: 03-15-2012

Within This Page

Introduction

This resource page provides an introduction to the concepts and principles of seismic design, including strategies for designing earthquake-resistant buildings to ensure the health, safety, and security of building occupants and assets.

The essence of successful seismic design is three-fold. First, the design team must take a multi-hazard approach towards design that accounts for the potential impacts of seismic forces as well as all the major hazards to which an area is vulnerable. Second, performance-based requirements, which may exceed the minimum life safety requirements of current seismic codes, must be established to respond appropriately to the threats and risks posed by natural hazards on the building's mission and occupants. Third, and as important as the others, because earthquake forces are dynamic and each building responds according to its own design complexity, it is essential that the design team work collaboratively and have a common understanding of the terms and methods used in the seismic design process.

In addition, as a general rule, buildings designed to resist earthquakes should also resist blast (terrorism) or wind, suffering less damage. For example, were the Oklahoma Federal Building designed to seismic design standards, the damage caused by the blast would have been much less (refer to FEMA BPAT Report – Publication 277). For more information, see WBDG Designing Buildings to Resist Explosive Threats section on Seismic vs. Blast Protection.

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Description

About half of the states and territories in the United States—more than 109 million people and 4.3 million businesses—and most of the other populous regions of the earth are exposed to risks from seismic hazards. In the U.S. alone, the average direct cost of earthquake damage is estimated at $1 billion/year while indirect business losses are estimated to exceed $2 billion/year.

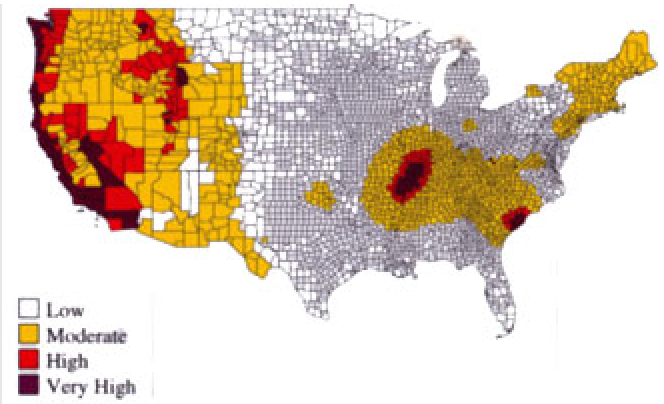


Fig. 1. Seismicity of the United States

A. Origin and Measurement of Earthquakes

Plate Tectonics, the Cause of Earthquakes

Earthquakes are the shaking, rolling, or sudden shock of the earth's surface. Basically, the Earth's crust consists of a series of "plates" floating over the interior, continually moving (at 2 to 130 millimeters per year), spreading from the center, sinking at the edges, and being regenerated. Friction caused by plates colliding, extending, or subducting (one plate slides under the other) builds up stresses that, when released, causes an earthquake to radiate through the crust in a complex wave motion, producing ground failure (in the form of surface faulting [a split in the ground], landslides, liquefaction, or subsidence), or tsunami. This, in turn, can cause anywhere from minor damage to total devastation of the built environment near where the earthquake occurred.

Fig. 2. *Left:* Ground failure-landslide—Alaska, 1964 *and Right:* Liquefaction damage—Niigata, Japan 1964

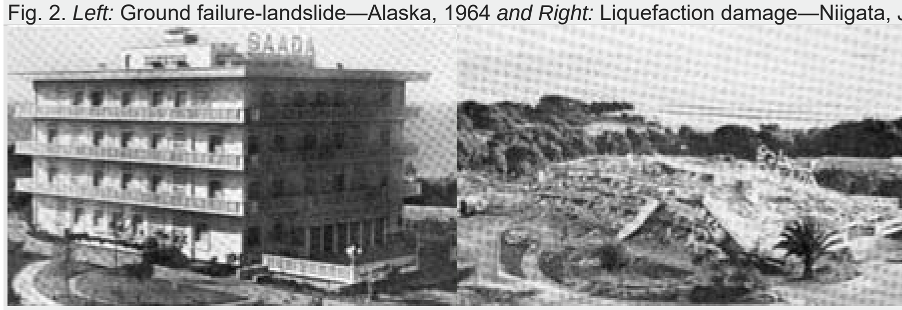


Fig. 3. *Left:* Saada Hotel (before)—Agadir, Morocco, 1960 *and Right:* Saada Hotel (after) ground shaking damage—Agadir, Morocco, 1960

