Architectural Registration Examination

Structural Systems

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Covering the Nation

STATE	LICENSE #
NCEES	22476
Arizona Mechanical	31808
Arizona Electrical	32191
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Connecticut	21298
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Idaho	P-11516
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Utah	333030-2202
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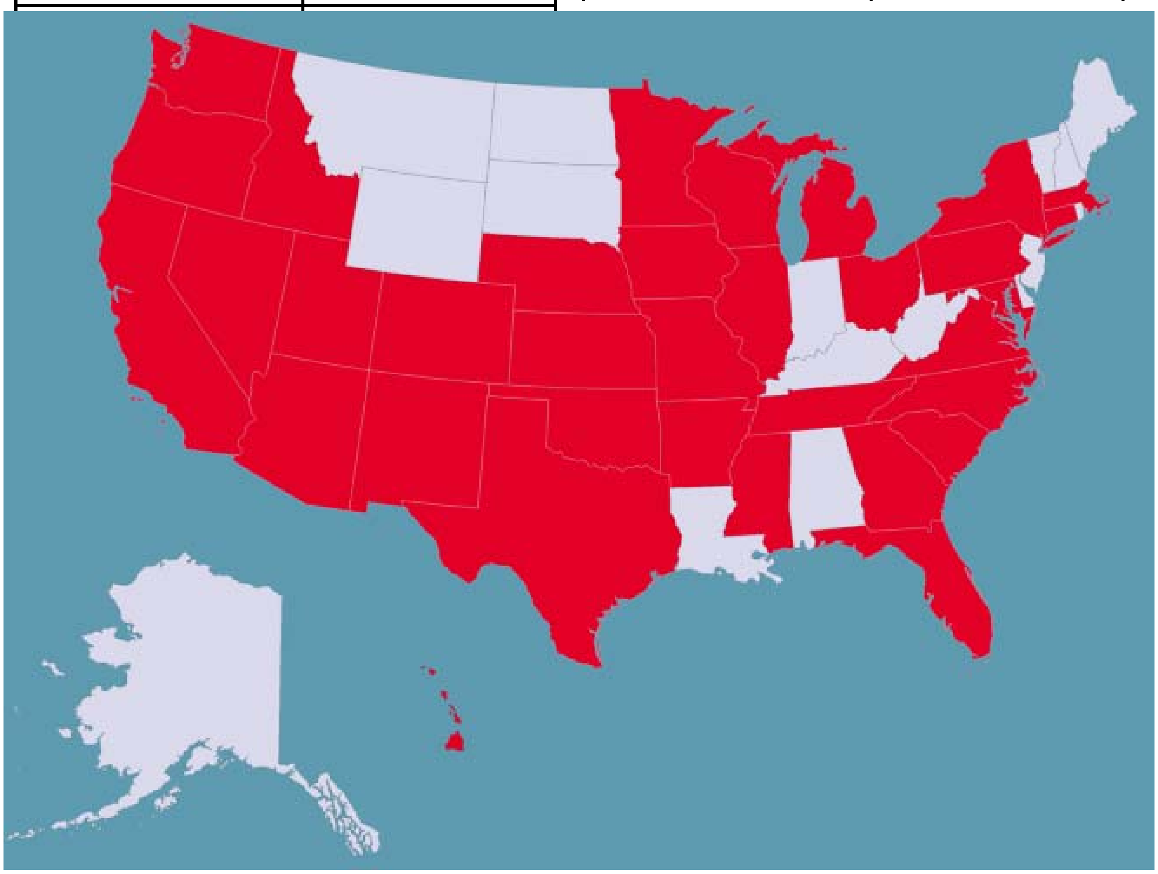
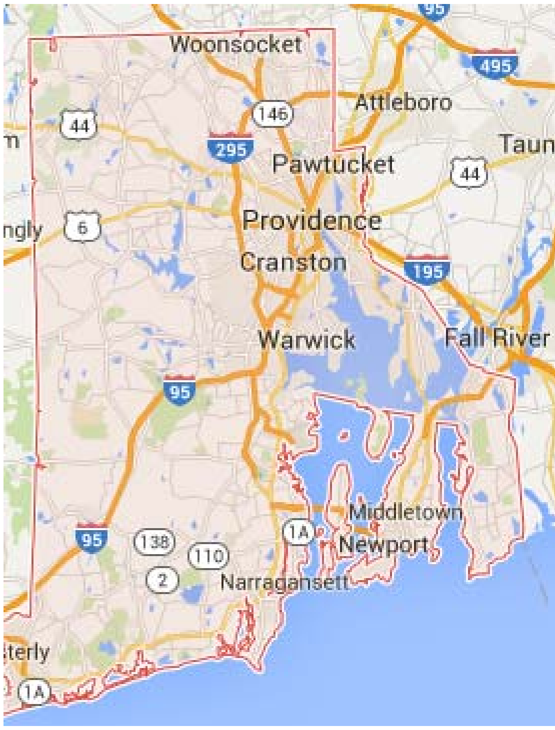
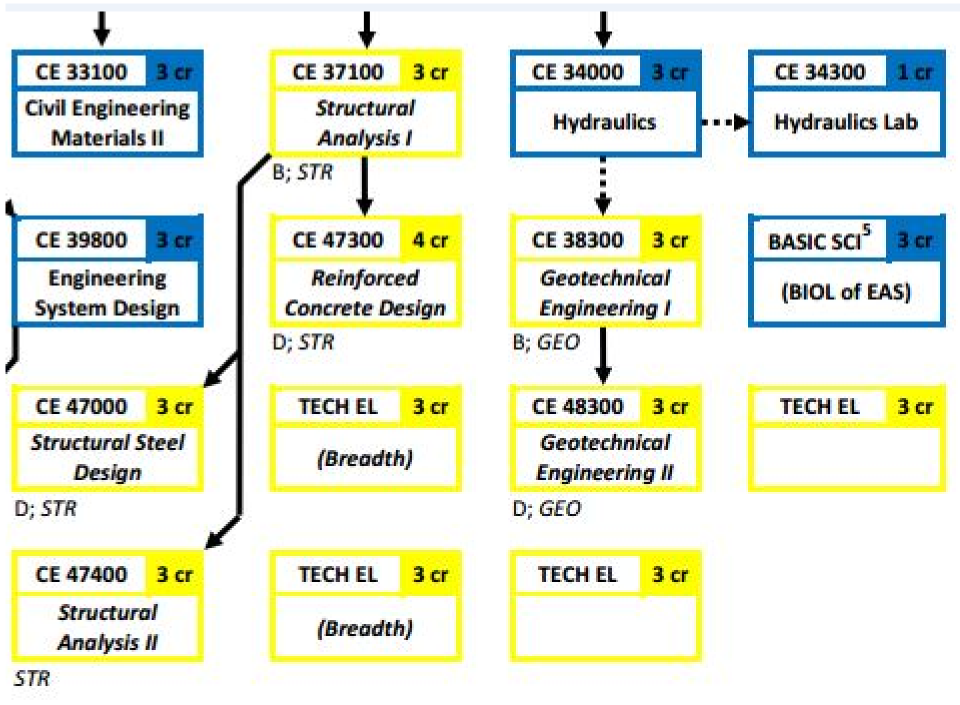




Rhode Island


CE 33100 3 cr
Civil Engineering Materials II
CE 37100 3 cr
Structural Analysis I
B; STR
CE 34000 3 cr
Hydraulics
CE 34300 1 cr
Hydraulics Lab
CE 39800 3 cr
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CE 47300 4 cr
Reinforced Concrete Design
D; STR
CE 38300 3 cr
Geotechnical Engineering I
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BASIC SCI5 3 cr
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Structural Steel Design
D; STR
TECH EL 3 cr
(Breadth)
CE 48300 3 cr
Geotechnical Engineering II
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TECH EL 3 cr
CE 47400 3 cr
Structural Analysis II
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Structural Components

Need -> Type of Building
Location -> Restrictions
Technology -> Building Materials
Man Power -> Construction Methods

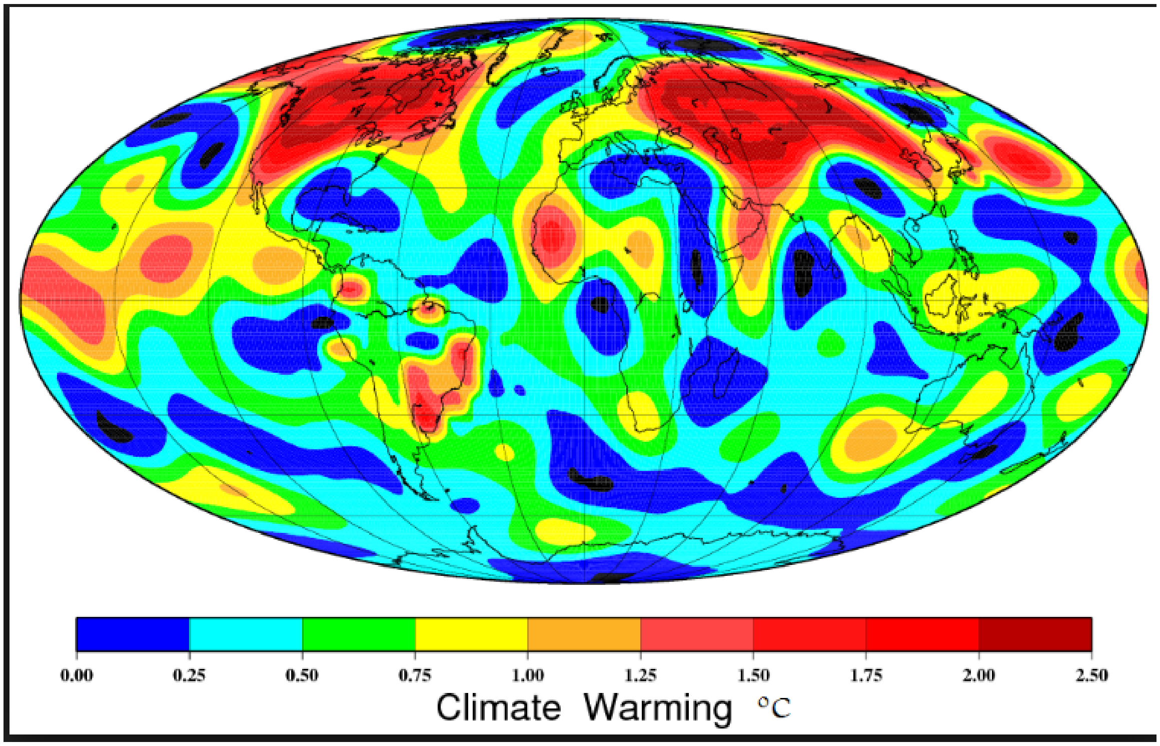
Building Types

Contents

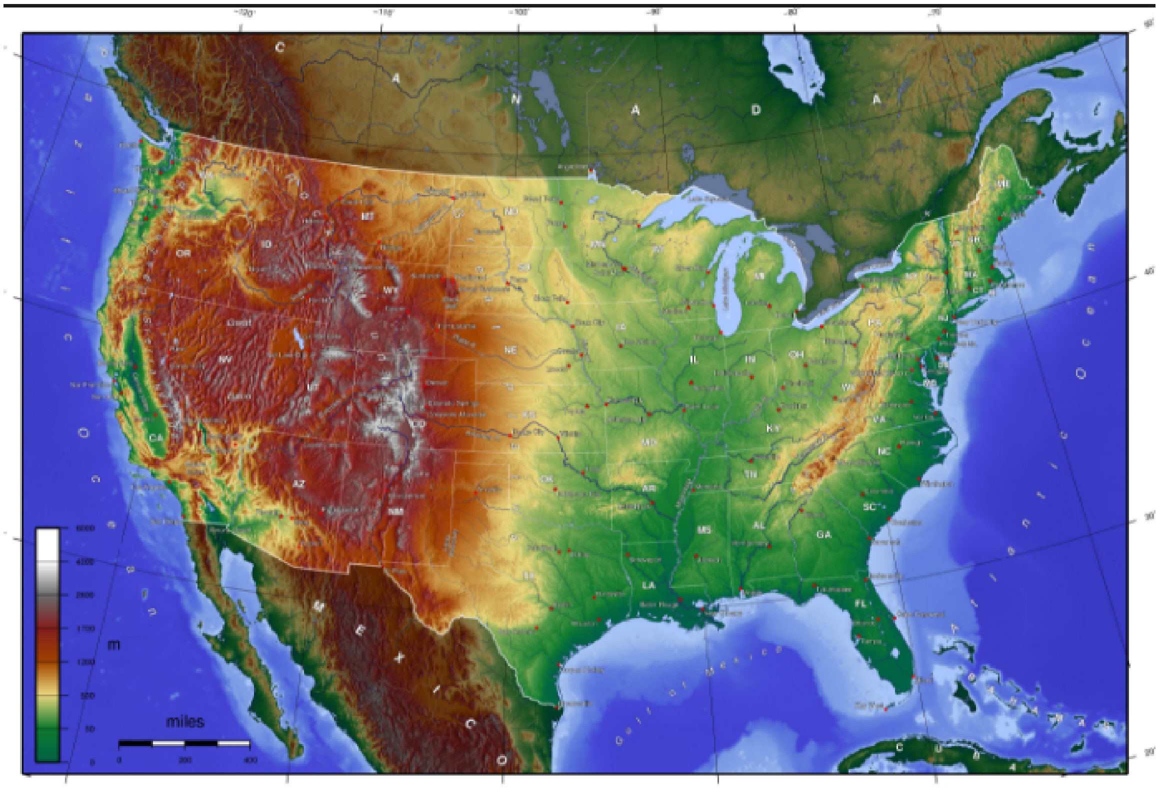
[hide]

- 1Agricultural buildings
- 2Commercial buildings
- 3Residential buildings
- 4Educational buildings
- 5Government buildings
- 6Industrial buildings
- 7Military buildings
- 8Parking structures and storage
- 9Religious buildings
- 10Transport buildings
- 11Infrastructure
- 12Power stations/plants
- 13Others

Climate or Locations



Topography



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Type of Building Materials

Catalogs[edit]

Catalogs distributed by architectural product suppliers are typically organized into these groups.

Material (articles)	*refer to:* **Category**
Compressed earth block, mud brick, rammed earth	Category:Appropriate technology
Concrete	Category:Concrete
Conveyor systems • Elevator or "lift" • Escalator	Category:Vertical transport devices
Composites	Category:Composite materials
Thermal protection • Building insulation	Category:Thermal protection
Moisture protection • Building envelope • Conformal coating • Damp (structural) • Housewrap	Category:Moisture protection
Doors • Stile and rail, raised panel, wood clad • Access, sliding glass doors, tambour • Folding doors, garage door, storefront • Door hardware	Category:Doors Category:Door furniture

Electrical systems and equipment • AC power plugs and sockets • Circuit breaker • Electrical connector • Electrical wiring • Switches	Category:Electrical systems
Surface finishing • Plaster & gypsum board • Cement render • Ceramic tile, quarry tile, pavers, mosaic • Dropped ceiling, coffered ceiling • Flooring – wide plank, terrazzo, carpet • Marble • Wall covering, wallpaper, acoustic • Paint, wood stain, faux finishing • Staff – a type of artificial stone • Stucco • Wood finishing	Category:Wood finishing materials Category:Wood finishing techniques • also "gyp-board" or "drywall" • Category:Roofs • Category:Ceilings • Category:Floors • Category:Walls • House painting
Fire suppression equipment	Category:Fire suppression
Furnishings	Category:Furniture
HVAC (Heating, ventilation and air conditioning)	Category:HVAC
Masonry, mortar (masonry), grout • Adobe, brick and brickwork, glass brick, terra cotta • Artificial stone • Cinder block or concrete block • Noxer block • Stone dry stacked or mortar set • Urbanite – broken-up concrete	Category:Masonry • Category:Bricks • *also:* "Concrete Masonry Units" (CMU) • Category:Stone
Metals • Structural steel: I-beam & column • Rebar	Category:Metals

• Wire rope and cables • Metal joist, decking, framing, trusses • Metal fabrications ◦ Stairway, ladder, railing, grating, Strut channel, roofing (including copper) • Decorative metal	
"Openings" include Doors & Windows	Category:Doors
Plastics	Category:Plastics
Plumbing fixtures and equipment	Category:Plumbing
Building safety	Category:Safety codes
Security systems	Category:Security
Specialties	Category:Architectural design
Telecommunications equipment	Category:Telecommunications

Wood, carpentry
 	
• Rough carpentry (unfinished)
  ◦ Heavy timbers, log home, timber framing or "post and beam"
  ◦ Bamboo
  ◦ Engineered wood, dimensional lumber
    ▪ Stud, joist, rafter
    ▪ Treated lumber & wood decking
  ◦ Sheathing, subflooring, Panelling
    ▪ Plywood, shiplap, tongue and groove
    ▪ Oriented strand board
  ◦ Parallel strand lumber or "*para-lam*"
  ◦ Glue-laminate or "*glue-lam*"
• Finish carpentry or "architectural woodwork"
  ◦ Veneer, plastic laminate, wood panel
  ◦ Case-building products
    ▪ Millwork, bookcase, cabinets
  ◦ Ornamental woodwork
  ◦ Trim, molding or "moulding"
	Category:Wood
	
	Category:woodworking
	
	See also: List of woods

• Chair rail, baseboard, casing, sill	
Windows • Casement, double hung, bay window • Curtainwall, skylight, dormer	Category:Windows

Building Construction Machinary

Start a Project.

A Home………..
Structural Components

Need -> Type of Building
Location -> Restrictions
Technology -> Building Materials
Man Power -> Construction Methods
Code -> Means and Methods of Construction

Once need is known.

Start from Roof to grade.
Roof Loading

APPENDIX A
WEIGHTS OF BUILDING MATERIALS

SECTION A101
GENERAL

In estimating dead loads for purposes of design, the actual weights of materials and constructions shall be used, provided that in the absence of definite information, values satisfactory to the building official may be assumed.

SECTION A102
DEAD LOADS

Dead loads of typed building materials and constructions are listed in Table A1 and Table A2.

TABLE A1
DEAD LOAD IN POUNDS PER SQUARE FOOT

COMPONENT	LOAD	COMPONENT	LOAD
CEILINGS		Rigid insulation, 1/2-in.	0.75
Acoustical fiber tile	1	Skylight, metal frame, 3/8-in. wire glass	8
Gypsum board (per 1/8 in.)	0.55	Slate, 3/16-in.	7
Mechanical duct allowance	4	Slate, 1/4-in.	10
Plaster on tile or concrete	5	Waterproofing membranes:	
Plaster on wood lath	8	Bituminous, gravel covered	5.5
Suspended steel channel system	2	Liquid applied	1.0
Suspended metal lath and cement plaster	15	Bituminous, smooth surface	1.5
Suspended metal lath and gypsum plaster	10	Single-ply, sheet (Fully adhered, mechanically attached)	0.7
Wood furring suspension system	2.5	Single-ply, sheet (Ballasted)	11.0
		Wood sheathing (per in.)	3
		Wood shingles	3
COVERINGS, ROOF AND WALL		Wood structural panel (per 1/8 in.)	0.4
Asbestos-cement shingles	4		

Live Load
Dead Load

Loads on Walls/Beams/Columns

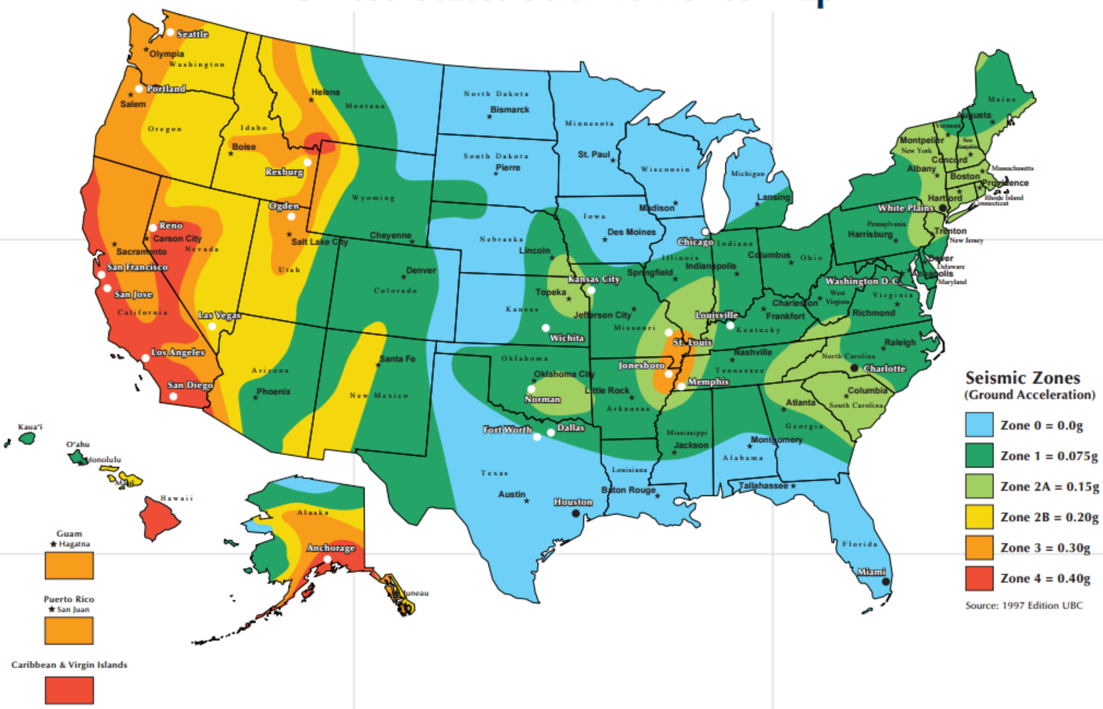
Then Second Floor Loading

Live Load
Dead Load

Loads on Walls/Beams/Columns

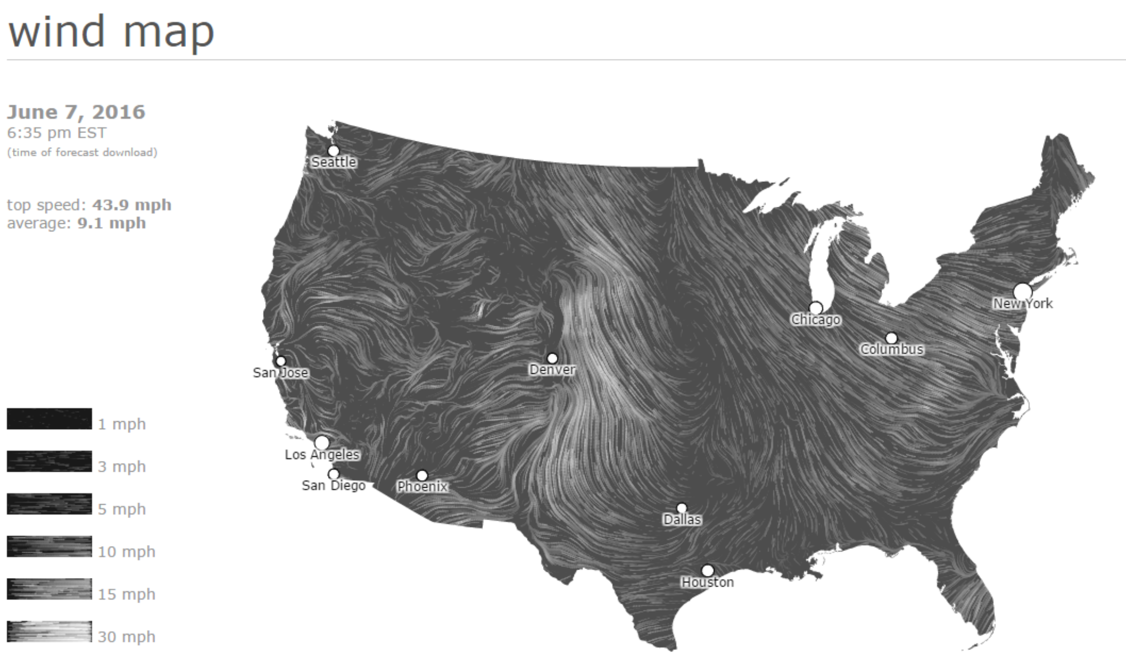
Then Loads on Soil
Foundation Design

United States Seismic Zones Map

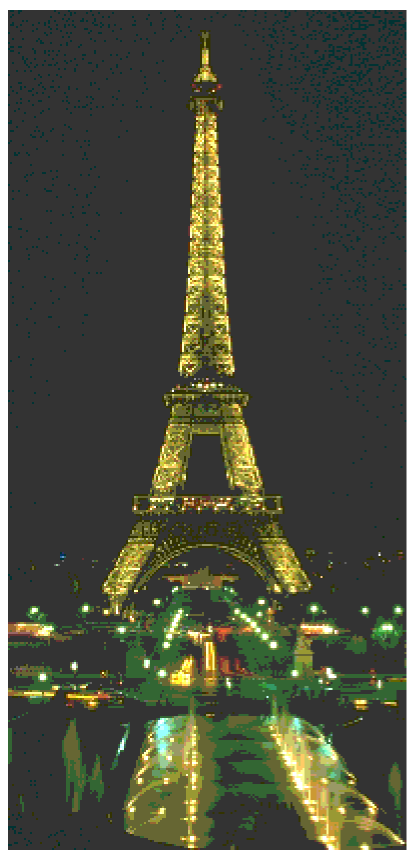


Wind loading

[Wind Map - Hint.fm]



What is Lateral Forces vs Seismic Forces?



Most lateral loads are live loads whose main component is a horizontal force acting on the structure. Typical lateral loads would be a wind load against a facade, an earthquake, the earth pressure against a beach front retaining wall or the earth pressure against a basement wall. Most lateral loads vary in intensity depending on the building's geographic location, structural materials, height and shape. The dynamic effects of wind and earthquake loads are usually analyzed as an equivalent static load in most small and moderate-sized buildings. Others must utilize the iterative potential of the computer. The design wind and earthquake loads on a building are substantially more complex than the following brief discussion and simple examples would indicate. The Uniform Building Code describes the design wind load determination in more detail for the various parts of the United States.

WIND LOADS

The most common lateral load is a wind load. The Eiffel Tower is one example of a building which has a structure that was designed to resist a high wind load. Wind against a building builds up a positive pressure on the windward side and a negative pressure (or suction) on the leeward side. Depending upon the shape of the structure it may also cause a negative pressure on the side walls or even the roof. The pressure on the walls and roof is not uniform, but varies across the surface. Winds can apply loads to structures from unexpected directions. Thus, a designer must be well aware of the dangers implied by this lateral load. The magnitude of the pressure that acts upon the surfaces is proportional to the square of the wind speed.

Wind loads vary around the world. Meteorological data collected by national weather services are one of the most reliable sources of wind data. Factors that effect the wind load include the geographic location, elevation, degree of exposure, relationship to nearby structures, building height and size, direction of prevailing winds, velocity of prevailing winds and positive or negative pressures due to architectural design features (atriums, entrances, or other openings). All of these factors are taken into account when the lateral loads on the facades are calculated. It is often necessary to examine more than one wind load case.

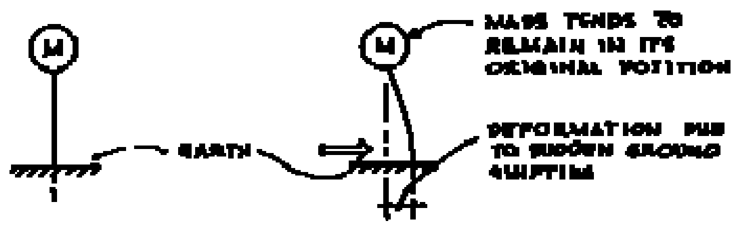
For this course, it will be assumed that wind loads, as well as the pressure they develop upon wall and roof elements, are static and uniform. They actually not only pound a structure with a constantly oscillating force, but also increase as a building increases in height. The loading of a tower can be very roughly approximated by an evenly distributed load. It is a vertical cantilever. The applet below allows you to investigate the variables which influence the structural behavior of a tall, thin tower. It does not represent actual methods of calculating the total wind force on a tall building. It is intended to demonstrate the interaction between the variables of the equations which govern the structural behavior.

EARTHQUAKE LOADS

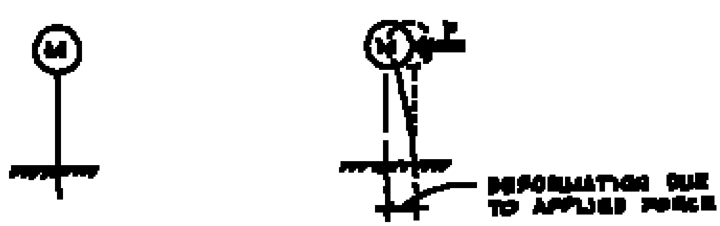
Earthquake loads are another lateral live load. They are very complex, uncertain, and potentially more damaging than wind loads. It is quite fortunate that they do not occur frequently. The earthquake creates ground movements that can be categorized as a "shake," "rattle," and a "roll." Every structure in an earthquake zone must be able to withstand all three of these loadings of different intensities. Although the ground under a structure may shift in any direction, only the horizontal components of this movement are usually considered critical in a structural analysis. It is assumed that a load-bearing structure which supports properly calculated design loads for vertical dead and live loads are adequate for the vertical component of the earthquake. The "static equivalent load" method is used to design most small and moderate-sized buildings.

The lateral load resisting systems for earthquake loads are similar to those for wind loads. Both are designed as if they are horizontally applied to the structural system. The wind load is considered to be more of a constant force while the earthquake load is almost instantaneous. The wind load is an external force, the magnitude of which depends upon the height of the building, the velocity of the wind and the amount of surface area that the wind "attacks." The magnitude earthquake load depends up the mass of the structure, the stiffness of the structural system and the acceleration of the surface of the earch. It can be seen that the application of these two types of loads is very different.

This movie is a representation of the movement of a free standing water tower in an earthquake. It can be seen that the as the ground moves, the initial tendency is for the water tower to remain in place. The shifting of the ground is so rapid that the tower cannot "keep up."



After a moment, the tower moves to catch up with the movement of the ground. The movement is actually an acceleratoin. From Newtonian Physics, it is know that an applied force=mass x acceleration. Thus, the force which is applied to the water tower depends upon the mass of the tower and the acceleration of the earth's surface.



The force in this last diagram may be thought of as the "equivalent static load" for which the structure would be designed. This idealized situation demonstrates a concept; it requires modification for actual buildings. These modifications account for building location, importance, soil type, and type of construction. This movement can also be seen in the following movie of lateral earth movement. Note how the mass slowly reacts to the movement of the earth. Eventually, the bending strength of the stem of the tower would be exceeded and it will fail.

Fluid and Earth Pressure Loads

Liquids produce horizontal loads in many structures. The horizontal pressure of a liquid increases linearly with depth and is proportional to the density of the liquid. This is similar for earth pressures. These last are a bit more complex in that the load due to earth pressure varies with its depth, any surcharge, the type of soil and its moisture content. The design live load for this soil pressure must not be less than that which would be caused by a fluid weighing 30 pcf.

Structural Systems

RE

Content Areas

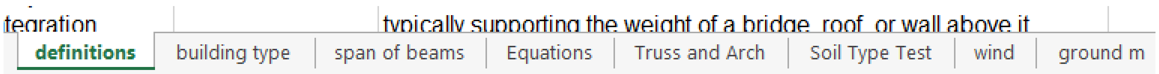
1. GENERAL STRUCTURES	%38- %42 percent of scored
2. SEISMIC FORCES	%28- %32 percent of scored
3. WIND FORCES	%14- %17 percent of scored
4. LATERAL FORCES	%13- %16 percent of scored

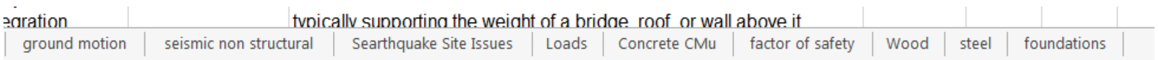
Vignette

STRUCTURAL LAYOUT

Design a schematic framing plan for a one story building With a mutli-level roof.

Excel Charts





Who is a Structural Engineer?

Any element, component, structure, building, monument, equipment must be held from free fall, gravity, seismic, wind, hurricane, heights, tsunamis, man-made or natural disasters. Otherwise that element will fall.

Of course the famous Hammurabi's building code states that if the building fails, and kills the son or daughter, the building owner can kill equivalent son or daughter of the designer.

When component is placed on 3rd floor of a building, the forces of the loads transfer from one member to another finally through columns; they are transferred to ground soil. This transfer requires a foundation. Foundation is like a shoe that permits a stable building. Eskimos wear shoes not to sink in snow in complete contrast to mountain hikers. The soil below the building is classified from A to F, from rock to very unstable soil. Foundation design is an art itself and correlates to geotechnical engineers' science.

If you begin designing and accommodating the load on that level, basic components of structural design are as follows:

o Basic Theories: Very simple static and strength of materials can provide necessary knowledge to understand the concept, even design a system. More advanced theories get involved with micro issues, joints, connections, curves, more elaborate structures. However, one can break down any structure to simpler and through superposition method, one can provide complete understanding of the forces acting on the structure and each component.

o Modeling: Modeling a structure comprises of geometric shape, coordinates, segments, angles, and properties of material. The statistical quantities are loads, reactions, and stresses. The resultant deformations must be checked with allowed deformation; hence the material or material size is altered till full code compliance is met.

o Assumptions: The materials are homogenous, continuous, isotropic and act as spring (Hooke's Law). The deformations do not alter the original geometry significantly. Since the loads applied are gradual, the superposition concept is valid. In superposition, one can apply each load independently and add the results. Therefore sum of effect of system of loads is equal to sum of effect of individual loads. Materials are constant and independent of time, therefore the system is assumed to be in static equilibrium.

o Type of loads:

- Single loads:
    - concentrated load,
    - moment applied by single load,
    - uniformly distributed load,
    - regularly varying load,
    - irregularly varying load,

- Systems of loads:
    - the combination of single loads,
    - symmetrical loads,
    - asymmetrical loads,
    - cyclo symmetrical,
    - cyclo antisymmetrical, and
    - unsymmetrical loads.

Forces acting on members can be complex and number of equilibrium conditions required to solve these forces vary from one type of force to the other.

Coplanar force system or single concentrated load in two dimensional (2D) and three dimensional (3D) requires 3 and 3 equations, respectively.

