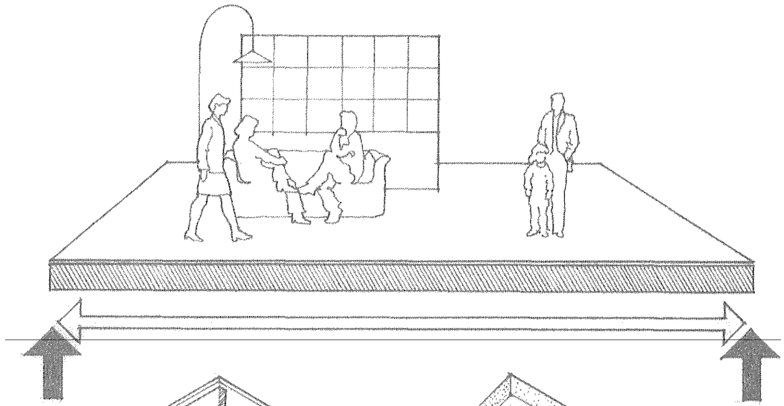
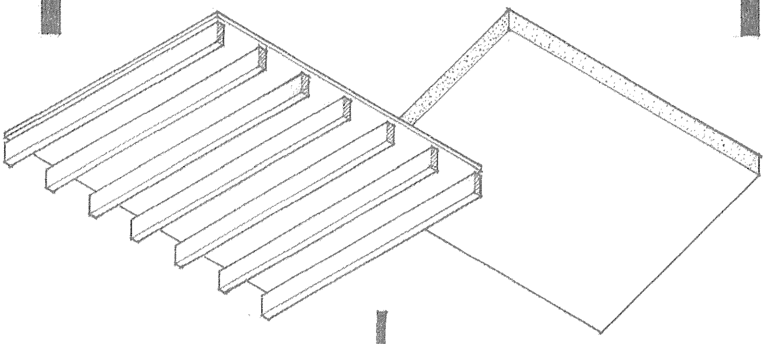
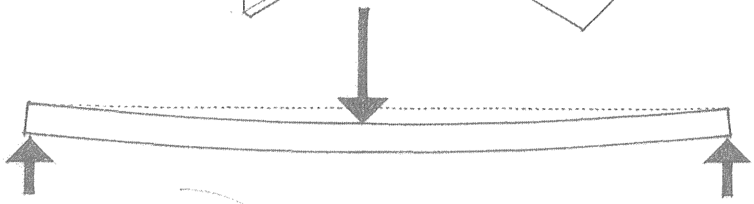
4

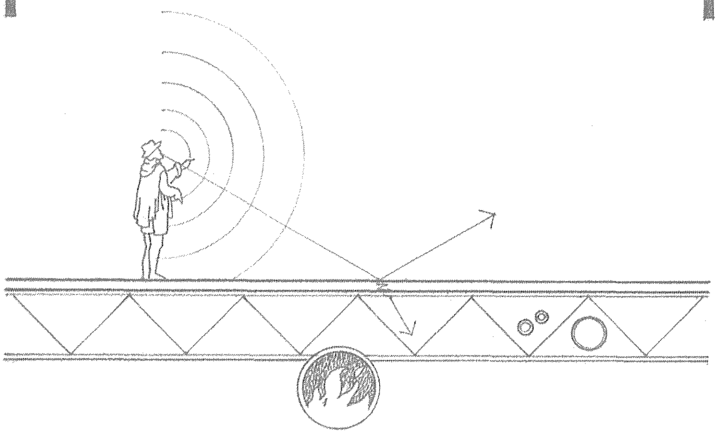
FLOOR SYSTEMS

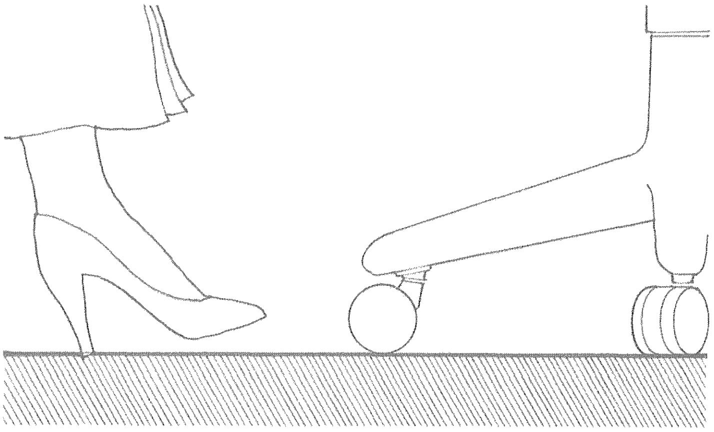
4.02 Floor Systems
4.04 Concrete Beams
4.05 Concrete Slabs
4.08 Prestressed Concrete
4.10 Concrete Formwork & Shoring
4.11 Precast Concrete Floor Systems
4.12 Precast Concrete Units
4.13 Precast Concrete Connections
4.14 Structural Steel Framing
4.16 Steel Beams
4.17 Steel Beam Connections
4.19 Open-Web Steel Joists
4.20 Open-Web Joist Framing
4.22 Metal Decking
4.23 Light-Gauge Steel Joists
4.24 Light-Gauge Joist Framing
4.26 Wood Joists
4.28 Wood Joist Framing
4.32 Wood Subflooring
4.33 Prefabricated Joists & Trusses
4.35 Wood Beams
4.36 Wood Beam Supports
4.37 Wood Post-Beam Connections
4.38 Wood Plank-and-Beam Framing
4.40 Wood Decking











Floor systems are the horizontal planes that must support both live loads—people, furnishings, and movable equipment—and dead loads—the weight of the floor construction itself. Floor systems must transfer their loads horizontally across space to either beams and columns or to loadbearing walls. Rigid floor planes can also be designed to serve as horizontal diaphragms that act as thin, wide beams in transferring lateral forces to shear walls.

A floor system may be composed of a series of linear beams and joists overlaid with a plane of sheathing or decking, or consist of a nearly homogeneous slab of reinforced concrete. The depth of a floor system is directly related to the size and proportion of the structural bays it must span and the strength of the materials used. The size and placement of any cantilevers and openings within the floor plane should also be considered in the layout of the structural supports for the floor. The edge conditions of the floor structure and its connection to supporting foundation and wall systems affect both the structural integrity of a building and its physical appearance.

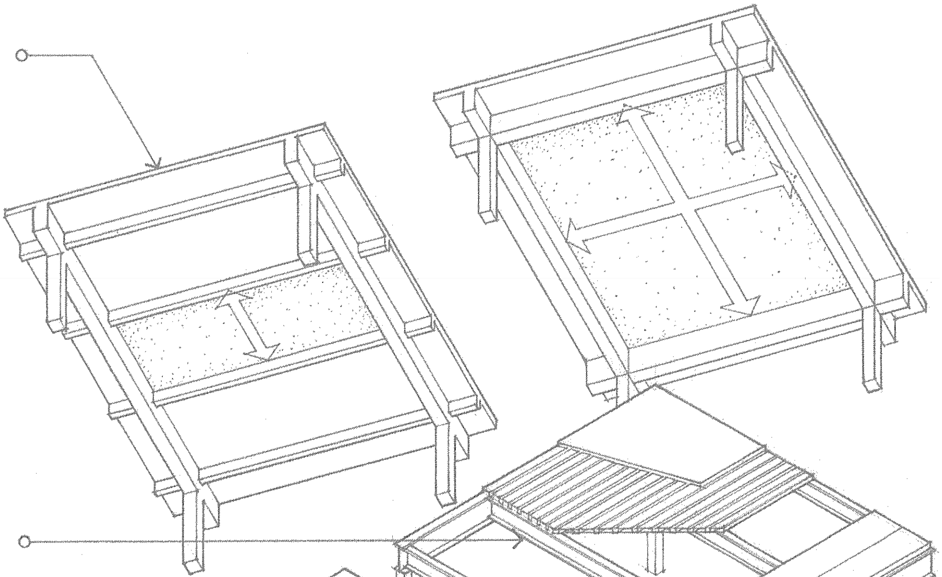
Because it must safely support moving loads, a floor system should be relatively stiff while maintaining its elasticity. Due to the detrimental effects that excessive deflection and vibration would have on finish flooring and ceiling materials, as well as concern for human comfort, deflection rather than bending becomes the critical controlling factor.

The depth of the floor construction and the cavities within it should be considered if it is necessary to accommodate runs of mechanical or electrical lines within the floor system. For floor systems between habitable spaces stacked one above another, additional factors to consider are the blockage of both airborne and structure-borne sound and the fire-resistance rating of the assembly.

Except for exterior decks, floor systems are not normally exposed to weather. Because they all must support traffic, however, durability, resistance to wear, and maintenance requirements are factors to consider in the selection of a floor finish and the system required to support it.

Concrete

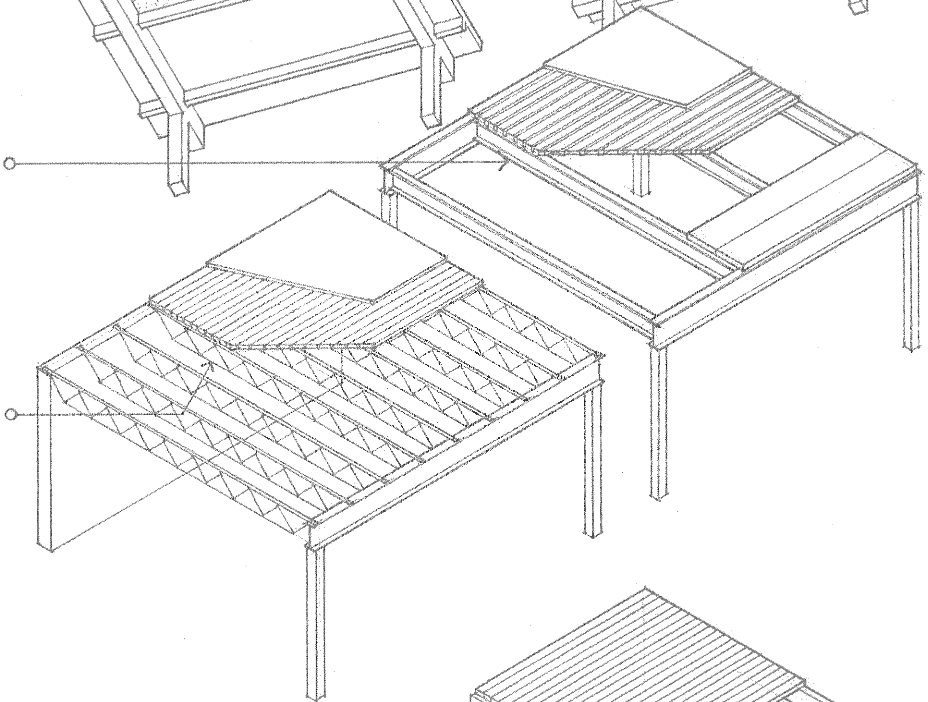
- Cast-in-place concrete floor slabs are classified according to their span and cast form; see 4.05–4.07.
- Precast concrete planks may be supported by beams or loadbearing walls.



Steel

- Steel beams support steel decking or precast concrete planks.
- Beams may be supported by girders, columns, or loadbearing walls.
- Beam framing is typically an integral part of a steel skeleton frame system.

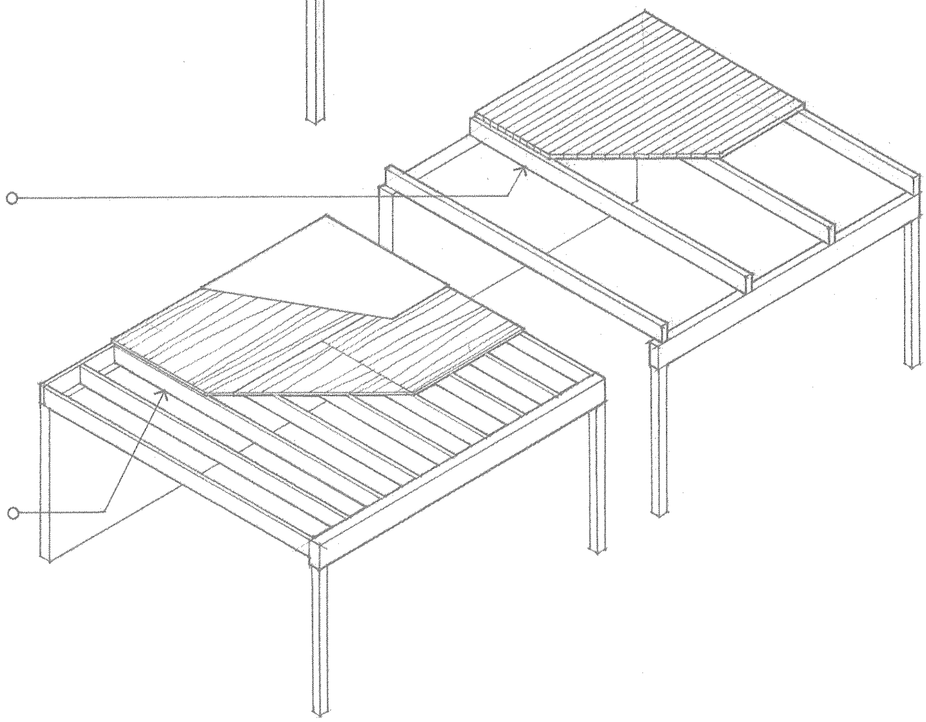
- Closely spaced light-gauge or open-web joists may be supported by beams or loadbearing walls.
- Steel decking or wood planks have relatively short spans.
- Joists have limited overhang potential.