Measuring Seismic Forces

In order to characterize or measure the effect of an earthquake on the ground (a.k.a. ground motion), the following definitions are commonly used:

- *Acceleration* is the rate of change of speed, measured in "g"s at 980 cm/sec² or 1.00 g.
  - For example,
    - 0.001g or 1 cm/sec² is perceptible by people
    - 0.02 g or 20 cm/sec² causes people to lose their balance
    - 0.50g is very high but buildings can survive it if the duration is short and if the mass and configuration has enough damping
- *Velocity* (or speed) is the rate of change of position, measured in centimeters.
- *Displacement* is the distance from the point of rest, measured in centimeters.
- *Duration* is the length of time the shock cycles persists.
- *Magnitude* is the "size" of the earthquake, measured by the Richter scale, which ranges from 1-10. The Richter scale is based on the maximum amplitude of certain seismic waves, and seismologists estimate that each unit of the Richter scale is a 31 times increase of energy. *Moment Magnitude Scale* is a recent measure that is becoming more frequently used.

If the level of acceleration is combined with duration, the power of destruction is defined. Usually, the longer the duration, the less acceleration the building can endure. A building can withstand very high acceleration for a very short duration in proportion with damping measures incorporated in the structure.

Intensity is the amount of damage the earthquake causes locally, which can be characterized by the 12 level *Modified Mercalli Scale* (MM) where each level designates a certain amount of destruction correlated to ground acceleration. Earthquake damage will vary depending on distance from origin (or epicenter), local soil conditions, and the type of construction.

B. Effects of Earthquakes on Buildings

Seismic Terminology (For definitions of terms used in this resource page, see Glossary of Seismic Terminology)

The aforementioned seismic measures are used to calculate forces that earthquakes impose on buildings. Ground shaking (pushing back and forth, sideways, up and down) generates internal forces within buildings called the *Inertial Force* ($F_{Inertial}$), which in turn causes most seismic damage.

$F_{Inertial}$ = Mass (M) X Acceleration (A).

The greater the mass (weight of the building), the greater the internal inertial forces generated. Lightweight construction with less mass is typically an advantage in seismic design. Greater mass generates greater lateral forces, thereby increasing the possibility of columns being displaced, out of plumb, and/or buckling under vertical load (P delta Effect).

Earthquakes generate waves that may be slow and long, or short and abrupt. The length of a full cycle in seconds is the *Period* of the wave and is the inverse of the *Frequency*. All objects, including buildings, have a *natural* or *fundamental period* at which they vibrate if jolted by a shock. The natural period is a primary consideration for seismic design, although other aspects of the building design may also contribute to a lesser degree to the mitigation measures. If the period of the shock wave and the natural period of the building coincide, then the building will "resonate" and its vibration will increase or "amplify" several times.

Fig. 4. Height is the main determinant of fundamental period—each object has its own fundamental period at which it will vibrate. The period is proportionate to the height of the building.

The soil also has a period varying between 0.4 and 1.5 sec., very soft soil being 2.0 sec. Soft soils generally have a tendency to increase shaking as much as 2 to 6 times as compared to rock. Also, the period of the soil coinciding with the natural period of the building can greatly amplify acceleration of the building and is therefore a design consideration.

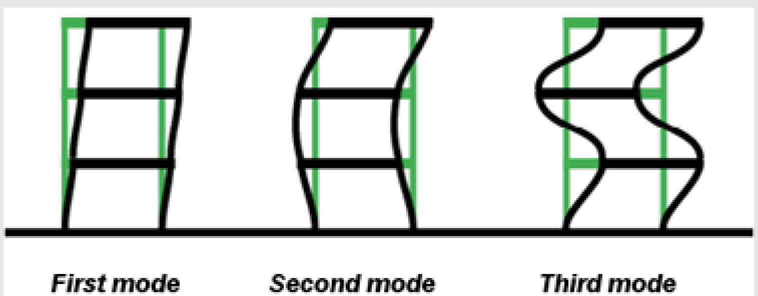


Fig. 5. Tall buildings will undergo several modes of vibration, but for seismic purposes (except for very tall buildings) the fundamental period, or first mode is usually the most significant.