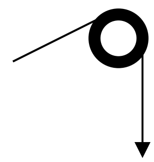
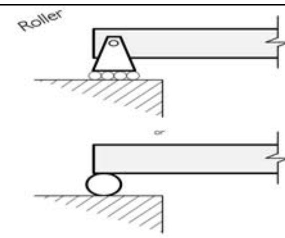
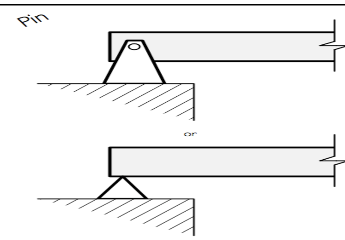
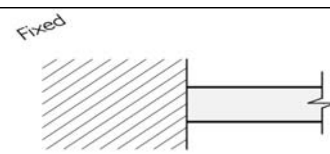
Collinear force system where all the forces share same line of action in 2D and 3D require 1 and 1 equilibrium conditions, respectively.

Parallel forces where all forces are in parallel (both directions) in 2D and 3D require 2 and 3 equilibrium conditions, respectively.

General three dimensional forces where all forces are in one plane (all directions) in 2D and 3D require 3 and 3 equilibrium conditions, respectively.

o Effects of the loads: Loads produce reaction forces on members, the produce stresses on members, and they deform the structural members.
Effect of loads produce reactions on the connections.

o Connections: Connections are movable hinged end, immovable hinged end, guided end, and rigidly fixed end. These connections carry moments and forces. If the member is free and able to move in a direction, reaction forces in that direction does not exist.

Two Dimensional Supports and Connections			
Type of connections	**Moments**	**Reaction Forces**	**Number of Unknowns**
Cable in tension, Link	None	Reaction in direction of link or cable	 1
Simple, roller, rocker, ball, frictionless surface	None	Forces normal to surface	 1
Frictionless guide or collar	None	Forces normal to surface of rail or guide	1
Frictionless Joints, pin connections, rough surface	None	Forces in any direction on hing	 2
Fixed support	One	Two forces acting in x and y	 3

o Static equilibrium: Since the body under load is assumed to be in equilibrium, algebraic sum of all forces are zero, and sum of al moments at any point is zero. The vector form of these forces can be broken into any coordinate systems, ie. Cartesian, cylindrical, spherical coordinates.

o Stresses: Three stresses at center of any materials are: Normal forces, shear forces, and bending moments.

Procedure to perform a design:
One begins with the statement of the problem. A single or multiple or complex load is on top of the structure. Is the structure fit to support the component, say in Los Angeles. As the steps was described, first, you model the building in simple lines and provide all elements that support this component from top to bottom, to foundation, and to the characteristics of the soil.

For example, a battery rack is on 6th floor. The load of the battery rack is on several floor joists. Each floor joist must carry tributary load of the component. Each joist acts as a beam supported by sub-purlines. sub-purlines can be supported by beam, beams sit on columns, columns sit of foundation. The floor joist acts as beam. Beams designs are checked by insuring the can carry the stress, shear, and deflection. Floor joists transmit the load to sub-purlines. The sub-purlines act as uniformly distributed loads plus the contribution of the batteries as concentrated load. Using the superposition, the resulting parameters will be added. Same pattern must be devoted to the purlines, then to main beams. Finally the load is transferred to the column. Then the column is checked for stress, deflection, and buckling. The load on the column is transferred to the foundation. The soil has a capacity, for stable soil, worst case is 1000 lbs per square feet. If the load is 5000 lbs, the base of the foundation area is 5 square feet. There are other issues such as bending of the building and its impact on the soil is also defined.

What we did not discuss was materials, localities, and equations. Materials vary from steel, wood, concrete, timber fiber composites, and non-traditional materials such as bamboo. Location of the building is also critical. The wind, hurricane, earthquake, seaside, and mountain sites make quite difference.
There are two methods of calculations: LRFD and ASD.

Allowable stress Design or ASD is very simple. The allowable stress of the materials is reduced by a safety factor and then the load effects are compared to this reduced value.

Load and Resistance Factor Design or LRFD simply increases the load effects introduced by components and then it compares them to allowable material capacities. There are also resistance factors as multipliers on load effects that play a role in final design.

In eater cased, ASD where material capacity is reduced, or LRFD where the load effects are increased, the safety factors built in varies and has created two separate philosophies in structural engineering.

Capacity is the capability of the building to carry demand, the load. The C to D ratio is a common terminology used by structural engineer in evaluating existing buildings.

Equilibrium or Static

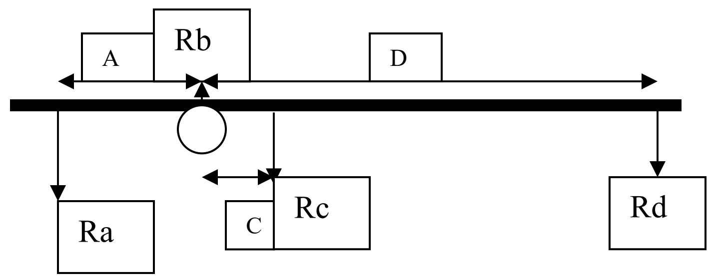
An object, i.e. a beam, a building is at equilibrium when sum of all forces in all directions (algebraic sum), moments and torques are at rest (or is zero) and are not moving, otherwise we would be in a mechanical engineering world called dynamics. Therefore, sum of all the (a) moments acting on the body, (b) vertical forces acting on the body, and (c) horizontal forces acting on the body must equal zero.

Equilibrium:
it must: (1) • Have no unbalanced force acting on it (aka: it can't move!) (2)
• Have no unbalanced moment acting on it (aka: it can't rotate!)
• The three conditions of equilibrium may be stated as follows:
• The summation of all the horizontal forces acting on the body must equal zero.
• The summation of all the vertical forces acting on the body must equal zero. _
• The summation of all the moments acting on the body must equal zero.

Example:

Assuming the beam's weight is negligible, the forces in the vertical direction algebraically are zero. Summation of all vertical forces are

$\boxed{Ra+Rc+Rd= Rb}$



Forces

The unit of force is pounds, lb or # (Newton (SI), N) or thousand pounds, Kips (KiloNewtons, KN). The issue is the seesaw created is stable and not move? To respond to this question, one must take a moment.

Moment at any point is similar to the seesaw, the hammer, the wedge science class in 5th grade. Moment is the force time the arm distance. Arm distance is from the pivot to the position where the force is applied. This is the reason for monumental constructions of the pyramids, temples, and castles nearly 3 thousand years ago.

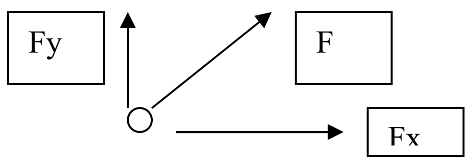
Moment at point b, or any other point, must be zero.

Therefore,

$$A.Rb= C.Rc+D.Rd$$

where the A, C, or D are arms or distances creating the torque.

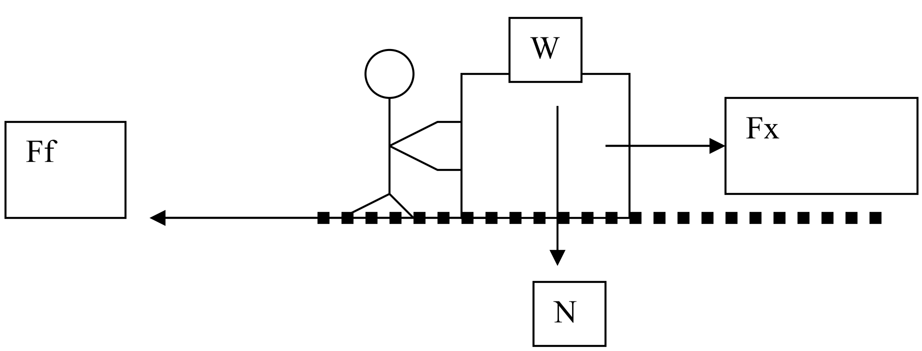
Algebraic sum is the sum of components of vectors.



Force is divided into X component and y component. Applying the equilibrium, sum of all forces in x direction must be zero. Then apply this to y directions.

Please note that Pythagorean theorem and trigonometric sine and cosines can also be used in these calculations.

Any load can be converted into simple diagrams, namely, free body diagram, where vectors correspond to forces acting on a body. Fx is the force pushed by guy, Ff is the surface friction opposing the Fx, W is the gravity force applied on the box, and N is the normal force acting against the box by earth. (You can omit the picture of the guy in structural engineering).



Loads (**Structural loads)** or **actions or active forces:**

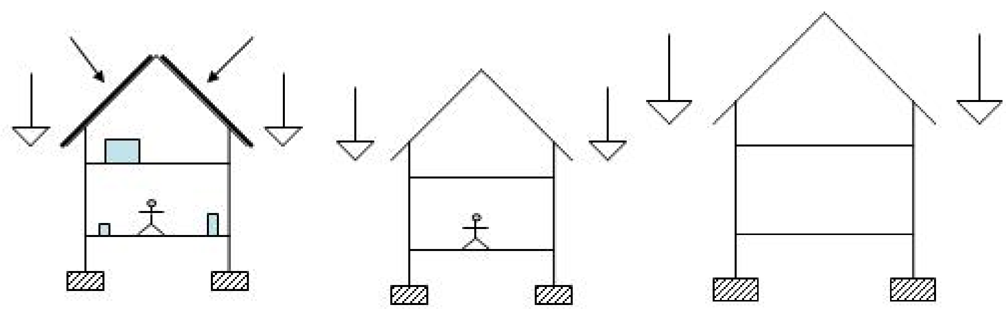
cause stress then deformation and displacement or acceleration.

Structural failures:

Excess loads on members and provide limits of the structural analysis when members fail. Safety Factors limit structural failure. Codes provide additional boundaries/restrictions and additional limits on safety factors, means and methods of construction, inspection required, and technical standards to provide uniformity.

Structural Load

external forces applied to a component of a structure or to the structure as a unit (types: uniformly distributed, point load, or variable loads)



Live snow load Imposed load Dead load

Dead load or permanent load
weights of material, equipment, or components that are relatively permanent on the structure, static forces (dead load) that are relatively constant for an extended time (in tension or compression).

Live (imposed) loads or dynamic loads
Live Load- forces that are variable (e.g. occupants), (unstable or moving loads). Some dynamic loads: impact, momentum, vibration, slosh dynamics of fluids, etc. are temporary, short duration, or moving. probabilistic loads (or live load) include all the forces that are variable within the object's normal operation cycle not including construction or environmental loads.

Impact load:
time of application on a material is less than one-third of the natural frequency of vibration of that material.

Roof live loads :

during maintenance by workers, equipment and materials, and, during the life of the structure by movable objects such as planters and by people.

Bridge live loads
vehicles traveling over the deck of the bridge.
Vibration load
repeated Loading varying with time and with frequency can lead to fatigue damage, cumulative damage, or failure.

Environmental loads

rain, snow, wind, seismic, temperature (thermal expansion/contraction), Lateral pressure of soil, ground water or bulk materials, fluids or floods; Dust loads, ponding, and other external forces from the climate, weather, topography and other natural phenomena.

Other loads

Support settlement or displacement, Fire, Corrosion, Explosion, Creep or shrinkage, Impact from vehicles or machinery, Loads during construction

Load combinations

A load combination results when more than one load type acts on the structure. Different factors are used to weight th eimpact of all loads combined on a member.

Load Reductions:

IBC Sections 1607.9 (floors) and 1607.11 (roofs) allow live loads set forth in IBC Table 1607.1 to be reduced.

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			In storage-type applications with heavier

	floors may be reduced by as much as 20 percent (plus one more exception).			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.

Loads

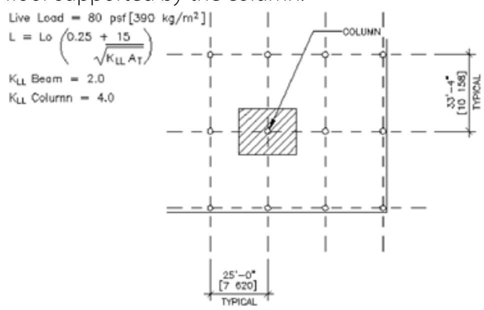
14. An 18th century farmhouse on the National Historic Register with exposed timber framing is to be restored and opened for tours. Limit the number of visitors in spaces to the available live load is the most historically correct method of addressing the lack of live load

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. Elevator and elevator machinery is 100% increase, Light machines, shafts or motor driven is 20% increase, reciprocating machines or power-driven units are 50% increase and floors and balconies are 33% increase in loads. All have to do with impact, or vibrations.

Not: 0 percent; 25 percent; 50 percent

7. When considering permitted live load reductions for the column shown above, 67 kips (kg) is the live load for the floor supported by the column.



I'm confused about this problem, are we not supposed to use the reduced live load formula L = Lo (0.25 + 15/ sq root of KLL x AT)?

The live load is less than 100 psf, and does not say if it is a public assembly space. so I used the formula with tributary area = 25'x33'-4" = 833.33 s.f., and KLL = 4 for column, and Lo=80 psf, and I get reduced live load = 40.78 psf. multiply by tributary area, and i get load supported by column = 33.983 kips.

but the answer is 67 kips. where does this come from?? i thought it may have been = 833.33 s.f. x 80 psf = 66.67 kips. but it doesnt make sense. could someone tell me what i missed? why is that??? the code doesnt say anything about that. wth i think this question is invalid.

As far as I understand you can reduce if LL if:

LL Less the 100 psf
Not a 1 story parking
Not a 1 public assembly

If more then 1 story : 20% reductions allowed in parking and public assembly

In no case LL reduction should exceed:

0.5 of Original Load if 1 story
0.4 of original load if more the one story

In office bdg or other with movable partitions and LL less then 80 psf add 20 psf to Live load corresponding to the movable partitions

Steel

12. 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

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

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 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 $\leq$ 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

Shear force:
acts parallel to area resisting force

The statical moment of an area with respect to an axis:
the area multiplied by the perpendicular distance from the centroid of the area to the axis.

centroid of an area
the center of gravity of the area

No Torsion:

If a load acts through something's center of gravity, then it has no tendency to
rotate, but will translate in the direction of the applied force

Ultimate strength of common materials:

Steel	58,000 - 80,000 psi
Concrete	3,000 - 6,000 psi (higher strengths possible)
Wood	2,000 - 8,000 psi

structures:
connect two points (eg: bridge), withstand natural forces (eg: dam), span and enclose space (eg: building), Structure is a 3-D art form, like sculpture, but it exists with a purpose, Most structural failures are during construction

Purpose of structural design:
Resolution of the conflict between the vertical direction of most load forces and the horizontal dynamics of mankind (eg: gravity and the way we work); All structures will be destroyed eventually; Many structural failures are caused by improper load assumptions; Most concerning types of stress in building design and construction are tension, compression and shear

Forces (or Loads) on Architectural Structures:

External (applied) loads

cause primary stresses.

Vertical forces:
Dead loads and Live Loads, Static and Dynamic, Concentrated versus Distributed, Vertical loads (gravity), People (which are both static and dynamic), Moveable equipment, Vehicles, Rain, Snow, Drifting Snow, Ponding, Buoyancy, Construction Materials (bricks, stockpile, materials, etc)

Dead loads
permanently fixed in a structure, and easier to predict

Live loads
move around on their own, or can be moved, and cause vibration, hard to predict and require a higher safety precaution

Deformation:
Dynamic: the load changes with respect to time, often suddenly (eg: earthquakes, wind), Static: the load moves with building accumulation, slowly. (walking in a classroom is static, siting in a chair is dynamic)

Horizontal forces or **LATERAL FORCES**:
Wind: hurricanes, tornados (no warning or unpredicted); Ice: Expansion force (as it freezes), footings below frost lines; Earthquakes- ground rupture (in the fault

zone), ground failure (sliding, settlement, liquefaction), tsunami (seismic sea waves, called a "seich" on inland bodies of water), ground shaking (vibration, repetitive dynamic motion), People: pushing on a window, balcony, etc. , Vehicles: impact loads (collisions), sudden starts and stops, Machinery: generators, oscillating equipment, vibration of equipment, Earth or Water: pressure on below grade structure, Transportation and Erection: (in transport to site and put in place), Lighting: powerful, Blast: explosions

Internal Forces
secondary stresses (> primary stresses) is the result of system or material characteristics, Movements (if resisted) are elastic (temporary) or inelastic (permanent) strains, Shrinkage: some takes place early (eg: concrete), Humidity Changes (eg: wood), Thermal Changes (eg: steel, metal, thin shell), Fabrication Errors (eg: incomplete concrete pour), Prestressing (they're all the same)

Deconstructive Agents
reduce capacity of structural element, Fire: the biggest issue! Heavy timber construction is the most preventative form, Chemical corrosion: parking lots are the worst, Erosion: wind/water, Insects/Plants/Animals

Materials and Systems
structural material:
require high strength (resist the three stresses (tension, compression, shear)), tension (withstand deformation, elongation, and failure mode (tearing), compression (shortening, crushing (strength) or buckling (stiffness), shear (deformation in angle or torsion or buckling, durability, stiffness (resist deformation), predictable, elasticity, resist shear (causing deformation in angle)

deformation:
primary deflection, predictable, small: high resistance, temporary (elastic), return to original position, Stability, Durability

Inelastic Deformation
Does not return to original position, permanent deformation (elastic is temporary deformation)

line of action
parallel to and in line with the force.

Concurrent Forces:
lines of action of several forces pass through a common point
(non-current if it does not pass through same point)

point:
the center of moments or axis of rotation

distance,
moment arm or lever arm, is measured in a direction perpendicular to the line of action of the force

force:
equal in magnitude to the resultant, but opposite in direction and on the same line of action as the resultant is called the **equilibrant.**

Resolving Forces:
to replace one force with two or more other forces that will produce the same effect on a body as the original force.

The higher the strength, the less ductile and more brittle it is

Temperature
modulus of elasticity reduces and the strength is reduced

Heat and Melting
Heat used to melt and shape a member, but once it is shaped, stiffness will still be altered

Charpy V-Notch Test:
A ductility test with a V notch cut on top of the piece. The specimen will be under the stree, the material is brittle if the time to go through the notch is fast and ductile if the notch is slow progression.

St. Venant's Principle for Direct Stress:
The stresses and strains in a body at points that are sufficiently remote from points of application of load depends only on the static resultant of the loads and not on the distribution of loads.

Direct Stress assumptions for this principle to be satisfied:
(1) The thing being loaded must be perfectly straight (2) Load must be applied axially (ie: the center of gravity at the cross section) (3) Cross section of the thing being loaded must be constant (4) Cross section under investigation has to be some distance away from the support/loaded ends (5) Loaded member must be made of a single material (6) Material must be homogenous (and strong, no soft spots!) (7) Load must be statically loaded (8) Elastic range stresses (don't go past yield stress!) (9)Loading must be pure tension, compression, or shear (no secondary effects)

Structural design Analysis Steps:
(1) Determine the loads (compute) (2) calculate the stresses (analyze) (3) Dimension and proportion the members and detail the connections such that the stresses are within the limits for the structural materials (design)

Finding Equilibrium
Objects that are at rest are at static equilibrium and use Three equations of static equilibrium (Horizontal Translational Equilibrium Equation: Sum of all forces parallel to the x axis and y axis = $\Sigma Fx = \Sigma Fy = 0$, Moment/Rotational Equilibrium Equation $\Sigma Mz = 0$

Solving A Direct Stress Problem:
Determine which equation to use f Allowable= P/A, then the cross section of the area of the form, then Figure out the stress, f = P/A. Ask question: Is it safe? What's the allowable stress we can use? Check the following:
Structural Steel Allowable Tension 22,000 psi, Concrete usable, compression in bearing 900 psi, Structural Lumber (doug fir) compression parallel to grain 1,150 psi

Solving a Direct Shear Problem:
Determine which equation to use f Allowable = P/A: Determine the area of the bolts A = (# of bots) x (πr^2) then Find allowable stress Pallowable = A x F allowable

Statics and Forces in a Nutshell

Forces are also known as loads. They are an action that has direction (an arrowhead that indicates if it points or pulls), magnitude (pounds or kips), and line of action (a given angle in degrees).

When a bunch of forces are acting on the same point, it is called the **resultant**, and it has the same effect as all of the individual forces combined.

Resultants are calculated by simple algebra when all of the magnitudes and lines of action are known. First, resolve the forces into individual vertical and horizontal components using **A2 + B2 = C2** and/or **SohCahToa.**

The sum of all of the vertical components gives the vertical component of the resultant, and the sum of all of the horizontal components gives the horizontal component of the resultant. When a force touches a member, the member becomes **stressed** and it tries to internally resist the external force.

Stresses can be **compression** (shorten or crush the member), **tension** (stretch the member), or **shear** (two members slide past each other)

The amount of stress (f) is calculated by taking all of the force that is touching the material (P) and dividing it by the area that it touches (A) **(f = P/A)**

Stressed members can't always resist external forces. **Strain** is the change in size, aka deformation, of a member caused by the forces acting on it.

The amount of strain in a unit (ε) is actually a ratio of the total deformation (e) to the original length of the member (L) **(ε = e/L)**

Strain is proportional to the amount of stress applied…but only up to a certain point, which depends on the type of material. that point is called the **elastic limit**.

Once the elastic limit is reached, the material which change length at a faster ratio than the applied force until it gets to the **yield point.**

The yield point is when the material continues to deform with little to no load applied. It's the point of no return…because after that the material will rupture once it hits its **ultimate strength.**

Materials want to put off reaching ultimate strength as long as they can, and the resistance is measured by the **Modulus of Elasticity.**

Resistance, or the Modulus of Elasticity (E) is therefore a ratio of the stress acting on the member (f) to the amount of strain (ε) **(E = f/ε)**

To make things easier for the designer, the building code lists typical Modulus of Elasticity values for most materials.

A more common calculation designers must solve is finding the total deformation of the member (e). It is a ratio of the force (P) and Length (L) to the Area (A) and Modulus of Elasticity (E) **(e = PL/AE)**

When force is applied to a member, it will try to cause the member to rotate around a point.

This called the **moment**.

If the force causes a clockwise rotation, then the moment is **positive.** If the force causes a

counter-clockwise rotation, then the moment is **negative**.

If a member doesn't rotate, then it means that the positive moments applied to it are equal to the negative moments. This is called **equilibrium** and is calculated by finding the **reactions.**

The reactions are usually located at each end of a member…lets say a beam. Select one of the Reactions, and use the given forces and dimensions from that reaction point.

R1 = P1(L) + P2(L) - R2(L)

Then solve for the other reaction by checking equilibrium. All upward forces equal all downward forces. **R2 = R1 - P1 - P2**

Properties of Sections in a Nutshell
Sections are just that…a slice of a member where forces can be examined further.
The point at which the mass of a member is concentrated is called the **center of gravity.**

The actual point at the center of gravity that measurements are taken from is called the **centroid.**
While the centroid is the center, it is not necessarily at the geometric center of the section. Only when a section is symmetrical (a rectangle beam for example) the center is located in the geometric center. Calculating the centroid of a symmetrical object is a simple problem. In the case of a rectangle with base (b) and depth (d) the centroid is at **b/2 and/or d/2**
When the section is unsymetrical, the **statistical moment** is calculated with respect to a neutral axis (typically at the base of the section). It is the area (A) times the distance to center from the neutral axis (X)
Divide the section into multiple simple shapes (typically rectangles) and find the area (A) of each, and the distance from the centroid of the simple shape to the neutral axis (x). Do this for each simple shape.
Multiply the areas and the distances together for each shape, and add them together.

(A1 x D1) + (A2 x D2) = ([A1 + A2] x overall distance to neutral axis X) . Then solve for X. That's the overall centroid.
While the modulus of elasticity measures how stiff a material is (through how it resists stress), the measure of bending stiffness of a section is called the

Moment of Inertia.
The moment of inertia of a section about a certain axis is the sum of all the small areas of the section (bd) multiplied by the square of the distance from the axis to each of these areas (d2). Also said as: (bd3)
For rectangle sections where the neutral axis is the axis that passes through the centriod, the moment of inertia **(I) = bd3/12.**
When the axis is at the base of a rectangular section, the moment of inertia for a rectangle changes to **(I) = bd3/3**
For composite sections, find the moment of inertial of each simple section around its centroid, then transfer to a new axis, typically the centroid of the composite section. The transferred moments of inertia of the simple sections are added to get the moment of inertia for the entire section.
Because the section's depth (d) is cubed, it has a greater bearing on the beam' resistance to bending. In other words, the bigger the depth of the beam, the stronger it is.

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
τ = the shear stress

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

Strain

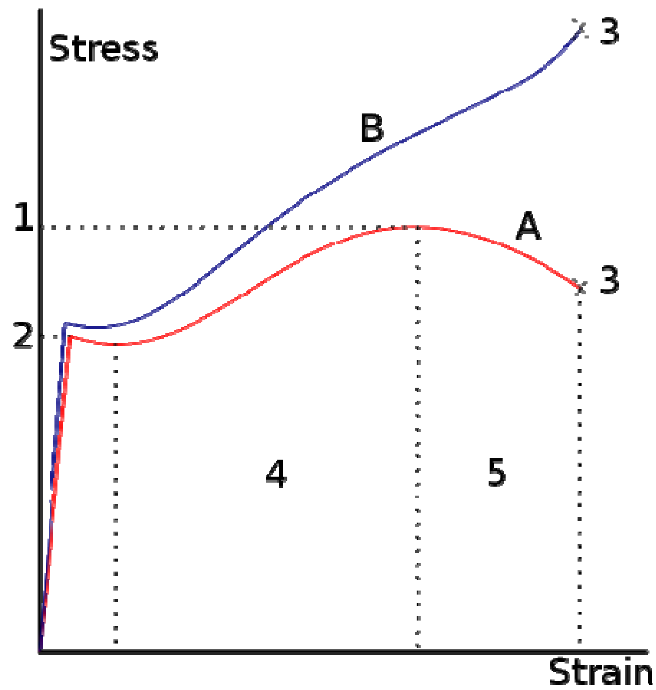
When the object is pulled or pushed, the object is under strain. In case of pulling, the object elongates. The level of deformation and displacement is known by strain. Strain is the change in distance of elongation by the original distance.

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.

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

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.

Soil

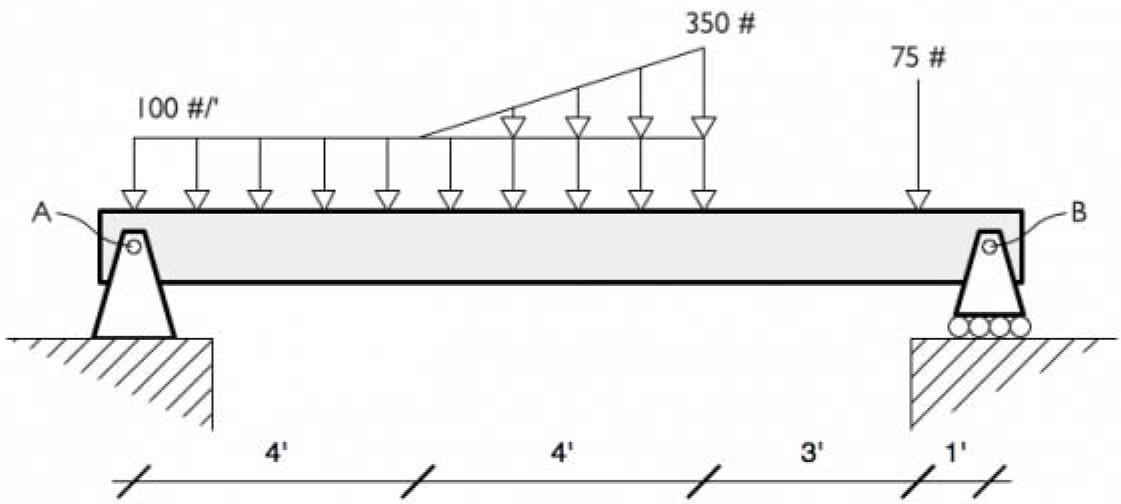
8. If the soil bearing capacity is 3000 psf [143 500 N/m_2] and the applied load is 48,000 lbs [212 kN], 16 sf [m2]is the area for the footing.

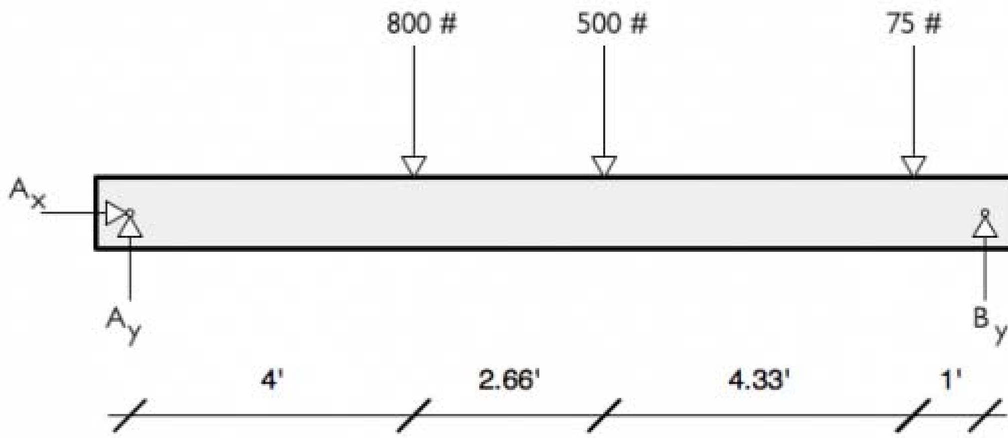
48 kip/3 kpsg = 16
sqrt (16) = 4'x4'

9. 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

27. A loss of soil shear strength resulting in the movement of the superficial 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 high water table; a low bearing capacity; a gently sloping site





step 1

100 #/' x 8' = 800#

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

step 2

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

step 3

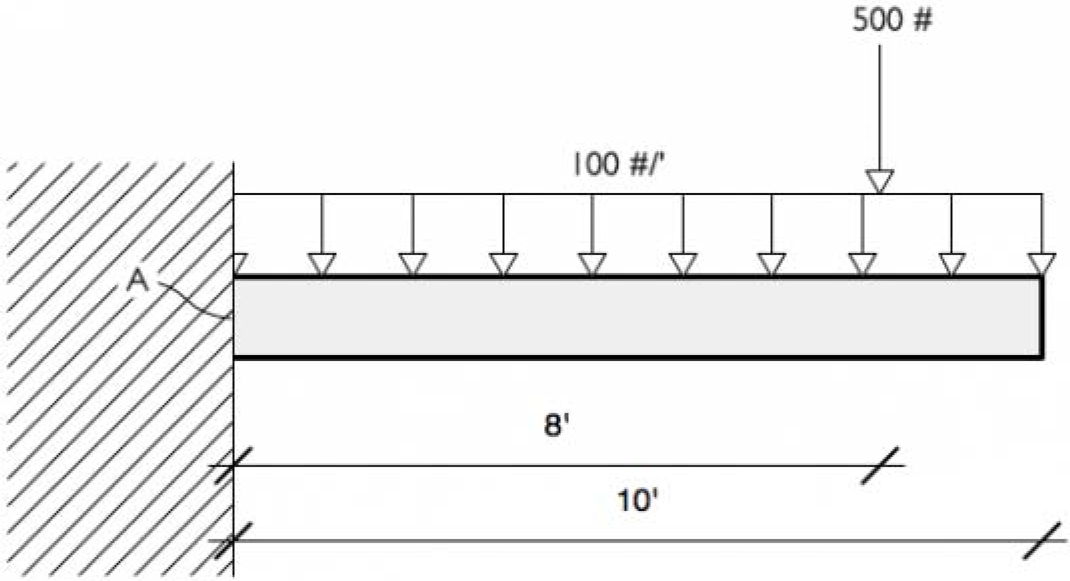
$\sum$ Fy= 0
Ay + By - 800# - 500# -75# = 0
Ay =1037 #

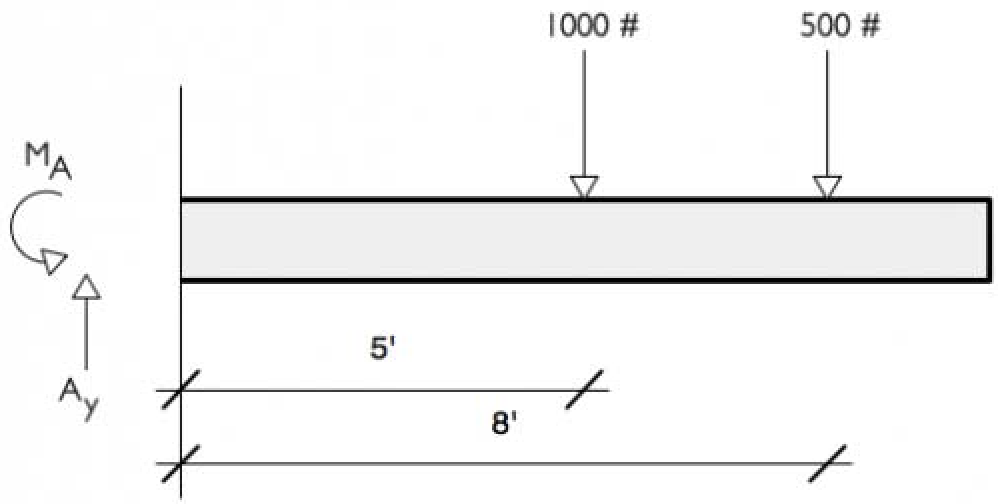
step 4

$\sum$ 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

$\sum F_y = 0$
$A_y - 1000\# - 500\# = 0$
$A_y = 1500\#$

step 2

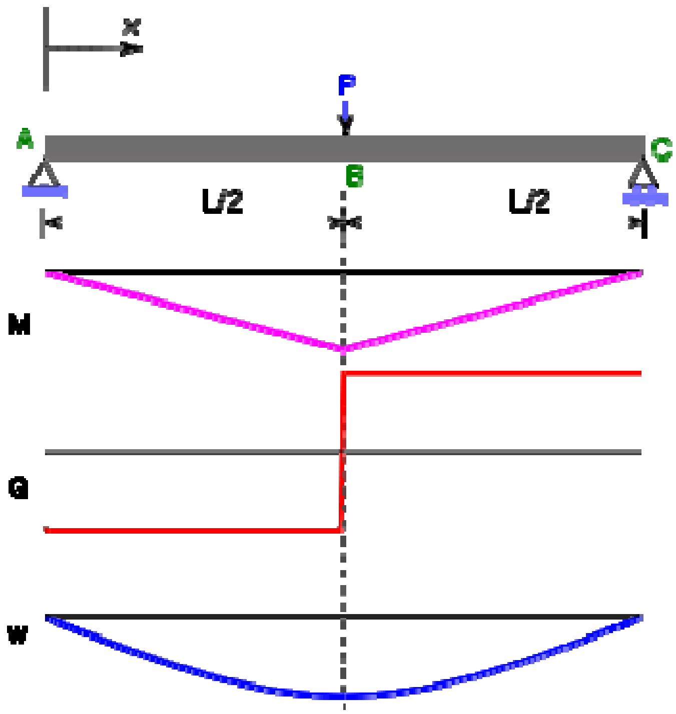
$\sum M = 0$
$-M_a + (1000\# \times 5') + (500\# \times 8') = 0$
$M_a = 9000\ \#'$

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.