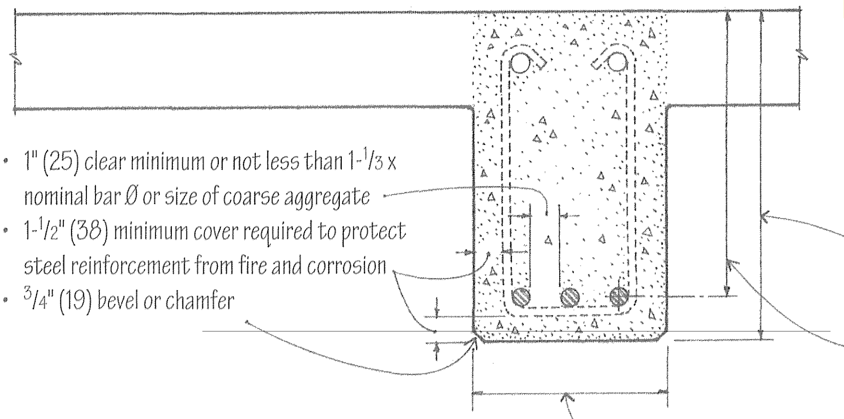
Wood

- Wood beams support structural planking or decking.
- Beams may be supported by girders, posts, or loadbearing walls.
- Concentrated loads and floor openings may require additional framing.
- Underside of floor structure may be left exposed; an applied ceiling is optional.

- Relatively small, closely spaced joists may be supported by beams or loadbearing walls.
- Subflooring, underlayment, and applied ceiling finishes have relatively short spans.
- Joist framing is flexible in shape and form.



Reinforced concrete beams are designed to act together with longitudinal and web reinforcement in resisting applied forces. Cast-in-place concrete beams are almost always formed and placed along with the slab they support. Because a portion of the slab acts as an integral part of the beam, the depth of the beam is measured to the top of the slab.



- 1" (25) clear minimum or not less than 1-1/3 x nominal bar Ø or size of coarse aggregate
- 1-1/2" (38) minimum cover required to protect steel reinforcement from fire and corrosion
- 3/4" (19) bevel or chamfer

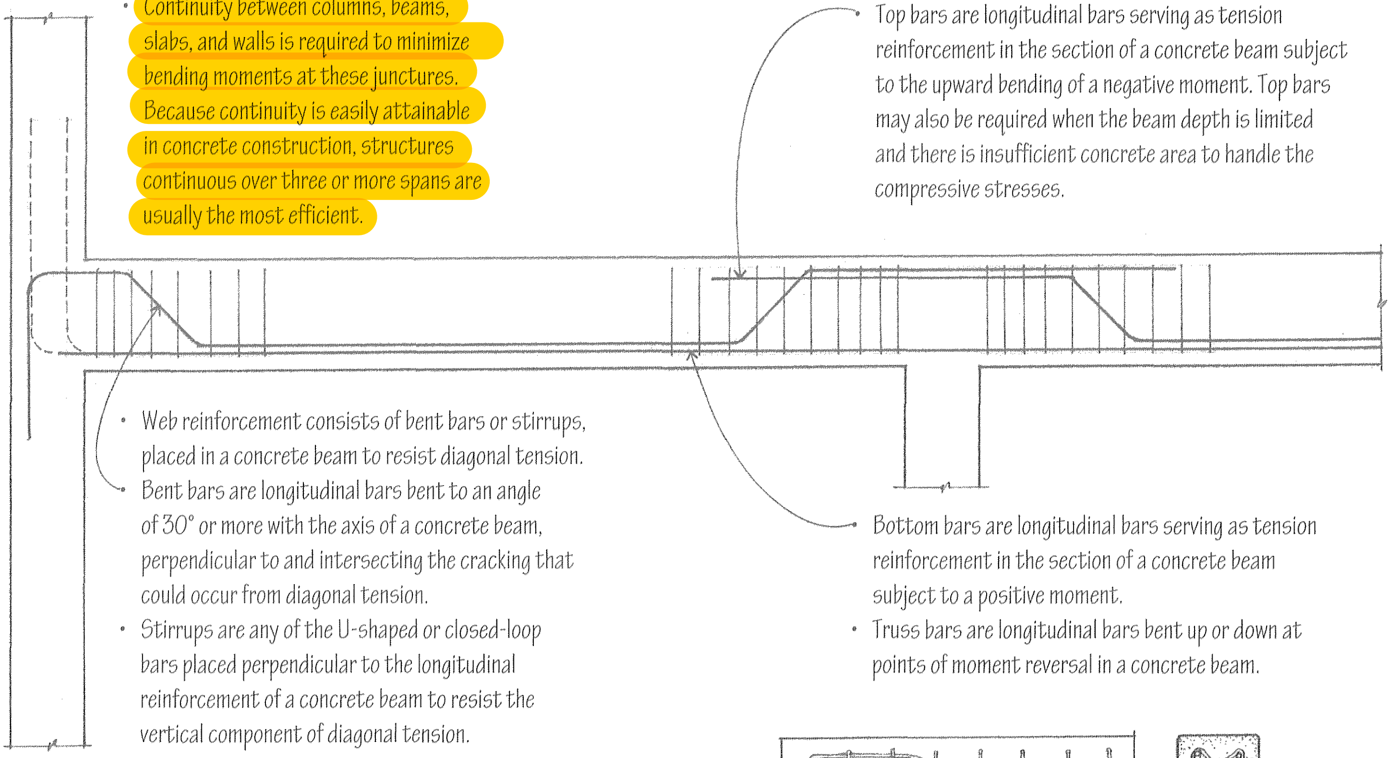
- Beam depth in 2" (51) increments
- Rule of thumb for estimating depth of a concrete beam: span/16

Effective depth is measured from the compression face to the centroid of tension reinforcement.

- Beam width is 1/3 to 1/2 of beam depth in 2" or 3" (50 or 75) multiples.
- Beam width should be equal to or greater than width of supporting column.
- Whenever possible, vary required steel reinforcement rather than beam size.

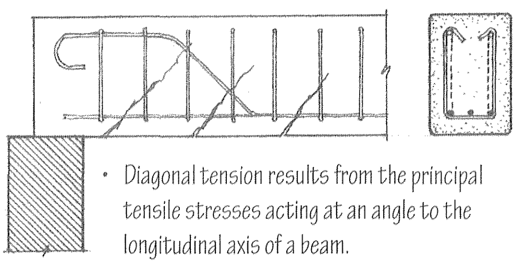
- Reinforcing bars extend into and down column support for structural continuity and to develop the required embedment length for anchorage.
- Continuity between columns, beams, slabs, and walls is required to minimize bending moments at these junctures. Because continuity is easily attainable in concrete construction, structures continuous over three or more spans are usually the most efficient.

- Top bars are longitudinal bars serving as tension reinforcement in the section of a concrete beam subject to the upward bending of a negative moment. Top bars may also be required when the beam depth is limited and there is insufficient concrete area to handle the compressive stresses.

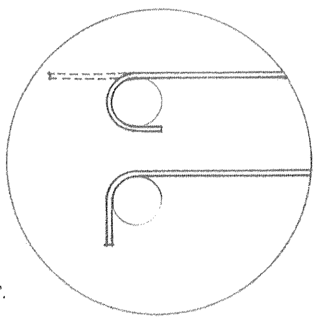


- Web reinforcement consists of bent bars or stirrups, placed in a concrete beam to resist diagonal tension.
- Bent bars are longitudinal bars bent to an angle of 30° or more with the axis of a concrete beam, perpendicular to and intersecting the cracking that could occur from diagonal tension.
- Stirrups are any of the U-shaped or closed-loop bars placed perpendicular to the longitudinal reinforcement of a concrete beam to resist the vertical component of diagonal tension.

- Bottom bars are longitudinal bars serving as tension reinforcement in the section of a concrete beam subject to a positive moment.
- Truss bars are longitudinal bars bent up or down at points of moment reversal in a concrete beam.



- Diagonal tension results from the principal tensile stresses acting at an angle to the longitudinal axis of a beam.



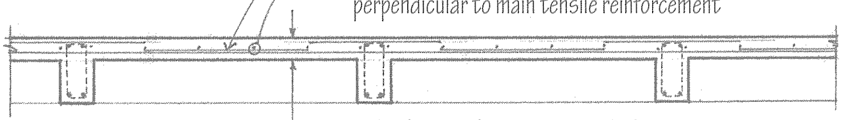
- Hooks are bends given to the end of tension bars to develop an equivalent embedment length for anchorage. A standard hook is a 90°, 135°, or 180° bend made at the end of a reinforcing bar according to industry standards with a radius based on the bar diameter.

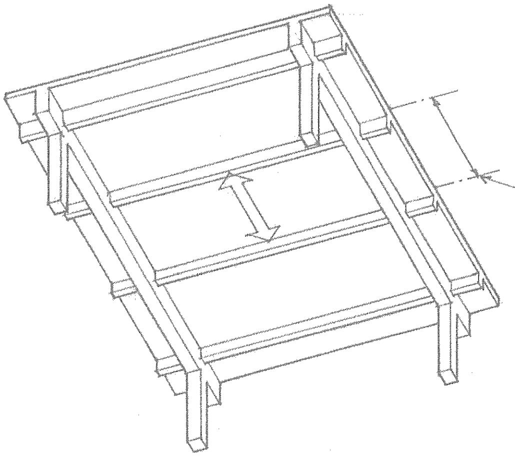
Concrete slabs are plate structures that are reinforced to span either one or both directions of a structural bay. Consult a structural engineer and the building code for the required size, spacing, and placement of all reinforcement.

CSI MasterFormat 03 20 00 Concrete Reinforcing
CSI MasterFormat 03 30 00 Cast-in-Place Concrete
CSI MasterFormat 03 31 00 Structural Concrete

One-Way Slab

A one-way slab is uniformly thick, reinforced in one direction, and cast integrally with parallel supporting beams.

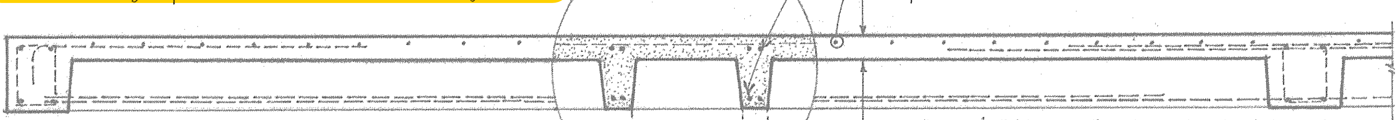


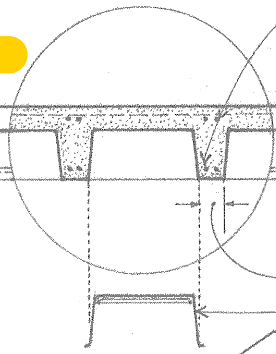


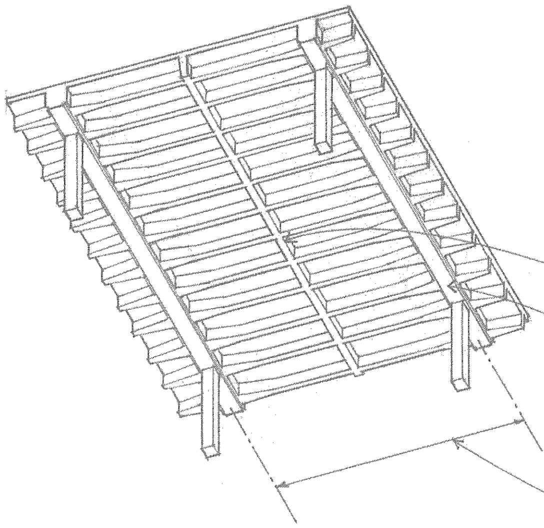
- Tensile reinforcement
- Shrinkage and temperature reinforcement perpendicular to main tensile reinforcement
- Rule of thumb for estimating thickness: span/30 for floor slabs; 4" (100) minimum span/36 for roof slabs
- Suitable for light to moderate loads over relatively short spans of 6' to 18' (1830 to 5490)
- Slab is supported on two sides by beams or loadbearing walls; beams, in turn, may be supported by girders or columns.

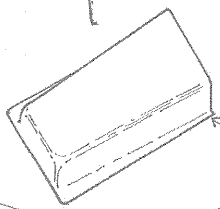
One-Way Joist Slab

A joist or ribbed slab is cast integrally with a series of closely spaced joists, which in turn are supported by a parallel set of beams. Designed as a series of T-beams, joist slabs are more suitable for longer spans and heavier loads than one-way slabs.