Seismic Design Factors

The following factors affect and are affected by the design of the building. It is important that the design team understands these factors and deal with them prudently in the design phase.

Torsion: Objects and buildings have a center of mass, a point by which the object (building) can be balanced without rotation occurring. If the mass is uniformly distributed then the geometric center of the floor and the center of mass may coincide. Uneven mass distribution will position the center of mass outside of the geometric center causing "torsion" generating stress concentrations. A certain amount of torsion is unavoidable in every building design. Symmetrical arrangement of masses, however, will result in balanced stiffness against either direction and keep torsion within a manageable range.

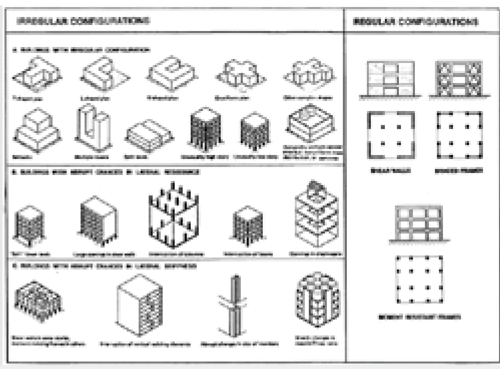
Damping: Buildings in general are poor resonators to dynamic shock and dissipate vibration by absorbing it. Damping is a rate at which natural vibration is absorbed.

Ductility: Ductility is the characteristic of a material (such as steel) to bend, flex, or move, but fails only after considerable deformation has occurred. Non-ductile materials (such as poorly reinforced concrete) fail abruptly by crumbling. Good ductility can be achieved with carefully detailed joints.

Strength and Stiffness: Strength is a property of a material to resist and bear applied forces within a safe limit. Stiffness of a material is a degree of resistance to deflection or drift (drift being a horizontal story-to-story relative displacement).

Building Configuration: This term defines a building's size and shape, and structural and nonstructural elements. Building configuration determines the way seismic forces are distributed within the structure, their relative magnitude, and problematic design concerns.

- *Regular Configuration* buildings have Shear Walls or Moment-Resistant Frames or Braced Frames and generally have:
  - Low Height to Base Ratios
  - Equal Floor Heights
  - Symmetrical Plans
  - Uniform Sections and Elevations
  - Maximum Torsional Resistance
  - Short Spans and Redundancy
  - Direct Load Paths
- *Irregular Configuration* buildings are those that differ from the "Regular" definition and have problematic stress concentrations and torsion.




Left: Fig. 6. Irregular and Regular Building Configurations View enlarged illustration

Right: Fig. 7. Buildings seldom overturn—they fall apart or "pancake"

Soft First Story is a discontinuity of strength and stiffness for lateral load at the ground level.

Discontinuous Shear Walls do not line up consistently one upon the other causing "soft" levels.

Variation in *Perimeter Strength* and *Stiffness* such as an open front on the ground level usually causes eccentricity or torsion.

Reentrant Corners in the shapes of **H**, **L**, **T**, **U**, **+**, or **[]** develop stress concentration at the reentrant corner and torsion. Seismic designs should adequately separate reentrant corners or strengthen them.

Knowledge of the building's period, torsion, damping, ductility, strength, stiffness, and configuration can help one determine the most appropriate seismic design devices and mitigation strategies to employ.

C. Seismic Design Strategies and Devices

Diaphragms: Floors and roofs can be used as rigid horizontal planes, or diaphragms, to transfer lateral forces to vertical resisting elements such as walls or frames.

Shear Walls: Strategically located stiffened walls are shear walls and are capable of transferring lateral forces from floors and roofs to the foundation.

Braced Frames: Vertical frames that transfer lateral loads from floors and roofs to foundations. Like shear walls, Braced Frames are designed to take lateral loads but are used where shear walls are impractical.

Moment-Resistant Frames: Column/beam joints in moment-resistant frames are designed to take both shear and bending thereby eliminating the space limitations of solid shear walls or braced frames. The column/beam joints are carefully designed to be stiff yet to allow some deformation for energy dissipation taking advantage of the ductility of steel (reinforced concrete can be designed as a Moment-Resistant Frame as well).