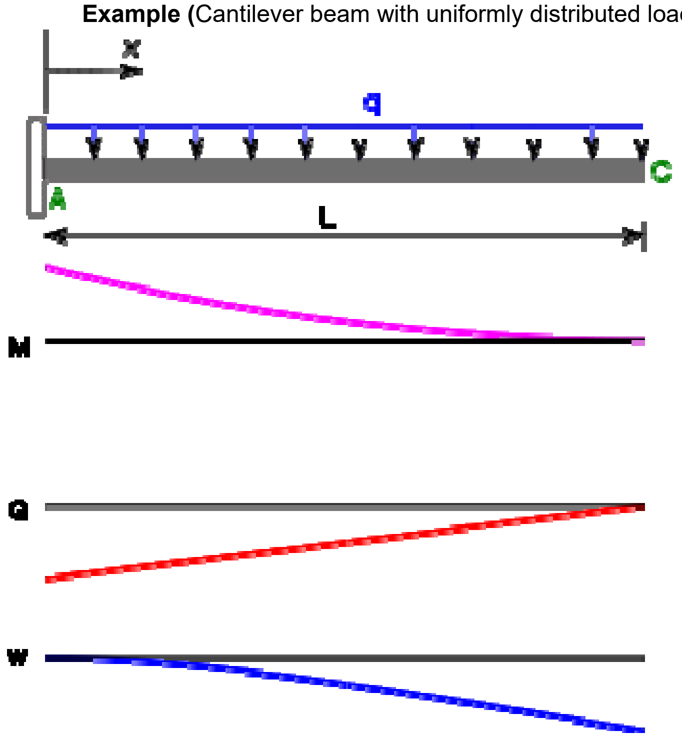
- **Process**- There are three steps to constructing the shear and moment diagrams. The first is to construct a loading diagram, the second is to calculate the shear force and the bending moment as a function of the position of the beam, and the third is to draw the shear and moment diagrams.
  1. **Loading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



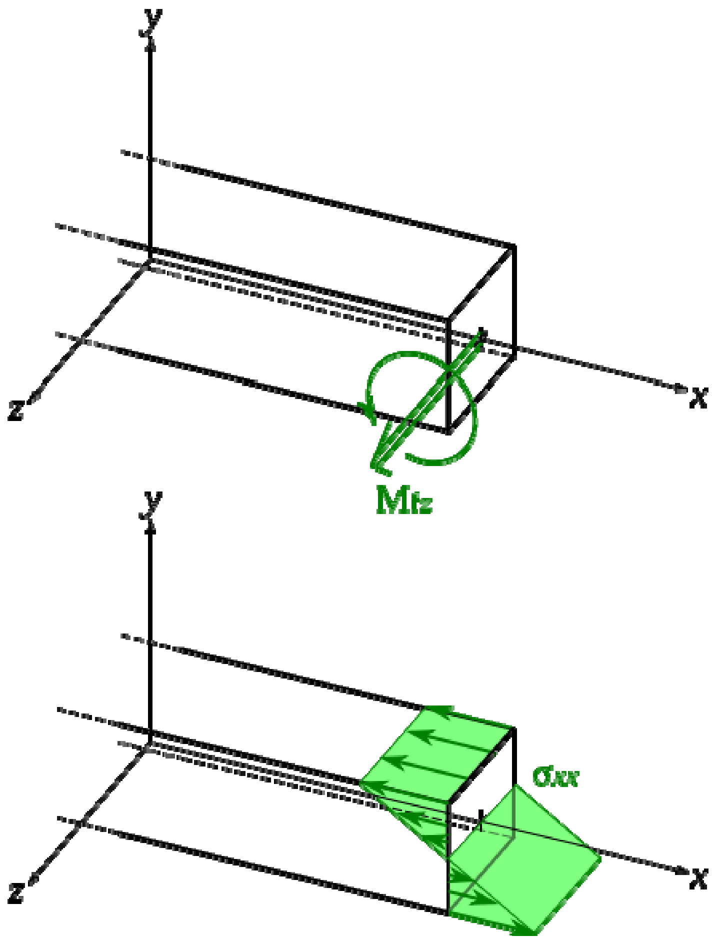
- **Misc Tips on Diagram**

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

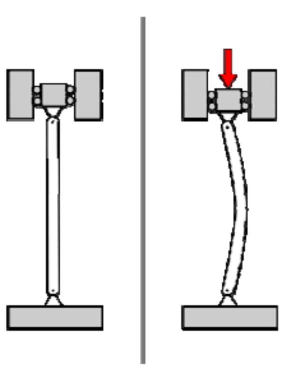
$$\Delta L = \frac{PL}{AE}$$

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.



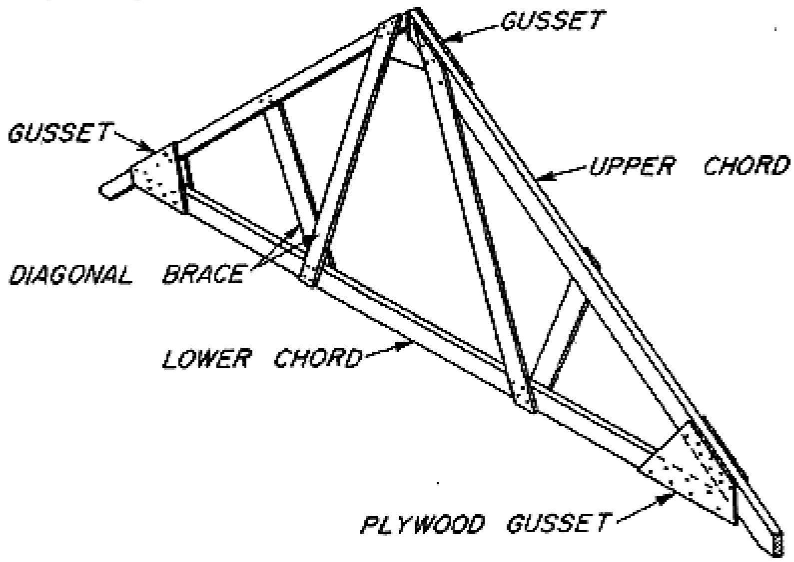
Walls

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.

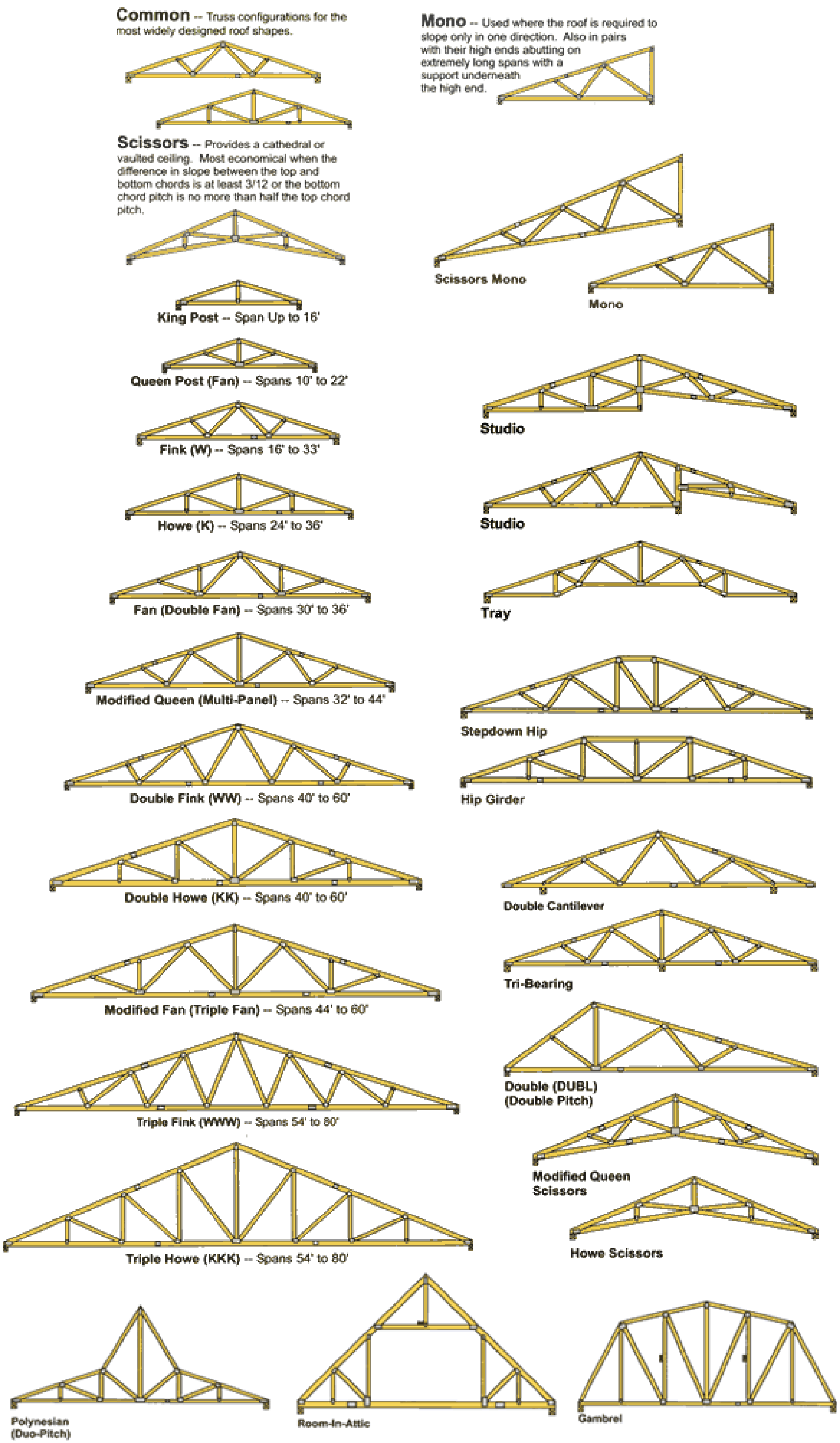
Non Load Bearing Wall- Curtain wall or a partition or sound wall is only to partition rooms and create the space as required. The wall is still carries its own weight, possible other elements, and must be engineering for seismic or other environmental issues.

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. Members
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.
Truss structure
every member of a truss is a 2 force member and assumed to be of negligible weight (compared to the loads they carry


carry).



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'
Howe (K) -- Spans 24' to 36'
Studio
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
Modified Fan (Triple Fan) -- Spans 44' to 60'
Tri-Bearing
Double (DUBL) (Double Pitch)
Triple Fink (WWW) -- Spans 54' to 80'
Modified Queen Scissors
Triple Howe (KKK) -- Spans 54' to 80'
Howe Scissors
Polynesian (Duo-Pitch)
Room-In-Attic
Gambrel

Truss Definitions/Terms:

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 I-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.

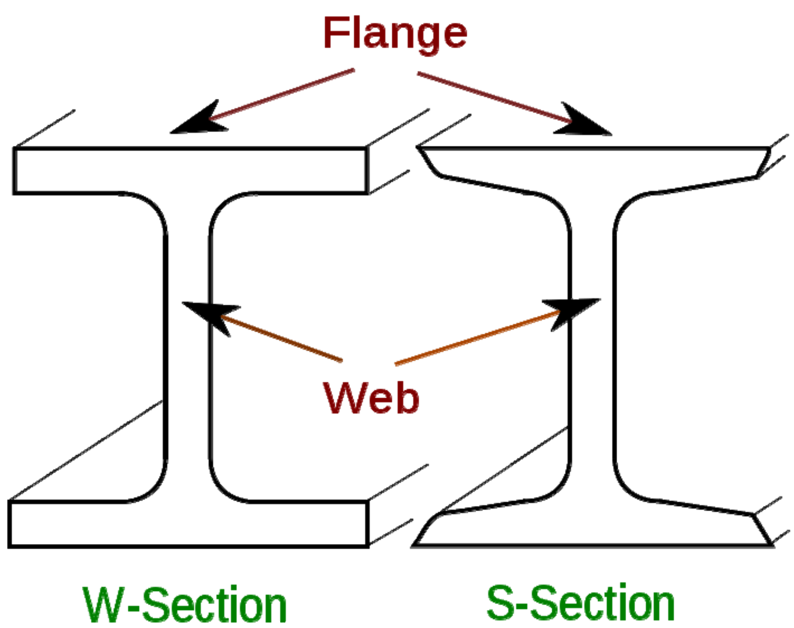
In fire with rising heat, steel lose their strength and cause failure. Encasing in fire resistive material is required.

Highly recyclable and sustainable.

Structural Uses

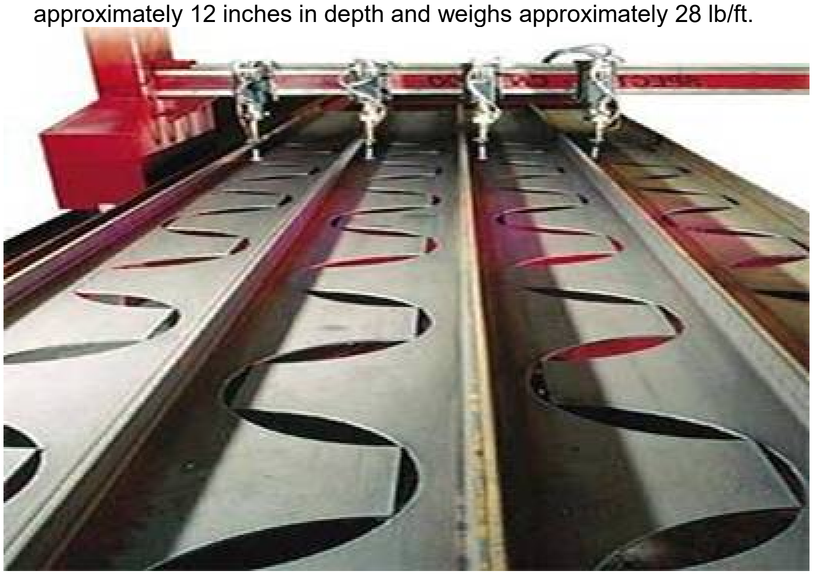
Beam - I-beams are widely used and are available in a variety of standard sizes. I-beams can be used both as beams (bending loads) and as columns (axial loads). It often used in combination of other material, typically concrete. There are two standard I-beam forms:

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

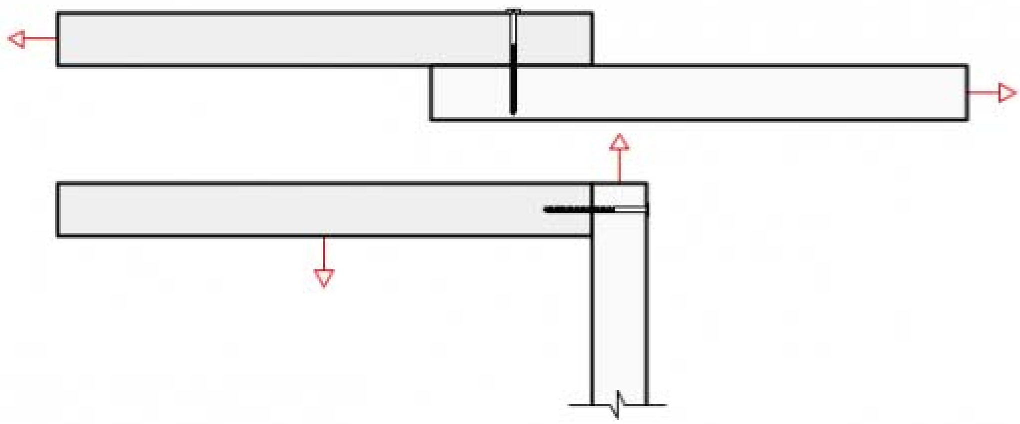
• Detailing Considerations

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

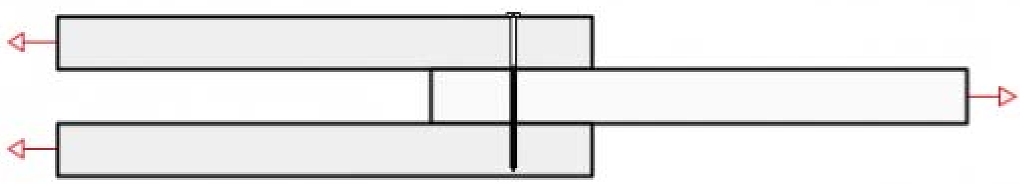
Connection Types

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

Connection in Shear

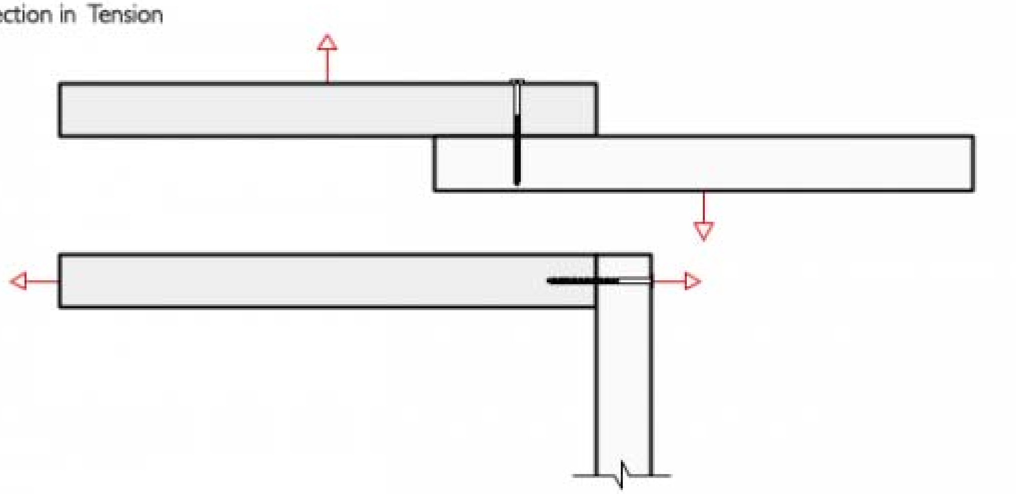


Connection in Double Shear

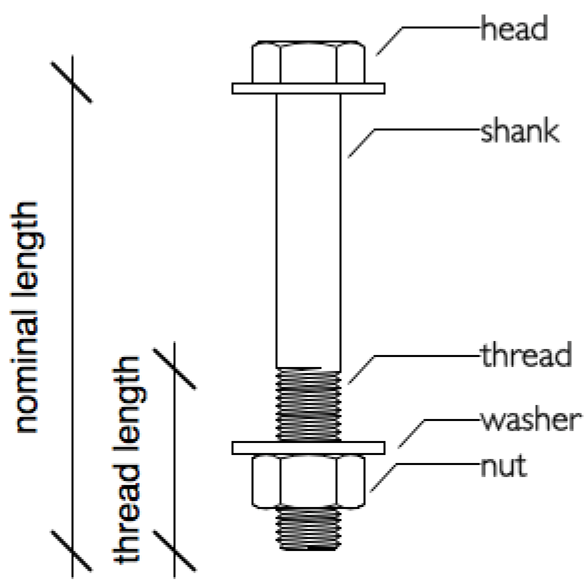


note: nails or screws in double shear will have twice the capacity of the same fasteners in single shear

Connection in Tension



Typical Bolt

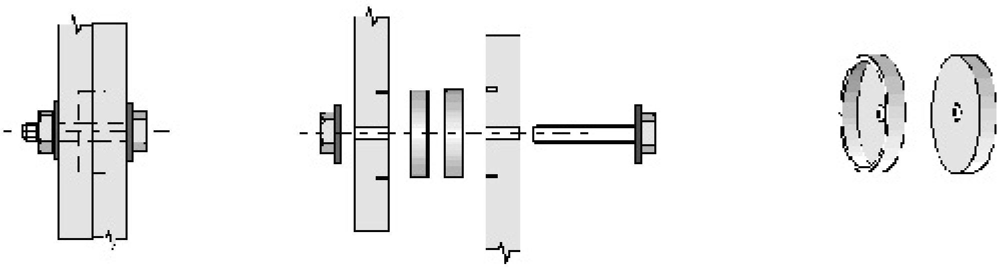


Nailed Connections	Bolted Connections
Nails part fibers - there is no discontinuity in the timber fibers	Bolts are installed into pre-drilled holes, so timber fibers are broken.
Nails are small diameter fasteners, allowing flexibility in the connection.	Bolts are large diameter fasteners and quite rigid.
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.

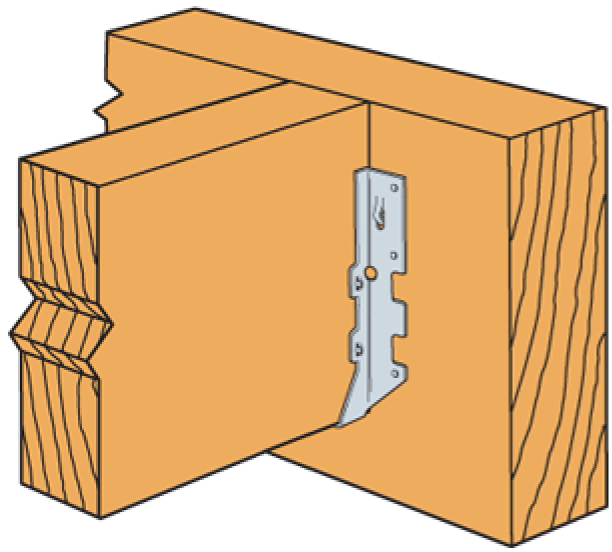
- **Specialized Hardware**

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.

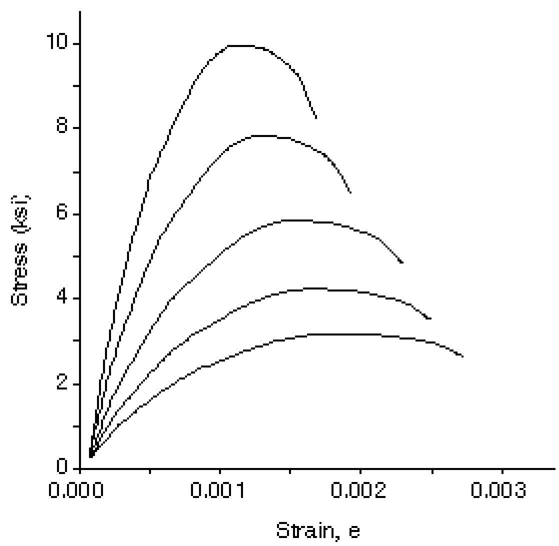


Figure 2.. Stress versus Strain curves.

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 dilemma is easily seen in the schematic graphs of Figure 3.

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

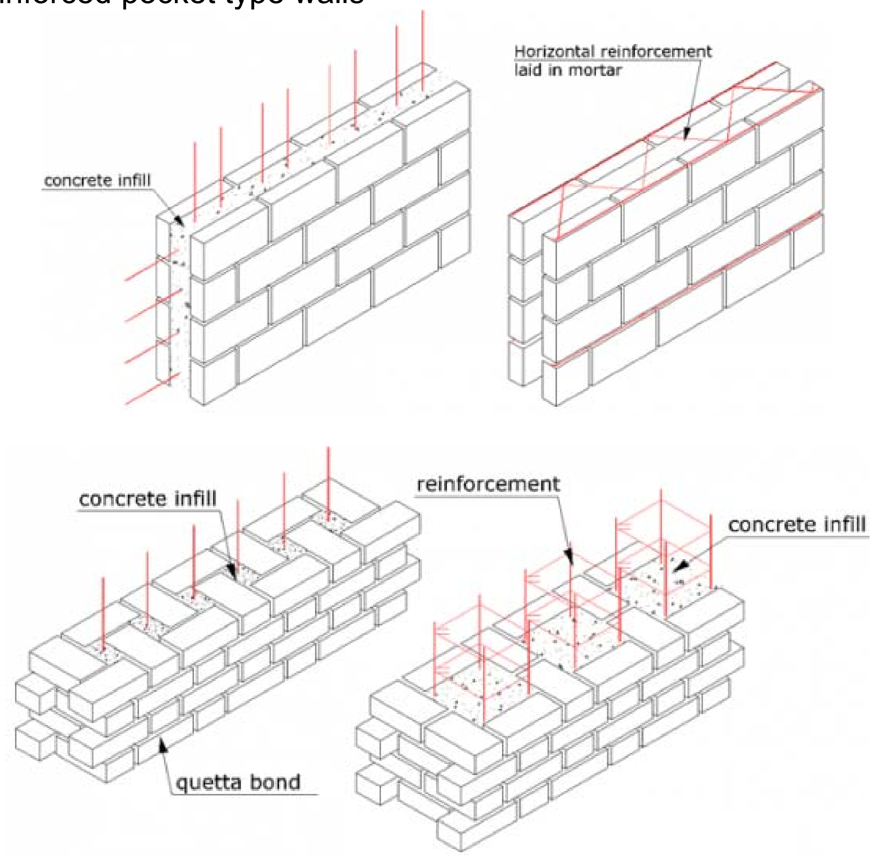
Not: weather conditions during curing; volume of the mixture;

Masonry

building of structures from individual units laid in and bound together by mortar; the term *masonry* can also refer to the units themselves. The materials of masonry construction are 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



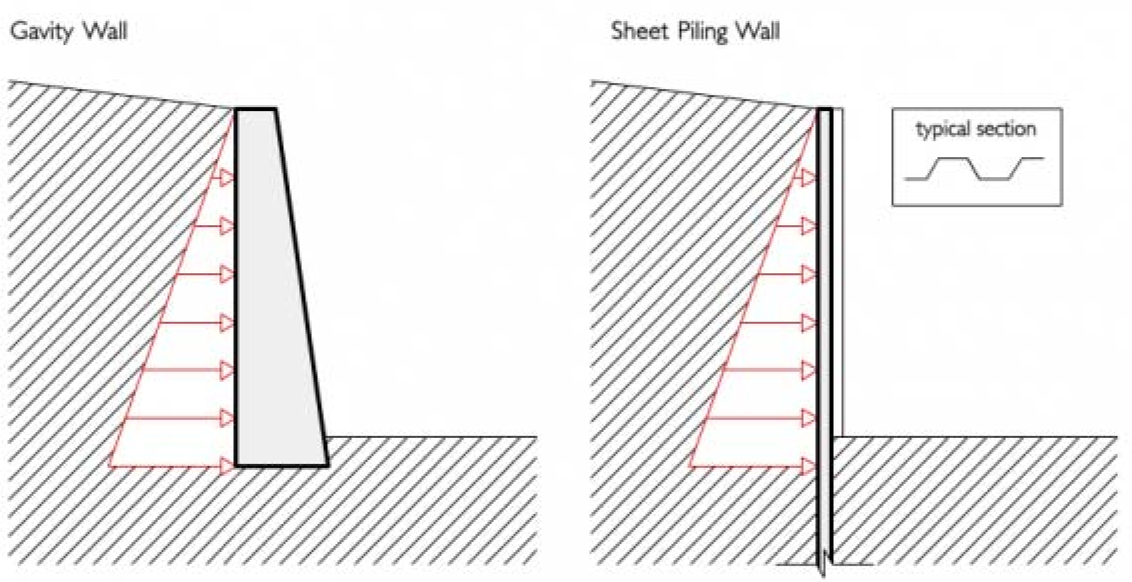
Concrete (Reinforced)

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.

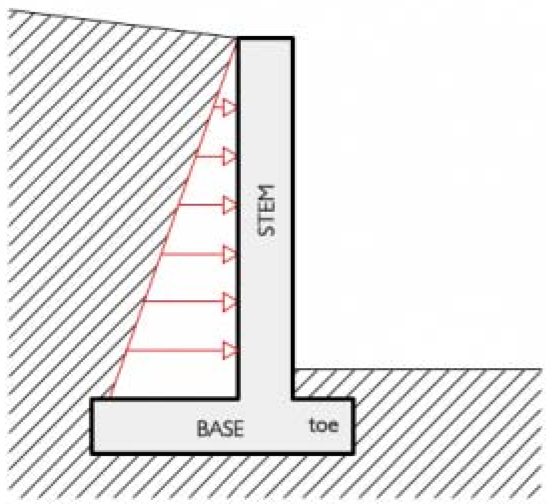
Retaining Wall is a structure designed and constructed to resist the lateral pressure of soil to serve a desired change in ground elevation.

- **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.

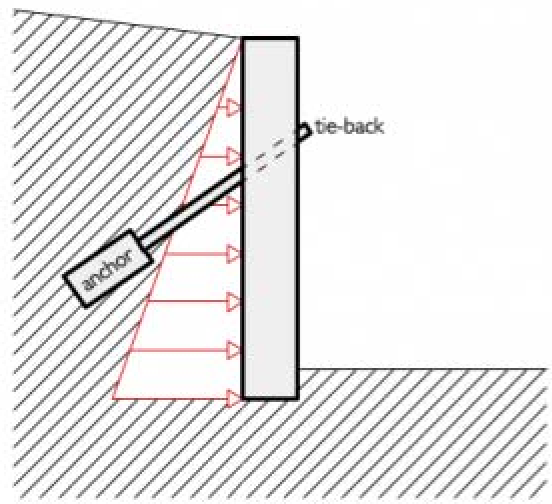


- **Cantilever**- Cantilevered retaining walls are made from an internal stem of steel-reinforced, cast-in-place concrete or mortared masonry typically in the shape of an inverted T
- **Anchored**- An anchored retaining wall can be constructed in any of the aforementioned styles but also includes additional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

Cantilever Wall



Anchored Wall



- # Foundations

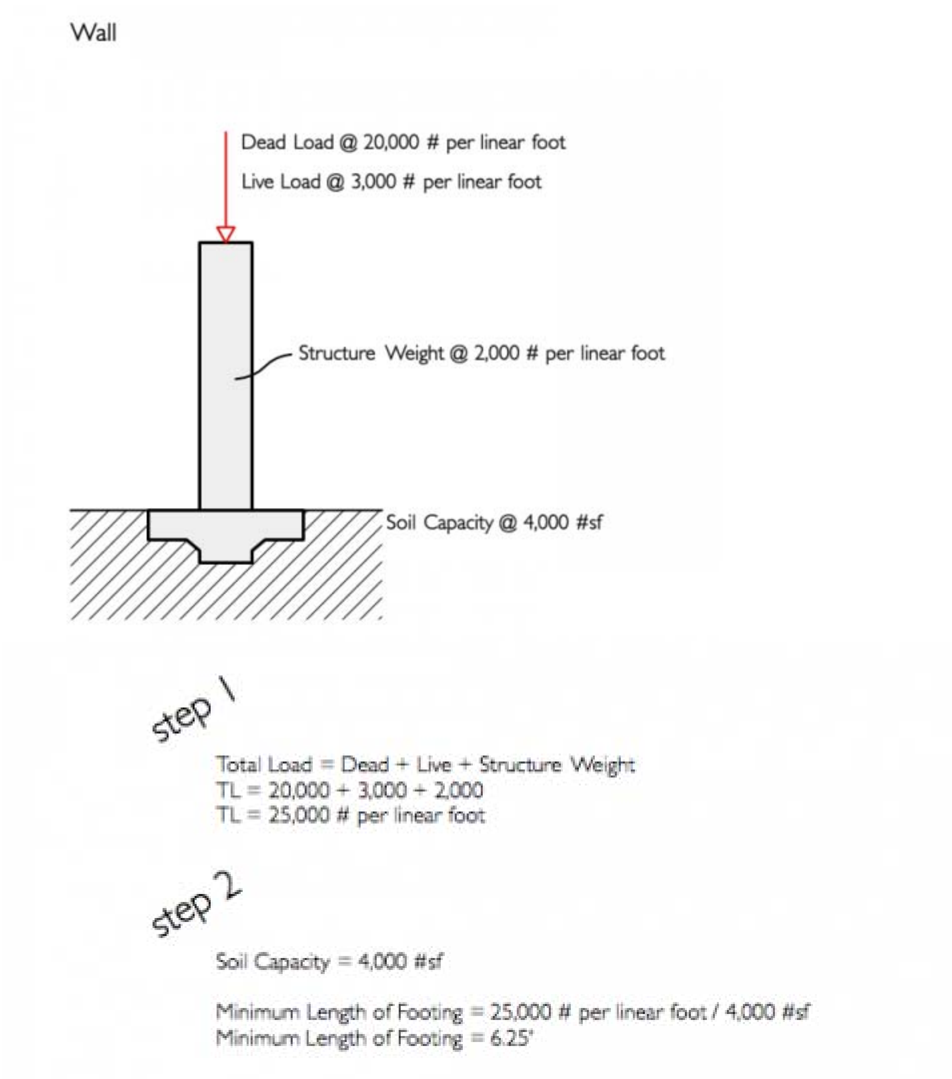
Foundation

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.