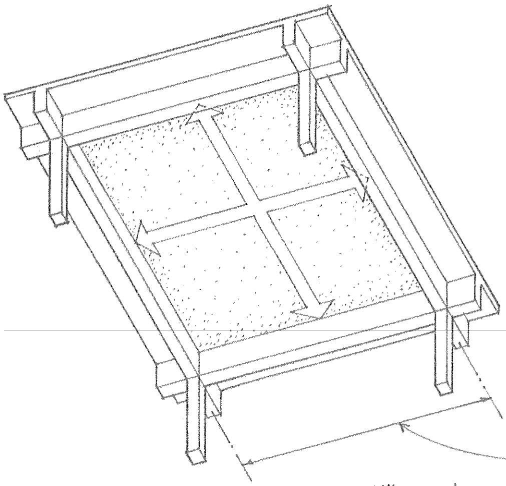


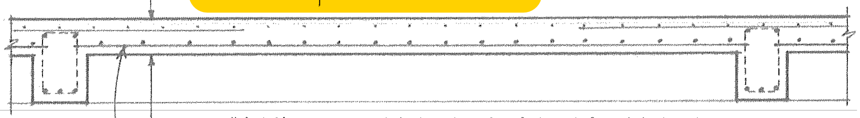
- Tensile reinforcement occurs in the ribs.
- Shrinkage and temperature reinforcement is placed in the slab.
- 3" to 4-1/2" (75 to 115) slab depth: rule of thumb for total depth: span/24
- 5" to 9" (125 to 230) joist width
- Pans are reusable metal or fiberglass molds, available in 20" and 30" (510 and 760) widths and from 6" to 20" (150 to 510) depths in 2" (51) increments. Tapered sides allow for easier removal.
- Tapered endforms are used to thicken joist ends for greater shear resistance.
- Distribution rib is formed perpendicular to the joists in order to distribute possible load concentrations over a larger area: one required for spans between 20' and 30' (6 and 9 m), and not more than 15' (4.5 m) o.c. for spans over 30' (9 m).
- Joist band is a broad, shallow supporting beam that is economical to form because its depth is the same as that of the joists.
- Suitable for light to medium live loads over spans of 15' to 36' (4 to 10 m); longer spans may be possible with posttensioning.

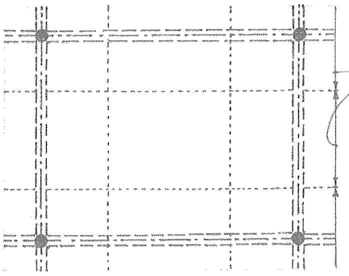
- See 12.04–12.05 for a discussion of concrete as a construction material.

Two-Way Slab and Beam

A two-way slab of uniform thickness may be reinforced in two directions and cast integrally with supporting beams and columns on all four sides of square or nearly square bays. Two-way slab and beam construction is effective for medium spans and heavy loads, or when a high resistance to lateral forces is required. For economy, however, two-way slabs are usually constructed as flat slabs and plates without beams.



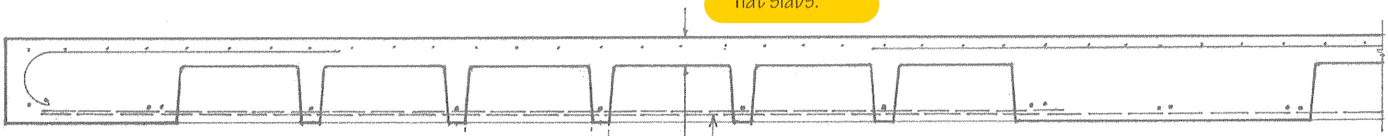


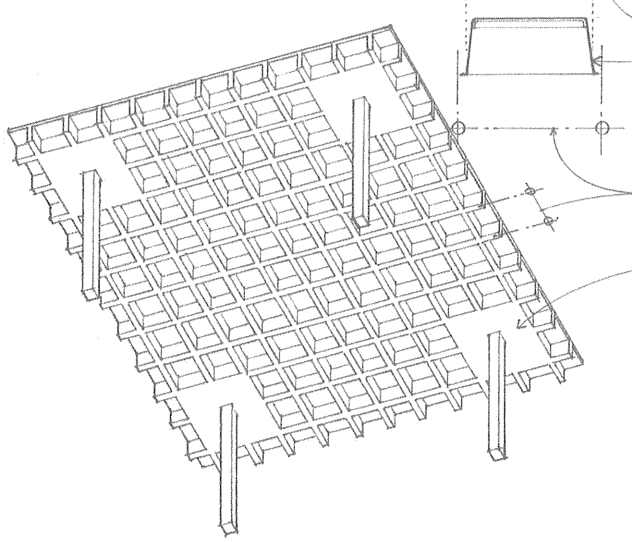


- 4" (100) minimum slab depth; rule of thumb for slab depth: slab perimeter/180
- Tensile reinforcement
- Two-way slabs are most efficient when spanning square or nearly square bays, and suitable for carrying intermediate to heavy loads over 15' to 40' (4.5 to 12 m) spans.
- To simplify the placement of reinforcing steel, two-way slabs are divided into column and middle strips, within which moments per foot are assumed to be constant.
- A continuous slab, extending as a structural unit over three or more supports in a given direction, is subject to lower bending moments than a series of discrete, simply supported slabs.

Two-Way Waffle Slab

A waffle slab is a two-way concrete slab reinforced by ribs in two directions. Waffle slabs are able to carry heavier loads and span longer distances than flat slabs.

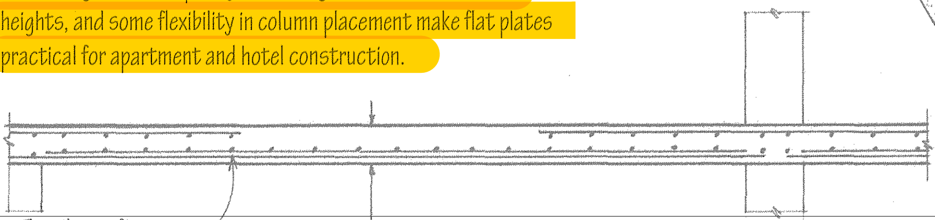


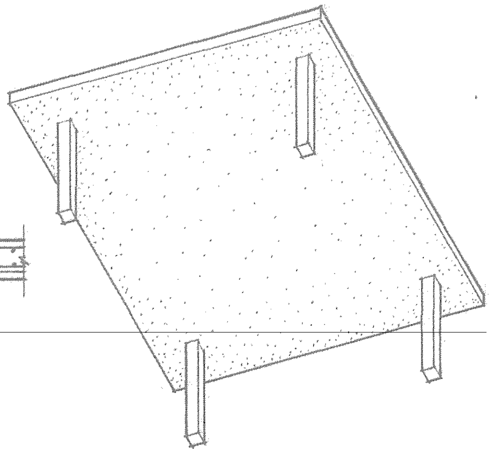


- Tensile reinforcement
- 3" to 4-1/2" (75 to 115) slab depth; rule of thumb for total depth: span/24
- 5" or 6" (125 or 150) rib width
- Square metal or fiberglass dome forms are available in 19" and 30" (485 and 760) widths and from 8" to 20" (205 to 510) depths in 2" (51) increments. Larger sizes are also available. Tapered sides allow for easier removal.
- 19" (485) domes and 5" (125) ribs create a 2' (610) module; 30" (760) domes and 6" (150) ribs produce a 3' (915) module.
- For greater shear strength and moment-resisting capacity, solid heads at column supports are formed by omitting dome forms; size depends on span and load conditions.
- Suitable for spans of 24' to 54' (7 to 16 m); longer spans may be possible with posttensioning.
- For maximum efficiency, bays should be square or nearly square as possible. Waffle slabs can be efficiently cantilevered in two directions up to 1/3 of the main span. When no cantilever is present, a perimeter slab band is formed by omitting dome forms.
- Coffered underside is usually left exposed.

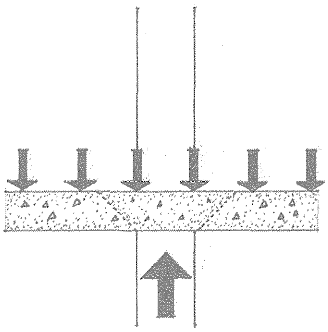
Two-Way Flat Plate

A flat plate is a concrete slab of uniform thickness reinforced in two or more directions and supported directly by columns without beams or girders. Simplicity of forming, lower floor-to-floor heights, and some flexibility in column placement make flat plates practical for apartment and hotel construction.



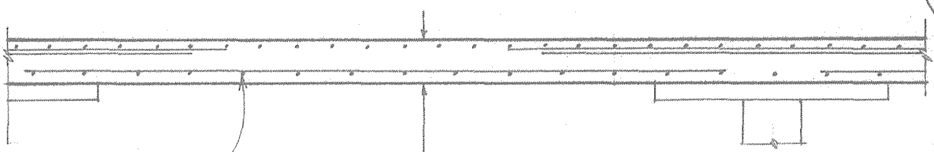


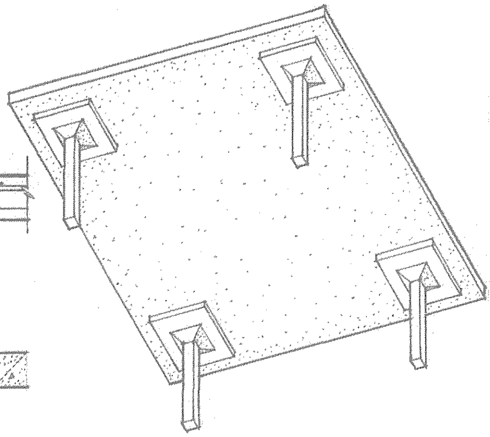
- Tensile reinforcement
- 5" to 12" (125 to 305) slab depth; rule of thumb for slab depth: span/33
- Suitable for light live to moderate loads over relatively short spans of 12' to 24' (3.6 to 7 m)
- While a regular column grid is most appropriate, some flexibility in column placement is possible.
- Shear at column locations governs the thickness of a flat plate.
- Punching shear is the potentially high shearing stress developed by the reactive force of a column on a reinforced concrete slab.



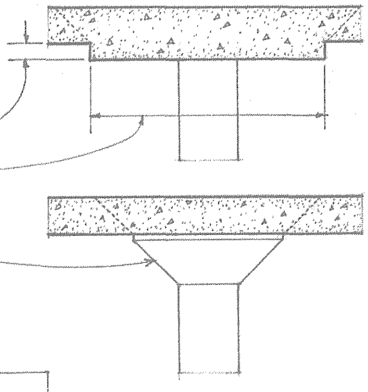
Two-Way Flat Slab

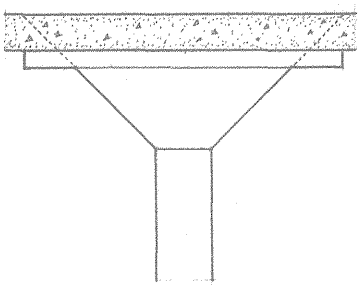
A flat slab is a flat plate thickened at its column supports to increase its shear strength and moment-resisting capacity.

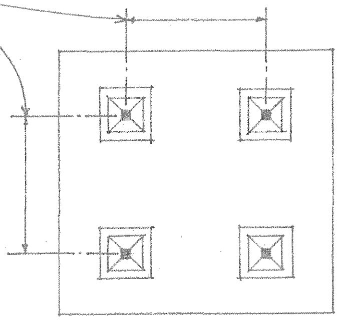




- Tensile reinforcement
- 6" to 12" (150 to 305) typical slab depth; rule of thumb for slab depth: span/36
- Drop panel is the portion of a flat slab thickened around a column head to increase its resistance to punching shear.
- Minimum projection of drop panel: 0.25 x slab thickness
- Minimum width of drop panel: 0.33 span
- Column capital may be used in place of or in conjunction with a drop panel for increased shear resistance.
- Suitable for relatively heavy loads and spans from 20' to 40' (6 to 12 m)





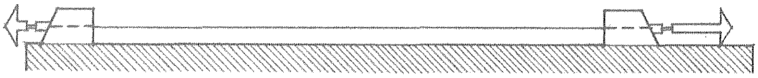


Prestressed concrete is reinforced by pretensioning or posttensioning high-strength steel tendons within their elastic limit to actively resist a service load. The tensile stresses in the tendons are transferred to the concrete, placing the entire cross section of the flexural member in compression. The resulting compressive stresses counteract the tensile bending stresses from the applied load, enabling the prestressed member to deflect less, carry a greater load, or span a greater distance than a conventionally reinforced member of the same size, proportion, and weight.

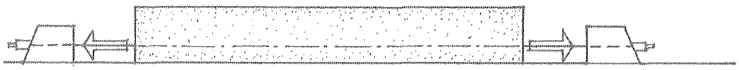
There are two types of prestressing techniques. Pretensioning is accomplished in a precasting plant, while posttensioning is usually performed at the building site, especially when the structural units are too large to transport from factory to site.

Pretensioning

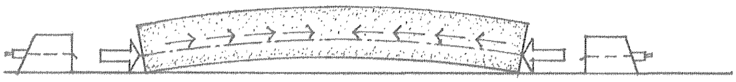
Pretensioning prestresses a concrete member by stretching the reinforcing tendons before the concrete is cast.



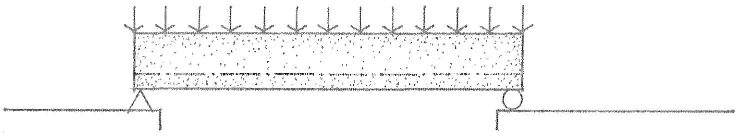
- Steel tendons are first stretched across the casting bed between two abutments until a predetermined tensile force is developed.



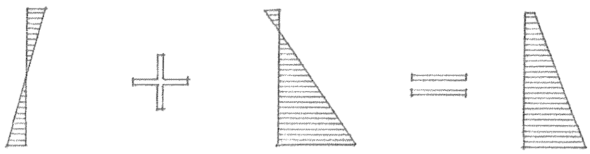
- Concrete is then cast in formwork around the stretched tendons and fully cured. The tendons are placed eccentrically in order to reduce the maximum compressive stress to that produced by bending alone.