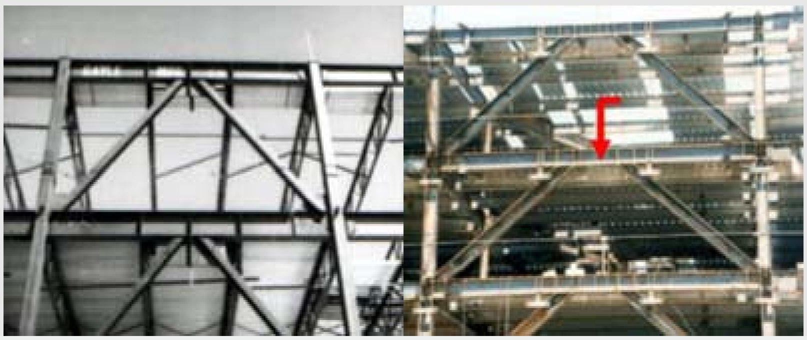


Fig. 8. *Left:* Concentric Braced Frame *and Right:* Eccentric Braced Frame, with link beams

Energy-Dissipating Devices: Making the building structure more resistive will increase shaking which may damage the contents or the function of the building. Energy-Dissipating Devices are used to minimize shaking. Energy will dissipate if ductile materials deform in a controlled way. An example is Eccentric Bracing whereby the controlled deformation of framing members dissipates energy. However, this will not eliminate or reduce damage to building contents. A more direct solution is the use of energy dissipating devices that function like shock absorbers in a moving car. The period of the building will be lengthened and the building will "ride out" the shaking within a tolerable range.

Fig. 9. Base Isolation Bearings are used to modify the transmission of the forces from the ground to the building

Base Isolation: This seismic design strategy involves separating the building from the foundation and acts to absorb shock. As the ground moves, the building moves at a slower pace because the isolators dissipate a large part of the shock. The building must be designed to act as a unit, or "rigid box", of appropriate height (to avoid overturning) and have flexible utility connections to accommodate movement at its base. Base Isolation is easiest to incorporate in the design of new construction. Existing buildings may require alterations to be made more rigid to move as a unit with foundations separated from the superstructure to insert the Base Isolators. Additional space (a "moat") must be provided for horizontal displacement (the whole building will move back and forth a whole foot or more). Base Isolation retrofit is a costly operation that is most commonly appropriate in high asset value facilities and may require partial or the full removal of building occupants during installation.

Fig. 10. Passive Energy Dissipation includes the introduction of devices such as dampers to dissipate earthquake energy producing friction or deformation.

The materials used for *Elastomeric Isolators* are natural rubber, high-damping rubber, or another elastomer in combination with metal parts. *Frictive Isolators* are also used and are made primarily of metal parts.

Tall buildings cannot be base-isolated or they would overturn. Being very flexible compared to low-rise buildings, their horizontal displacement needs to be controlled. This can be achieved by the use of *Dampers*, which absorb a good part of the energy making the displacement tolerable. Retrofitting existing buildings is often easier with dampers than with base isolators, especially if the application is external or does not interfere with the occupants.

There are many types of dampers used to mitigate seismic effects, including:

- Hysteric dampers utilize the deformation of metal parts
- Visco-elastic dampers stretch an elastomer in combination with metal parts
- Frictive dampers use metal or other surfaces in friction
- Viscous dampers compress a fluid in a piston-like device
- Hybrid dampers utilize the combination of elastomeric and metal or other parts

D. Nonstructural Damage Control

All items, which are not part of the structural system, are considered as "nonstructural", and include such building elements as:

- Exterior cladding and curtain walls
- Parapet walls
- Canopies and marquees
- Chimneys and stacks
- Partitions, doors, windows
- Suspended ceilings
- Routes of exit and entrance
- Mechanical, Plumbing, Electrical and Communications equipment
- Elevators

- Furniture and equipment

These items must be stabilized with bracing to prevent their damage or total destruction. Building machinery and equipment can be outfitted with seismic isolating devices, which are modified versions of the standard Vibration Isolators.