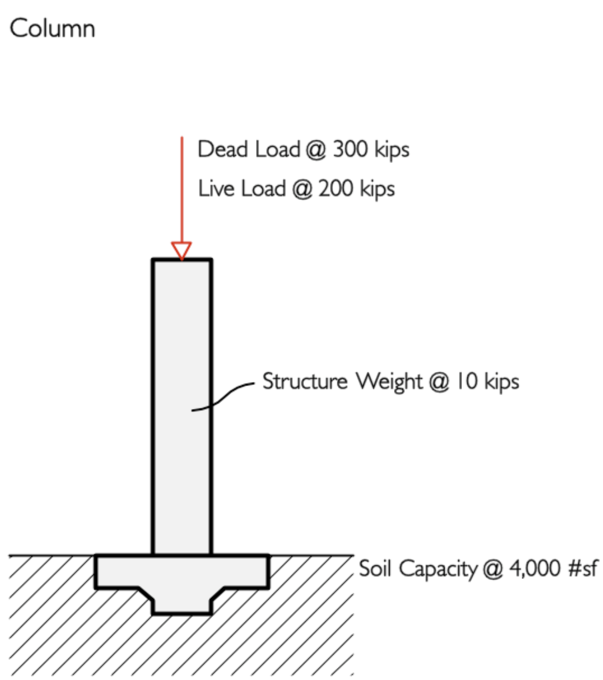
Design

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

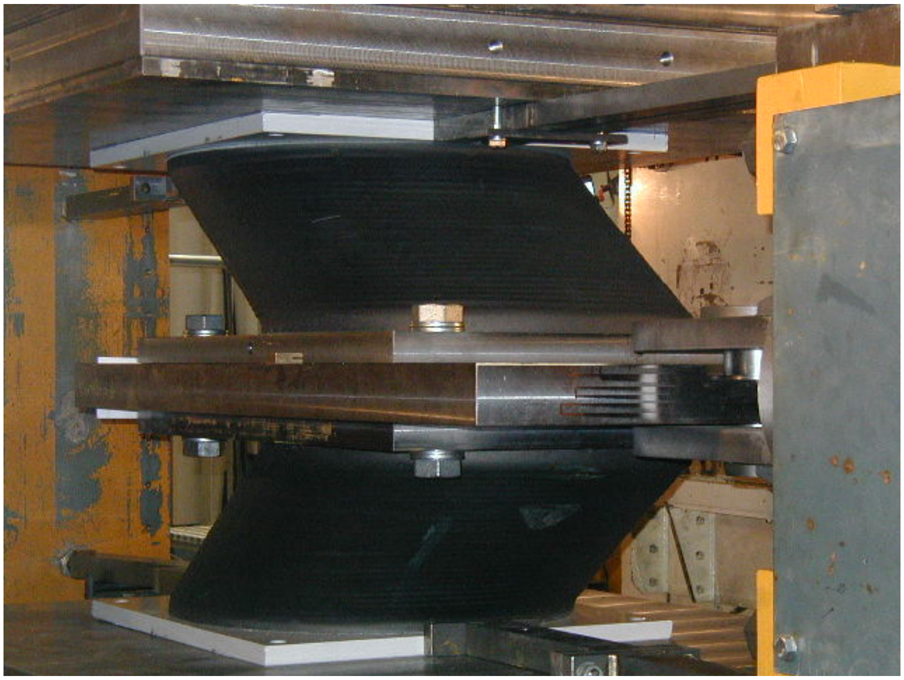
1. **Pile Cap** – Concrete block into which the heads of the piles are embedded

- **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:

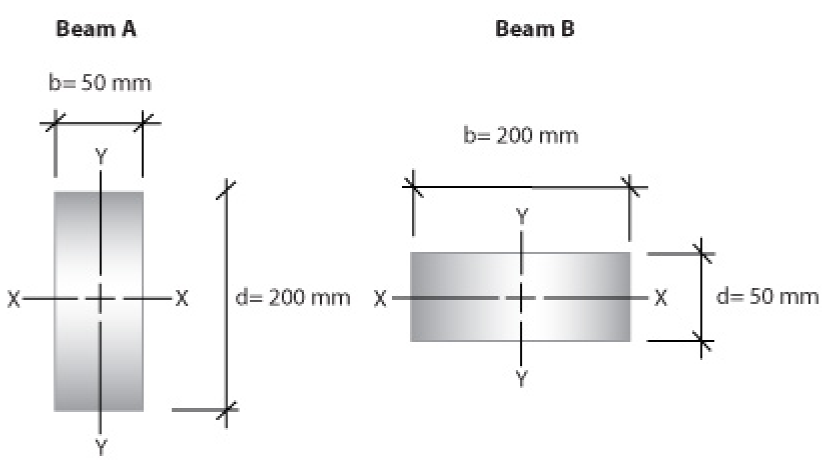
$Z_{xx} = \frac{Ixx}{y}$ where $I_{xx} = \frac{bd^3}{12}\ mm^4$

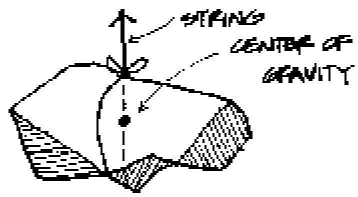
and y = $\frac{1}{2}$ depth or $\frac{d}{2}$ mm

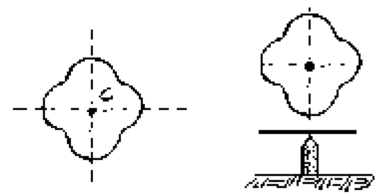
This gives the formula for **Z** as: $Z = \frac{bd^2}{6}\ mm^3$

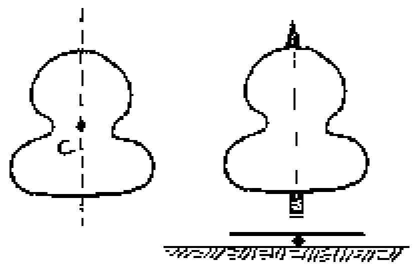
Note: The standard form of writing the value of **Z** is to write it as a number x $10^3\ mm^3$, eg a value of 2,086 is written as 2.086 x 10^3.

Calculating Z









Centroids &Moment of Inertia

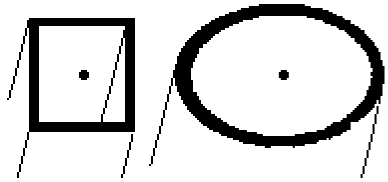
The **centroid**, or center of gravity, of any object is the point within that object from which the force of gravity appears to act. An object will remain at rest if it is balanced on any point along a vertical line passing through its center of gravity. In terms of moments, the center of gravity of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

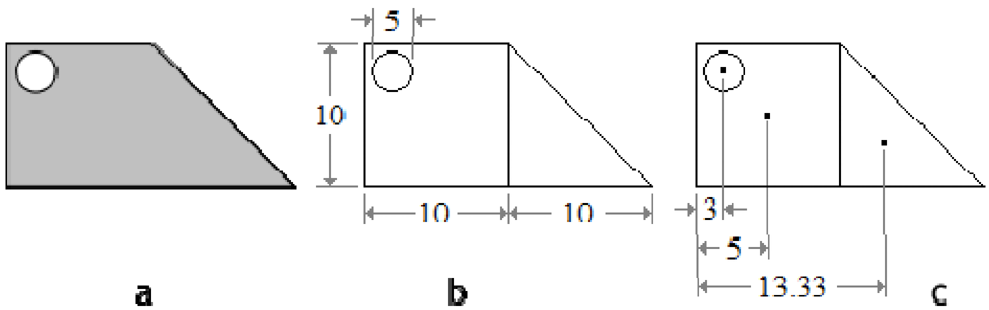
Centroid- the geometric center of the object's shape, the center of mass and center of gravity.

- **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.

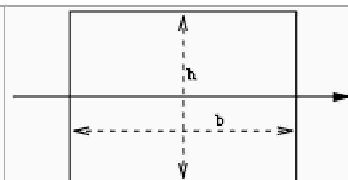
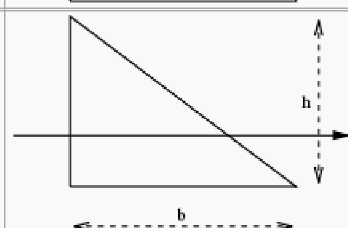
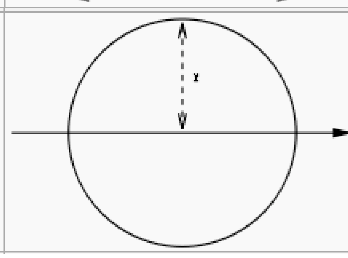
For example, the figure below (a) is easily divided into a square and a triangle, both with positive area; and a circular hole, with negative area (b).



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

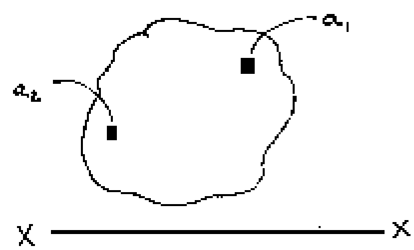
The **Moment of Inertia (I)** is a term used to describe the capacity of a cross-section to resist bending. It is always considered with respect to a reference axis such as X-X or Y-Y. It is a mathematical property of a section concerned with a surface area and how that area is distributed about the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

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

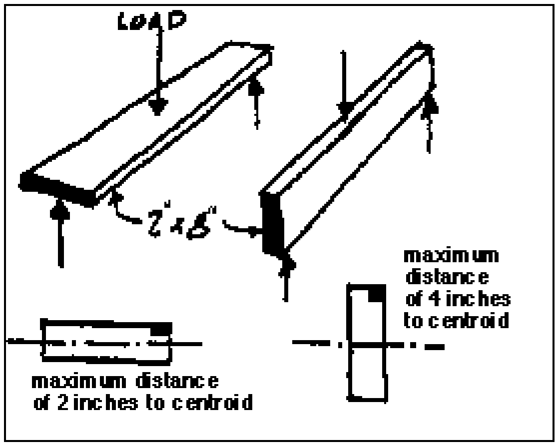
In which:

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.



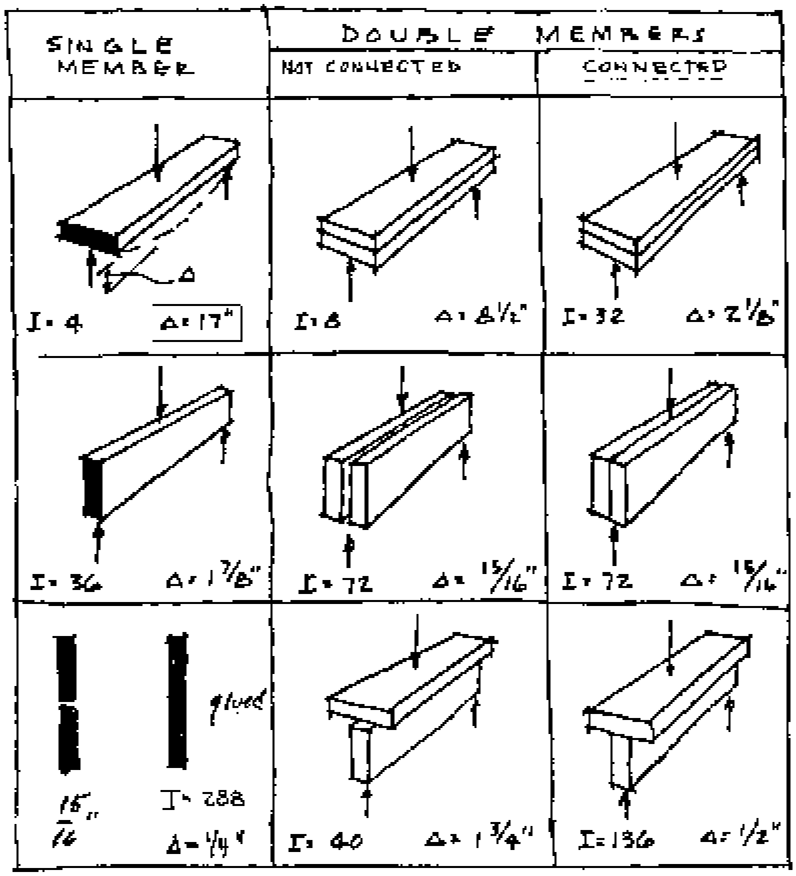
Calculus is ordinarily used to find the moment of inertia of an irregular section. However, a simple formula has been derived for a rectangular section which will be the most important section for this course.

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

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

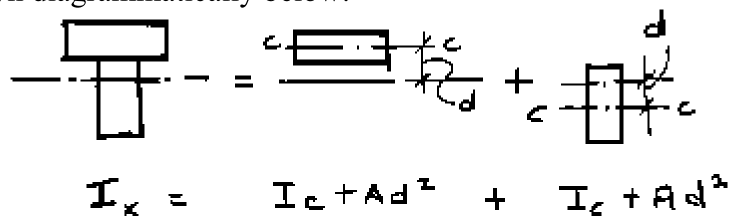
TRANSFER FORMULA
There are many built-up sections in which the component parts are not symmetrically distributed about the centroidal axis. The easiest way to determine the moment of inertia of such a section is to find the moment of inertia of the component parts about their own centroidal axis and 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:

- $\mathbf{I_x}$ = 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)
- $\mathbf{A}$ = area of the section (in^2)
- $\mathbf{d}$ = 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 in^3 [cm^3] the section modulus for the geometric section illustrated above.

$$S = I/c$$

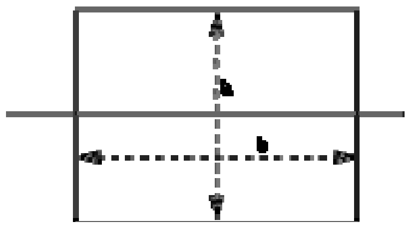
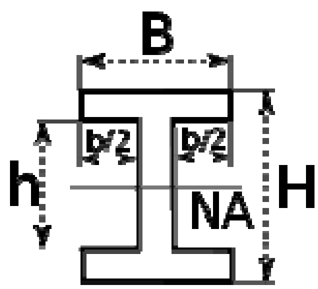
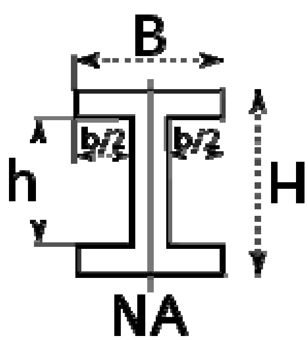
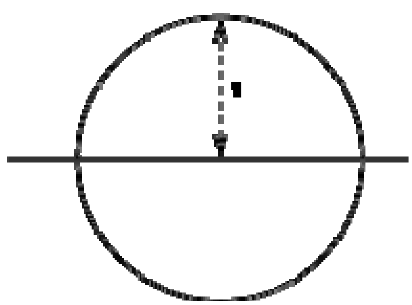
Section modulus is a geometric property for a given cross-section used in the design of beams or flexural members. Other geometric properties used in design include area for tension, radius of gyration for compression, and moment of inertia for stiffness. Any relationship between these properties is 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).

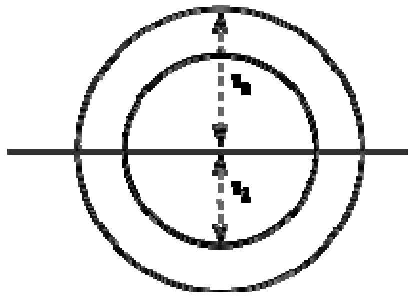
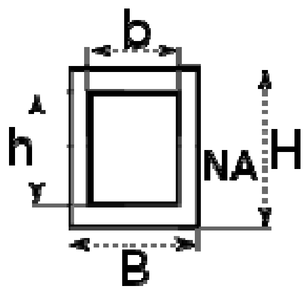
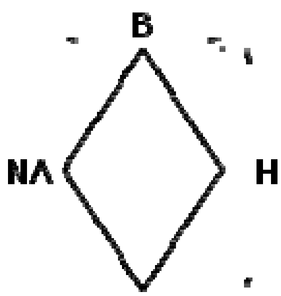
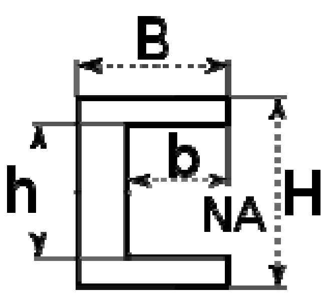
Elastic section modulus

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]

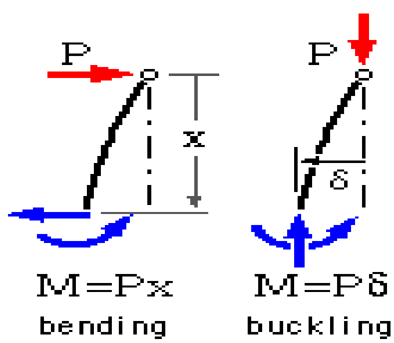
Cross-sectional shape	Figure	Equation	Comment
Rectangle		$S = \frac{bh^2}{6}$	Solid arrow represents neutral axis
doubly symmetric I-section (strong axis)		$S = \frac{BH^2}{6} - \frac{bh^3}{6H}$	NA indicates neutral axis
doubly symmetric I-section (weak axis)		$S = \frac{B^2(H-h)}{6} + \frac{(B-b)^3}{6B}$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

Circular tube		$S = \frac{\pi\left(r_2^4 - r_1^4\right)}{4r_2} = \frac{\pi(d_2^4 - d}{32d_2}$	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

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

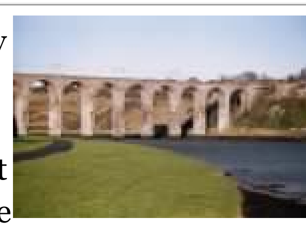
unstable -in which case deformations increase instantaneously, the load carrying capacity nose- dives and the structure collapses catastrophically.

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.

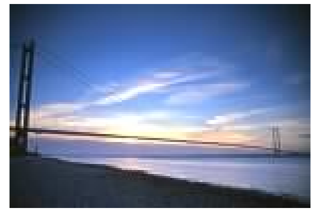
Buckling has become more of a problem in recent years since the use of high strength material requires less material for load support - structures and components have become generally more slender and buckle- prone. This trend has continued throughout technological history, as is demonstrated by bridges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

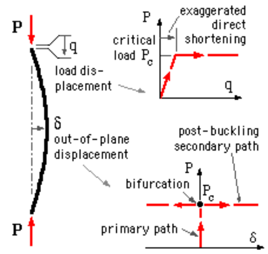


The Royal Border Bridge, Berwick upon Tweed, was built by Robert Stephenson whose father George built the Stockton and Darlington Railway (the first public railway) in 1825. Opened in 1850, the bridge continues today as an important link in the busy King's Cross (London) - Edinburgh line. The increased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

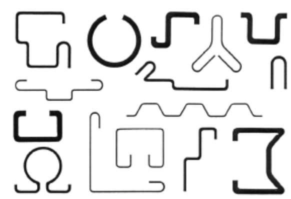
The Crymlyn Viaduct over the Ebbw Alley opened in 1857 as Welsh coal mining expanded. It was constructed of wrought and cast iron, and remained the highest railway viaduct in the UK until its closure in 1964 due to increased locomotive weights (1908 photo). The advance from masonary to the slender metal 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.

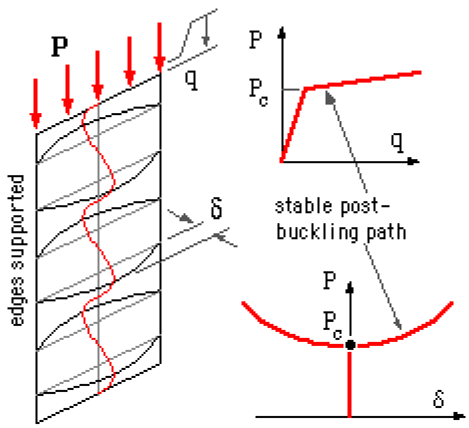
The slender elastic pin-ended ***column*** is the protoype for most buckling studies. It was examined first by Euler in the 18th century. The model assumes perfection - the column is perfectly straight prior to loading, and the load when applied is perfectly coaxial with the column.

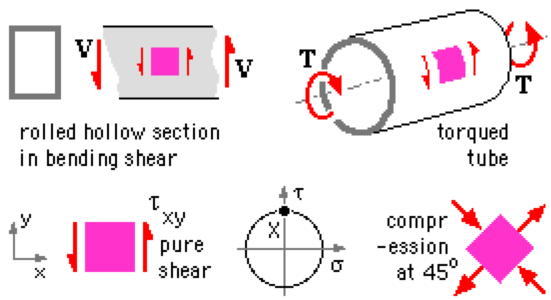
The behaviour of a buckling system is reflected in the shape of its load-displacement curve - referred to as the ***equilibrium path***. The lateral or 'out-of-plane' displacement, δ, is preferred to the load displacement, q, in this context since it is more descriptive of buckling.

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

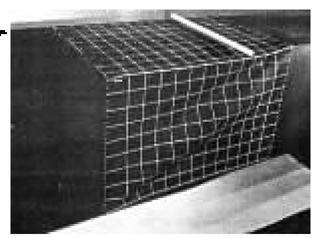
primary path - which lasts until the increasing load reaches the critical ***Euler load*** $P_c = \pi^2 EI_{min}/L^2$ a constant characteristic of the column *(for a derivation of this, see below or Timoshenko & Gere op cit. for example).*

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



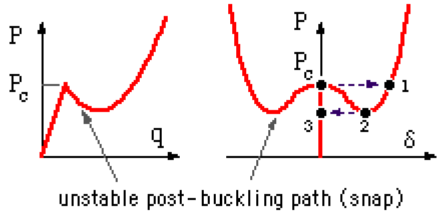
generally withstand loads greater than critical. However the P-q curve illustrates plates' greatly reduced stiffness after buckling, so plates cannot be used in the post-buckling region unless the behaviour in that region is known with confidence.

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.

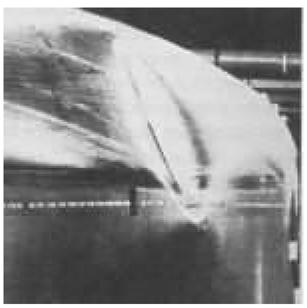
Inclined striations are caused by shear loading in the web of a beam or in a torqued tube giving rise to compressive buckling stresses at 45° to the longitudinal direction as predicted by Mohr's circle.

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.

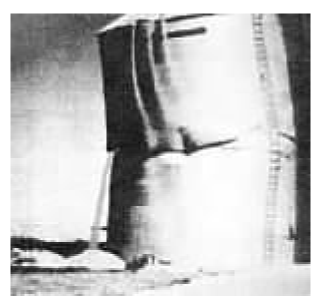
Since the displacements are uncontrolled in most practical systems, shells behave in a snap- buckling mode - ie. as an increasing load reaches the bifurcation point, the cylinder must undergo an instantaneous increase in deflection *("snap")* to the point **1** in order to accomodate the increasing load. 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.



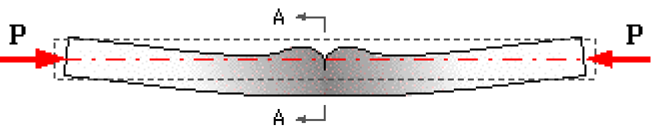
It has been noted that a pressure vessel ***head*** is subjected to a **compressive hoop stress** at its junction with the cylinder.

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.

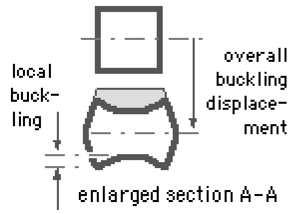
Longitudinal stresses in a vertical cylinder may also promote buckling as these two photographs illustrate *(from Rhodes & Walker op cit)*.
Warning of impending failure of the 7.3 m diameter vitreous enamelled silo on the left is provided by the visible buckles. Grain pours out of the buckled bin on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

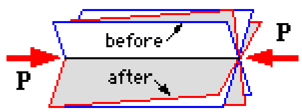


Torsional buckling of columns can arise when a section under compression is very weak in torsion, and leads to the column rotating about the force axis.

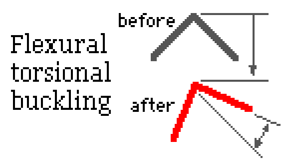


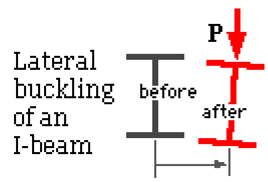
Local and overall buckling interaction in a hollow box column





Torsional buckling

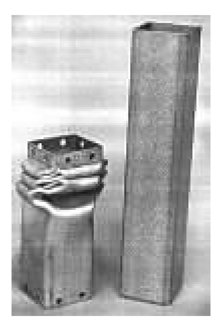




More commonly, where the section does not possess two axes of symmetry as in the case of an angle section, this rotation is accompanied by bending and is known as ***flexural torsional buckling.***
Lateral buckling of beams is possible when a beam is stiff in the bending plane but weak in the transverse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

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)**:

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

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

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

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:

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

The upper bound value for C_s tends to govern for relatively stiff structures that exhibit a small (short) fundamental period of vibration (**T**). The lower bound values for 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)

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 (I_E= 1.5), while buildings where people congregate (such as schools, auditoriums, etc.) also have relatively high seismic importance factors (I_E = 1.25). Other structures have a seismic importance factor of unity (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 (I_E = 1.0).

Designers should note that the seismic importance factor (I_E) is not identical to the importance factor for wind (I_w) nor the importance factor for snow (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 (h_n):

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

where C_t = 0.02 for wood structures
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 $\boldsymbol{x}$

$\boldsymbol{w_x}$ is the portion of the building weight assumed to be ìlumpedî at level **x**. $\boldsymbol{w_x}$ 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 s $< \mathbf{T} < 2.5$ s
$\mathbf{k} = 2$	when $\mathbf{T} > 2.5$s

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

$\mathbf{F_x} = 0.01\ \boldsymbol{w_x}$ (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)

$$\mathbf{F_x = (1.2)\ (2/3)\ F_a\ S_s}\ \boldsymbol{w_x}\ \mathbf{/\ R}$$ (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, $\mathbf{h_x}$, when calculating base shear, **V**, and story forces, $\mathbf{F_x}$.

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 ($\boldsymbol{w}_1 = \boldsymbol{w}_2 = \boldsymbol{w}_3 = \mathbf{W}/3$), and

- Equal distance (height) between each level of the structure ($\mathbf{h}_1 = \mathbf{h}$; $\mathbf{h}_2 = 2\mathbf{h}$; $\mathbf{h}_3 = \mathbf{h_n} = 3\mathbf{h}$).

Since the total height ($\mathbf{h_n} = 3\mathbf{h}$) of a 3-story wood structure will be less than 73.1 ft, this means that $\mathbf{k} = 1$. 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 ($\mathbf{F}_3 = \mathbf{F}_n = \mathbf{V}/2$)

- 33% of the base shear at the 2nd level of the structure
($\mathbf{F}_2 = \mathbf{V}/3$)

- 17% of the base shear at the 1st level of the structure
($\mathbf{F}_1 = \mathbf{V}/6$)

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

$$\mathbf{F}_1 = \mathbf{F}_2 = \mathbf{F}_3 = \mathbf{V}/3$$

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: $\mathbf{F}_{px} > (0.15)\,(2/3)\,\mathbf{F}_a\mathbf{S}_s\,\mathbf{I}_E\,w_{px}$

Upper bound: $\mathbf{F}_{px} < (0.30)\,(2/3)\,\mathbf{F}_a\mathbf{S}_s\,\mathbf{I}_E\,w_{px}$

where w_{px} is the portion of the building weight assumed to be "lumped" with the diaphragm at level x.

w_{px} is similar to w_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.

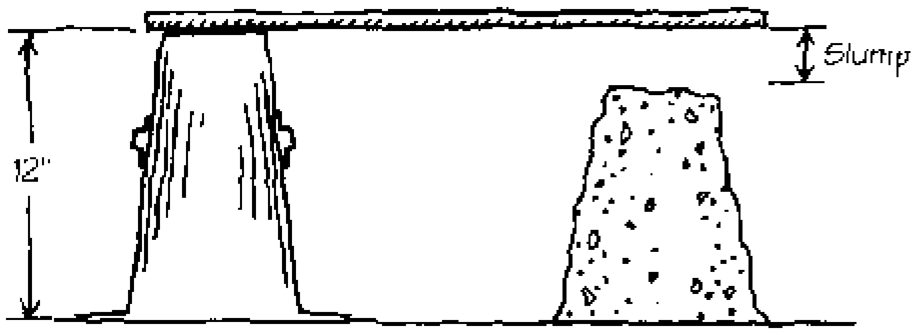


Figure 4. Slump Test..

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

Boethius, A. and Ward1-Perkins, J. B. (1970). Etruscan and roman Architecture, Penguin Books, Middlesex, England.

Cassie, W. F. (1965). "The First Structural Reinforced Concrete," Structural Concrete, 2(10).

Collins, P. (1959). Concrete, The Vision of a New Architecture, Faber and Faber, London.

Condit, C. W. (1968). American Building, Materials and Techniques from the First Colonial Settlements to the Present, University of Chicago Press.

Drexler, A. (1960). Ludwig Miles van der Rohe, George Braziller, New York.

Farebrother, J. E. C. (1962). "Concrete - Past, Present, and Future," The structural Engineer, October.

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.

E. United States. American Institute of Steel Construction, Inc. Steel Construction Manual; 13th Edition. Chicago, Illinois, 2005.

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.

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  - 7.6 Any cross section defined as polygon
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[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).
- dA is an elemental area
- n, m are the perpendicular distances respectively from the line i and j to the element dA

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

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

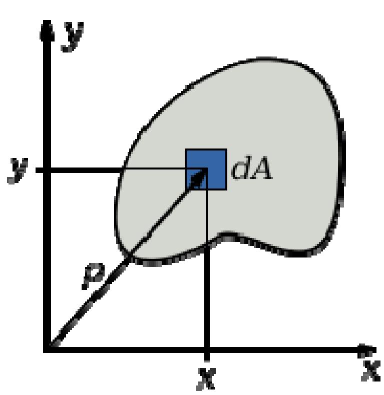
where δ_{ij} is the Kronecker delta.

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:

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

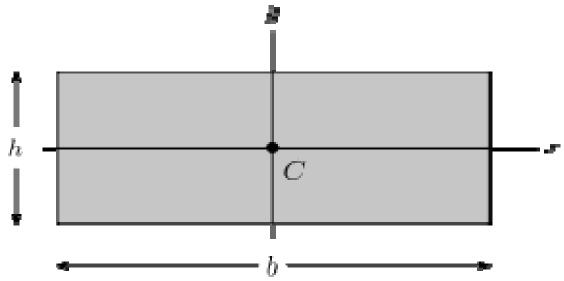
If additionally the beam is only subjected to bending about one axis, the formula simplifies further:

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

[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

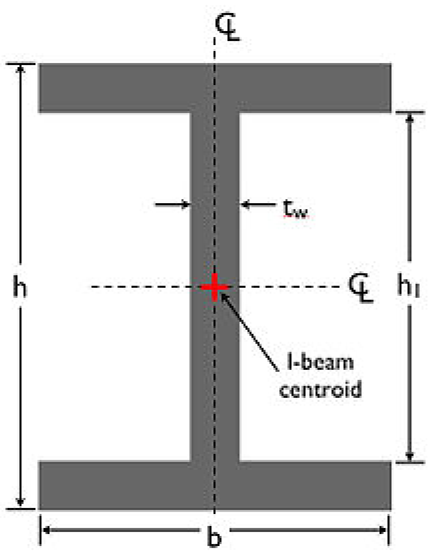
[edit] Composite cross section

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



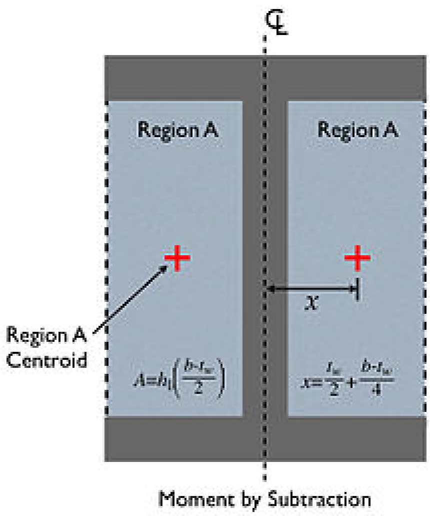
I-beam

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.

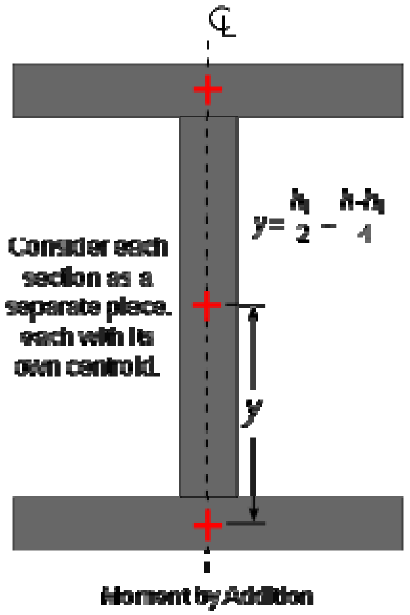
$$J_{xx} = \frac{bh^3 - 2\left(\frac{b-t_w}{2}\right){h_1}^3}{12}$$

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 = $\frac{h+h_1}{4}$

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

[edit] Any cross section defined as polygon

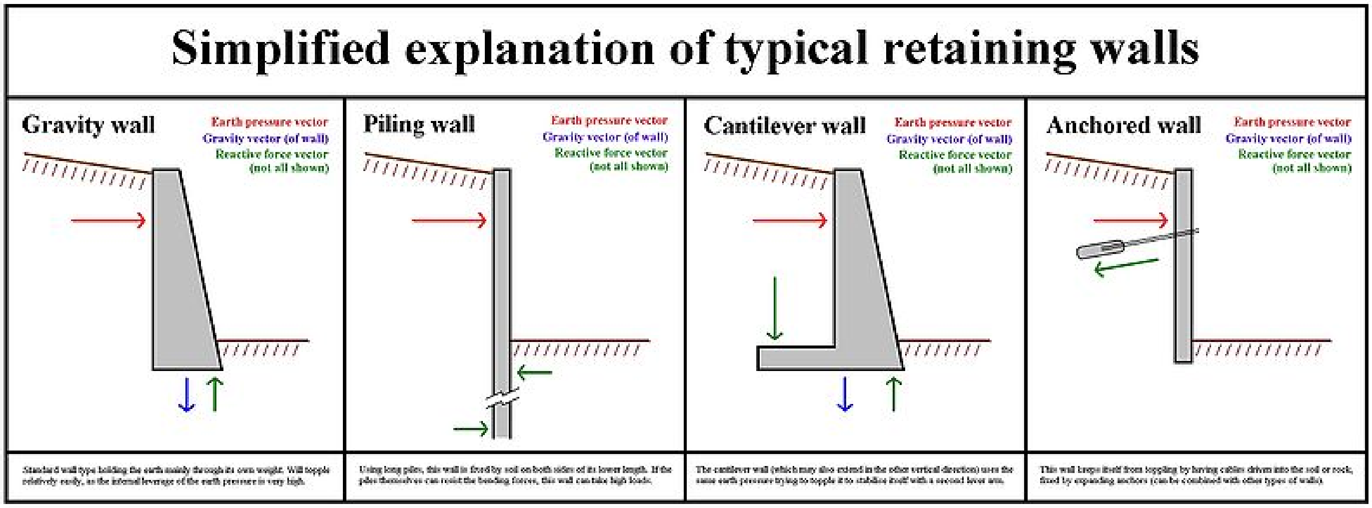
The second moments of area for any cross section defined as a simple polygon on XY plane can be computed in a generic way by summing contributions from each segment of a polygon.