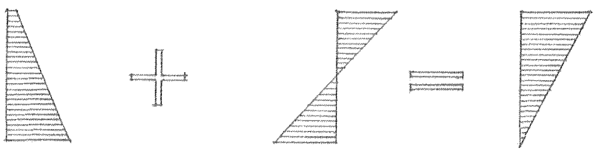
- When the tendons are cut or released, the tensile stresses in the tendons are transferred to the concrete through bond stresses. The eccentric action of the prestressing produces a slight upward curvature or camber in the member.



- The deflection of the member under loading tends to equalize its upward curvature.



- Dead load stresses
- Prestress stresses
- Combined dead load and prestress stresses

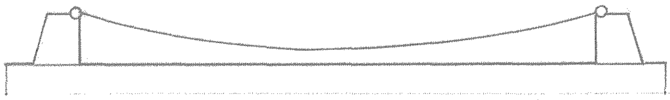


- Dead load and prestress stresses
- Live load stresses
- Final combined stresses

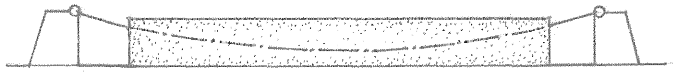
- A certain amount of initial prestress is lost due to the combined effects of elastic compression or creep of the concrete, relaxation of the steel tendons, frictional losses, and slippage at the anchorages.

CSI MasterFormat 03 38 00 Posttensioned Concrete
CSI MasterFormat 03 40 00 Precast Concrete

- The extremely high-strength steel tendons may be in the form of wire cables, bundled strands, or bars.



- Unstressed steel tendons, draped inside the beam or slab form, are coated or sheathed to prevent bonding while the concrete is cast.

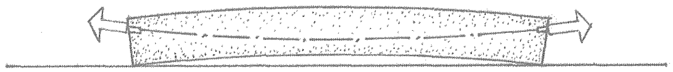


- After the concrete has cured, the tendons are clamped on one end and jacked against the concrete on the other end until the required force is developed.

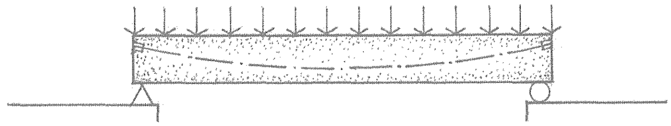
Posttensioning

Posttensioning is the prestressing of a concrete member by tensioning the reinforcing tendons after the concrete has set.

- Posttensioned members tend to shorten over time due to elastic compression, shrinkage, and creep. Adjoining elements that would be affected by this movement should be constructed after the posttensioning process is completed and be isolated from the posttensioned members with expansion joints.

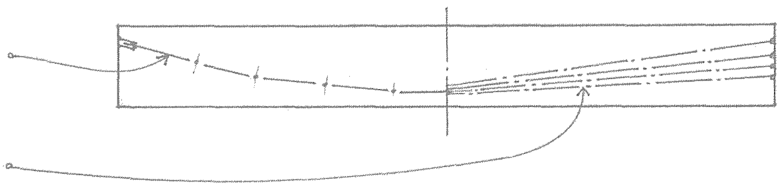


- The tendons are then securely anchored on the jacking end and the jack removed. After the posttensioning process, the steel tendons may be left unbonded, or they may be bonded to the surrounding concrete by injecting grout into the annular spaces around the sheathed strands.



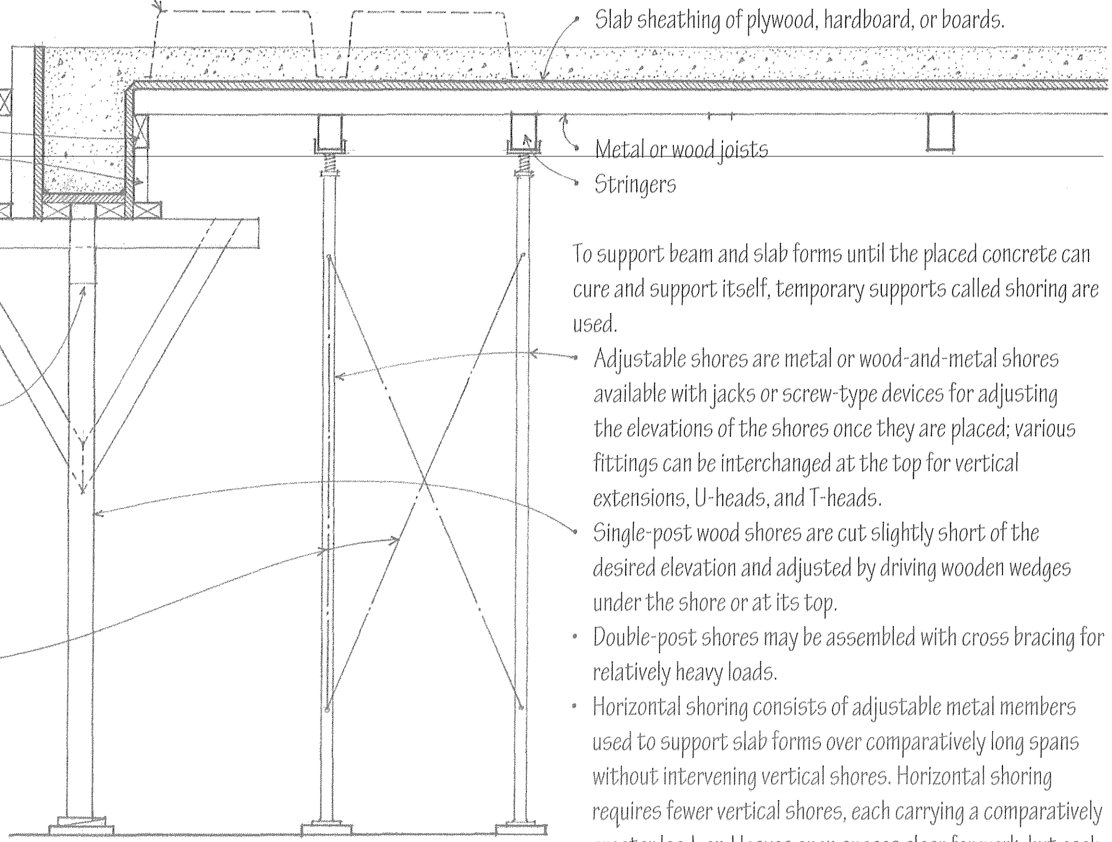
- The deflection of the member under loading tends to equalize its upward curvature.

- Load balancing is the concept of prestressing a concrete member with draped tendons, theoretically resulting in a state of zero deflection under a given loading condition.
- Draped tendons have a parabolic trajectory that mirrors the moment diagram of a uniformly distributed gravity load. When tensioned, the tendons produce a variable eccentricity that responds to the variation in applied bending moment along the length of the member.
- Depressed tendons approximate the curve of a draped tendon with straight-line segments. They are used in the pretensioning process because the prestressing force does not allow for draping the tendons. Harped tendons are a series of depressed tendons having varying slopes.



Fresh concrete must be shaped and supported by formwork until it cures and can support itself. This formwork is often designed as a separate structural system by an engineer because of the considerable weight and fluid pressure a concrete mass can exert on it.

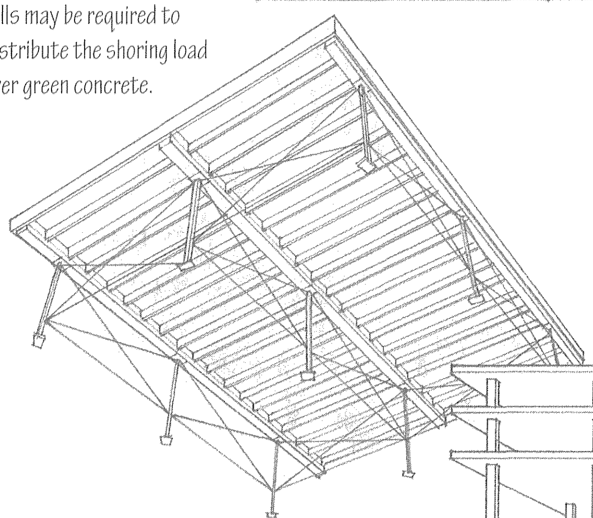
- Proprietary systems are used to form joist and waffle slabs.
- For economy, standard forms should be used in a repetitive manner whenever possible.



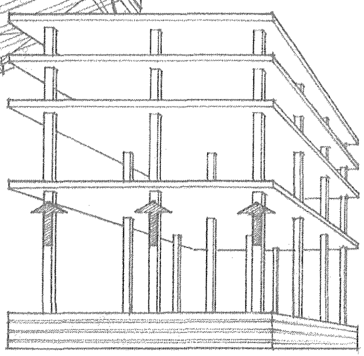
To support beam and slab forms until the placed concrete can cure and support itself, temporary supports called shoring are used.

- Adjustable shores are metal or wood-and-metal shores available with jacks or screw-type devices for adjusting the elevations of the shores once they are placed; various fittings can be interchanged at the top for vertical extensions, U-heads, and T-heads.
- Single-post wood shores are cut slightly short of the desired elevation and adjusted by driving wooden wedges under the shore or at its top.
- Double-post shores may be assembled with cross bracing for relatively heavy loads.
- Horizontal shoring consists of adjustable metal members used to support slab forms over comparatively long spans without intervening vertical shores. Horizontal shoring requires fewer vertical shores, each carrying a comparatively greater load, and leaves open spaces clear for work, but each vertical support carries a greater concentration of load.
- After a concrete slab or beam has cured sufficiently to carry its own weight, the original formwork is removed and the slab or beam is reshored until the concrete reaches it full strength.

- Braced T- and L-heads provide support for beam forms.
- Using columns and beams of a constant section and varying the amount of steel reinforcement to carry the imposed loads results in greater economy.
- Shoring must be braced in both the vertical and horizontal planes to stiffen and prevent buckling of individual members of the formwork.
- Sills may be required to distribute the shoring load over green concrete.



- See 5.07–5.08 for the formwork required for concrete columns and walls.

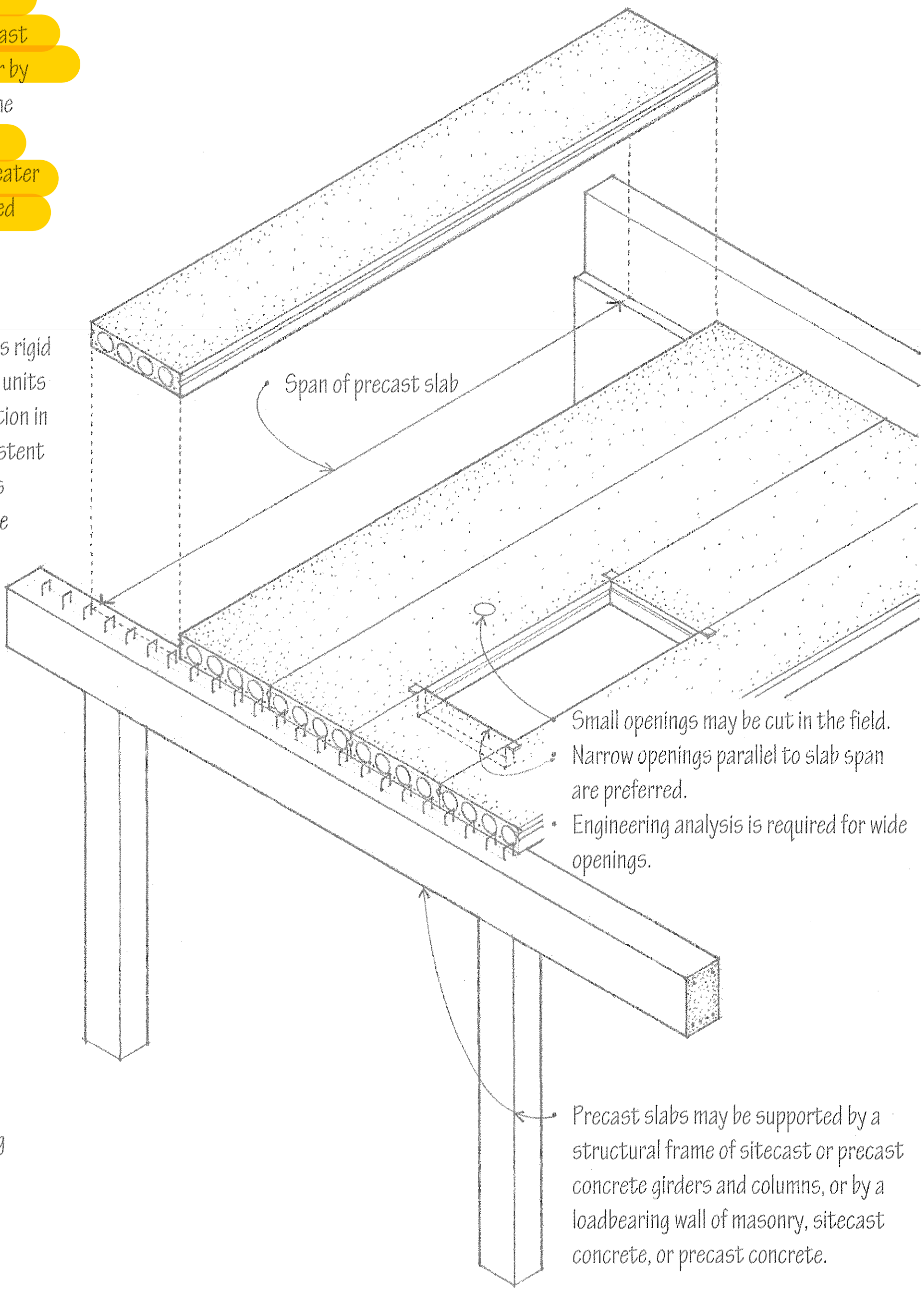


- Flying forms are large sections of formwork, including supporting trusses, beams, or scaffolding, that can be moved by a crane in constructing the concrete floors and roofs of multistory buildings.