Loss arising from nonstructural damage can be a multiple of the structural losses. Loss of business and failure of entire businesses was very high in the Loma Prieta, Northridge, and Kobe earthquakes due to both structural and nonstructural seismic damages.

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Application

The principles and strategies of seismic design and construction are applied in a systematic approach that matches an appropriate response to specific conditions through the following major steps:

1. Analyze Site Conditions

The location and physical properties of the site are the primary influences the entire design process. The following questions can serve as a checklist to identify seismic design objectives.

1. Where is the location of the nearest fault?
2. Are there unconsolidated natural or man-made fills present?
3. Is there a potential for landslide or liquefaction on or near the site?
4. Are there vulnerable transportation, communication, and utilities connections?
5. Are there any hazardous materials on the site to be protected?
6. Is there potential for battering by adjacent buildings?
7. Is there exposure to potential flood from tsunami, seiche, or dam failure?

Consider mission critical or business continuity threats of seismicity on adjacent sites or elsewhere in the vicinity that may render the project site inaccessible or causes the loss of utilities, threat of fire, or the release of toxic materials to the site. Conduct subsurface investigations to discover loose soils or uncontrolled fill that could increase ground motion. Hard dense soils remain more stable, while solid dense rock is the most predictable and seismically safe building base.

2. Establish Seismic Design Objectives

A performance-based approach to establishing seismic design objectives is recommended. This determines a level of predictable building behavior by responding to the maximum considered earthquake. A threat/vulnerability assessment and risk analysis can be used to define the level of performance desired for the building project. Some suggested seismic design performance goals are:

- Conform to local building codes providing "Life Safety," meaning that the building may collapse eventually but not during the earthquake.
- Design for repairable structural damage, required evacuation of the building, and acceptable loss of business for stipulated number of days.
- Design for repairable nonstructural damage, partial or full evacuation, and acceptable loss of business for stipulated number of days due to repair.

- Design for repairable structural damage, no evacuation required, and acceptable loss of business for stipulated number of days due to repair.
- No structural damage, repairable nonstructural damage, no evacuation, and acceptable loss of business for stipulated number of days due to repair.
- No structural or nonstructural damage, and no loss of business caused by either (excluding damage to tenants' own equipment such as file cabinets, bookshelves, furniture, office equipment etc. if not properly anchored).

Regarding the magnitude of the earthquake it may also be stipulated as "Low," "Moderate," or "Large" as another matrix of grading threat and establishing corresponding building performance goals.

3. Select/Design Appropriate Structural Systems

Seismic design objectives can greatly influence the selection of the most appropriate structural system and related building systems for the project. Some construction type options, and corresponding seismic properties, are:

- Wood or timber frame (good energy absorption, light weight, framing connections are critical).
- Reinforced masonry walls (good energy absorption if walls and floors are well integrated; proportion of spandrels and piers are critical to avoid cracking)
- Reinforced concrete walls (good energy absorption if walls and floors well integrated; proportion of spandrels and piers are critical to avoid cracking)
- Steel frame with masonry fill-in walls (good energy absorption if bay sizes are small and building plan is uniform)
- Steel frame, braced (extensive bracing, detailing, and proportions are important)
- Steel frame, moment-resisting (good energy absorption, connections are critical)
- Steel frame, eccentrically braced (excellent energy absorption, connections are critical)
- Pre-cast concrete frame (poor performer without special energy absorbing connections)

Structural and architectural detailing and construction quality control is very important to ensure ductility and natural damping and to keep damages to a limited and repairable range. The prospect of structural and nonstructural damage is not likely to be eliminated without the prudent use of energy-dissipating devices. The cost of adding energy-dissipating devices is in the range of 1-2% of the total structural cost. This is not a large number, particularly when related to the life-cycle cost of the building. Within a 30-50 year life cycle the cost is negligible.

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Relevant Codes and Standards

Many building codes and governmental standards exist pertaining to design and construction for seismic hazard mitigation. As previously mentioned, building code requirements are primarily prescriptive and define seismic zones and minimum safety factors to "design to." Codes pertaining to seismic requirements may be local, state, or regional building codes or amendments and should be researched thoroughly by the design professional.

Many governmental agencies at the federal level have seismic standards, criteria, and program specialists who are involved in major building programs and can give further guidance on special requirements.