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

2. SEISMIC FORCES

%28-%32 percent of scored

A. Principles

Apply seismic forces principles to building design and construction.

1. Building Design

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

2. Building Systems and their Integration

Consider seismic force 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

Consider impact of design for seismic forces considering cost, building configuration and function, historic preservation, and construction schedule.

B. Materials & Technology

Consider the impact of applying design decisions on the selection of systems, materials, and construction details to accommodate for seismic forces.

1. Construction Details and Constructability

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

2. Construction Materials

Select construction materials pertaining to their resistance to seismic forces.

C. Codes & Regulations

Incorporate building codes, specialty codes, and other regulatory requirements in the design for seismic forces.

1. Government and Regulatory Requirements and Permit Processes

Examine construction details and non-structural elements pertaining to their resistance to 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

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 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

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

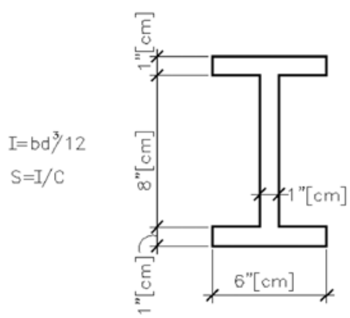
Recommended deflection criteria due to wind loading on a brick veneer wall utilizing a metal stud back-up system is L/600

Not: L/360; L/400; L/720

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

6. 57.3 in^3 is the section modulus for the geometric section illustrated.



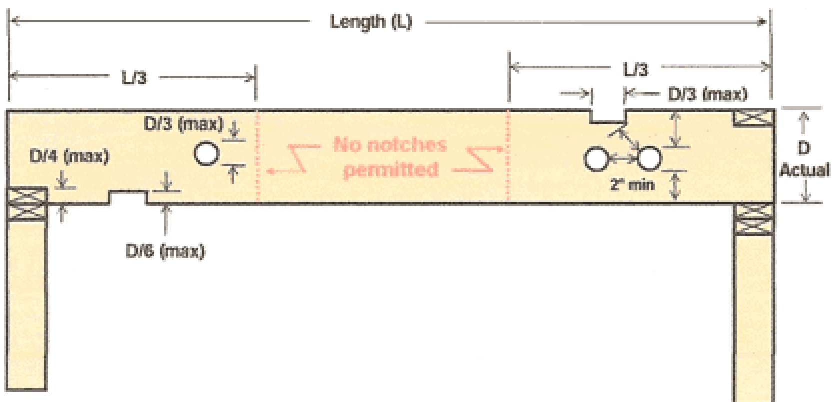
section 4.10 of the ASCE7-02.

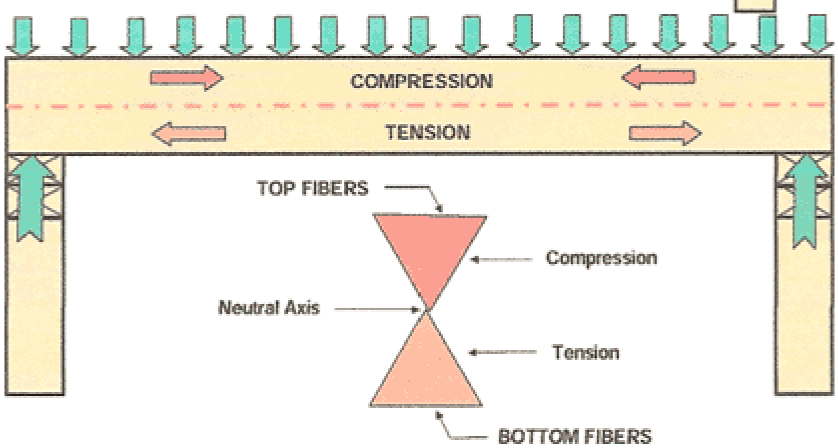
Wood

13. 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





17. 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
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]

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

15. 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: 1/2 in [12 mm]; 3/4 in [19 mm]; 1 in [25 mm]

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"

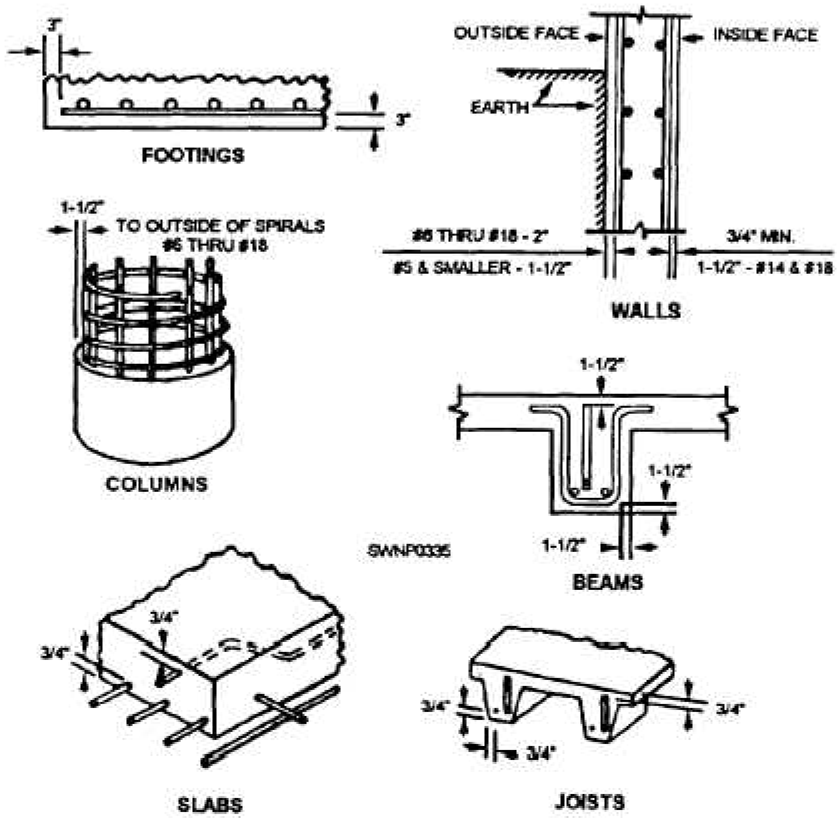
ALL OTHERS PER LATEST EDITION OF ACI 318.

OR

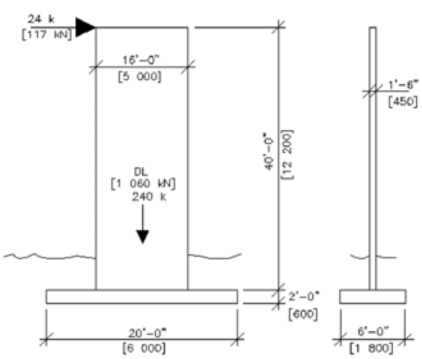
MAINTAIN THE FOLLOWING CONCRETE COVERAGE'S FOR CONCRETE REINFORCING:

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.



31. 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



4. 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

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

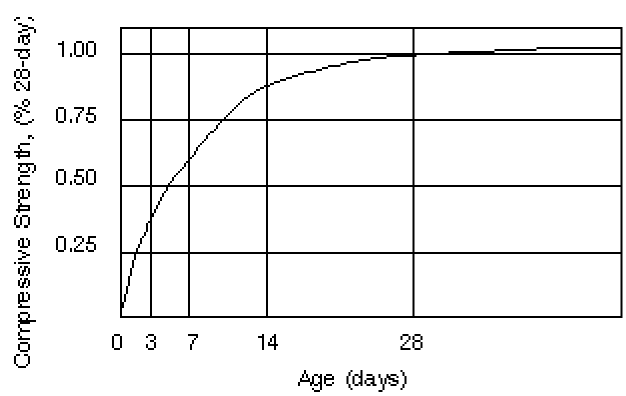


Figure 1. Typical strength-gain curve.

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 .

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

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

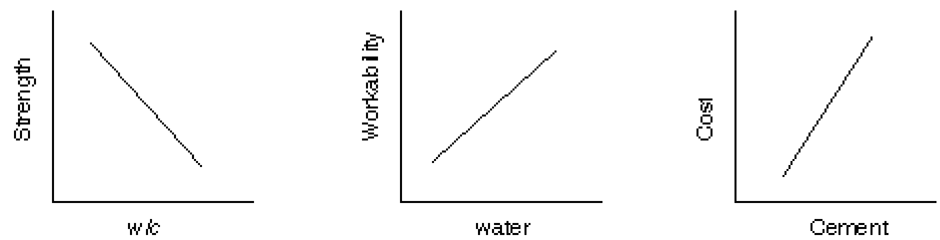


Figure 3. Mix Proportion relationships.

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.

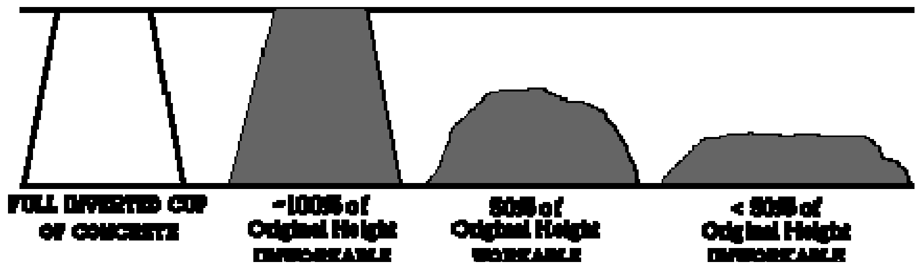
Suggestions:

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 superplasticizers. They will probably be willing to give you some at no charge.
10. 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

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

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.

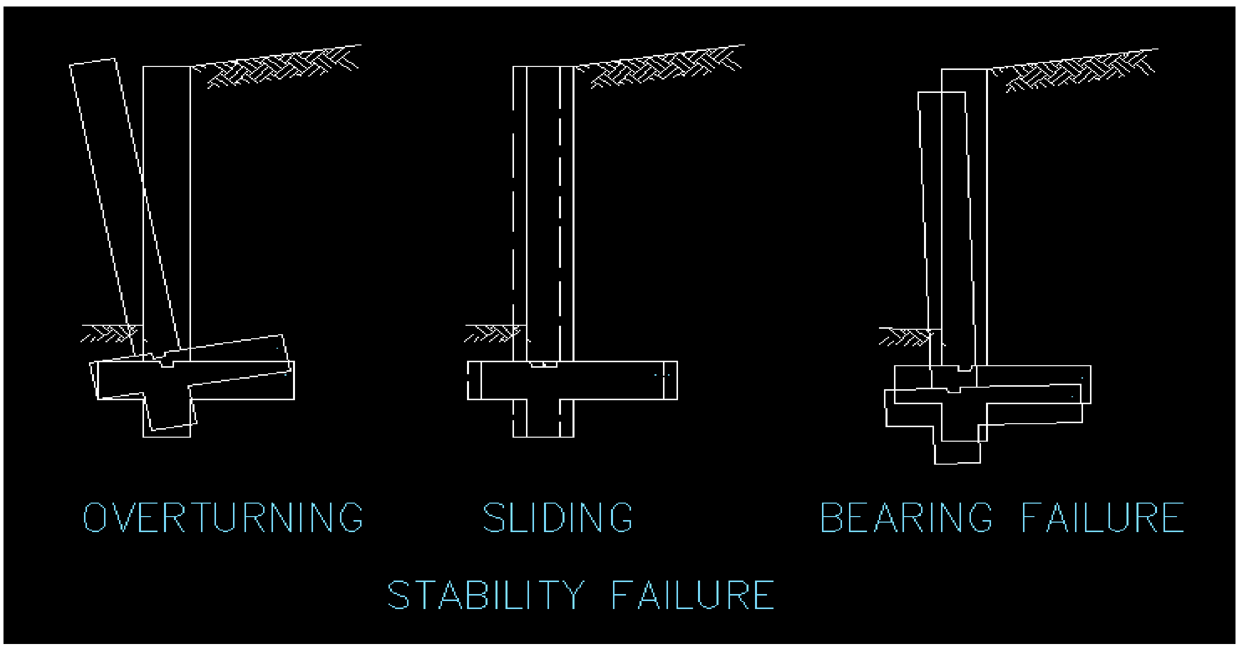
Not: Building codes often make it difficult to obtain approval for their use; design fees are substantially greater than for more conventional structures; materials (concrete and steel) are too costly

Design of concrete cantilever retaining wall

Introduction

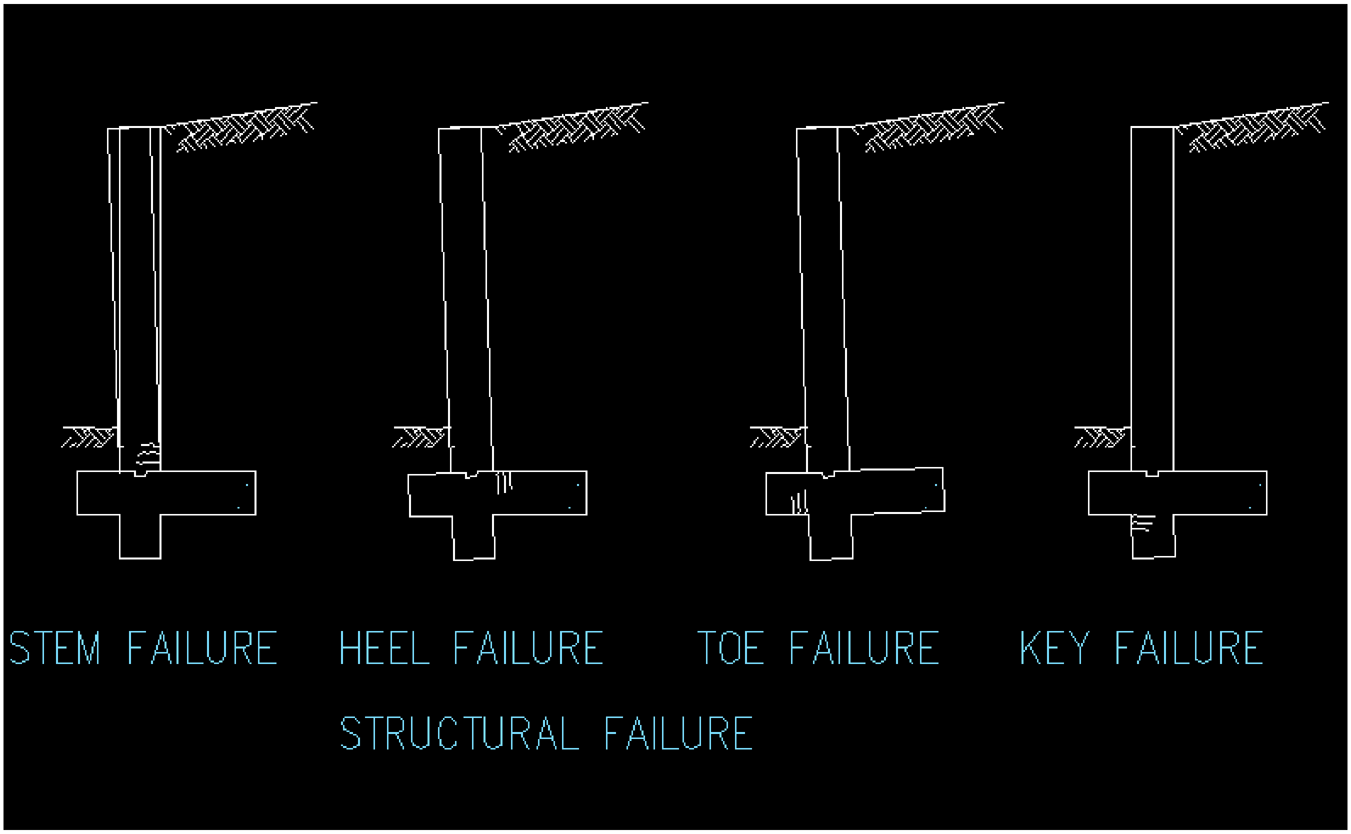
Common failure of retaining wall:

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.

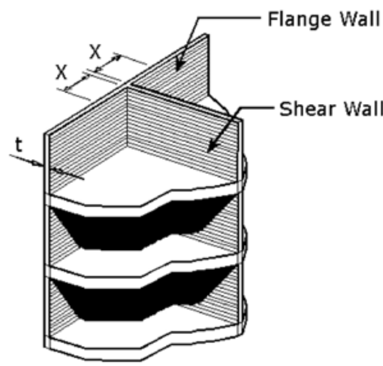
Design procedure for cantilever retaining wall:

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



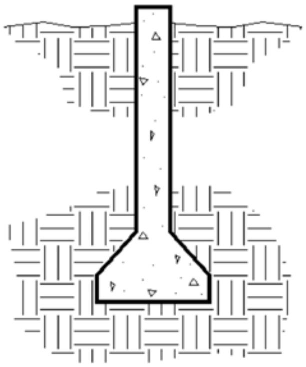
X = Effective flange width

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/m2] and the applied load is 48,000 lbs [212 kN], 16 sf [1.5 m2] 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:

Angle of Internal Friction
Bearing Capacity Factors
Cohesion

External Friction Angle
Factor of Safety
Lateral Earth Pressure Coefficients
Modulus of Vertical Subgrade Reaction
Soil Unit Weights
Young's Modulus or modulus of elasticity

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

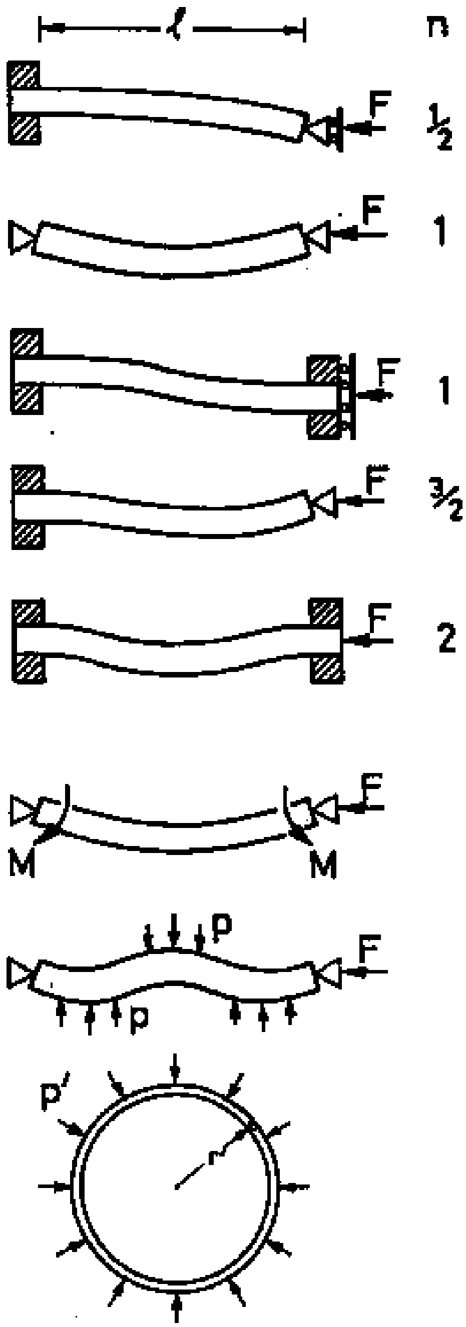
Buckling of Columns, Panels and Shafts

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.



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

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

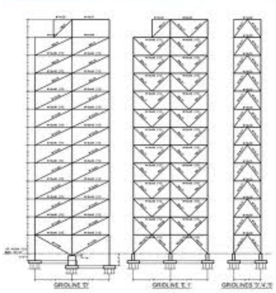
Lateral Forces

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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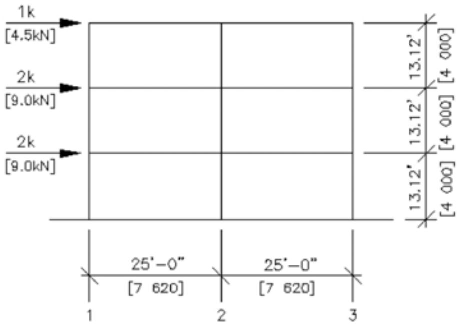
23. For the rigid frame structure shown, the approximate horizontal shear at the base of column 2 (assuming all column stiff nesses are equal) is 2.5 k [kN]



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.

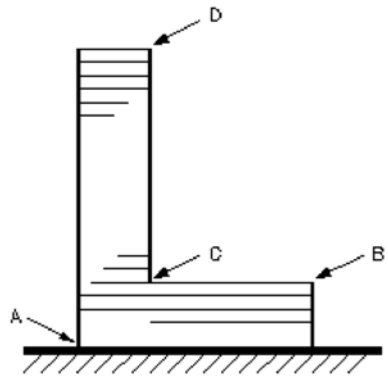
More recently, it has become more and more popular to apply the plasticity theory to the construction calculation. It is related to the developed knowledge in this area, the greater power of computer calculations as well as to the introduction of the simplified computational method, taking the plasticity 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 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 $\leq$ 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 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				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

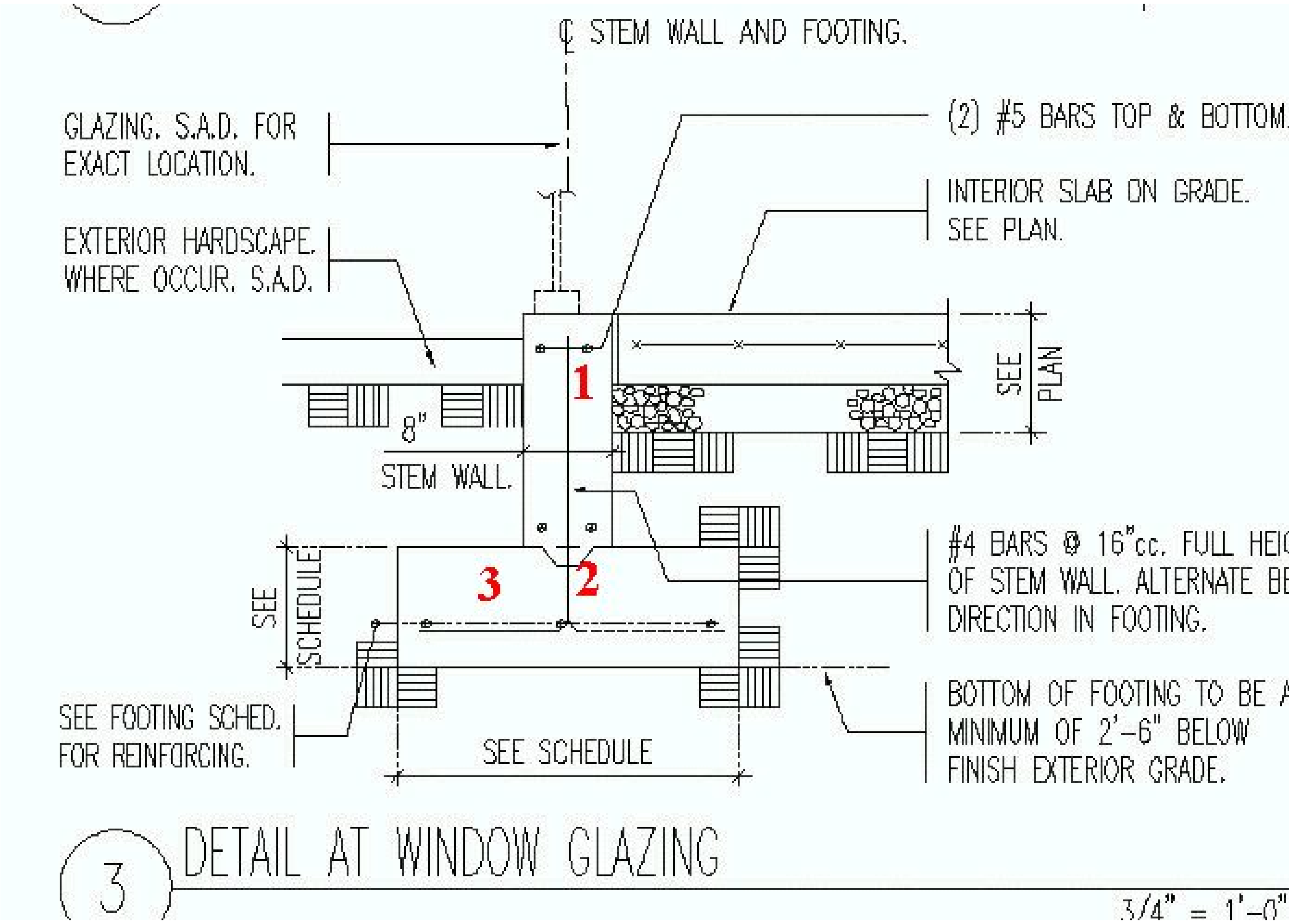
- 2 x Lumber
- Plywood
- Symons
- Gang
- Slip

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

CONTENT AREA: GENERAL STRUCTURES
Building Design
Definitions
- **Force:** the push or pull exerted on an object, including its magnitude, direction, and point of application
- **Collinear forces:** vectors lie along the same straight line
- **Concurrent forces:** lines of action meeting at common point
- **Non concurrent forces:** lines of action do not pass through a common point
- **Coplanar forces:** lines of action all lie within the same plane
- **Structural forces:** any combination of forces (e.g.: truss is sets of concurrent coplanar forces)
- **Load (p):** a force applied to a body (also called an external force)
- **Stress (f):** the resistance of a body to a load (also called an internal force) and measured in kips (K)
- **Unit Stress:** stress/unit of area at the section, measured in psi or ksi (kips/sq.in.)
- **Allowable Stress:** maximum permissible unit stress
- **Factor of Safety:** ratio of the ultimate strength of material to its working stress
- **Strain:** the deformation of a material caused by external loads. Tensile loads stretch, and compressive loads shorten.
- **Shear:** a strain produced by pressure in the structure when its layers are lateral shifted in relation to each other
- **Moment:** the tendency of a force to cause rotation about a given point or axis
- **Modulus of Elasticity:** a material's resistance to non permanent (or elastic) deformation
- **Reaction:** the force acting at the supports of a beam that holds it in equilibrium
- **Eccentric Load:** A load imposed on a structural member at some point other than the centroid of the section
- **Truss:** framework consisting of rafters, posts, and struts
- **Moment of Inertia:** measure of an object's resistance to changes to its rotation.
- **Section Modulus:** is the ratio of a cross section's second moment of area to the distance of the extreme compressive fiber from the neutral axis
- **Deflection:** the displacement of a structural element under a load
- **Hook's Law:** unit stress is proportional to unit strain up to the elastic limit
- **Yield Point:** the amount of stress that causes a material to deform without additional load added
- **Composite Structural Member**: more than one material working together (eg: reinforced concrete, box beam, flitch beam)
- Resilience: ability of material to absorb energy while undergoing elastic range stresses
- Ductility: ability of a material to absorb energy prior to fracture...toughness!

Equations: (MEMORIZE THOSE IN PURPLE)

• **Equilibrium:**

$\Sigma M = 0; \Sigma V = 0; \Sigma H = 0$

• Stress (f) =

Total Force (P) / Area (A)

f = P/A

• **Force Equations {units = kips or lbs}**

• To find force: Force (F) = Mass (M) x Acceleration (a)

F = Ma

• To find
shear diagram shear force
Shear Resisting Force (R) = (V) =

uniform load per foot (w) x distance (L) / 2

R= V = wL / 2

• To find the
horizontal force on a retaining wall

Force (F) =
soil pressure (w) x height of wall (h)2 / 2

F = w2h / 2

• **Moment Equations {units = kip ft, lb ft, kip in, or lb in}**

• To find
equilibrium by taking moments about a point:

Moment (M) =
Force (P) x distance (d)

M = Pd

• To find the
eccentric load (the same as finding equilibrium)

Moment (M) =
Force (P) x eccentricity (e)

M = Pe

• To find
uniform load

Moment (M) =
uniform load (w) x length (L)2 / 8

M = wL2 / 8

• To find
point/concentrated load at the center of a member:

Moment (M) =
Point Load (P) x length (L) / 4

M = PL / 4

• To combine Point Load and Uniform Loads:

M = wL2 / 8 + PL / 4

• **Section Modulus Equations {units = inch3}**

• To find
Section Modulus (both moment and stress are in kips or lbs)

Section Modulus (S) =
Base (b) x diameter (d)2 / 6

S = bd2 / 6

Section Modulus (S) =
Moment (M) / Bending Stress (Fb)

S = M / Fb

Section Modulus (S) =
Moment of Inertia / given constant (c)

S = I / c

• To find
Section Modulus for a roof beam

Section Modulus (S) =
Moment (M) / 1.25 x Bending Stress (Fb)

S = M / 1.25Fb

• **Moment of Inertia Equations {units = inch4}**

• To find
Moment of Inertia (occurs about the centroidal axis)

Moment of Inertia (I) =

Base (b) x diameter (d)3 /12
$I = bd^3 / 12$
Rectangle Moment of Inertia (I) = Base (b) x diameter (d)3/ 3
$I = bd^3 / 3$
Moment of Inertia at base (Ibase) =
Moment of Inertia (I) + Area (A) x distance from centroid to base (y)2
$I_{base} = I + Ay^2$

- **Stress Equations {units = ksi or psi}**
- To find

bending stress (max bending stress occurs at the extreme fibers)

Bending Stress (fb) =
Moment (M) / Section Modulus (S)
$f_b = M / S$
_ _ Bending Stress (fb) =
Moment (M) x constant (c) / Moment of Inertia (I)
(so…the greater the c, the greater the bending stress!)
$f_b = Mc / I$

- To find

axial stress (max axial stress occurs along entire cross section)

Axial Tension or Compression Stress (fa) =
Axial Tension (P) / Area (A)
(axial stress is the same as both tension and compression!)
$F_a = P / A$

- To find

shear stress (max shear stress occurs at the neutral axis and is the same at both the vertical and horizontal axis)
Shear Stress (fv) = 1.5 x Shear Force (V) / Area (A
$f_v = V / A$

Shear Stress (fv) = Shear Force (V) x Neutral Axis of area above plane (Q) /
Moment of Inertia (I) x width of beam (b)
$f_v = VQ / Ib$
Neutral axis of area above Plane (Q) =
section area (A) x distance from centroid of rectangle to centroid of section above neutral axis (d)
$Q = Ad$

- **Modulus of Elasticity Equation**

Modulus of Elasticity (E) =
Stress (f) / Strain (ε)
$E = f / \varepsilon$

- **Strain Equation**

Strain (ε) =
Deflection (e) / Original Length (L)
$\varepsilon = e / L$

- **Deflection Equations {units = inches}**
- To find

shortening of a column or elongation of a horizontal member
Deflection (e) =
Force (P) x Length (L) / Area of cross section (A) x Modulus of elasticity (E)
$e = PL / AE$

- To find

deflection of a beam
Deflection (Δ) =
5 x weight in lbs (w) x length in feet x 12"4 (L4) / 384 x 12" modulus of Elasticity (E) x Moment of Inertia (I)
$\Delta = 5wL^4 / 384EI$

- **Thermal Equations {units = inches}**
- To find

shortening or elongation due to temperature change
Thermal Change (Δ) =
Coefficient of Thermal Linear Expansion (e) x original length (L) x temperature change (Δt)
$\Delta = eL\Delta t$

- To find

thermal strength in a restrained member
Thermal Stress (ft) = Modulus of Elasticity (E) x Coefficient of Thermal Linear Expansion (e) x temperature change (Δt)
$f_t = Ee\Delta t$

- **Slenderness Ratio (Loading Capacity) Equations {units = inches}**
- To find

slenderness ratio of a steel column (should be less than or equal to 200)
Slenderness Ratio (SR) =
end condition (k) x unbraced length in inches (L) / radius of gyration (r)
$SR = kL / r$

Radius of gyration (r) =
√moment of inertia (I) / Area
$r = \sqrt{I / A}$

• To find
slenderness ratio of a wood column (should be less than or equal to 50)
Slenderness Ratio (SR) =
end condition (k) x unbraced length in inches (L) /cross section width of rectangle (b)
$SR = kL / b$

Equilibrium:			$\Sigma M = 0$; $\Sigma V = 0$; $\Sigma H = 0$
Stress (f) =	Stress (f) =	Total Force (P) / Area (A)	**f = P/A**
Force Equations {units = kips or lbs}			
force:	Force (F) =	Mass (M) x Acceleration (a)	**F = Ma**
shear diagram shear force	Shear Resisting Force (R) = (V) =	uniform load per foot (w) x distance (L) / 2	**R= V = wL / 2**
horizontal force on a retaining wall	Force (F) =	soil pressure (w) x height of wall (h)2 / 2	**F = w2h / 2**
Moment Equations	**{units = kip ft, lb ft, kip in, or lb in}**		
equilibrium by taking moments about a point:	Moment (M) =	Force (P) x distance (d)	**M = Pd**
eccentric load (the same as finding equilibrium)	Moment (M) =	Force (P) x eccentricity (e)	**M = Pe**
uniform load	Moment (M) =	uniform load (w) x length (L)2 / 8	**M = wL2 / 8**
point/concentrated load at the center of a member:	Moment (M) =	Point Load (P) x length (L) / 4	**M = PL / 4**
		To combine Point Load and Uniform Loads:	**M = wL2 / 8 + PL / 4**
Section Modulus Equations {units = inch3}			
Section Modulus (both moment and stress are in kips or lbs)	Section Modulus (S) =	Base (b) x diameter (d)2 / 6	**S = bd2 / 6**
	Section Modulus (S) =	Moment (M) / Bending Stress (Fb)	**S = M / Fb**
	Section Modulus (S) =	Moment of Inertia / given constant (c)	**S = I / c**
Section Modulus for a roof beam	Section Modulus (S) =	Moment (M) / 1.25 x Bending Stress (Fb)	**S = M / 1.25Fb**
Moment of Inertia Equations	**{units = inch4}**		

Moment of Inertia (occurs about the centroidal axis)	Moment of Inertia (I) =	Base (b) x diameter (d)3 /12	**I = bd3 / 12**
	Rectangle Moment of Inertia (I) =	Base (b) x diameter (d)3/ 3	**I = bd3 / 3**
	Moment of Inertia at base (Ibase) =	Moment of Inertia (I) + Area (A) x distance from centroid to base (y)2	**Ibase = I + Ay2**
Stress Equations {units = ksi or psi}			
bending stress (max bending stress occurs at the extreme fibers)	Bending Stress (fb) =	Moment (M) / Section Modulus (S)	**fb = M / S**
(so…the greater the c, the greater the bending stress!)	Bending Stress (fb) =	Moment (M) x constant (c) / Moment of Inertia (I)	**fb = Mc / I**
axial stress (max axial stress occurs along entire cross section)	Axial Tension or Compression Stress (fa) = *(axial stress is the same as both tension and compression!)*	Axial Tension (P) / Area (A)	**Fa = P / A**
shear stress (max shear stress occurs at the neutral axis and is the same at both the vertical and horizontal axis)	Shear Stress (fv) =	1.5 x Shear Force (V) / Area (A	**fv = V / A**
	Shear Stress (fv) =	Shear Force (V) x Neutral Axis of area above plane (Q) /Moment of Inertia (I) x width of beam (b)	**fv = VQ / Ib**
	Neutral axis of area above Plane (Q) =	section area (A) x distance from centroid of rectangle to centroid of section above neutral axis (d)	**Q = Ad**
Modulus of Elasticity Equation	Modulus of Elasticity (E) =	Stress (f) / Strain (ε)	**E = f / ε**
Strain Equation	Strain (ε) =	Deflection (e) / Original Length (L)	**ε = e / L**
Deflection Equations {units = inches}			

shortening of a column or elongation of a horizontal member	Deflection (e) =	Force (P) x Length (L) / Area of cross section (A) x Modulus of elasticity (E)	**e= PL / AE**
deflection of a beam	**Deflection (Δ) =**	5 x weight in lbs (w) x length in feet x 12"4 (L4) / 384 x 12" modulus of Elasticity (E) x Moment of Inertia (I)	**Δ = 5wL4 / 384EI**
Thermal Equations {units = inches}			
shortening or elongation due to temperature change	**Thermal Change (Δ) =**	Coefficient of Thermal Linear Expansion (e) x original length (L) x temperature change (Δt)	**Δ = eL**Δt
thermal strength in a restrained member	Thermal Stress (ft) =	Modulus of Elasticity (E) x Coefficient of Thermal Linear Expansion (e) x temperature change (Δt)	**ft = Ee**Δt

Building Systems and their Integration

Vocabulary:

- **Post:** long, sturdy piece of timber or metal set upright in the ground used to support
- **Beam:** a member that supports loads perpendicularly to its longitudinal axis
- **Simple Beam:** rests on a support at each end and ends are free to rotate
- **Cantilever Beam:** supported at one end and restrained from rotation at that end
- **Overhanging Beam:** rests on 2+ supports and has one or both ends cantilevered beyond the support
- **Fixed End Beam:** fixed against rotation at both ends
- **Frame:** a structural system that supports other components of a physical construction
- **Truss:** a framework, typically consisting of rafters, posts, and struts, supporting a roof, bridge, or other structure
- **Gage line:** standard dimension from corner edge of an angle to centerline of bolt holes. depends on size of angle
- **Arch**: a curved symmetrical structure spanning an opening and typically supporting the weight of a bridge, roof, or wall above it.