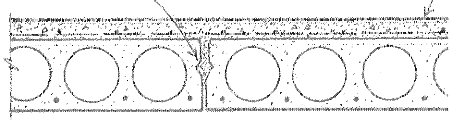
- Lift-slab construction is a technique of constructing multistory buildings in which all horizontal slabs are cast at ground level and, when cured, are raised into position by hydraulic jacks.

Precast concrete slabs, beams, and structural tees are one-way spanning units that may be supported by sitecast concrete, precast concrete, or masonry bearing walls, or by steel, sitecast concrete, or precast concrete frames. The precast units are manufactured with normal-density or structural lightweight concrete and prestressed for greater structural efficiency, which results in less depth, reduced weight, and longer spans.

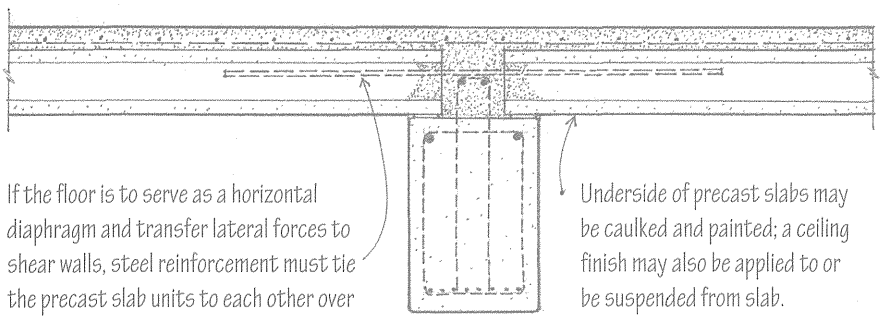
The units are cast and steam-cured in a plant off-site, transported to the construction site, and set in place as rigid components with cranes. The size and proportion of the units may be limited by the means of transportation. Fabrication in a factory environment enables the units to have a consistent quality of strength, durability, and finish, and eliminates the need for on-site formwork. The modular nature of the standard-sized units, however, may not be suitable for irregular building shapes.



- A 2" to 3-1/2" (51 to 90) concrete topping reinforced with steel fabric or reinforcing bars bonds with the precast units to form a composite structural unit.
- Grout key



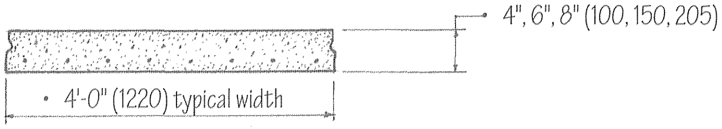
- The topping also conceals any surface irregularities, increases the fire-resistance rating of the slab, and accommodates underfloor conduit for wiring.
- When the flooring is to be pad and carpet, the topping may be omitted if smooth-surface units are used.



- If the floor is to serve as a horizontal diaphragm and transfer lateral forces to shear walls, steel reinforcement must tie the precast slab units to each other over their supports and at their end bearings.

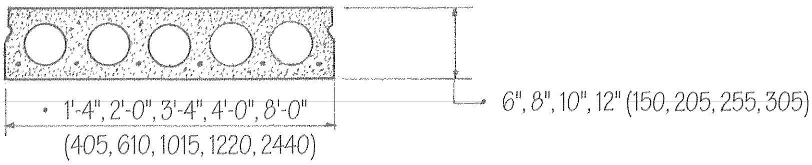
Underside of precast slabs may be caulked and painted; a ceiling finish may also be applied to or be suspended from slab.

CSI MasterFormat 03 40 00 Precast Concrete
CSI MasterFormat 03 50 00 Cast Decks & Underlayment

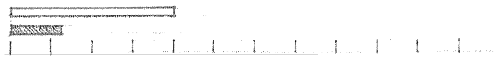


Solid Flat Slabs

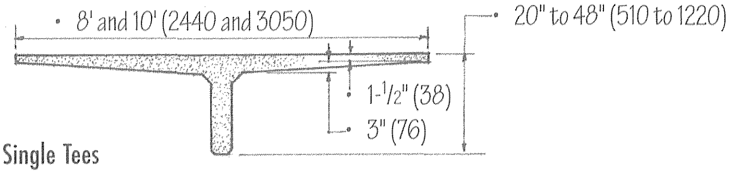
- 12' to 24' (3.6 to 7 m) span range
- Rule of thumb for depth: span/40



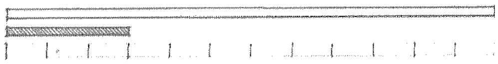
Hollow Core Slabs



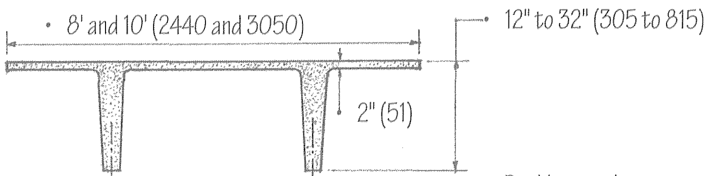
- 12' to 40' (3.6 to 12 m) span range
- Rule of thumb for depth: span/40



Single Tees



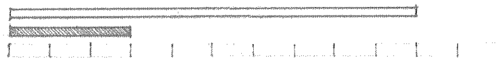
- 30' to 120' (9 to 36 m) span range
- Rule of thumb for depth: span/30



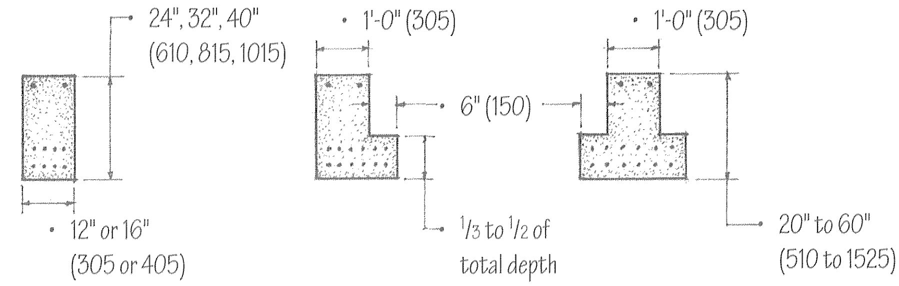
4' and 5' (1220 and 1525)

Double Tees

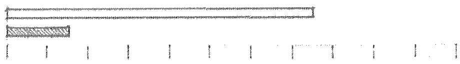
- Double tees do not require temporary support against tipping.



- 30' to 100' (9 to 30 m) span range
- Rule of thumb for depth: span/28

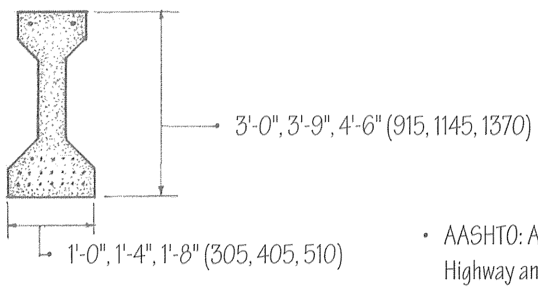


Rectangular Beams / L-Shaped Beams / Inverted Tee Beams



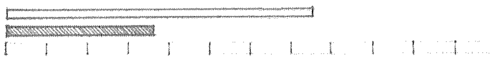
- 15' to 75' (4.5 to 22 m) span range
- Rule of thumb for depth: span/15

- Use the span ranges indicated for preliminary sizing only. Consult manufacturer for availability of sizes, exact dimensions, connection details, and span-load tables.

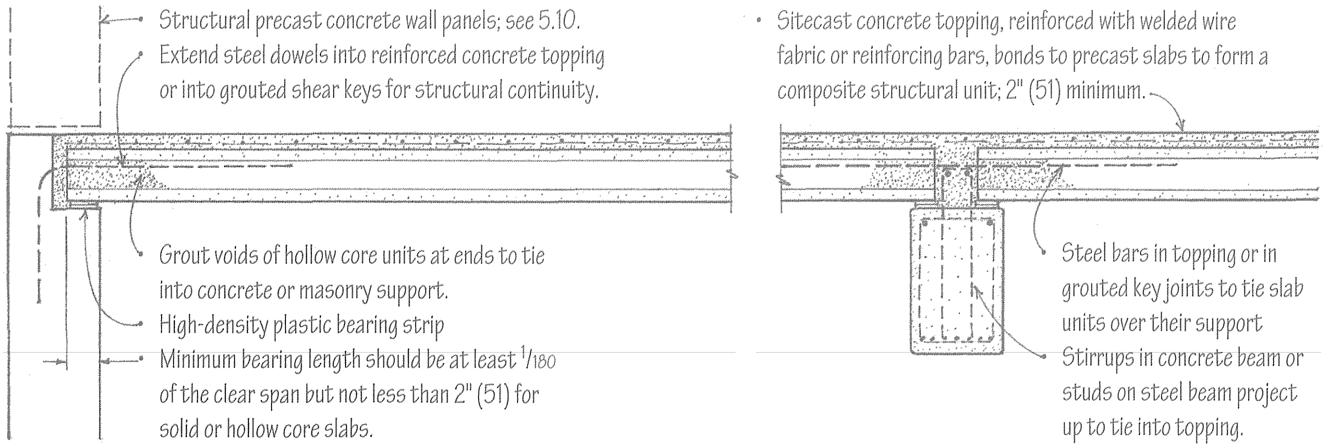


AASHTO Girders

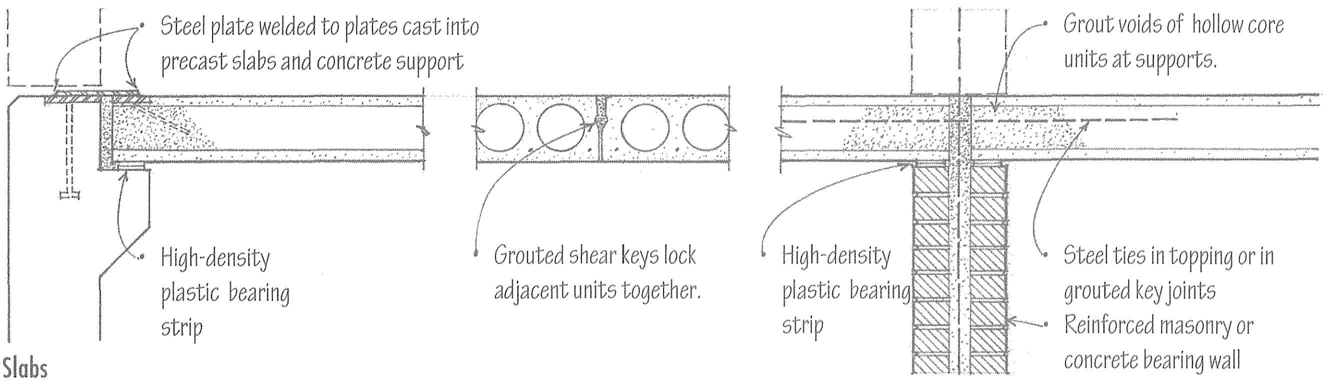
- AASHTO: American Association of State Highway and Transportation Officials
- Designed originally for bridge structures but used sometimes in building construction.