- Federal Emergency Management Agency (FEMA)
  Provides a number of web-based "Disaster Communities," organized around multi-hazard issues, including an Earthquake Disaster Community with major seismic related FEMA publications.
- International Code Council (ICC)
  ICC was established in 1994 to developing a single set of comprehensive and coordinated national model construction codes. The founders of the ICC are Building Officials and Code Administrators International, Inc. (BOCA), International Conference of Building Officials (ICBO), and Southern Building Code Congress International, Inc. (SBCCI).
- National Earthquake Hazards Reduction Program (NEHRP)
  FEMA's earthquake program was established in 1977, under the authority of the Earthquake Hazards Reduction Act of 1977, enacted as Public Law 101-614. The purpose of the National Earthquake Hazards Reduction Program (NEHRP) is to reduce the risks of life and property from future earthquakes. FEMA serves as lead agency among the four primary NEHRP federal partners, responsible for planning and coordinating the Program.
- Standards of Seismic Safety for Existing Federally Owned and Leased Buildings—a report of the NIST Interagency Committee on Seismic Safety in Construction (ICSSC RP 6) (NISTIR 6762)

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Additional Resources

For definitions of terms used in this resource page, see Glossary of Seismic Terminology.

WBDG

Design Objectives

Functional / Operational—Ensure Occupant Safety and Health, Secure / SafeSecure / Safe—Resist Natural Hazards, Secure / Safe—Provide Security for Building Occupants and Assets

Products and Systems

Building Envelope Design Guide: Wall Systems Branch; Federal Green Construction Guide for Specifiers

Organizations

- American Council of Engineering Companies
- American Society of Civil Engineers
- Building Seismic Safety Council (NIBS)—The Building Seismic Safety Council (BSSC), established by the National Institute of Building Sciences develops and promotes building earthquake risk mitigation, regulatory provisions for the nation.

Websites

- Federal Emergency Management Agency (FEMA) Mitigation Division—One of the features of FEMA's site is a map library, containing: GIS mapping products and data for the latest disasters, along with current and prior year disasters and custom hazard maps that can be created by entering a zip code and selecting from a variety of hazard types to help determine disaster risks in any community. In addition, the Mitigation Directorate's Flood Hazard Mapping Technical Services Division maintains and updates the National Flood Insurance Program maps.
- Natural Hazards Center—The Natural Hazards Center, located at the University of Colorado, Boulder, Colorado, USA, is a national and international clearinghouse for information on natural hazards and human adjustments to hazards and disasters.
- Seismosoft—A large ad hoc worldwide web community for seismic engineering with links to popular web sites, publications, and tools.
- USGS National Earthquake Information Center

Publications

- *Design Guideline for Seismic Resistant Water Pipeline Installations* by American Lifelines Alliance. 2005.
- *UFC 1-200-01 General Building Requirements*
- *UFC 3-310-04 Seismic Design for Buildings*

3. WIND FORCES
%14-%17 percent of scored

A. Principles
Apply lateral force principles into the design and construction of buildings to resist wind.

1. Building Design
Analyze behavior of building structural systems when subjected to wind load, including load path, loading effects and building response, nature of wind loads on structures, and causes and characteristics of wind.

2. Building Systems and their Integration
Consider wind force resisting systems and elements including braced frames, shear walls, rigid frames, flexible and rigid membranes, and foundations to integrate into the design.

3. Implications of Design Decisions
Examine impact of design for wind forces considering cost, building configuration, building function, historic preservation, and construction schedule.

B. Materials & Technology

Analyze the impact of design decisions on the selection of systems, materials, and construction details related to wind forces.

1. Construction Details and Constructability
Examine construction details and non-structural elements pertaining to resistance to wind.

2. Construction Materials
Ascertain construction materials pertaining to resistance to wind.

C. Codes & Regulations
Incorporate building codes and other regulatory requirements related to wind forces.

1. Government and Regulatory Requirements and Permit Processes
Incorporate building and life safety codes and regulations for inclusion in design of structures for resistance to wind.

Wind forces in structural design are based on probability as a result of historical analysis/
Not: Water pressures; Dead loads; Soil pressures

Recommended deflection criteria due to wind loading on a brick veneer wall utilizing a metal stud
back-up system is L/600

Not: L/360; L/400; L/720