Facts/Rules:

• A concentrated load acts at one point on a beam
• A distributed load acts over a length of a beam
• If the load/unit of length of the beam is constant it’s a uniformly distributed load
• Simple beams, cantilever beams, and overhanging beams that rest on 2 supports are statically determinate
• Wood
• The oldest and most common system
• One way structural system (load is transmitted through members in one direction)

Type	Width	Spacing	Spans	Top/Bottom	Use	Advantage
Joists	2" Nominal	12" to 16" On Center	20 to 25 ft	Bridging supports bottom edge, sheathing holds top in place	Between beams or bearing walls	Tried and true method
I-Joist	1 3/4" to 3 1/2"	12" to 24" On Center	8 to 24 ft	9-1/2” - 16” depth OSB webs and microllam (thick plywood) flanges connect to wall with hangers	Residential/ light commercial	Efficient structural shape as shop fabrication eliminates common defects
Glulam	3 1/8", 5 1/8", 6 3/4", 8 3/4"	Varies	15 to 60 ft	Several layers of timber bonded together with glue and connected with plates and/or bolts	Columns and beams, commercial, public	can be left exposed, can be tapered or curved
Plank/ Beam Framing	4" to 6"	4' or 6' or 8'	10 to 20 ft	Wood decking span between beams, underside finish ceiling	Between girders or bearing walls, residential	Easy to insulate
Truss	Varies	24" on Center	24 to 40 ft	12 to 36 inch deep made of of strand wood members connected with plates	Residential, Commercial, Public	MEP can pass through
Box Beam	Upto 30 ft	Varies	50 ft	Plywood panels glued & nailed to 2x4	Residential, Commercial, Public	Looks like solid timber, custom made

• Steel

• Most commonly used structural material due to its high strength, availability, adaptability, **ductility** (can deform and return to original shape/bends before it breaks)
• Suited for multi-floor construction due to strength and structural continuity
• Beams span shorter distances of 8’ - 10’
• Girders span longer distances of 25’ - 40’

• Concrete

• **Cast-in-place concrete:** typically involves steel reinforcement (rebar), sometime post-tensioning is used
• **Precast structural members:** high-strength steel cables are pre-stressed/stretched and concrete is poured on top. When concrete reaches minimum allowable strength cables are cut from formwork. and compressive stresses are transferred to concrete that resists tension forces of own weight/live load
• Post-tensioned concrete: steel tendons are laid out in desired direction and concrete is poured on top. When concrete is cured tendons are tensioned and force is transferred to the concrete through end anchorages.
• **Beam & Girder system:**
• Large girders carry intermediate beams which support a slab with spans of 15'-30'
• Easy to form and construct making it economical
• Slabs can be penetrated (unlike PT slabs that have tendons)
• **One Way Concrete Joist system (pan joists):**
• Prefab metal pan forms are used to create frame to support light/medium loads with spans of 20' - 30' and depths of 1' - 2'
• Formed with prefab metal pan forms spaced 24" – 36" apart in one direction
• Two Way Concrete Joist system:
• Like One Way Joist but with beams in each direction
• Typically used in rectangular bays where distance between columns is equal (or close to) in both directions
• Flat plate system:
• Basically a Two-Way slab with no supporting beams, only columns.
• Reinforced slab spans in both directions directly into columns at 25' with 6" - 12" thickness
• Typically used for light loads, short spans, when floor-floor height must be minimized, and/or when simple under-side of slab appearance is required
• Has low shear capacity and low stiffness
• **Drop panel system:**
• Like a Flat Plate system, but the slab thickness is increased around the columns for greater shear failure resistance.
• Used with greater live loads or larger spans.
• Flat slab system:
• A two way slab with column capitals, drop panels, or both with spans of 30'
• **Waffle slab system:**
• Ribs formed with reusable prefab metal/fiberglass forms and span up to 40'
• Provides the largest spans of conventional concrete floor systems
• Lift-slab system:
• Floor/roof slabs are cast on top of the previous and then jacked up to the desired height
• **Singe tee/double tee system:**
• Prestressed ribs (one or two) with a 2" topping slab connected.
• Typically used for larger spans

• Masonry

• System has high compressive strength and is weak in tension and bending.
• Advantages include strength, flexibility, appearance, fire resistance, sound insulation, doesn't weather (much), and can be used as a thermal mass for passive solar energy
• Horizontal joints are reinforced at 16" o.c. to strengthen walls and control cracking.
• Joints tie multi-wythe walls together and anchor veneer facing to structural backup wall
• **Single Wythe Masonry Walls:**
• One unit thick
• Non structural wythe of brick is called veneer
• No requirements for reinforcing or grouting and rely on a substrate for support
• Double Wythe Masonry Walls:
• Two units thick
• Material for both wythes may be the same and may be grouted/reinforced or ungrouted
• **Cavity Walls:**
• Two masonry skins (eg: brick exterior and cmu interior) with a hollow space between.
• Cavity is used for drain water out of wall through weep holes
• May be grouted and reinforced or ungrouted
• A cavity wall is a double wythe wall, but a double wythe wall is not always a cavity wall (kinda like, a square is a rectangle, but a rectangle isn't always a square)
• Composite Construction
• Two or more materials designed to act together to resist loads (reinforced concrete construction is the most typical example)
• Arches
• Have hinged or fixed supports (though fixed are less common)
• Arches are usually top hinged to allow it to remain flexible and avoid developing high bending stresses under live loading and loading due to temperature changes and settlement
• Hinged arch is primarily subjected to compressive forces
• Conceptually, uniform loads supported across the span form a parabola
• Actually, no arch is subject to just one set of loads...there's always compression and bending stresses
• Supports have vertical reactions and horizontal actions
• Three hinged arches have an additional hinged connection at apex which makes structure statically determinate (two hinged/fixed charges are statically indeterminate)
• Generally, loads acting on an arch force it to spread out
• Ultimate goal of arch design is that thrust must be resisted
• For a given span thrust is inversely proportional to the rise/height of the arch
• If rise is reduced by one half, the thrust doubles Tie rods: hold two lower portions together

- Foundations are designed to to prevent thrust
- Shape of arch selected for aesthetic appeal not always ideal shape for loading

- Typical arch spans:
- Wood: 50’ – 240’
- Concrete: 20’ – 320’
- Steel: 50’ – 500’

• Trusses

Trusses need to be designed so member is symmetric on both sides of centroid axis in the plane of the truss

- Typical depth-to-span ratios range from 1:10 to 1:20
- Typical spans: 40’ - 200’ and typical spacing: 10’ - 40’ o.c.
- Residential & light commercial trusses are smaller, 2x4 or 2x6 members at 24”o.c.
- Flat trusses require less overall depth than pitched trusses
- Roof loads transferred from decking to purlins attached to truss at panel points
- If concentrated loads between panel points or uniform loads applied to top chords, member must be designed for axial loading as well as for bending…Like beams
- Compression in top chord & tension in bottom chords
- Forces in a parallel chord truss increase towards center
- If concentrated loads or uniform loads on any chord member between panel points, member must resist bending stresses
- Steel trusses with double angles back-to back with 3/8” or 1/2” gusset plate with tee sections or wide flange
- Wood trusses: web members between double top and bottom chords or with all members in same plane connected with gusset plate
- With light loads, bars or rods can be used for tension members
- Centroidal axes of intersecting members must meet at a point to avoid eccentric loading
- Rigid Fames
- In rigid frame construction vertical and horizontal members work as a single structural unit
- Efficient because three members resist vertical and lateral loads together
- Beam are restrained by columns and becomes more rigid to vertical bending forces
- Columns resist lateral forces as they are tied together by beam
- With single concentrated load, cable assumes shape of two straight lines (not counting the intermediate sag due to the weight of cable)
- Since rigid frames only resist loads in tension, instability due to wind must be stabilized or stiffened with heavy infill material (eg: cables attached to ground)
- Air Supported Structures
- Simplest form, single membrane anchored continuously at ground level, inflated, and stabilized with cables over the top of the membrane.

• Only resist loads in tension and are held in place with constant air pressure that is greater than the outside air pressure
• The double skin inflatable structure is created by inflation of a series of voids

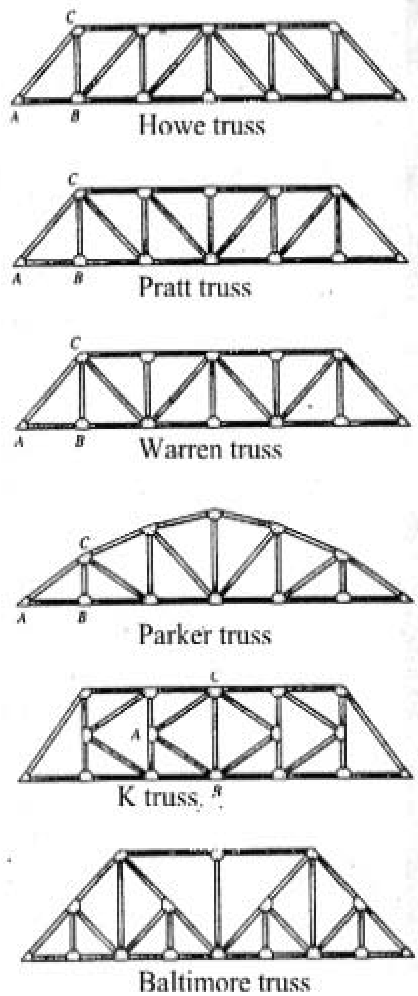


Fig. 4.4 Common Bridge Trusses

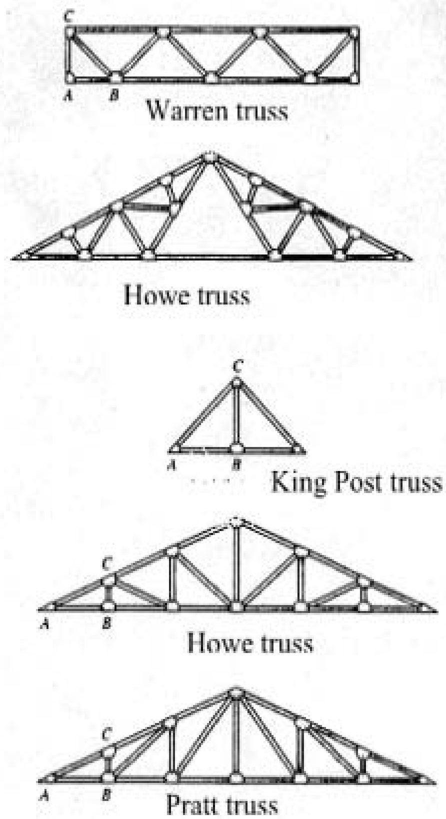


Fig. 4.5 Common Roof Trusses

Concepts/Goals:

- Selecting a Structural System
- Primary consideration is resistance to loads
- Anticipated loads are calculated given the known weights of materials, equipment, other dead loads, and requirements of international and local building code (the most stringent of which applies)
- Unanticipated loads like changes in use, snow, ponding of water, degradation of the structure must also be considered
- Building use and function is a major consideration
- What's the occupancy type (wouldn't use the same system for a parking garage and a school)
- Client's programmatic needs (hospital surgery needs major mechanical systems above ceiling and below ICU on floor above)

Processes:
Selecting a Structural System Based on Economy, Span, and/or Shape

If the building has...	**And you want...**	**Then your options are...**
Irregular Form	Simple floor & roof framing fabricated onsite	• Site cast concrete with any slab system without beams/ribs • Light Gauge Steel Framing • Masonry with concrete slab/wood light floor framing
Irregular Colum Grid	Something without beams/joists in the floor or roof	• Site cast concrete 2 way flat plate • Metal space frame
Exposed Structure	Fire/Heat resistance	• All concrete systems (except ribs) • Heavy timber frame
Minimum Floor Thickness or Minimum Total Building Height	Thinnest floor system	• Pre stressed Concrete slabs • Site cast concrete 2 way flat plate • Post tensioned 1 way slab
Minimum area occupied by columns and/or bearing walls	A Long Span System	• Heavy wood trusses • Glue lam wood beams • Glue lam wood arches • Steel frame • Steel trusses • Open Web Structural Joists • Waffle Slab • Single or Double Tee Concrete
Changes in use over time	Short Span, one Way Systems that can easily be modified	• Light Gauge/Conventional Steel Frame • Wood systems (including masonry) • Site Cast 1 way concrete slab • Precast concrete slab
Exposure to Adverse Weather	No reliance on onsite chemical processes	• Steel • Wood • Precast Concrete without toppings or grouting
Minimal off-site fabrication time	On site construction with easily formed materials	• Site cast concrete • Light Gauge Steel Framing • Platform Framing • Masonry

Minimal on-site erection time	A lot of prefab/modular components	• Single story rigid steel frame • Steel frame with hinged connections • Precast concrete • Heavy timber frame
1-2 stories with minimal construction time	Lightweight/easy to form/prefab	• Any steel • Heavy timber frame • Platform frame
4-20 stories with minimal construction time	Lightweight/ easy to form/prefab	• Precast concrete • Conventional Steel Frame
30+ stories with minimal construction time	Strong, lightweight, easy to assemble	• Steel Frame • Sometime Site/Precast Concrete
Minimal diagonal bracing or shear walls	Rigid Joint System	• Site cast concrete (With beams/ deep slab around columns • Single frame with welded connections • Single story rigid steel frame
Minimal dead load on foundation	Lightweight/Short Span	• Any Steel • Any Wood
Minimal structural distress due to unstable foundation	Frame without rigid joints	• Steel frame with bolted connections • Heavy timber frame • Precast concrete system • Platform framing
Concealed Spaces for MEP	Not add height to building	• Truss • Open web joists • Light Gauge Steel Framing • Platform Framing
General	Minimize Separate Trades/Contractors	• Masonry • Precast, Load bearing Wall Panels

Implications of Design Decisions

Facts/Rules:

- A steel building weighs less than a concrete/masonry building of the same parameter
- Timber _ =_ 7-10 lbs/sf typical construction weight/floor
- Steel__ _ =_ 15-20 lbs/sf typical construction weight/floor
- Concrete/Masonry_ =_ 150-200 lbs/sf typical construction weight/floor
- Light loads/Pneumatic =_ lightest system, but must deal with wind

Concepts/Goals:
• When selecting a system, it often comes down to **Time and Money** when choosing what will be appropriate. The owner's budget and schedule must be considered as well as the seismic design requirements and conditions
• Getting a contractor on board early to help in the selection process will help.
• Cost Implications vary depending on the type of building, location, and economy.
• Precast Concrete: cast offsite and trucked in and installed with a crane
• Subject to wide price swings depending on how it's used
• Can be an expensive solution
• Prices are competitive with other systems when there are numerous pieces of the same size/shape
• Formwork is one of the most expensive components
• Can save time as it is prefab and can be erected quickly
• Don't have to worry about fire proofing
• Cast in Place Concrete: poured into forms, on decking, or ground at location
• Probably the most expensive and slowest structural system
• Good for irregular shapes and fireproofing/durability needs
• Slip Forming (forming that slides up each floor as it's poured helps save cost
• Steel: beams, columns, floors and roof decks (concrete poured over decking as a structural part of the floor system)
• More economical framing system than concrete
• Takes less time than concrete to fabricate and erect
• More economical when spanning open spaces
• Durable
• Must be fireproofed
• Pre-Engineered Metal: standardized metal components are engineered to maximize use of the material's structural properties and includes structure, metal roof, and metal wall panels (or tilt-up concrete panels)
• Use without modifying standard design
• It's actually pretty difficult to modify as structure is designed close to max limit
• Light Gauge system with 20 – 30 year life span
• The least expensive way to quickly enclose a large area
• Wood: wood columns, beams, and framing floors, roofs and walls
• Smaller commercial or residential
_ Economical up to 3 stories
_ Inexpensive for non-fire resistive construction
• Historic Preservation efforts include upgrades to building structure to protect the building from seismic and wind forces
•Historic buildings are especially vulnerable they have not been designed and constructed to absorb swaying ground motions…can have major structural damage, or outright collapse
•More and more communities are beginning to adopt stringent requirements for seismic retrofit of existing buildings.
•Although historic and other older buildings can be retrofitted to survive

earthquakes, many retrofit practices damage or destroy the very features that make such buildings significant.
•Life-safety issues are foremost and there are various approaches which can save historic buildings both from the devastation caused by earthquakes and from the damage inflicted by well-intentioned but insensitive retrofit procedures.
•Three important preservation principles should be kept in mind when undertaking seismic retrofit projects:
• Historic materials should be preserved and retained to the greatest extent possible and not replaced wholesale in the process of seismic strengthening
• New seismic retrofit systems, whether hidden or exposed, should respect the character and integrity of the historic building and be visually compatible with it in design
• Seismic work should be "reversible" to the greatest extent possible to allow removal for future use of improved systems and traditional repair of remaining historic materials.

Construction Details and Constructability

Vocabulary:

- **Connection:** two or more members joined with one or more fasteners which provide continuity to the members and strength/stability to the system
- **Dowel Type Fasteners:** (nails, screws, bolts) that transmit lateral loads via bearing stresses between the fastener and members of the connection OR that transfer withdrawal loads parallel to the fasteners axis via friction or bearing to the connected materials
- **Bearing Type Fasteners:** (shear plates) that transmit lateral loads only by shear forces via bearing on the connected materials
- **Hangers:** combination of dowel and bearing type fasteners that support one structural member and are connected to another member by a combination of dowel and bearing action
- **Plate Girder:** assembly of steel plates, or plates and angles, fastened together to form an integral member
- **Underpinning:** the process of strengthening and stabilizing the foundation of an existing building
- **Shoring:** supporting a structure in order to prevent collapse so that construction can proceed. (e.g.: support beams and floors of building while a column/wall is removed, shoring in trenches for worker safety in excavation)
- **Stabilization:** retrofitting of platforms/foundations as building for the purpose of improving the bearing capacity of the supported building.
- **Counter forts:** reinforced concrete webs act as diagonal braces
- **Critical net section:** section where the most wood has been removed
- **Connectors Spacing:** the distance between centers of connectors, the minimum of which is typically given in building codes
- **End distance:** distance measured parallel to the grain from the center of connector to square cut end of member
- **Edge distance:** distance from edge of member to center of connector closest to it

Equations:

• Area of Footing = total wall or column load + weight of footing + any soil on top of footing / allowable soil bearing pressure
• Earth Pressure on a wall (P) = 30 lb/ft3 x height of wall

Facts/Rules:

Foundation Types	
Spread Footing:	Most economical…$ method. Delivers load directly to soil over a large area Area of the footing = load/safe bearing capacity.
Wall Footings	Most common method. Under a continuous foundation wall that supports a bearing wall
Column Footing:	one footing supports one column
Combined Footing:	when 2+ columns are too close to each other or a property line for separate footings, one footing is poured for them all
Strap/Cantilever Footing:	like a combined footing, but columns are far apart
Mat Foundations:	Very expensive…$$$ method. Typically it's only used when the strata is weak, It acts as one continuous foundation.
Pile Foundations:	used when soil is unsuitable for spread footings (e.g.: expansive soils or clay near surface) by transmitting loads through soil to a more secure bearing farther below • Located in groups or in alignment under a bearing wall • Load transferred from wall to pile caps. • Piles are either driven (timber, steel, precast conc) or drilled (caissons) Belled Caissons: holes are drilled to firm strata and concrete poured. • They're basically really, really deep spread footings
Friction Pile:	Driven into softer soil. Friction transmits the load between pile and soil Bearing capacity is limited by whichever is weaker: strength of the pile or soil_
Socketed Caissons:	like Belled Caissons, but the hole is drilled deep into the strata. Bearing capacity comes from end baring and frictional forces.
End Bearing Piles:	2-3x cost of spread footings. Driven until tip meets firm resistance from strata

Retaining Wall Types

Cantilever wall:	(most common type) constructed of reinforced concrete • resists forces by the weight of the structure and weight of the soil on the heel of the base slab • A **key** projects form the bottom to increase the resistance to sliding • 20’ - 25’ max height due to economics
Counterfort walls:	like cantilever walls, with a conterforts spaced at distances approximately half the wall height
Gravity walls:	resist forces by own weight and made of non reinforced concrete • Retaining walls fail as a whole by overturning or sliding. • To prevent this, the friction between the footing and the surrounding soil/earth pressure in front of the toe must be 1.5 the pressure that typically causes the wall to slide

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Wood Connection Types
• Depends on the species/condition of the wood, fire retardant or not, type of load, and angel of load to the grain
• Use nails and screws for light loads and timber connectors for large loads
• Wood can carry a greater max load for short duration than for long durations
• Connections can be adjusted given the type/duration of load
• Connections are typically designed for 10 year loading duration, PLUS any of the given factors:
• Permanent Loading beyond 10 years = + 0.90
• Snow Loading (2 month duration) = + 1.15
• 7 day duration = + 1.25
• Wind or earthquake = + 1.60
• Impact loads = + 2.00
• Partially seasoned or wet wood reduces the holding power of the connectors
• The environment where the connection will be used (wet/dry/etc) will affect the connector
• Any condition other than always dry or always wet will reduce the holding power
• Treated wood doesn't hold connectors as well as untreated wood
• If the load is other than parallel or perpendicular to the grain, the compressive stress at an angle must be calculated to determine the connection.
• **Nails:** weakest connection, but also most common
• Identified by **penny size (d),** the price for 100 nails in 15th century England...the larger the nail, the higher cost per 100.

• 2d = 1”, 6d = 2”, 10d = 3”, 20d = 4”, 40d = 5”, 60d = 6”
• Box nails: 6d - 40d, smallest diameter
• Wire nails: 6d to 60d, medium diameter
• Wire spikes: 10d - 8.5” with 3/8” diameter, largest diameter
• Nails should be fastened lateral in side grain where the holding power is the greatest
• The design values of shear are equal, regardless of the angle of load to grain
•
Screws: like nails, but best when used laterally in side grain, rather than in withdrawal from side grain
• No withdrawal from end grain
• Lead holes are drilled for insertion of wood screws
• Size depends on species and if strew is in lateral resistance or withdrawal resistance
• Lag Screws/Bolts: like screws threaded with pointed end but with head like a bolt
• Lead holes and screwing fastener into wood with wrench
• Diameters (measured at the non-threaded shank): 1/4” to 1 1/4”
• Lengths: 1” – 12”
• Design values for lateral loading and withdrawal resistance depends on species, angle of load, diameter of lag, thickness of side member, length of screw
• **Bolts:** used for moderate to heavy loading
• Design and spacing is based on thickness of main member and ratio of bolt length in main member to bold diameter number of members joined
• **Split Ring Connectors:** transmit loads between two pieces of wood by placement in precut grooves. Half of the ring is in each section and held together with a bolt
• **Shear plates:** flat plates with a flange extending from the face of the plate with a hold in the middle where a bolt is placed to hold two members
• Good for connections that must be disassembled
• Used for two pieces of wood, or one piece of wood and a steal plate
• Transfer larger loads than bolts/screws alone. Often used in trusses.
• Steel Bolt Connection Types
• **Bearing Type:** resist shear loads on bolts through friction.
• **Slip Critical:** when any slippage cannot happen as it would risk the structure (e.g.: when the joints are subject to fatigue loading, the joints have oversized holes, the entire load is carried by friction)
• Standard round holes are 1/16” larger than the diameter of the bolt
• Slotted holes are used where some adjustment is needed
• The effect of reducing cross sectional area of the members or **net area** must be checked.
• Connection’s shear failure is parallel to the load
• Connection’s tension failure is perpendicular to the load
• Spacing of bolts and edge distance from the last bolt to the edge of the member is critical
• Welding Connections:
• Best for moment connections
• Often used with bolting as members have to be held in place until welding is finished

- Single plate can be welded to a column and connected with beams
- Used over bolts because gross cross section of member can be used instead of net section
- Construction is more efficient with no angles/blots/washers to use
- **Electrical Arc Welding Process:** (most common) one electrode from power source is attached to steel member being joined while other is the welding rod. Heat generated by the arch formed by arc when welding rod is brought close to members and base metal and the end of the electrode melt into the joint and the materials fuse together
- Type of weld depends on configuration of the joint, magnitude and direction of the load, cost, and erection process
- Indicated on drawings by standard symbols either above or below a leader
- Symbol above means the weld is on the opposite side of the leader
- Symbol below means the weld is on the same side as the leader
- Lap, Butt, Tee welds are most common
- Plug/Slot welds are holes cut in one side of the member and the area is filled with the weld
- Throat is the distance from the corner of the connection to the hypotenuse of the weld
-

Concrete Connection Types

- **Rebar Dowels:** reinforcing for the purpose of tying two pours of concrete together instead of transmitting loads
- **Shear Connections:** steel and concrete tied together so forces are transmitted from one to the other via connectors that are welded to the top of beams

Concepts/Goals:
• Bolt material strength is determined by the alloy and processing method.
• Tensile strength (or ultimate strength) is the stress level where the material breaks
• Yield strength is the stress level where the material yields or permanently deforms
• Fasteners should be below the yield stress
• Materials with large difference between the yield and tensile strength are considered ductile, which means they will stretch substantially before breaking
• Underpinning of an existing building's foundation may be required for various reasons
• Original foundation isn't strong or stable enough
• Use of structure has changed
• Properties of soil have changed (due to subsidence) or were misidentified previously
• Construction of nearby structures requires excavation of soil suppuration existing foundations (e.g.: underpinning the neighboring building during your projects construction)
• More economical to work with existing that for new construction
• When designing footings, investigate
• Shear and bending
• Flexural shear/diagonal tension so that footings will not fail in bending when lower surface cracks under flexural loading
• Unit loading so that allowable bearing pressure is not exceeded and differential settlement is eliminated
• Spread footings at like inverted beam (or a column)
• Soil pressures acts as a continuous upward load that is resisted by downward load
• Compression near the top of and tension near the bottom of the column
• A lot of tension requires reinforcement near the bottom of the footing
• After calculating the area of a footing, it's designed for shear, moment, and other loads
• Study the face of wall where bending moment is the greatest
• Study the distance from the face of the wall footing where flexural shear is greatest
• Forces on retaining walls comes from the pressure of the earth being retained, acting in a horizontal direction
• Earth pressure increases proportionally from 0 at the top of the wall to max pressure at the bottom

Processes:

• Truss Analysis Process:

1. Find the reactions like a typical beam design $\Sigma M = 0$; $\Sigma V = 0$; $\Sigma H = 0$
2. Check reactions, and verify Moment = 0
3. Draw free body diagrams (method of joints) for each joint and solve forces starting with the diagram you have the most information for
4. By the time you get to the last joint, the forces should already be figured out from previous free body diagrams and is therefore a "check". If it doesn't = 0 then something is wrong somewhere.