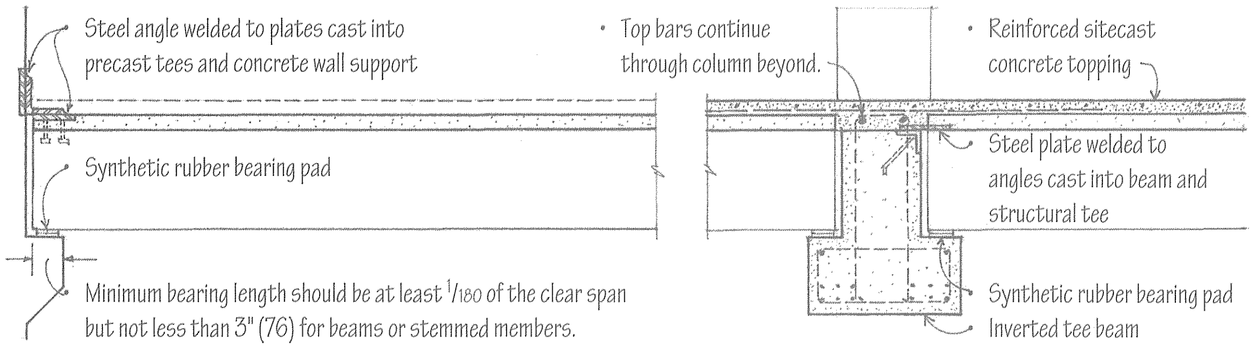
- 36' to 60' (10 to 18 m) span range



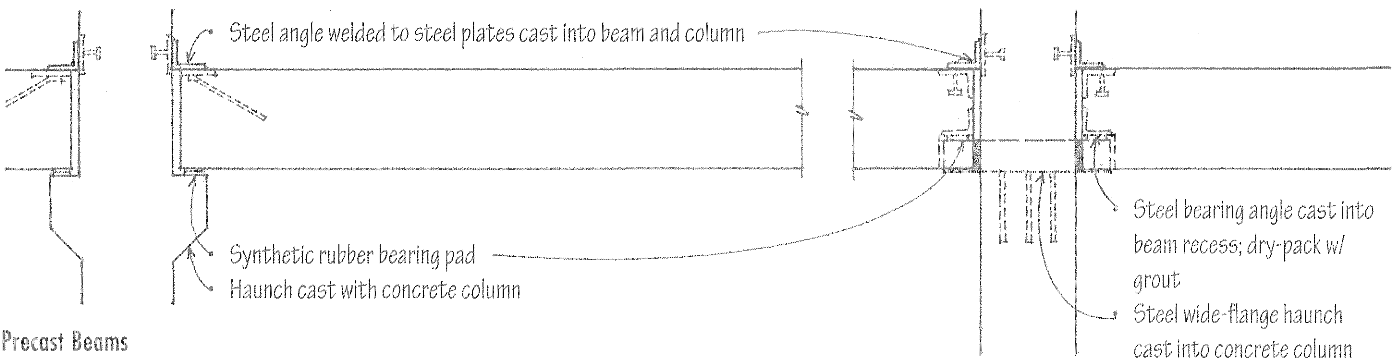
Precast Slabs



Precast Slabs



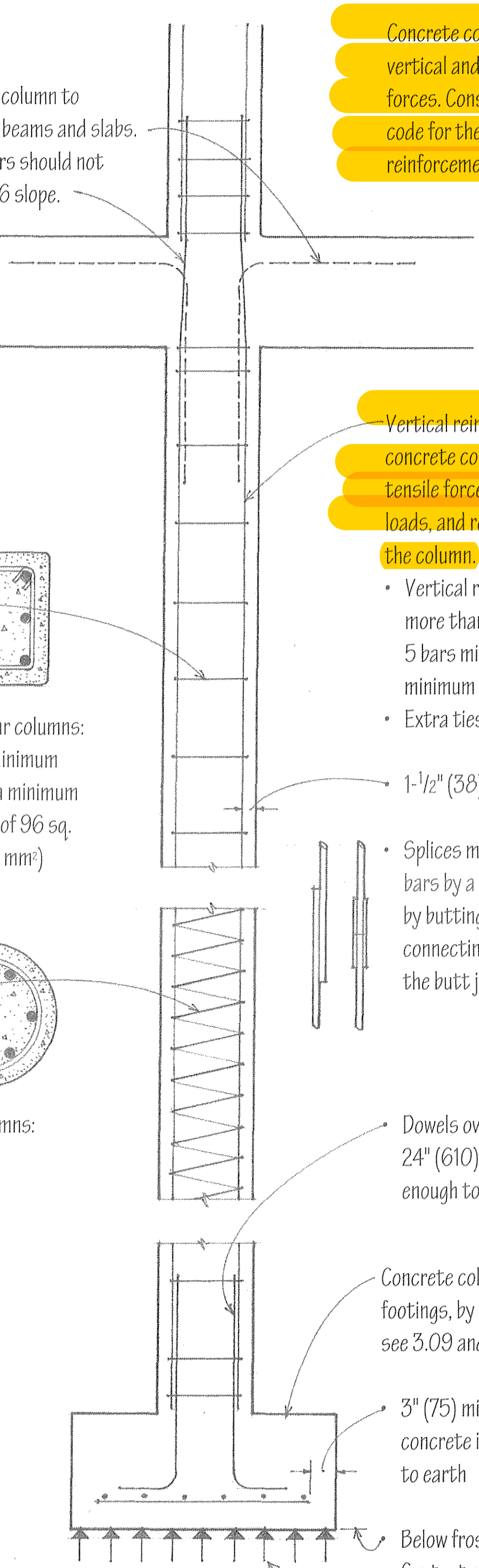
Precast Structural Tees



Precast Beams

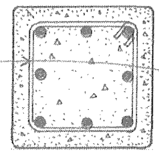
Concrete columns are designed to act together with vertical and lateral reinforcement in resisting applied forces. Consult a structural engineer and the building code for the required size, spacing, and placement of all reinforcement.

- Dowels tie column to supported beams and slabs.
- Inclined bars should not exceed a 1:6 slope.



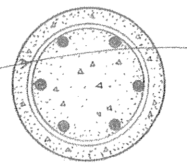
Lateral Reinforcement restrains the vertical reinforcement and strengthens the column against buckling.

- Lateral ties should have a minimum ø of 3/8" (10), spaced apart not over 48 tie ø, 16 vertical bar ø, or the least dimension of the column section. Each corner and alternate longitudinal bar should be laterally supported by the bend of a tie having an included angle of not more than 135°, with no bar being more than 6" (150) clear from such a supported bar.



- Rectangular columns: 8" (205) minimum width and a minimum gross area of 96 sq. in. (61,935 mm²)

- Spiral reinforcement consists of an evenly spaced continuous spiral held firmly in place by vertical spacers.
- Spiral reinforcement should have a minimum ø of 3/8" (10), with a maximum center-to-center spacing between spirals of 1/6 of the core diameter, and a clear space between spirals not more than 3" (75) nor less than 1-3/8" (35) or 1-1/2 x the size of the coarse aggregate.
- Extend spiral 1-1/2 turns for anchorage at ends.



- Round columns: 10" (255) minimum ø

Vertical reinforcement augments the ability of a concrete column to carry compressive loads, resists tensile forces when the column is subject to lateral loads, and reduces the effects of creep and shrinkage in the column.

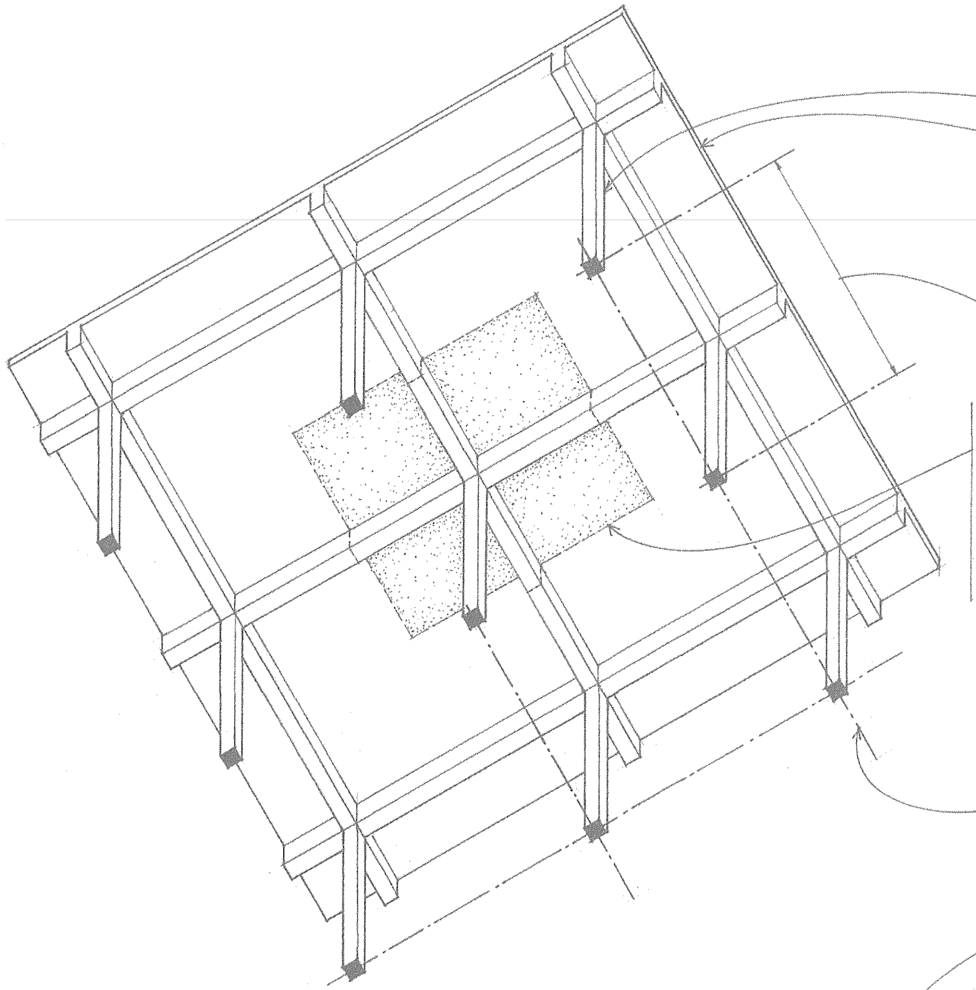
- Vertical reinforcement should not be less than 1% nor more than 8% of gross cross-sectional area; four No. 5 bars minimum for tied columns or six No. 5 bars minimum for spiral columns.
- Extra ties may be required at support points.
- 1-1/2" (38) minimum cover for steel reinforcement
- Splices may be made by lapping the ends of vertical bars by a length specified in bar diameters, or by butting the ends of vertical bars and either connecting them with a sleeve clamp or arc-welding the butt joint.
- Dowels overlap vertical bars 40 bar diameters or 24" (610); extend down into footing or pile cap far enough to develop adequate length for anchorage.

Concrete columns may be supported by isolated footings, by a mat or combined footing, or by pile caps; see 3.09 and 3.16.

- 3" (75) minimum cover for steel reinforcement when concrete is cast against and permanently exposed to earth
- Below frostline
- Contact area of footing distributes column load to ensure that the allowable bearing capacity of the supporting soil is not exceeded; 1'-8" (510) minimum.

CSI MasterFormat 03 20 00 Concrete Reinforcing
CSI MasterFormat 03 30 00 Cast-in-place Concrete
CSI MasterFormat 03 31 00 Structural Concrete

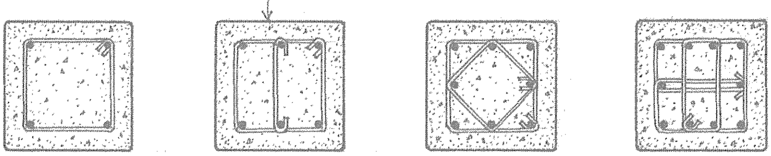
Reinforced concrete columns are usually cast with concrete beams and slabs to form a monolithic structure.

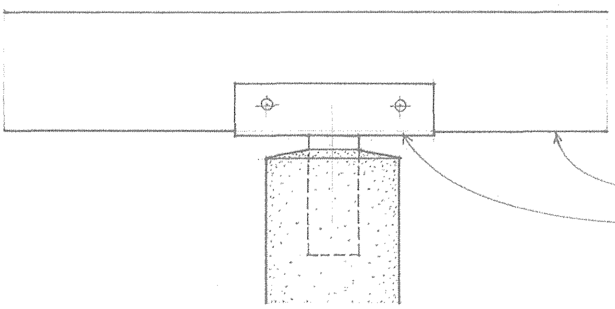


- Reinforced concrete columns
- Reinforced concrete beams and slabs; see 4.04–4.05
- Reinforced concrete two-way slabs; see 4.06–4.07
- Column spacing = beam or slab span
- Column spacing determines imposed loads

- 12" (305) column can support up to 2000 sf (185 m^2) of floor and roof area.
- 16" (405) column can support up to 3000 sf (280 m^2) of floor and roof area.
- 20" (510) column can support up to 4000 sf (372 m^2) of floor and roof area.

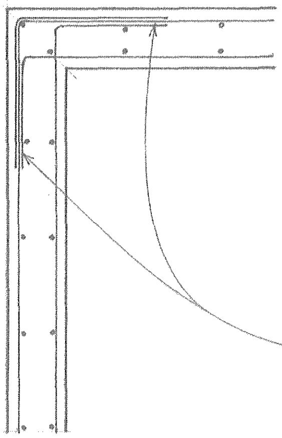
- Lay out columns along a regular grid for economical forming of beams and slabs.
- Columns should be continuous to the building foundation.
- Whenever possible, vary required steel reinforcement rather than column size; when necessary, vary only one dimension of a column at a time.