Construction Materials

Vocabulary:

- **Coefficient of Thermal Expansion:** ratio of unit strain to temperature change, a constant, given for each material.
- **Fatigue:** progressive damage that occurs when a material is subject to cyclic loading
- **Creep:** tendency of a material to move slowly or deform permanently under stress
- **Moisture Content:** weight of water in wood as a fraction of the weight of oven-dry wood
- **Hydration:** chemical hardening of concrete
- **Abrams Law:** compressive strength of concrete is inversely proportional to ratio of water to cement
- **Laitance:** an accumulation of fine particles on the surface of fresh concrete due to upward movement of water. Occurs when there's too much water in the mixture. Concrete appears "chalky"

Facts/Rules:

- **Wood Material**
- Moisture content affects shrinkage, weight, strength and withdrawal resistance of nails
- Ideally moisture content of wood should be equal to prevailing humidity to which it will be exposed when installed (though not often possible)
- Dry lumber max moisture content = 19%
- Kiln dry lumber max moisture content = 15%
- Wood shrinks perpendicular to the grain
- Notched beams should be avoided. If they can't (e.g.: have to run pipes) then,
- Notches can't exceed 1/6" the depth and can't be located in the center third of the beam
- Notches at supports can't exceed 1/4" of the beam depth
- **Structural Lumber Grading:**
- Done under standards by the US Dept of Commerce, American Lumber Standards Committee and enforced by regional organizations (e.g.: Western Wood Products Association)
- Load carrying capacity influence by the size/number of knots/spits/defects, direction of grain, specific gravity of wood
- Visually graded lumber is divided into categories based on nominal size.
- Same grade of lumber in a species can have different allowable stresses based on what category it's' in
- **Boards:** 1" - 1.5" thick and 2"+ wide
- **Dimensional Lumber:** 2" - 4" thick and 2"+ wide
- **Timbers:** 5" thick and 5"+ wide
- Further subdivided into five categories based on size classifications
- **Structural light framing:** nominal dimension of 2" - 4" thick and 2" - 4" wide, and divided into separate grades: Select Structural, No. 1, No. 2, and No. 3.
- Select structural is the best in terms of strength (also, most expensive)
- **Light framing:** nominal dimensions of 2" - 4" thick and 2" - 4" wide and is divided into separate grades: construction, standard, and utility
- **Stud:** nominal dimensions of 2" - 4" thick and 2" - 6" wide. There's only one grade
- **Decking:** divided into two grades, select decking and commercial decking
- **Structural Joists and Planks:** nominal dimensions of 2" - 4" thick and 5" or greater width, typically divided into separate grades: select structural, No. 1, No. 2, and No. 3

Steel Material

- Composed primarily of iron with small amounts of carbon and other materials (manganese, silicon, phosphorous, sulfur)
- Medium carbon steel is typical for construction
- more carbon in the steel increases the strength but ductility and weldabilty decreases
- ASTM A572 grade 50 is the most common type of steel used in structures
- Shapes and Sizes of steel shapes
- **Wide Flange Members (H):** width of flange is deeper than standard I-beams and are suitable for columns because the width of the span almost equals the depth of the section, so it has similar rigidity in both directions
- **Wide Flange Sections (W):** nominal depth in inches, weight in lbs/ft
- **American standard I-Beams (S):** flange is more narrow in relation to depth, and unlike wide flanges,
- Actual depth in any group size is also the nominal depth
- Only used for beams
- Heavier sections are made by adding thickness to the flanges on the inside face only
- **American standard Channel Section (C):** "C" shape channel used for frame openings and stair stringers, and a structural member with a flush face
- Not usually used as a beam as it buckles due to the asymmetrical shape
- **Steel Angles (L):** can either have equal on unequal legs, used in pair as members for steel trusses, or miscellaneous bracing
- **Structural Tubing (ST):** rectangular or round pipes, used as light columns, in large trusses, or space frames
- **Structural Tee:** made by cutting a wide flange or wide beam, often used for chords of steel trusses
- **Steel Columns:** support a load based on the area, allowable unit stress, and unbraced length of the column.
- Area and moment of inertial resist buckling
- **Built up Sections:** like wide flanges, but MUCH heavier
- **Open Web Steel Joists:** lightweight, efficient members that allow for ductwork
- Allowable stresses for structural steel are expressed as a % of the minimum specified yield point
- Percentages used are based on the type of stress
- A36 steel = yield point of 36ski
- Goal of steel beam design is to find the lightest, least expensive section that will resist bending and shear forces within the allowable limits.
- Lateral support of beams:
- When load is applied to the top flange in compression, the beam will buckle
- To resist, compression flange needs to be larger or supported laterally by:
- Steel deck welded to the beam
- Top flange embedded in concrete
- Composite construction
-

Concrete Material
• Made up of aggregate, cement, and water (and sometime admixtures)
• **Portland cement:** binding agent in concrete made of lime, silica, iron oxide, and lumina which interacts with water that combines to form paste that binds aggregates together
• **Type I:** standard cement used for general construction
• **Type II:** modified cement where heat of hydration needs to be controlled
• **Type III:** high early strength cement where quick set is required
• **Type IV:** low heat cement for very slow setting, used to avoid damage caused by heat
• **Type V:** sulfate resisting cement, where exposed to water or soil with hight alkaline content
• **Water:** potable water is used to create a paste with cement that "glues" aggregates together
• Too much water decreases concrete strength, it remains in paste and forms force that can't resist compressive forces
• Must use potable water to make sure there's no foreign matter that could interfere with the adhesion
• Water/cement ratio is the most critical factor in determining strength
• Minimum water to cement ratio is .35 - .40 by weight (4 gallons per 94lbm sack of cement)
• **Aggregates:** sand, natural gravel, and stone, as well as recycled aggregates from construction demo
• Account for 70% - 75% of total concrete volume
• Type of aggregates used are determined by the space size/spacing of the form and the rebar
• No larger than 3/4x the smallest distance between bars
• No larger than 1/5 x the smallest dimension of form or 1/3 depth of slab
• Cement is expensive, aggregate isn't...so use a mixture where you can use as much aggregate as possible
• Concrete varies in weight depending on components
• Standard concrete = 150 lb./ft3
• Lightweight structural concrete = 80 - 120 lb./ft3
• Non-structural insulating concrete = 50 - 80 lb./ft3
• Concrete reaches design strength after it cures and hardens for **28 days**
• Typical strength range = 2,000psi - 4,000psi
• Most common strength = 3,000 psi
• Higher strengths = 12,000 psi
• **Admixtures:** chemicals and/or misc materials added to the mixture to speed up hydration, improve workability, add color (either dye or colored stone), etc
• **Accelerators:** speed up hydration of cement to achieve strength faster
• Often used when need to speed up curing time due to cold weather/elements
• **Plasticizers:** reduce the amount of water required while maintaining consistency for placement/compaction. Reducing water makes it possible to mix higher strength concrete
• **Retarders:** slow down setting time to reduce heat of hydration

- **Waterproofing:** decrease the permeability of concrete
- **Fly ash:** waste material obtained from coal fired power plants, increases strength, decreases permeability, reduces temperature rise, improves workability

• **Reinforcing Steel (Rebar) Material**
• Used as a tensioning device in reinforced concrete/masonry structures
• Job is to hold concrete in compression
• Formed from carbon steel and given ridges for better anchoring into the concrete
• Deformed to provide a mechanical interlocking of rebar and concrete
• Three forms of reinforcing steel:
• **Bars:** used for standard cast in place concrete
• **Wire or strands:** used for pre-stressing and post tensioning
• **Welded wire fabric:** used for slab reinforcement
• Rebar diameter size ranges from 3/8" - 2 1/4" at 1/8" increments
• rebar ID number is based on the diameter. #3 = 3/8", #4 = 4/8", #8 = 8/8 (or 1"), and so on…
• Rebar grade is equal to the minimum yield strength of the bar in KSI
• 60 rebar (most common) = minimum yield strength of 60 ksi
• 40, 60, and 75 are typically manufactured
• Rebar should be located at a minimum distance from the exposed face of the concrete. It needs to be as close to the edge as possible to work as a tensioning device, but it stil has to be protected from the site/elements
• Slabs and walls = 3/4" distance from face of conc
• Beams and columns = 1 1/2" distance from face of conc
• Exposed to weather or in contact with soil = 1 1/2" distance from face of conc
• Exposed to weather or in contact w/soil
(larger than No. 5 rebar) = 2" distance from face of conc
• Concrete poured direction on soil = 3" distance from face of conc
• Pre-tensioning Steel is stranded cables draped in forms and jacked by tension forces
• Concrete is poured and allowed to cure, then cables are cut and compressive force is transferred to the concrete
• Pos-tensioning Steel: hollow sleeves/conduits are placed in forms on site and steel tendons are run through it.
• Concrete is poured around it, and tendons are stressed with on-site hydraulic jacks after the concrete has cured
• Welded Wire Fabric is pieces of w or rebar welded together to form a grid pattern and used to minimize shrinkage cracking in the surface of the concrete
• Typically a square 4" x 4" up to 8" x 8"
• Rebar Chairs: are metal wire devices placed on a form to hold the rebar above the bottom at the required distance.
• Concrete hardens and gets its strength by curing though the chemical reaction between water and cement NOT THROUGH DRYING!!
• Must have proper moisture/temperature condition for **7 days** minimum for proper curing
• Can be up to 2 weeks for critical work
• If concrete cures too fast, it can loose around 30% of its strength
• If concrete is too cold/freezes it can loose around 50% of its strength
• Final 28 day design strength depends on the initial curing conditions
• Concrete must beg placed to avoid segregation (separation of aggregates/water/sand from each other)
• Typically happens when concrete is "dropped" from high distances (eg: concrete

pumper hose too high) or if there’s excessive lateral movement
• Maximum drop is 5’-0”
• After placement, compact concrete so that it gets into all the nooks and corners, as well as totally in contact with the rebar.

Concepts/Goals:

- Wood Construction Requirements
- Bottom of wood joists must be at least 18” above exposed ground
- Bottom of wood girders must be at least 12” above ground (unless treated or made of a species with a natural resistance to decay)
- End of wood girders entering masonry/concrete walls must be provided with a 1/2” air space on top/sides/end unless wood is of natural resistance to decay or treated
- Foundation plates and sills must be treated or made of foundation redwood
- Under floor areas (crawl spaces) must be ventilated with openings having a net area of not less than 1sf for each 150sf of under floor area and the must be place to provide cross ventilation
- Wood used for construction of permanent structures located nearer than 6” to earth must be treated or wood of natural resistance to decay
- All wood used as structural members must be protected from exposure to the weather and water with approved protection

- Steel Construction Requirements
- Roofs without sufficient slope for drainage must ensure stability under ponding conditions
- Horizontal framing members be designed for deflection criteria and ponding requirements
- Trusses longer than 80’-0” can be cambered for the dead load deflection

• Concrete Construction Requirements
• Construction loads cannot be supported or any shoring removed until concrete has sufficient strength to safely support its weight and loads placed on it
• There are limitations on amount and placement of conduits and other pipes embedded in concrete so as to not decrease the load resisting area.
• Aluminum conduits cannot be embedded unless effectively coated to cover to prevent aluminum-concrete reaction or electrolytic action between steel and aluminum
• Pipes carrying fluids or gasses must be pressure tested prior to placement of concrete
• The size and bending of reinforcement are clear to ensure that a sufficient bond is developed between the concrete and steel and that all reinforcement acts together
• **Water**
• Load developed from water is equal to the unit weight of the fluid in pounds per cubic foot multiplied by its depth
• Water weighs approx 62lbf/ft3
Processes:

Soil

Soil: A mixture of rock particles, minerals, decayed organic materials (humus), water and air. Soils are different due to variation in compositions. Soil layer covers regolith layer or loose rocks then the earth crust.

Gravel:	well drained and able to bear loads (+2 mm)
Sand:	well drained and can serve as foundation when graded (0.5 - 2 mm)
Silt:	stable when dry, swells when frozen, do not use when wet (.002 - .05 mm)
Clay:	must be removed, too stiff when dry and too plastic when wet (< .002 mm)

Levels of Soil:
A Level= Topsoil (organic/mineral material); Top layer: tiny rocks, humus, dark color, spongy, holds more water
B Level= Minerals; High iron and clay, minerals through rain travel to this
C Level= Partially weathered/fractured rock
D Level= Bedrock

Alluvium: soil, sand or mud deposited by flowing water
Humus: soft dark soil containing decomposed organic matter, poor bearing capacity
Loam: rich soil containing equal parts of sand, silt, and clay

Soil of the World:
Forest, prairie, Desert, Polar, Mountain, Grassland, Tropical

Forest:
Soil in Forest are not fertile
Very Acidic: Leaves such as pine needle, twigs
Heavy Rain leaches minerals into lower layers (Horizon B)
Top soil is thin
Trees have deep roots for food

Prairie
prairie soils are fertile
Less rain therefore less leaching
Top soil is deep
High Humus
Without plant covering the soil becomes dry and wind blows away
When no top soil nothing grows

Desert:
Very Fertile
less humus

sparse of top soil with high minerals
irrigation: Crops grow
After two years of irrigation, top soi is too salty to grow

Polar:
Horizon B only.
Perma frost (Permanently frozen)
Tudra areas
Soil is black
water logged
no evaporation or drainage
short seasons
Plants are small
little to decay to make humus

Mountain
Depends on the side of the mountain
Rainy side-
    Lots of Humus
    Top soils to support trees and shrubs
Little grows on the other side
In tropical zone: More top soil if further away from equator

Grassland
High calcium- Whitish color
Not enough rain to leach
Humus rich and deep
grow wheat and rye
Fertile for grazing

Tropical
Variety of animals and plants
Fragile soil: Rainfall leaches all minerals
Only Aluminum oxides ($Al2O3$) and clay to remain
Rusty red color
No accumulation of top soil due to use of humus from dead plants and animals
If no trees, all surfaces would be clay and after the rain, the surface becomes clay rock

Determine Potential Land Problems
(1) Water within 6'-0" of land surface: pump out excavation, waterproof basement, resist hydrostatic pressure (continuous drain pipe installed at foundation)
(2) Rock at/near surface of site: use explosives to reduce manual labor
(3) Soil is soft clay, water bearing sand or silt: construct deeper foundations or drive piles, remove poor soil
(4) Underground streams: avoid and be cautious of siting of structure
(5) Cut and Fill: balance it. There shouldn't be more taken away than added or vice versa

Complete Soil Testing					
Bearing Capacity:		max pressure a foundation soil can take with harmful settlement			
		Bedrock=		10,000 psf	
		Well graded gravel/sand =		3,000 - 12,000 psf	
		Compacted sand/fill =		2,000 - 3,000 psf	
		Silt/Clay =		1,000 - 4,000 psf	
Borings:		locations depend on nature of the building and should be 20'-0" past firm strata			
		Open warehouses:		one in each corner and one in the middle	
		Large structures:		50'-0" spacing	
		Uniform conditions:		100 - 500' spacing	
Wash boring:		the drilling of a test hold to locate bedrock beneath very compact soil. A pipe is driven into the soil while water forces the material to the surface. It can penetrate all materials other than rock.			
Auger boring:		soil testing that uses an auger drill big fastened to a rod to bring the soil to the surface. Most efficient in sand and clay because the bit is easily obstructed. It has limited depth			
Core boring:		an intact cylindrical sample is extracted by drilling through all types of soil including bedrock. Very reliable and expensive			
Test pit:		an excavation of an open pit that allows for a visual examination of the existing conditions as well as the ability to take intact samples for further testing.			

		Can determine the depth of the water table.			

Testing Concrete:	
Slump Test:	measures the workability of fresh concrete/ the consistency of the concrete in that specific batch and done on the jobsite • Concrete is poured in a cone mold that is 12” tall with 8” diameter at the bottom and 4” diameter at the top is made • The mold is removed and the concrete is allowed to slump naturally, due to the effects of gravity • The amount the sample “slumps” is measured. (Good = 1” and Bad = 6”) • If it slumps too much, then there’s too much water in the mix, if it doesn’t slump very much, then it will be difficult to work with • It’s a simple test, but that means there’s a wide variability in the manner in which it’s performed.
Cylinder Test:	Measures the compressive strength in PSI of concrete and done in a lab • Results are compared to the concrete design values and tested at 7 day intervals

Core Cylinder Test:	Like a cylinder test, but the portion of the concrete is already in place. A core is drilled and taken to a lab (expensive!!!)
Ke**lly Ball Test:**	a half-spherical steel ball is dropped onto a slab of concrete to measure its consistency • The amount it penetrates into the concrete is measured and compared to the half values of the slump test (a 1” penetration of the kelly ball = 2” of slump)
Impact Hammer Test:	a spring loaded plunger is snapped against a concrete surface and the rebound is measured

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Government and Regulatory Requirements and Permit Processes

Vocabulary:

- **Fire Code:** set of standards established and enforced for fire prevention and safety incase of fire. Addresses fire prevention and building construction features/ratings
- **Life Safety Code (NFPA 101):** consensus standard widely adopted (but NOT a legal code) that addresses construction, protection, and occupancy feature necessary to minimize danger to life from, including smoke, fumes, or panic.

Equations:

• Reduced design live load per sf of area supported by the member (L) = Design live load in Table 1607.1 (LO) x (0.25 x 15/√Live Load element factor in Table 1607.9.1(KLL) x Tributary area in sf (AT)

$L = Lo \times (0.25 + 15/\sqrt{KLLAT})$

Facts/Rules:
• The building code (in general) is the set of provisions that must be used when designing a structure. It addresses:
• How loads must be determined
• What stresses are allowed in structural members
• Formulas for designing structural members out of various materials
• The **International Building Code: Chapter 16** contains the necessary information
• Essentially, if followed, the code ensures that a path has been provided for all forces and loads from their point of origin to the load resist elements chosen.
• Designing a structural system requires the distribution of:
• Horizontal Shear
• Horizontal torsional moments
• Stability against overturning
• Anchorage, or resisting uplift/sliding forces of a structure
• Buildings must be designed to resist the most critical structural situation
• Structural systems and members shall be designed to have adequate stiffness to limit deflections and lateral drift
• The total lateral force shall be distributed to various vertical elements of the lateral force resisting system in proportion to their rigidities
• Consider the rigidity of the horizontal bracing system or diaphragm
• Rigid elements that aren't a part of lateral force resisting system are allowed to be incorporated into buildings so long as their effect on the structure is taken into consideration
• Occupancy Categories of Building and other Structures (Table 1604.5)
• Category I: buildings/structures that represent a low hazard to human life in the even of failure (eg: agriculture facilities, minor storage)
• Category II: buildings/structures that aren't in category I, III, or IV
• Category III: buildings/surfaces that represent substantial hazard to human life in the event of failure (e.g.: schools, jails, anything with occupancy greater than 5,000, healthcare facilities with more than 50 occupants but no surgery/ED)
• Category IV: buildings/structures designated as essential (e.g.: hospitals with ED/surgeries, fire/police/rescue stations/garages, emergency shelters, defense, air traffic control)
• Dead Loads (Section 1606):
• The actual weights of materials of constructions and equipment will be used
• If no weight information is available, values are subject to the approval of the building official
• Live Loads (Section 1607):
• Live loads used in the design of buildings and other structures will be the maximum loads expected by the intended use/occupancy OR the the minimum uniformly distributed unit loads required, whichever is greater
• Where partitions are likely to change (such as office buildings) partition weight will be made
• Handrail/guard assemblies will resist a load of 50 pal applied ina ny direction at the top and to transfer this load through the supports to the structure
• Grab bars/shower seats/dressing room bench systems will resist a single

concentrated old of 250 lobs applied in any direction at any point.
• Live loads include allowance for impact considerations. Unusual impact forces or vibrations should have additional structural design
• Minimum Uniformly Distributed/Concentrated Live Loads (Table 1607.1)
• *Note: this is a given resource on the exam...no need to memorize, just understand*
• Gives the required floor live loads in psf (for uniform loads) or lbs (for concentrated loads) for different occupancy types or uses
• (e.g.: Heavy Manufacturing occupancy requires a uniform live load of 250 psf, OR a concentrated live load of 3,000 lbs)
• The type of load you use depends on what the question is asking
• Except for roof uniform live loads, all other minimum uniformly distributed live loads in table 1607.1 are permitted to be reduced
• May not be reduced for any public assembly occupancy with live
_ _ loads ≤ 100 psf
• May not be reduced for any member supporting 1 floor of a parking garage
• Floors must also accommodate concentrated loads
• If a concentrated load acting on any area that’s 2’-6” x 2’-6”, the stresses would be greater than the uniform load of the area and would therefore fail.
• Live loads for each floor of commercial or industrial buildings must be conspicuously posted

- **National Design Specification for Wood Construction**
- Allowable stresses for units in structural lumber and gluelam timber
- Allowable stresses for extreme fiber in bending
- Tension is parallel to the grain
- Horizontal shear
- Compression is perpendicular and parallel to the grain

- **Allowable Stresses for Structural Steel**
- Expressed as a fraction of the yield stress of the steel and varies with the type of stress the member is under (be it shear, compression, bending, tension) and with the unsupported lengths and geometry of the section
- Code requirement for allowable stresses:
- Tension on the gross area **Ft = 0.6Fy**
- Tension on the net effect area **Ft = 0.5Fu**
- Shear on gross sections **Fv = 0.4Fy**
- Allowable stresses for bolts, rivets, etc are based on the type of load paced on them and given in in KSI
- Allowable stresses for welds are based on yield strength of the base metal or the nominal tensile strength of the weld metal

• **Allowable Concrete Construction**
• International Building Code Chapter 19 references the code requirements for reinforced concrete
• Concrete construction is based on the specified compressive strength F’c given in PSI
• Samples for strength tests must be taken for each class of concrete used
• Taken once per day
• Taken for each 150yd3
• Taken for each 5,000 sf of surface area of slab/wall
• The average of all sets of three 3 consecutive strength tests be ≥ f’c
• No individual test can be 500 psi below f’cn
Processes:
• Per Fire Code:
• Fire stops are required in walls at the ceiling and floor levels and at 10’-0” intervals both vertical and horizontal
• Fire stops are required at interconnections between concealed vertical and horizontal spaces such as soffits and dropped ceilings
• Fire stops are required in concealed spaces in stairway construction and in vertical openings between floors and the roof that could afford a passage for fire

CONTENT AREA: SEISMIC FORCES

Building Design

Vocabulary:

• **Acceleration** - Rate of change of velocity with time.
• **Aftershock** - An earthquake, usually a member of an aftershock series often
• within the span of several months following the occurrence of a large earthquake (main shock). The magnitude of an aftershock is usually smaller than the main shock.
• **Amplification** - A relative increase in ground motion between one type of soil and another, or an increase in building response as a result of resonance.
• **Amplitude** - Maximum deviation from mean of the center line of a wave.
• **Base Isolation** - A method whereby a building superstructure is detached from its foundation in order to change the characteristics of earthquake forces transmitted to the building.
• **Base Shear** - Calculated total shear force acting at the base of a structure, used in codes as a static representation of lateral earthquake forces. Also referred to as "equivalent lateral force."
• **Bracketed duration:** the time between the first and last peaks of motion that exceeds a threshold acceleration value of 0.05g
• **Velocity** refers to the rate of motion of the seismic waves as they travel through the earth in inches per second. It's VERY fast… the **P-Wave** travels at 7,000 – 18,000 mph, the **S-Wave** travels at 4,500 – 11,000 mph
• **Displacement:** the distance that points on the ground are moved from their initial locations by the seismic waves, measured in inches.
• **Fundamental Period:** the rate at which an object will move back and forth if they are given a horizontal push
• **Period:** the time (in seconds) that is needed to complete one cycle of a seismic wave
• Frequency: the inverse of period, or the number of cycles that will occur in 1 second measured in **Hertz.**
• **Hertz:** a measurement of frequency, 1 Hertz = 1 cycle per second.
• **Structural Configuration** - The size, shape and arrangement of the vertical load carrying and lateral force resistant components of a building.
• **Drift** - Vertical deflection of a building or structure caused by lateral forces.

Equations:
• Force (F) = Mass (M) x Acceleration (A)_ _ _ **F = MA**
• Mass is equivalent to the weight of the building at ground level
• Acceleration measured in terms of acceleration due to gravity (1g = 32 ft per second per second)
Facts/Rules:
• The human body can feel accelerations as small as 0.001g, (free fall is 1g)
• Poorly constructed buildings begin to suffer damage at 0.1g
• Moderate earthquakes acceleration is approximately 0.2g
Concepts/Goals:
• **FEMA 454: Designing For Earthquakes Chapter 4/Earthquake Effects on Buildings**
• Seismic body and surface waves create inertial forces within a building
• Inertial forces are created within an object when an outside force tries to make it move it's at rest or change its rate/direction of motion if its moving
• Light buildings (e.g. wood framed houses) tend to perform better in earthquakes than large heavy ones because the smaller mass means less force. (F = MA)
• Acceleration is a key factor in determining the forces on a building
• A more significant measure is that of acceleration combined with duration which takes into account forces over time.
• Typically a number of cycles of moderate acceleration over time can be more difficult to withstand than a single larger peak.
• Continued shaking weakens a building structure and reduces its resistance to earthquake damage
• The velocity of motion on the ground caused by seismic waves is quite slow (remember, huge chunks of rock and earth are getting moved around) so typically building motion is slow and the distances are small, even thought thousands of tons of steel and concrete are jolted in all directions several times per second
• Earthquake shaking is initiated by a fault slippage in the underlying rock
• As the shaking moves to the surface, it might be amplified, but that depends on the intensity of the shaking, the nature of the rock, and (most importantly) the type/depth of surface soil
• Soft soil (few ft – 100 ft deep) have an amplification factor of 1.5 - 6 over rock shaking
• Earthquake damage tends to be more severe in areas of soft ground
• Seismic codes have very specific requirements that relate to the characteristics of the site, including designing for higher force levels and specific foundations on poor soil
• Determining earthquake waves' period, or frequency, (eg: waves that are quick and abrupt or slow and rolling) is important for determining building seismic forces.
• All objects have a natural or fundamental period
• Natural periods vary depending on the height of the object. (Building period = number of stories / 10)
Filing Cabinet_ =_ 0.05 sec nat. period =_ 1/0.05 frequency =_ 20 Hertz
1 Story Bldg_ =_ 0.1 sec nat. period =_ _ 1/0.1 frequency =_ 10 Hertz
4 Story Bldg_ =_ 0.5 sec nat. period = _ _ 1/0.5 frequency =_ 2 Hertz
20 Story Bldg=_ 2.0 sec nat. period = _ 1/2 frequency =_ .5 Hertz
60 Story Bldg=_ 7.0 sec nat. period = _ 1/7 frequency = _ .14 Hertz

• Other factors (eg: structural system, materials, contents, geometric proportions) also affect the period, but height is the most important
• Building period may also be changed by earthquake damage.
• **Buildings At Risk Seismic Design Basics for Practicing Architects**
• Seismic is not confined to the west coast region. Happened in South Carolina and Missouri, with aftershocks felt between the Rocky Mts and Boston/Washington DC
• Architects are seen as playing a critical role in seismic design

- Chapter 1: Nature of Ground Motion
    - Earth's crust is divided into several major plates
- Earthquakes are initiated when (due to slowly accumulated pressure) the ground slips along a fault plane on/near a plate boundary
- Waves of vibration in the earth create ground motion on the earth
- Epicenter occurs on surface directly above the focus point or fault rupture.
- Surface faulting is the crack/split on the surface that is the layperson's vision of earthquakes
- We design against the vibrations caused by fault slippage and try to ensure that building are not built over fault zones
- Earthquakes also trigger failure in the form of landslides, liquefaction, and subsidence
- Avoiding sites with a potential for liquefaction, landslides or subsidence requirements the best design approach
- Ground shaking triggers subsidence/liquefaction in soils that are unconsolidated/ saturated with water
- Shaken sandy, water saturated soils cause the bearing capacity to reduce as it liquefies and flows both laterally and vertically
- Well built structures are vulnerable if site conditions/foundation design are ignored
- Most common cause of earthquake damage is ground shaking
    - Affects the building in three ways: internal forces, period/resonance, and torsion
- Shaking causes damage by internally generated internal forces that come from the vibration of the building's mass
- Increase in mass (or the weight of the building) will result in an increase in the force for a given execration
- That's why lightweight construction is good!!
- Failure of vertical elements like columns or walls can occur by buckling, when mass pushed down due to gravity experts its force on a member bent or moved out of plumb
- All objects have a natural/fundamental period...the rate at which they will vibrate if they are given a horizontal push
- Natural period for a building varies from 0.05 to 2 seconds ish
    - Stiffness of construction materials and geometric proportions affect the period
- Height is the most important consideration when dealing with period
- Natural ground period is 0.4 seconds to 1.5 seconds
- This is within the grange of common building periods
- It's possible the motion the ground transmits to the building will be at its natural period
- Amplification in building vibration is undesirable… so try to ensure that the building period won't coincide with the ground
        - A shot stiff building with short period isn't appropriate on a soft site with a long period
- Earthquake shaking tends to be greater on soft ground than on hard ground
- Earthquakes are more sever in areas of soft ground
- Response spectrum: shows the accelerations that may be expected at varying periods

• Base isolation is based on shifting the building period towards the long period of the spectrum where the response is reduced
• Locations closer to the fault from where the energy is release will experience higher frequency/shorter period ground motion
• The farther the building is from the earthquake touch may be subjected to considerable long-period motion
• The center of mass, or center of gravity of an object is the point at which it could be exactly balance without any rotation resulting
• Uniformly distributed mass results in the coincidence of a plan’s geometric center with the center of mass
• If the mass within a floor is uniformly distributed, then the resultant force of the horizontal acceleration of all its particles of mass is exerted through the floor’s center
• If the resultant of the resistance (walls or frames) pushes back through tis point, balance remains
• Torsion is a twisting action on a building...very undesirable

• Three basic characteristics of buildings help resist and dissipate the effects of seismically induced motion: damping, ductility, and straight/stiffness

Damping affects:
the dynamic behavior of the building and modifies its response to ground motion. When damped, buildings are inefficient in their vibration and when set in
motion, return to their starting position quickly.

Ductility
the property of certain materials, typically steel, to fail only after considerable inelastic (permanent) deformation occurs; Good ductility requires special detailing of joints
•
Strength and stiffness
are two of the most important characteristic of any structure. Analysis of forces is not precise and deliberately errs on the conservative side. Deflection is a measure of stiffness…In the sizing of floor joists, deflection rather than strength governs because no one wants a bouncy floor...even though it’s safe
• Resisting a given load without exceeding a safe stress in the material is a strength problem
• In the design of a floor system, the joists might tolerate a certain deflection but the ceiling finish cannot.
• Relative rigidities of members are a concern of seismic analyst
• As soon as a rigid horizontal element or diaphragm is tied to vertical resisting elements, it will force those elements to deflect the same amount

- Chapter 2: Site Issues
- Seismic design isn't limited to the actually project site, but the to a broad environmental analysis of regional and community vulnerability
- Factors that impact site vulnerability include proximate to active earthly faults, susceptibility of the site to ground shaking, the potential for ground failure (subsidence, spreading, liquefaction landslides) adjacent structures and land uses
- If a structure is built over an active fault trace is should be designed to accommodate displacement or fault offset
- In many areas development is limited/prohibited within defined zones adjacent to active faults
- Geology of a region plays a significant role in determining the potential for shaking and ground failure damage
- Understanding the regional and local geology can tell the designer a great deal about the relative risk of an individual site
- Damage to lifeline systems (water, sewer, power, transport, communication) can isolate a structure and cease its ability to operate, even if the structure is ok
- Only occasionally is the architect responsible for site selection… most of the time the client provides it, unaware of the risks and vulnerability
- Site analysis should include an assessment of the environment beyond the property line and include adjacent structures and site conditions that could "spill over" onto the site

Building Systems and their Integration

Vocabulary:

• **Bearing Wall:** A wall providing support for vertical loads; it may be interior or exterior.
• **Nonbearing Wall (Partition):** A wall that does not provide support for vertical loads other than its own weight as permitted by the building code. It may be interior or exterior.
• **Shear Wall:** A wall, bearing or nonbearing, designed to resist seismic forces acting in the plane of the wall.
• **Bearing Wall System:** A structural system with bearing walls providing support for all or major portions of the vertical loads. Seismic resistance may be provided by shear walls or braced frames.
• **Braced Frame:** One which is dependent upon diagonal braces for stability and capacity to resist lateral forces. In concentric braced frames, diagonal braces are arranged concentric to column/beam joints; in eccentric braced frames, they are eccentric.
• **Moment Frame:** A space frame in which members and joints are capable of resisting lateral forces by bending as well as along the axis of the members. Varying levels of resistance are provided by Ordinary, Intermediate and Special Moment Frames as defined in the NEHRP Provisions with Special Frames providing the most resistance.
• **Space Frame:** A structural system composed of interconnected members, other than bearing walls, that is capable of supporting vertical loads and that may also provide resistance to seismic forces.

Concepts/Goals:
• Moment resisting frames provide the most architectural design freedom
• Chapter 3: Building Configuration
• Building configuration is used in seismic design to define the architectural form
• Configuration: building size and shape, the size and location of structural elements, and the nature, size and location of non structural elements that may affect structural performance (e.g.: heavy non structural walls, heavy equipment)
• Building configuration primarily determines the way forces are distributed throughout the structure and the relative magnitude of those forces
• Seismic codes distinguish between regular and irregular configurations and it is the latter that may have a detrimental influence on the effectiveness and cost of seismic engineering and the seismic performance itself.
• Regular/uniform configurations that are seismically optimal are:
Shear walls
Moment resistant frames
Braced frames
• Because they have:
Low height to base ratio
Equal floor heights
Symmetrical plan
Uniform section and elevations
Maximum torsional resistance
Balanced resistance
Short spans/redundancy
• Direct load paths
• Buildings with circular plans form are even better because of their total symmetry, but are structurally more complex, and not very useful in urban design
• Very large forces may build up in diaphragms that must be resisted by shear walls of frames. While ideally seismically, it can present deficit internal planning
• Irregular configuration occur when the building deviates from a simple regular symmetrical form in plan and sections. Causes problem in torsion and stress concentration
• Torsional problems are most typically associated with plan irregularity or geometers
• Stress concentrations occur when an undue proportion of the overall seismic force is concentrated at one or few location in the building...like at a set of beams or columns
• Many buildings fail because of the lack of balanced resistance which results in stress being placed on the member, which consequently over stresses of fails the system
• Irregularity in shape often occurs for sound planning or urban design...not necessarily because of whim.
• Essentially, the seismic design problem is too complex to be dealt with by code rules...it must be left to engineering.