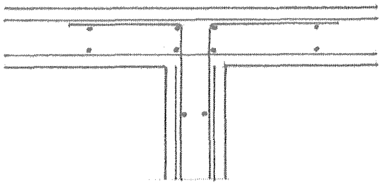




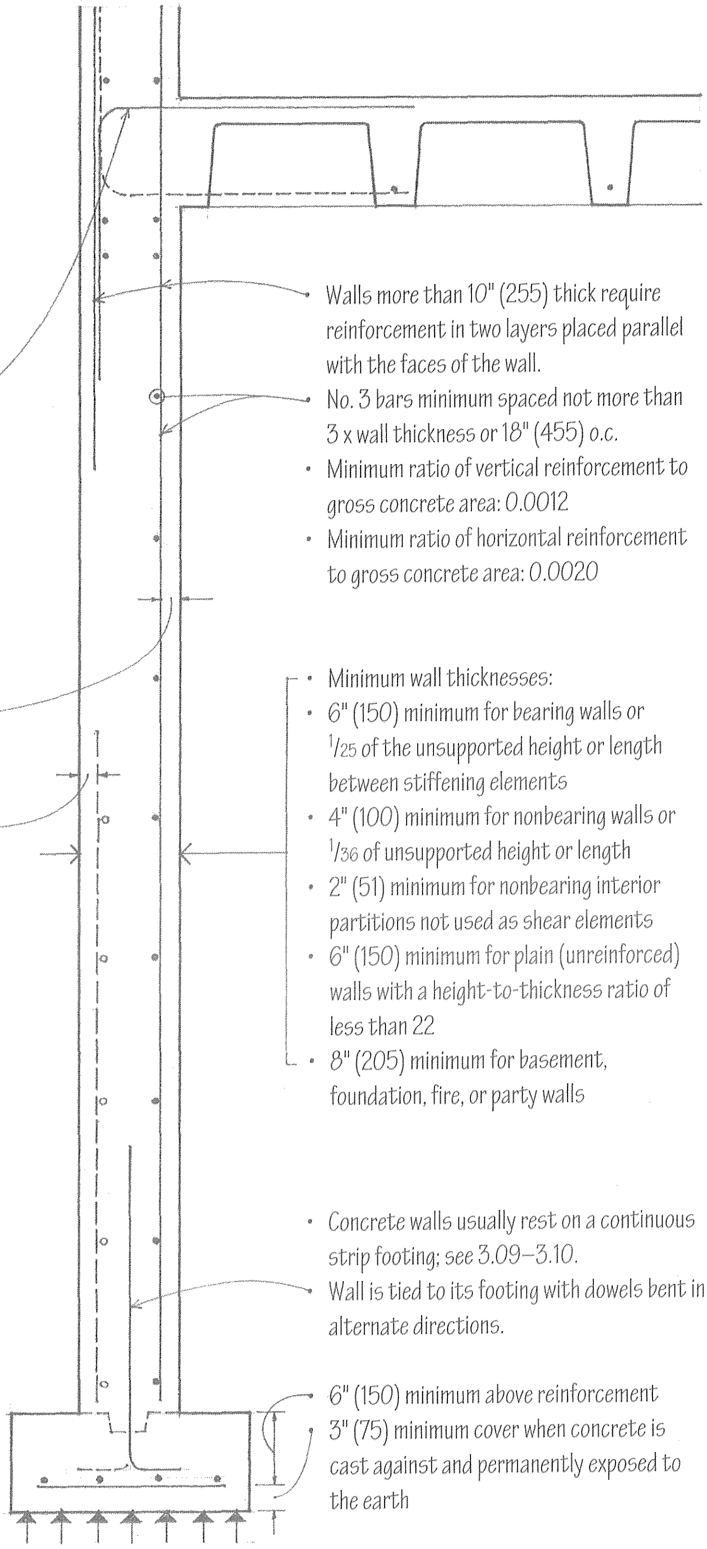
With the aid of a variety of steel connectors, reinforced concrete columns can also support a grid of timber or steel beams.

- Timber or steel beams
- Steel connectors are required to support and anchor wood or steel beams to concrete columns.

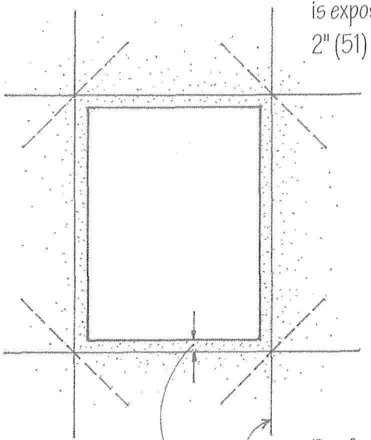




- Anchor reinforced concrete walls to floor slabs, columns, and intersecting walls with No. 3 bars minimum @ 12" (305) o.c. for each layer of wall reinforcement.
- Bend horizontal reinforcement at corners and wall intersections for structural continuity.



- Walls more than 10" (255) thick require reinforcement in two layers placed parallel with the faces of the wall.
- No. 3 bars minimum spaced not more than 3 x wall thickness or 18" (455) o.c.
- Minimum ratio of vertical reinforcement to gross concrete area: 0.0012
- Minimum ratio of horizontal reinforcement to gross concrete area: 0.0020
- 3/4" (19) minimum cover when concrete is not exposed to ground or weather.
- 1-1/2" (38) minimum cover when concrete is exposed to earth or weather; 2" (51) minimum for No. 6 bars and larger
- Minimum wall thicknesses:
- 6" (150) minimum for bearing walls or 1/25 of the unsupported height or length between stiffening elements
- 4" (100) minimum for nonbearing walls or 1/36 of unsupported height or length
- 2" (51) minimum for nonbearing interior partitions not used as shear elements
- 6" (150) minimum for plain (unreinforced) walls with a height-to-thickness ratio of less than 22
- 8" (205) minimum for basement, foundation, fire, or party walls



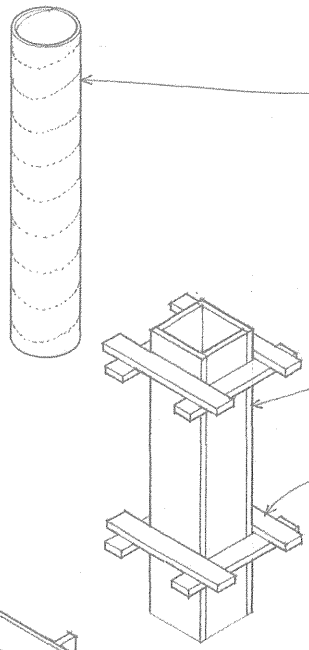
- Reinforce door and window openings with a minimum of two No. 5 bars extending at least 24" (610) beyond the corners of the opening.
- 2" (51) clear
- Diagonal bars optional

- Concrete walls usually rest on a continuous strip footing; see 3.09–3.10.
- Wall is tied to its footing with dowels bent in alternate directions.
- 6" (150) minimum above reinforcement
- 3" (75) minimum cover when concrete is cast against and permanently exposed to the earth

- Consult a structural engineer and the building code for the required size, spacing, and placement of all reinforcement.
- See 12.04–12.05 for a discussion of concrete as a construction material.

CSI MasterFormat 03 20 00 Concrete Reinforcing
CSI MasterFormat 03 30 00 Cast-in-place Concrete
CSI MasterFormat 03 31 00 Structural Concrete

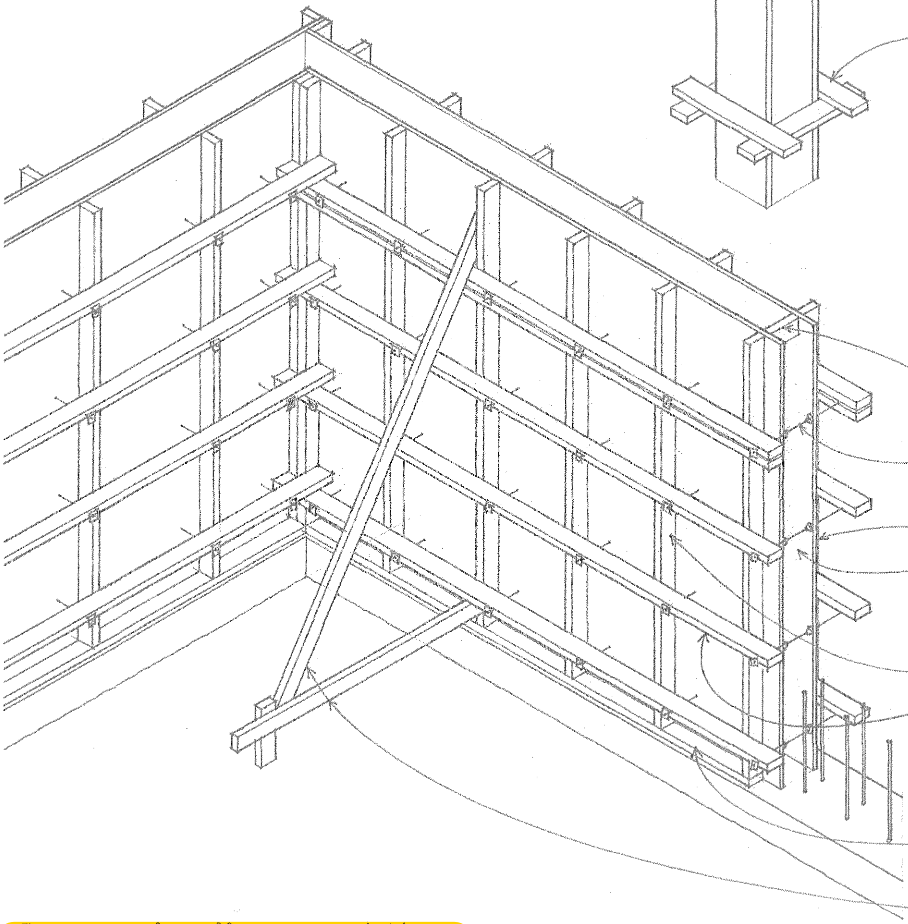
Concrete formwork for columns and walls may be custom-built for a specific job, but prefabricated, reusable panels are used whenever possible. The framework and bracing must be able to maintain the position and shape of the forms until the concrete sets.



Column Forms

- Fiber forms have a smooth or spiral pattern finish and are disposable.
- 1'-0" to 3'-6" (305 to 1065) in diameter
- Sonotube is a trademark for a brand of cylindrical column form made of compressed, resin-impregnated paper.

- Wood formwork
- Reusable forms may have a square or rectangular cross section.
- Yokes are clamping devices for keeping column forms and the tops of wall forms from spreading under the fluid pressure of newly placed concrete.



Wall Forms

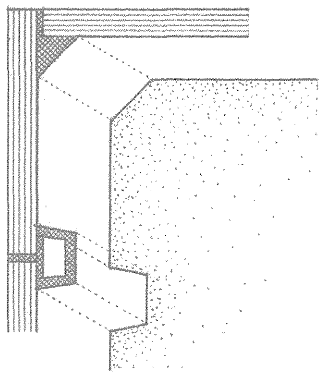
- Spreaders, usually of wood, space and keep the wall or forms apart.
- Form ties; see 5.08

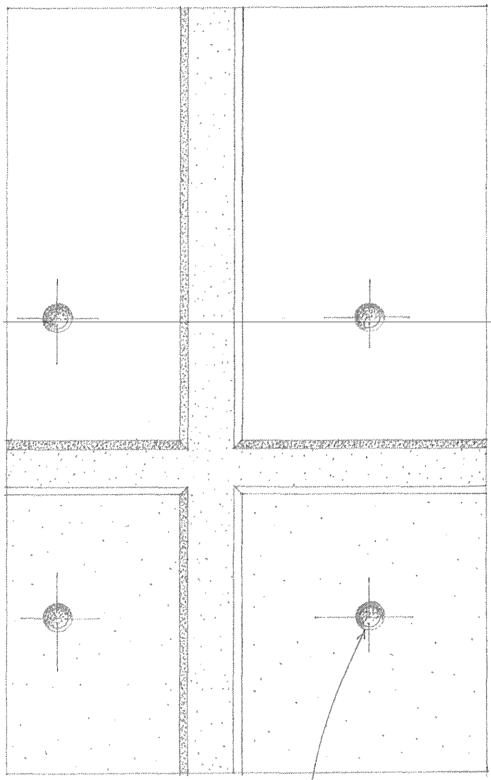
- Plywood sheathing
- Inner surface of panels leaves an impression on the concrete

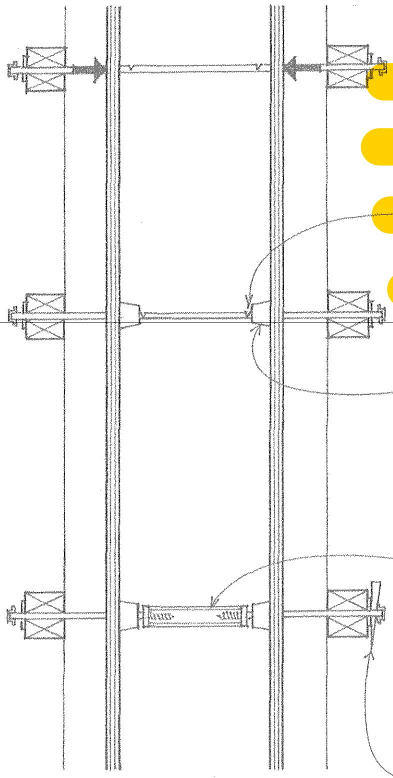
- Wood studs
- Horizontal walers reinforce the vertical members of formwork.
- If necessary, strongbacks provide vertical support for aligning and reinforcing walers.
- Sill plate

- Bracing

- The contact surfaces of forms are coated with a parting compound—oil, wax, or plastic—to aid in their removal. From a design standpoint, the shape of a concrete section must allow for the easy removal of the formwork. Tapered sections are used where the formwork might otherwise be trapped by the surrounding concrete. Sharp external corners are usually beveled or rounded to avoid chipping and ragged edges.



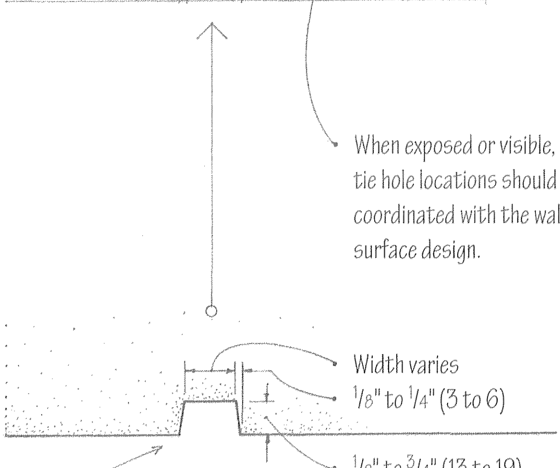




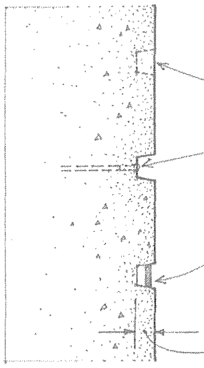
Form ties are required to keep wall forms from spreading under the fluid pressure of newly placed concrete. While various proprietary forms are available, there are two basic types: snap ties and she bolts.