• Soft First Stories
• Ground level story has adequate strength but is less stiff than those above
• Structures with weak stories are limited to two stories or 30’ height
• A building’s deflection under horizontal forces being distributed equally among the upper floors it’s accommodated almost entirely in the first floor
• Avoid the soft story through design...if not possible, then add columns or bracing
• Discontinuous Shear Walls
• When shear walls form the main lateral resisting elements of the building, they may be required to resist very high lateral forces.
• If these walls do not line up in plan from one floor to the next, the forces cannot flow directly down through the walls from roof to foundation, and the consequent indirect load path can result in serious overstressing at the points of discontinuity
• A discontinuity in vertical stiffness and strength leads to a concentration of stresses and ultimately to damage and collapse, and the story which must hold up the remaining stories in a building should be the last, rather than the first, component to be sacrificed
• Variations in Perimeter Strength and Stiffness
• A building's seismic behavior is strongly influenced by the nature of the perimeter design.
• If there is wide variation in strength and stiffness around the perimeter, the center of mass will not coincide with the center of resistance, and torsional forces will tend to cause the building to rotate around the center of resistance
• Design a frame structure of approximately equal strength and stiffness for the entire perimeter
• Increase the stiffness of open facades by adding shear walls at/near the open face
• Use a very strong moment resistant or braced frame at the open front
• Design a stiff diaphragm to transfer forces abc into a resisting structural systems
• Reentrant corner is the common characteristic of building forms that assume the shape of an L, T, H, etc
• These shapes tend to produce variations of rigidity and hence differential motions between different portions of the building, resulting in a local stress concentration at the reentrant corner
• Torsion is caused because the center of mass and the center of rigidity cannot geometrically coincide
• The stress concentration at the "notch" and the torsional effects are interrelated. The magnitude of the forces and the seriousness of the problem will depend on:
• the mass of the building,
• the structural system,
• the length of the wings and their aspect ratios, and
• the height of the wings and their height/depth ratios

• Configuration problems originate in the schematic design of a building
• Chapter 4: Seismically Resistance Structural Systems:
• Structural engineers typically equate design capacity with loads imposed on it (live loads, wind loads, etc.)
• Appropriate safety factors ensure that materials never exceed the elastic range of behavior
• Diaphragms
• Horizontal resistance elements (floors/roofs) transfer lateral force between vertical resistance elements
• Size and location of penetration is critical to the effectiveness of the diaphragm
• Shear Walls
• Vertical cantilever walls designed to receive lateral forces from diaphragms and transmit them to the ground
• Size and location is very important
• Braced Frames:
• Act like shear walls but may be of lower resistance and stiffness depending on design
• Vibrating forces may cause bracing to elongate or compress...and then it loses its effectiveness and permits large deformations or collapse
• Can be designed in a variety of systems
• Moment Resistant Frames
• Lateral forces are resisted by rotations of the beam/column joints
• Induces shear and bending forces in the frame members
• Joints become highly stressed and design and construction becomes critical
• Most are steel structures with stiff welded joints in which the natural ductility of the material is of advantage
• Use of moment frames obviates the need for shear walls or braced frames and the tend to be much more flexible than shear walls type structures
• Eccentric bracing combines the ductility of the moment frame with the rigidity or drift control of the conventional brace
• Dual moment frame/shear wall combines ductility with rigidity
• Progressive Resistance Systems combine 2 or 3 systems that progress in loadcarrying capacity from rigidity to ductility at predetermined load levels
• Base isolation, in which the superstructure of the building is partially isolated from ground by motion and use of bearings
• Selecting a structural system in a highly seismic area is a complex task
• The factors that must be considered when selecting a system are:
• Anticipated level of earthquake ground motion
• Site geology and its impact on the structure
• Building occupancy and impact on building form and structural system
• Building configuration which may be arbitrary or dictated by site, zoning, program
• Structural system relative to the configuration
• Structural details
• Non structural components (Cladding, ceilings, partitions, etc.) in relation to the primary structure
• Construction quality and its impact on structural continuity

- Seismic requirements in code are intended only to assure life safety
- Only the primary structure must be protected to prevent collapse

Implications of Design Decisions

Vocabulary:

- **Triggers:** events or actions that require seismic retrofit

Concepts/Goals:

• Chapter 6: Nonstructural Damage:
• Nonstructural components are those that aren’t part of the structural system
• Nonstructural damage is the cause of much economic loss and its repair may leave building unusable for weeks
• Four types of safety hazards presented by nonstructural components are:
• Direct hazard - the possibility of casualties because of broken glass, light fixtures, appendages, etc.,
• Loss of critical function - casualties caused by loss of power to hospital life support systems in bed panels, or functional loss to fire, police or emergency service facilities,
• Release of hazardous materials - casualties caused by release of toxic chemicals, drugs, or radioactive materials and,
• Fire caused by nonstructural damage - damage to gas lines, electrical disruption, etc.
• Economic loss refers to the direct cost of repairing nonstructural damage
• Nonstructural elements may modify the designed structural response in ways detrimental to the safety of the building
• Nonstructural damage is due to acceleration or replacement
• Chapter 8: Seismic Design Process
• Overall responsibility for seismic design is shared between architect and structural engineer
• Damage free seismic design can’t be guaranteed
• Higher level of seismic design can be done..but at a higher construction cost
• Chapter 9: The Planning Process:
• City/regional planning policies play a significant role providing for the growth, development, governance, and maintenance of communities.
• The key decision maker for providing seismic safety to communities is the local government
• Comprehensive Planning includes nearly every topic related to public safety, social equality and environmental quality.
• Primary concern to public safety is damage or collapse of older structure built during a period when seismic code didn’t exist or were inadequate to resist earthquake forces

Construction Details and Constructability

Vocabulary:

- **Nonstructural:** systems and components that are part of a building that don’t like in the primary load bearing path of the building

Facts/Rules:
• Non Structural Components have historically received little attention from designers regarding seismic performance. The following are typically included in that set:
• Interior nonstructural walls and partitions
• Cantilever elements
• Parapets
• Chimneys
• Exterior nonstructural wall elements and connections
• Light wall elements (metal insulated panels)
• Heavy wall elements (precast concrete)
• Body of panel connections
• Fasteners of the connecting systems
• Veneer
• Limited deformability elements
• Low deformability elements
• Penthouse (separate from main building structure)
• Ceilings
• Suspended
• Attached to rigid sub-frame
• Cabinets
• Storage cabinets and laboratory equipment
• Access floors
• Appendages and ornamentation
• Signs and billboards
• Other rigid components
• Other flexible components
• General mechanical
• Boilers and furnaces
• Pressure vessels freestanding and on skirts
• Stacks
• Large cantilevered chimneys
• Manufacturing and process machinery
• General
• Conveyors (nonpersonnel)
• Piping system
• High deformability elements and attachments
• Limited deformability elements and attachments
• Low deformability elements and attachments
• HVAC system equipment
• Vibration isolated
• Nonvibration isolated
• Mounted in-line with ductwork
• Elevator components
• Escalator components
• Trussed towers (freestanding or guyed)
• General electrical

• Distributed systems (bus ducts, conduit, cable trays)
• Equipment
• Lighting fixtures
• Surface mounted to structure
• Suspended from structure
• Supported by suspended ceiling grid, surface mounted, or hung from suspended ceiling
• Construction details for appropriate seismic design of nonstructural elements
• Suspended ceilings are braced by wires or rigid members no more than 144 square feet
• Lighting fixtures must be supported independently, so if the lay-in ceiling falls, the light won't
• Heavy partitions like CMU should be separated from surrounding structure to avoid local stiffing and to avoid transmitting racking forces to the wall
• Metal studs that terminate at a lay-in ceiling should e braced independently (kickers) to the building structure
• Heavy parapets should be braced back to the roof structure
• Sheet metal ductwork should be anchored and hung with threaded rods
• Vibration isolated equipment is fitted with "snubbers" that limit lateral motion to prevent the equipment toppling off the isolators and suffering damage
• Emergency power equipment needs a positive restraint
• Tall shelving need longitudinal bracing and attachment to the floor
• Gas water heaters need restraint to prevent it from toppling over and breaking the gas connection
Concepts/Goals:
• Chapter 7: Seismic Rehabilitation of Existing Buildings:
• Seismic criteria for new buildings is generally inappropriate for use with old buildings
• It's either too expensive or unworkable
• Primary goal of seismic rehabilitation is to provide for life safety by minimizing the collapse exposure
• Unreinforced masonry bearing wall building with poorly tied floor and roof framing lack integrity and stability and usually fail by wall collapse in out of plane motion
• Non ductile concrete frames are subject to sudden shear failure of the weak unconfined columns
• Steel diagonally braced structures can suffer non ductile fractures of the braces or connections
• Adding strength alone is not enough to ensure seismic stability
• Base isolation is becoming common for rehabilitation of historic structures
Processes:
• Dynamic structural analysis: Tall buildings with complex shapes or unusual conditions a computer
• model is used to study what forces are developed
-Most cases building codes allow a static analysis of the loads
• Static analysis method: total horizontal shear at base is calculated according to standard formula
-Total lateral force is distributed to various floors

Construction Materials

Vocabulary:

- **Brittle Failure:** Failure in a material which generally has a very limited plastic range; material subject to sudden failure without warning.
- **Elastic:** The ability of a material to return to its original form and condition after a displacing force is removed.
- **Ductility** - Property of some materials, such as steel, to distort when subjected to forces while still retaining considerable strength.
- **Energy Dissipation** - Reduction in intensity of earthquake shock waves with time and distance, or by transmission through discontinuous materials with different absorption capabilities.
- **Inelastic** - The inability of a material to return to its original form and condition after a displacing force is removed; permanent distortion.

. **Intensity** - A subjective measure of the force of an earthquake at a particular place as
measured by its effects on persons, structures and earth materials. Intensity is a measure of energy. The principal scale used in the United States today is the Modified Mercalli, 1956 version.

- **Liquefaction** - Transformation of a granular material (soil) from a solid state into a liquified state as a consequence of increased pore-water pressure induced by vibration.

Concepts/Goals:
• Required lateral strength of a seismic system is traded off with ductility (The ability to deform in elastically) remember...higher strength requires lower ductility
• At higher levels of shaking, the exterior walls of unreinforced masonry bearing wall buildings have relatively consistently fallen away from their buildings

Government and Regulatory Requirements and Permit Process

Vocabulary:

- **Design earthquake ground motion:** the earth quake ground motion that buildings and structure are specifically proportioned to resist in the IBC
- **Maximum considered earthquake ground motion:** the most severe earthquake effects considered by IBC
- **Mechanical systems:** in terms of seismic design, this includes HVAC and plumbing • **Orthogonal:** to be in two horizontal directions at 90degrees to each other
- **Seismic Design Category:** classification assigned to a structure based on its occupancy category and the severity of the design earthquake ground motion at the site
- **Seismic Force Resisting System:** the part of the structural system that has been considered in the design to provide the required resistance to the prescribed seismic forces
- **Site Class:** classification assigned to a site based on the types of soils present and their engineering properties (A: hard rock, B: rock, C: dense soil, D: stiff soil, E: soft soil, E: varies, F: varies w/multiple characteristics)

Facts/Rules:
• I “Every structure and portion thereof, including nonstructural components that are permanently attached to structures and their supports and attachments, shall be designed and constructed to resist the effects of earthquake motions in accordance with ASCE 7, excluding Chapter 14 and Appendix 11A.”
•Exceptions (earthquake analysis not required):
•Detached one- and two-family dwellings in Seismic Design Categories A, B or C.
•Seismic-force-resisting wood-framed structures complying with IBC Section 2308.
•Agricultural buildings with no human occupancy.
• IBC Earthquake Design Data (1603.1.5) must be addressed with construction documents
• Seismic importance factor **I** and occupancy category
• Mapped spectral response accelerations **Ss** and **SI**
• Site class
• Spectral response coefficients **SSD** and **SDI**
• Seismic design category
• Basic seismic force resisting systems
• Design base shear
• Seismic response coefficient(s) **CS**
• Response modification factor(s) **R**
• Analysis procedure used
Concepts/Goals:
• Chapter 5: The basics of Seismic Code
• Most codes have the stated goal of maintaining life safety
• Damage control is included in codes for hospitals/critical buildings
• The primary purpose of seismic code is to provide a simple uniform method to determine the seismic forces for any location with enough accuracy to ensure a safe and economical design
• Code needs to provide for approximate uniformity of results so that no building owner, type, or material supplier is unfairly discriminated against.
• Horizontal force on a building can be represented as a horizontal shear force trying to push the base of the building across the ground where it’s attached to its foundation
• **FEMA 454: Designing For Earthquakes Chapter 1/Introduction**
• Earthquakes must be accepted as a natural environmental process
• Characteristics of the site, the earthquake and the structure influence seismic performance
• Economic losses can be very high in industrialized countries for earthquakes that kill relatively few people due to the fragility of buildings’ interior, systems, and enclosures
• Good seismic engineering can provide structures that can survive to a useful degree of predictability
• Key players in ensuring safe seismic design are the seismologist and structural engineer
• Architect initiates the building design and determines issues related to configuration (eg: size, shape, form/location of structural elements) that influence the seismic performance

• Inspection and analysis of earthquake-damaged buildings play important roles in understanding the effectiveness of seismic design
Processes:
• Simplified Seismic Design Process: (PROBABLY OVERKILL FOR THE EXAM)
• Determine Ground Motion Spectral Response Acceleration
• SS = Ground acceleration at short (0.2 second) period
_ = see Figure 1613.5(1)
• S1 = Ground acceleration at longer(1 second) period
_ _ = see Figure 1613.5(2)
• Determine "Site Class":
• Site class is based on seismic shear wave velocity, vs, traveling through the top 100 feet of ground.
• Site class is determined from Table 1613.5.2 on p. 303
•
• Determine "Maximum Considered Earthquake" Spectral Response:
• SMS = FaSS
• where: Fa = Site coefficient based upon Site Class
= From Table 1613.5.3(1) p. 304
• SM1 = FvS1
_ where: Fv = Site coefficient based upon Site Class
= From Table 1613.5.3(2) p. 304
• Determine Design Spectral Response Acceleration:
• SDS = 2/ 3 (SMS) per IBC Equation 16-39
• SD1 = 2/3 (SM1) per IBC Equation 16-40
• Determine "Response Modification Coefficient R
• From ASCE 7 Table 12.2.1
• Determine the Effective Seismic Weight of Structure "W"
• W = Effective seismic weight of structure
• = Total dead load of structure +
• In areas used for storage, a minimum of 25% of the reduced floor live load (floor live load in public garages and open parking structures need not be included)
• Where an allowance for partition load is included in the floor load design, the actual partition weight or a minimum weight of 10 PSF of floor area, whichever is greater.
• Total operating weight of permanent equipment
• 20% of uniform flat roof snow load where the flat roof snow load "Pf" exceeds 30PSF.
• Determine Seismic Importance Factor
• Per Occupancy Category IBC 1604.5
• I or II _ _ _ =_ _ _ 1.0
• III__ _ _ =_ _ _ 1.25
•IV_ _ _ =_ _ _ 1.5
• Determine Seismic Base Shear "V"
• V = CsW
• Determine Vertical Distribution of Seismic Shears

- $F_x = C_{vx}V$ where: $C_{vx} = w_xh_x$

Σw_ih_i
- where: h = height above base (feet)
- w = portion of weight at that level

CONTENT AREA: WIND FORCES

Building Design

Vocabulary:

• **Building drift:** the distance a building moves in wind
• **Straight Line Wind:** most common wind type, blows in a straight line
• **Down Slope Wind:** wind that flows down the slope of a mountain
• **Special Wind Regions:** mountainous areas in the continental US
• **Thunderstorm:** rapidly forming storm that produces high wind speed
• **Downburst:** An area of significantly rain-cooled air that, after reaching ground level, spreads out in all directions producing strong winds. Associated with thunderstorms
• **Northeaster:** cold, violent storm that occurs along NE coast and last for days
• **Hurricane:** spiraling wind systems that converge with increasing speed towards the storm's center (eye)
• **Tornado:** rotating column of air that extends from base of thunderstorm to the ground
• **Exposure:** classification for the characteristics of the ground roughness and surface irregularities in the vicinity of a building
• **Basic Wind Speed:** the wind speed with a 50 year average recurrence interval measured at 33'-0" above grade in Exposure C (flat, open terrain) It is a peak gust speed
• **Aerodynamic Pressure:** the interaction between the wind and the building

Facts/Rules:
• Hurricane forward movement (translational speed) varies between 5 – 25 mph
• Saffir-Simpson Hurricane Scale rates intensity of hurricanes
• Category I (weakest) – Category V (strongest)
• Hurricanes have the greatest potential for devastating a large geographical area
• Tornado path widths are less than 1,000 ft (but have been reported 1-mile across)
•Fujita scale categorizes severity based on observed damage
• F0 (light damage) – F5 (incredible damage)
• F0/F1 are most common, but F2/F3 frequently occur
• When wind interacts with a building, both positive and negative (suction) pressure occurs simultaneously. If wind is approaching front wall, then:
• Front Wall _ _ _ =_ _ _ Positive pressure
• Rear Wall_ _ _ =_ _ _ Negative pressure
• Side Walls_ _ _ =_ _ _ Negative pressure
• Roof_ _ _ _ =_ _ _ Uplift
• Otherwise said: positive pressure occurs on the windward side of a building and Negative pressure (suction) occurs on the on leeward side & roof
• Pressure is greater at corners, overhangs & parapets
• Exposure Categories:
• **Exposure B:** rough terrain, urban, suburban, and wooded areas
• **Exposure C:** flat open terrain with scattered obstructions and areas adjacent to oceans in hurricane prone regions
• **Exposure D:** smoothest terrain, areas adjacent to large water surfaces outside hurricane-prone regions, mud flats, salt flats, and unbroken ice
• The smoother the terrain, the greater the wind load. (eg: office buildings in exposure D would receive higher wind loads than those in Exposure B)
• Most of country has a basic wind speed (peak gust) of 90 mph, but it’s much higher in places like Alaska or in hurricane prone regions
• Abrupt changes in topography (isolated hills, ridges, etc) cause wind to speed up.
• Wind speed increases with height above ground. The taller the building the greater the wind speed and wind loads
• Wind striking a building causes internal pressure, either positive or negative, because of the porosity of the building envelope (openings around doors/window frames, and other walls that aren’t airtight)
• Damage typically begins with peak gusts of 70 – 80 mph
• Tall building can drift several feet
• The max drift allowed = 1/500 x height of building
Concepts/Goals:
• Different wind types and storms occur in different areas of the country
• Thunderstorms produce high winds and create heavy rain…sometime leads to hail and tornadoes
• Move through an area rapidly, causing high wind at a given location for a few moments
• Can stall and become stationary
• Pressures, directions and timing of wind is constantly changing
• For purpose of calculation however wind is considered a static force based on:

• Velocity: pressure on building varies as the square of the velocity
• Height of wind above ground
• Surroundings: other buildings, trees and topography
• Size, shape and surface texture
Processes:
• When designing for wind, consider the following:
• Regular winds: low to moderate wind that occurs daily. Damage is not expected to occur at this speed
• Stronger winds: winds with a basic wind speed of 70-80mph peak gusts that occur a few times a year.
• Design Level Winds: can cause extensive damage to building and structure.
• Tornadoes: only a few areas frequently experience tornadoes, but areas that do should consider design. Well designed/built/maintained buildings should experience little damage, except for window breaks.
• Risk Reduction Strategy:
• Siting:
• Don't locate a building in Exposure D if possible
• Avoid locating on upper half a hill
• Trees with 6"+ diameter, light/flag/power poles shouldn't be placed near building
• Provide at least two means of site egress for office/public buildings
• Building Design:
• Good, design (including details and specifications), materials, application, maintenance, and repair
• Calculate Loads on the system (structure, building envelope, rooftop equipment)
• Determine load resistance, reasonable safety factor, or reasonable load factor.
• Design, detail, and specify structural system, building envelop, exterior MEP to meet the design loads and ID load path clearly on construction documents
• Ensure durability of materials. Weather can damage or destroy building components designed to protect the structure from failure
• Minimize water damage and subsequent development of mold.
• Peer Review
• Either in house or from experts, especially when building is:
• Located in an area with a peak gust greater than 90 mph
• Will be used for emergency response after a storm
• Will be used for a hurricane shelter
• Will incorporate a tornado shelter
• Construction contract Administration
• Review submittals
• Conduct field observations
• Post Occupancy Inspections, Maintenance, Repair, and Replacement
• It's important for the building owner to understand that over time, a building's ability to resist wind loads will degrade due to exposure to

elements. It must be periodically repaired
• The goal is to repair or replace items before the fail in a storm…it’s less messy and less expensive!

Building Systems and their Integration

Facts/Rules:

- Damage to buildings from wind ranges from minimal to severe
- Roof covering damages: rooftop mechanical/electrical moved, flashing lifted, built-up membrane peeled, etc.
- Exterior wall coverings and soffit damages: exterior wall fail or collapse
- Structural damage: roof blows off, exterior bearing walls collapse, entire building collapses

Concepts/Goals:

- High wind performance of building envelopes has historically been poor due to inadequate design attention
- Well designed/constructed/maintained buildings may be damaged by wind forces much strong than it was designed for…though it's rare (except for tornados)
- Most damage occurs because building elements have limited resistance due to poor design, material deteriorate, or roof system abuse
- In tornado prone regions, consideration should be given to designing a portion of the building for occupant protection
- Damage to buildings and structure cause certain ramifications:
- Property damage: repair/replacement of damaged components, repair/ replacement of damaged internal components, mold remediation, furniture/ equipment damage from water entering building
- Debris can blow from building and damage cars and other buildings (HVAC equipment, wall coverings, etc)
- Injury or death: either building occupants or people struck by debris
- Interrupted use: can't use the building while it's being repaired

Processes:

- Evaluating buildings for risk from high winds (other than tornadoes)
- Determine basic wind speed.
- As it increases beyond 90mph, the risk of damage increases
- Design, construction and maintenance enhancements are recommended for higher wind speeds
- If building is outside of hurricane prone region, determine if building will be used for emergency response after a storm
- If yes, then design/build/maintain like building is in hurricane prone region
- If building is in hurricane prone region, determine if it will be used for emergency response after a storm

Implications of Design Decisions

Facts/Rules:

_ Buildings used for emergency response after a storm typically require design decisions that add little cost to the total cost of construction

Concepts/Goals:

_ For many parts of the USA, high wind is the most severe load that affects a building

·Annually, wind damage to buildings/structures exceeds all other natural disaster combined

·Hurricane Katrina = $96 – 125 billion in damages (including flood damage)

Construction Details and Constructability

Facts/Rules:

- Good design details can help save a building in the event of a wind storm
- High wind forces travel through the load path of a structure
- Good connections that tie the floor, walls and roof together provide continuity in the load path and better building performance

- Light Wood Frame Construction:
- Nail roof sheathing along ends of the sheathing of intermediate roof framing
- Tie gable end walls back to the structure (one of the weakest connection points)
- Sheath gable end walls with wood structural panels (plywd or OSB)
- Use seismic/hurricane framing anchor to attach roof framing to the exterior side of the wall to prevent uplift and shear stress failure
- Nail upper and lower story sheathing to common wood structural panel to provide lateral and uplift load continuity
- Continuously sheath all walls with wood structural panels including around openings for windows/doors
- Extend structural panel sheathing to lap the sill plate
- The connection of the wall sheathing to sill plate is where uplift forces are transferred into the plate and into the foundation through anchor bolts
- Space anchor bolts about 32” – 48” o.c.

Concepts/Goals:

- Large openings in walls like windows/sliding glass doors/garage doors are vulnerable to damage in high wind
- Consider windows/doors that are rated for high wind and impact damage
- Hip roofs have a long history of superior performance in high wind events compared to gable end styles

Construction Materials
Facts/Rules:
_ Structural System
·Greatest reliability is offered by cast-in place concrete.
•There are no repots of any cast in place concrete buildings experiencing significant structural problems during even the most severe wind events
·Exterior load bearing walls of masonry/precast concrete should be designed to have sufficient strength to resist internal/external loads
·CMU walls should have vertical and horizontal grout to resist wind load
·Connections of precast concrete wall panels should have sufficient strength to resist wind loads
·Detail and specify connections for concrete, steel, or wood sheathing roof decks
·For steel roof decks, specify screw attachments rather than puddle welds
·For wood sheathed roof decks, specify screws, ring-shank nails in the corner regions of the roof (and at perimeters with peak wind is +90mph)
·For precast concrete decks, design deck connections to resist the design of uplift loads. The dead load of the deck itself is often inadequate to resist uplift
·For precast Tee decks, design the reinforcing to accommodate the uplift loads in addition to the gravity loads, otherwise it can fail due to its own pre-stress forces when the uplift load exceeds the dead load of the tee
·Single-ply or modified bitumen membranes on decking should meet requirements
•Exterior Doors (egress, garage, and rolling)
·Door assembly (door, hardware, frame) will resist positive and negative design wind pressure
·Anodized aluminum of galvanized doors/frames with stainless steel anchors are good when corrosion is a problem
·Door hardware should minimize the possibility of door being pulled upon by wind suction (eg: doors with top and bottom rods instead of latches)
•Weatherstripping
·Pre-manufactured components protect building from water infiltration at doors/ windows
•Drip: shed water away from opening between the frame and door head, and between the door bottom and threshold
•Door Shoes and Bottoms: minimize the gap between the door and threshold and can incorporate a drip
•Thresholds: must meet ADA requirements at high traffic doors
•Loads and Resistance
·Exterior non load bearing walls, wall coverings, and soffits need to be able to resist positive/negative wind pressure
·If a soffit is blown away and the wall doesn’t extend to the roof deck, wind driven water can be blown into the attic and lead to damage and collapse
·Exterior non load bearing masonry walls must designed to resist the positive and negative wind load so they don’t collapse
·Brick veneer, EIFS, metal wall panels, stucco and aluminum and vinyl siding often exhibit poor wind performance.
·Veneers (eg: ceramic tile, stucco) over concrete and cement-fiber panels and siding

have also blown off.
·Blow-off of wood siding and panels is rare.
·Another performance failure is deterioration of fasteners over time caused by water infiltration. Because the fasteners are often unseen, concealed within the wall assembly, this can ultimately lead to wall covering failure under wind loads.
•Roof Systems
·IBC requires load resistance of the roof assembly to be evaluated by one of the test methods listed in IBC's Chapter 15
·the highest uplift load occurs at roof corners
·The traditional edge flashing/coping attachment method relies on concealed cleats that can deform under wind load and lead to disengagement of the flashing/coping
·use of exposed fasteners to attach the vertical flanges of copings and edge flashings has been found to be a very effective and reliable attachment method
•Windows/Skylights
·IBC requires the window, curtain wall, or skylight assembly (i.e., the glazing, frame, and frame attachment to the wall or roof) to have sufficient strength to resist the positive and negative design wind pressure
·In tornado-prone regions, for critically important buildings it may be desirable to have laminated glazing installed at exterior openings in order to provide windborne debris protection during weak tornadoes.
•Exterior Mounted MEP/Communications Equipment
·Exterior-mounted mechanical (e.g., exhaust fans, HVAC units, relief air hoods, boiler stacks), electrical, and communications equipment (e.g., light fixtures, antennae, satellite dishes) are often damaged during high winds
·Damaged equipment can impair the use of the building, the equipment can become missiles, and water can enter the facility where equipment was displaced
·Problems typically relate to inadequate equipment anchorage, inadequate strength of the equipment itself, and corrosion.
·It is common for equipment components such as fan cowlings and access panels to be blown off during storms. Design of these elements is the responsibility of the equipment manufacturer.
Concepts/Goals:
• Most common problem with materials is blow-off of the roof deck

Government and Regulatory Requirements and Permit Process

Vocabulary:

•**Main Wind Force Resisting System (MWFRS):** a structural assembly that provides for the overall stability of the building and receives wind loads from more than one surface (eg: shear walls, diaphragms, rigid frames, space structures)

Equations:
_ Velocity pressure (qz) evaluated at height “z” _ _ **qz = 0.00256KzKdV2Iw**
_ qz = _ velocity pressure at height “z” in lbs. per square foot
_ Kz = _ velocity pressure exposure coefficient evaluated at height “z” and
_ Exposure B, C or D (from IBC 1609.4)
_ Kd = _ wind directionality factor, ranging from 0.85 (buildings) or 0.95 (chimneys)
_ V = _ basic wind speed in MPH for 3-second gust at 33 ft. above ground in
_ Category C as shown in IBC Figure 1609
_ Iw = _ Importance factor for wind design as shown in IBC Table 1604.5
_ Design Wind Pressure (p) **p = qzGCp – qz(GCpi)**
p = _ design wind pressure for main wind force-resisting system (MWFRS), psf
_ qz = _ velocity pressure at height “z” (see above)
_ G = _ 0.85
_ Cp = _ external pressure coefficient (typically given)
_ GCpi = 0.0 for open buildings
_ = +0.55 or -0.55 for partially enclosed buildings
_ = +0.18 or -0.18 for enclosed buildings

Facts/Rules:

• IBC Wind Design Data (1603.1.4) must be addressed with construction documents

• Basic wind speed (3 second gust) in MPH

• Wind importance factor **I**, and occupancy category

• Wind exposure, if more than one is utilized, the wind exposure and applicable wind direction shall be indicated

• Applicable internal pressure coefficient

• Components and cladding. (the design wind pressure in terms of psf to be used for the design of exterior components and cladding materials not specifically designed by the registered design professional)

• Wind Loads (Section 1609)

• Decreases in wind loads will not be made of the effect of shielding by other structures

• In wind born debris regions, glazing in buildings will be impact-resistance or ate least protected by an impact-resistant covering

• Areas vulnerable to hurricanes are:

• The US Atlantic Ocean and Gulf of Mexico coasts where basic wind speed is greater than 90mph

• Hawaii, Puerto Rico, Guam, Virgin Islands, and American Samoa

• Basic wind speed in mph for wind loads is based on Figure 1609 in the IBC

• Special wind regions (near monotonous regions, gorges, etc) must meet local jurisdiction requirements

• In non hurricane regions, basic wind speed is estimated from regional climactic data

• Wind loading will be determined per Chapter 6 of ASCE 7 or by Section 1609.6 “simplified wind load method”

Concepts/Goals:

• IBC, American Society of Civil Engineers (ASCE), *Minimum Design Loads for Buildings and other Structures,* do not provide guidance on wind speeds in special wind regions

• Local building departments typically establish basic speed. If not, then consult with wind engineers or meteorologists

• The cost for complying with the IBC should be considered as the minimum baseline cost

REFERENCES

areforum

ARE Lateral Force Primer Last Updated March 5, 2012

APA -The Engineered Wood Association. Introduction to Lateral Design. 2003
_ http://www.areforum.org/up/Lateral%20Forces/APA%20intro%20LF%20X305.pdf

Brandon's GS Notes (Ballast) from areforum FTP site
_ http://www.areforum.org/up/GeneralStructures/Brandon's%20GS%20notes
_ %20(Ballast)/

Common Trusses from the areforum FTP Site
http://www.areforum.org/up/GeneralStructures/must%20read/CommonTrusses.pdf

Foundation Bolting from the areforum FTP site
_ http://www.areforum.org/up/Lateral%20Forces/4Bolt%20MUD%20SILL.pdf

Rich's General Structural Study Notes from areforum FTP site
_ http://www.areforum.org/up/GeneralStructures/Rich's%20GS%20Study%20Notes.pdf

System Summary from the arefourm FTP site
http://www.areforum.org/up/GeneralStructures/system summary.rft

other websites

"Construction Basics – Wind & Weather Resistance" by APA
http://www.apawood.org/level_b.cfm?content=app_bas_wind

How to Approach the Structural System Vignette by Dustin G Offron
http://www.dustingoffron.com/ARE/HowtoApproachtheStructuralSystemsVignette.pdf

"Lecture 24 - Wind Load" by Assoc. Prof. Dave Hultenius. State University of New York @ Delhi http://faculty.delhi.edu/hultendc/AECT210-Lecture%2024.pdf

"Lecture 27 – Seismic Loads per IBC" by Assoc. Prof. Dave Hultenius. State University of New York @ Delhi http://faculty.delhi.edu/hultendc/AECT360-Lecture%2027.pdf

"Lumber Grading." http://timber.ce.wsu.edu/Supplements/Production/grading.htm

"Structural Systems" http://www.bdcorr.ca.gov/cppd/more%20for%20less/4-c.pdf

"The Seismic Retrofit of Historic Buildings Keeping Preservation in the Forefront" by David W Look, AIA, Terry Wong, PE, and Silvia Rose Augustus. National Park Service
http://www.nps.gov/hps/tps/briefs/brief41.htm

"Wind Safety of the Building Envelope" by Tom Smith, AIA. Whole Building Design Guide
http://www.wbdg.org/resources/env_wind.php

texts
“Chapter 16”. 2006 International Building Code. International Code Council
Buildings At Risk: Seismic Design Basics for Practicing

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

<u>Fiber Mesh</u>

Call vendors for pricing information if you need it.

<u>PT Cable</u>

Call vendors for pricing information if you need it.

<u>Shoring</u>

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

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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.

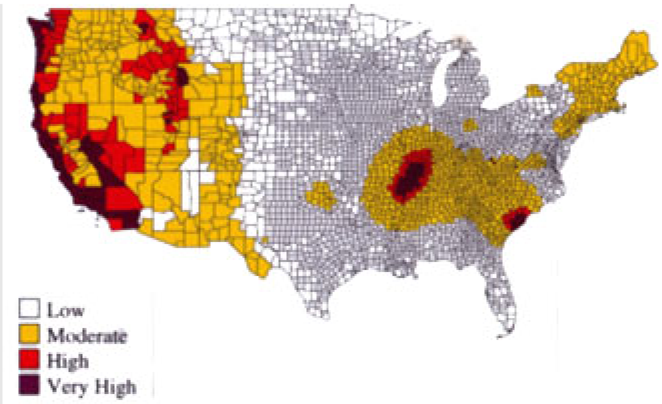


Fig. 1. Seismicity of the United States

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.

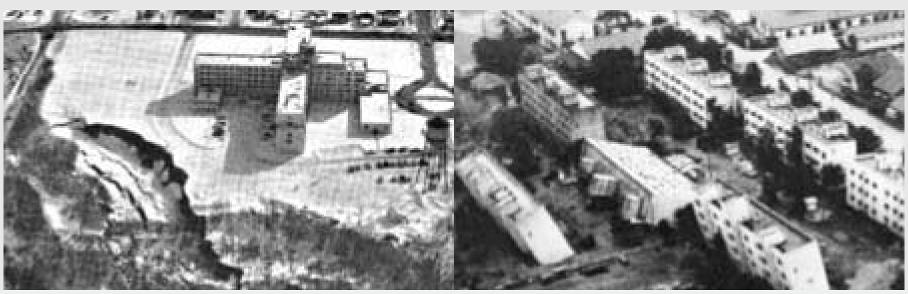


Fig. 2. *Left:* Ground failure-landslide—Alaska, 1964 *and Right:* Liquefaction damage—Niigata, Japan 1964

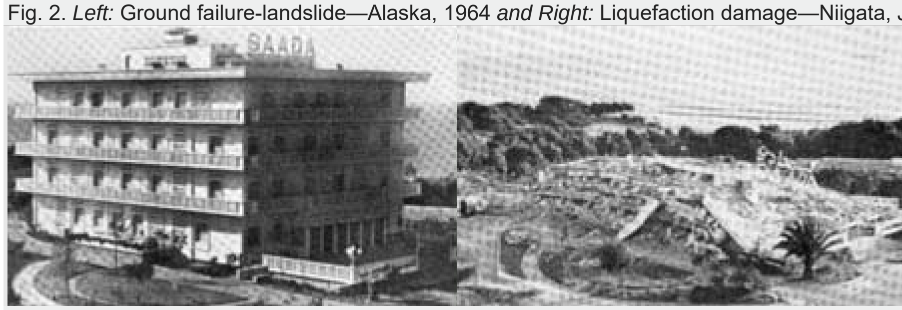


Fig. 3. *Left:* Saada Hotel (before)—Agadir, Morocco, 1960 *and Right:* Saada Hotel (after) ground shaking damage—Agadir, Morocco, 1960

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/sec^2 is perceptible by people
    - 0.02 g or 20 cm/sec^2 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.

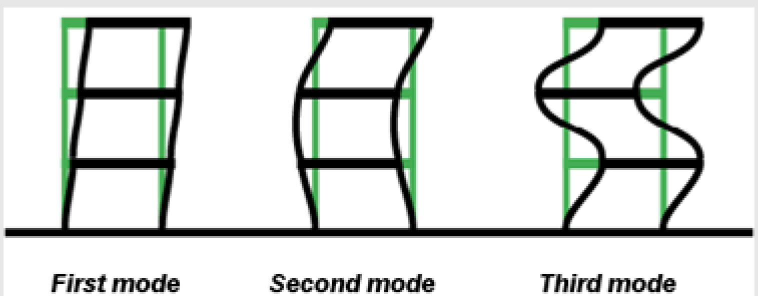


Fig. 5. Tall buildings will undergo several modes of vibration, but for seismic purposes (except for very tall buildings) the fundamental period, or first mode is usually the most significant.

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.

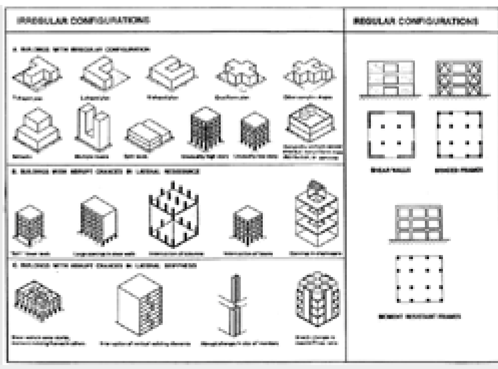
Damping: Buildings in general are poor resonators to dynamic shock and dissipate vibration by absorbing it. Damping is a rate at which natural vibration is absorbed.

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).

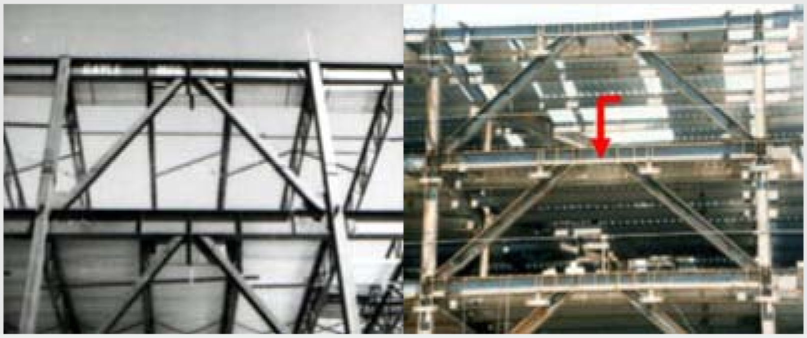


Fig. 8. *Left:* Concentric Braced Frame *and Right:* Eccentric Braced Frame, with link beams

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. *Fricitive 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*