- Snap ties have notches or crimps that allow their ends to be snapped off below the concrete surface after stripping of the forms. Either cones or washers are used to maintain the correct wall thickness.
- Small, truncated cones of wood, steel, or plastic, attached to form ties to space and spread wall forms, leave a neatly finished depression in the concrete surface to be filled or left exposed.
- She bolts consist of waler rods that are inserted through the form and threaded onto the ends of an inner rod. After stripping, the waler rods are removed for reuse while the inner rod remains in the concrete.
- A variety of wedges and slotted devices tighten the formwork and transfer the force in a form tie to the walers.

- When exposed or visible, the tie hole locations should be coordinated with the wall's surface design.



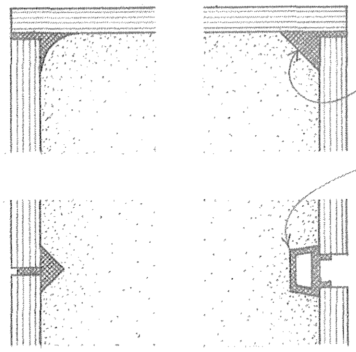
- Width varies
- 1/8" to 1/4" (3 to 6)
- 1/2" to 3/4" (13 to 19)



Tie holes may be:

- Patched to match the surrounding finish
- Left exposed with the exposed tie end epoxied
- Filled with a plastic cap
- 1-1/2" (38)

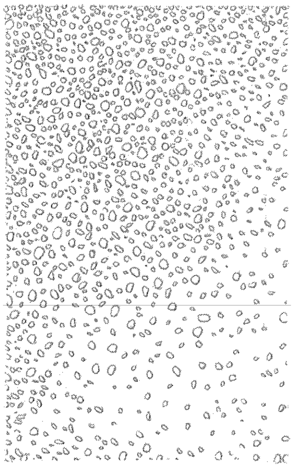
- Linear recesses can be used to create a pattern on the surface of a concrete wall, separate different wall surface treatments, and help conceal construction joints.



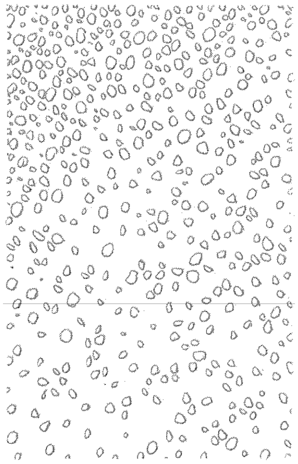
- Chamfer strips of wood or other material are attached to the inside of a form to produce a smooth, rounded, or beveled edge on the outside corner of a concrete member.
- Rustication strips of wood or other material are attached to the inside face of a form to produce a groove in the surface of a concrete member. These strips are also available as parts of plastic formliner systems.

CSI MasterFormat 03 11 16 Architectural Cast-in Place Concrete Forming
CSI MasterFormat 03 11 16.13 Concrete Form Liners

A variety of surface patterns and textures can be produced by the following methods.



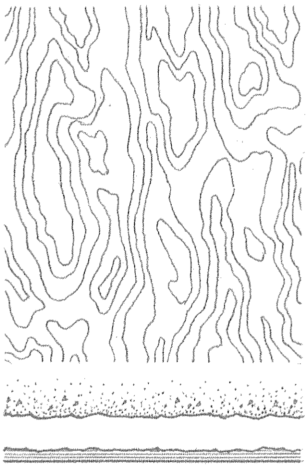
Exposed Fine Aggregate



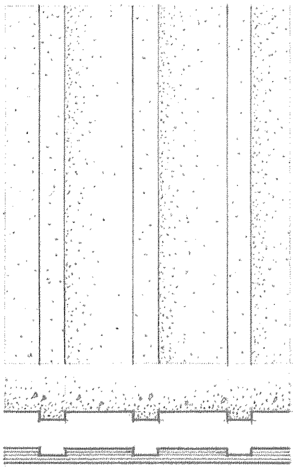
Exposed Coarse Aggregate

Selection of the Concrete Ingredients

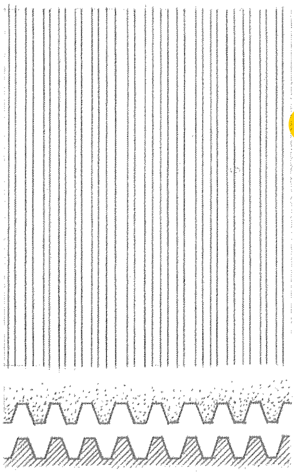
- The color of concrete can be controlled with the use of colored cement and aggregates.
- Exposed aggregate finishes are produced by sandblasting, etching with an acid, or scrubbing a concrete surface after the initial set in order to remove the outer layer of cement paste and expose the aggregate. Chemicals can be sprayed on the forms to help retard the setting of the cement paste.



Sandblasted Plywood



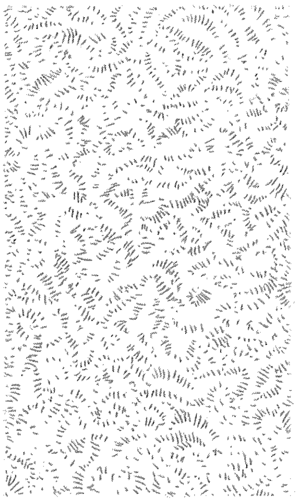
Board-and-Batten Pattern



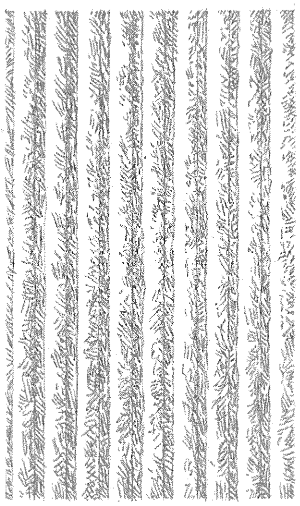
Ribbed Texture Formliner

The Impressions Left by the Forms

- Béton brut refers to concrete that is left in its natural state after formwork is removed, especially when the concrete surface reflects the texture, joints, and fasteners of a board form.
- Plywood forms can be smooth, or be sandblasted or wirebrushed to accentuate the grain pattern of the face ply.
- Sheathing lumber produces a board texture.
- Metal or plastic formliners can produce a variety of textures and patterns.



Bushhammered Surface

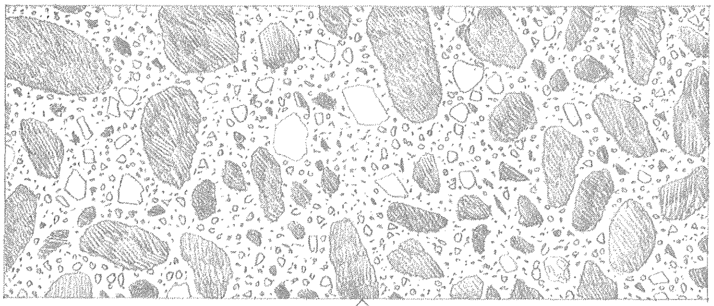


Ribbed Surface Bushhammered

Treatment after the Concrete Sets

- Concrete can be painted or dyed after it has set.
- The concrete surface can be sandblasted, rubbed, or ground smooth.
- Both smooth and textured surfaces can be bush- or jackhammered to produce coarser textures.
- Bushhammered finishes are coarse-textured finishes obtained by fracturing a concrete or stone surface with a power-driven hammer having a rectangular head with a corrugated, serrated, or toothed face.

12.04 CONCRETE



Concrete is made by mixing cement and various mineral aggregates with sufficient water to cause the cement to set and bind the entire mass. While concrete is inherently strong in compression, steel reinforcement is required to handle tensile and shear stresses. It is capable of being formed into almost any shape with a variety of surface finishes and textures. In addition, concrete structures are relatively low in cost and inherently fire-resistant. Concrete's liabilities include its weight—150 pcf (2400 kg/m^3) for normal reinforced concrete—and the forming or molding process that is required before it can placed to set and cure.

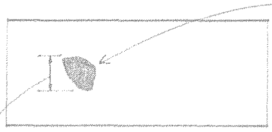
Cement

- Portland cement is a hydraulic cement made by burning a mixture of clay and limestone in a rotary kiln and pulverizing the resulting clinker into a very fine powder.

- Type I normal portland cement is used for general construction, having none of the distinguishing qualities of the other types.
- Type II moderate portland cement is used in general construction where resistance to moderate sulfate action is required or where heat buildup can be damaging, as in the construction of large piers and heavy retaining walls.
- Type III high-early-strength portland cement cures faster and gains strength earlier than normal portland cement; it is used when the early removal of formwork is desired, or in cold-weather construction to reduce the time required for protection from low temperatures.
- Type IV low-heat portland cement generates less heat of hydration than normal portland cement; it is used in the construction of massive concrete structures, as in gravity dams, where a large buildup in heat can be damaging.
- Type V sulfate-resisting portland cement is used where resistance to severe sulfate action is required.
- Air-entraining portland cement is a Type I, Type II, or Type III portland cement to which a small quantity of an air-entraining agent has been interground during manufacture; it is designated by the suffix A.

Water

- The water used in a concrete mix must be free of organic material, clay, and salts; a general criterion is that the water should be fit for drinking.
- Cement paste is a mixture of cement and water for coating, setting, and binding the aggregate particles together in a concrete mix.



- 1/3 the depth of a slab, 1/5 the thickness of a wall, or 3/4 of the clear space between reinforcing bars or between the bars and the formwork

Lightweight Concrete

- Structural lightweight concrete, made with expanded shale or slate aggregate, has a unit weight from 85 to 115 pcf (1362 to 1840 kg/m^3) and compressive strength comparable to that of normal concrete.
- Insulating concrete, made with perlite aggregate or a foaming agent, has a unit weight of less than 60 pcf (960 kg/ m^3) and low thermal conductivity.

Aggregate

- Aggregate refers to any of various inert mineral materials, as sand and gravel, added to a cement paste to make concrete. Because aggregate represents from 60% to 80% of the concrete volume, its properties are important to the strength, weight, and fire-resistance of the hardened concrete. Aggregate should be hard, dimensionally stable, and free of clay, silt, and organic matter that can prevent the cement matrix from binding the particles together.
- Fine aggregate consists of sand having a particle size smaller than 1/4" (6).
- Coarse aggregate consists of crushed stone, gravel, or blast-furnace slag having a particle size larger than 1/4" (6).
- The maximum size of coarse aggregate in reinforced concrete is limited by the size of the section and the spacing of the reinforcing bars.

Admixtures

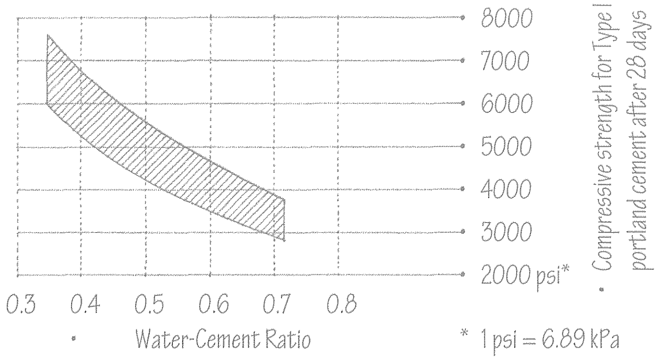
Admixtures may be added to a concrete mix to alter its properties or those of the hardened product.

- Air-entraining agents disperse microscopic, spherical air bubbles in a concrete mix to increase workability, improve resistance of the cured product to the cracking induced by free-thaw cycles or the scaling caused by deicing chemicals, and in larger amounts, to produce lightweight, insulating concrete.
- Accelerators hasten the setting and strength development of a concrete mix, while retarders slow the setting of a concrete mix in order to allow more time for placing and working the mix.
- Surface-active agents, or surfactants, reduce the surface tension of the mixing water in a concrete mix, thereby facilitating the wetting and penetrating action of the water or aiding in the emulsifying and dispersion of other additives in the mix.
- Water-reducing agents, or superplasticizers, reduce the amount of mixing water required for the desired workability of a concrete or mortar mix. Lowering the water-cement ratio in this manner generally results in increased strength.
- Coloring agents are pigments or dyes added to a concrete mix to alter or control its color.

CSI MasterFormat Division 03 – Concrete

Water-Cement Ratio

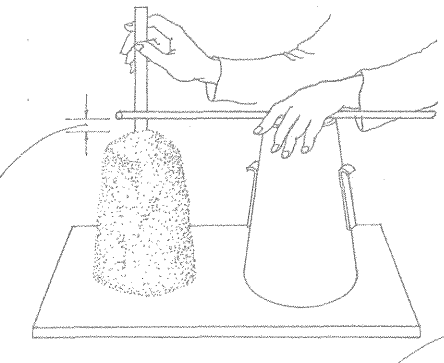
Water-cement ratio is the ratio of mixing water to cement in a unit volume of a concrete mix, expressed by weight as a decimal fraction or as gallons of water per sack of cement. The water-cement ratio controls the strength, durability, and watertightness of hardened concrete. According to Abrams' law, formulated by D. A. Abrams in 1919 from experiments at the Lewis Institute in Chicago, the compressive strength of concrete is inversely proportional to the ratio of water to cement. If too much water is used, the concrete mix will be weak and porous after curing. If too little water is used, the mix will be dense but difficult to place and work. For most applications, the water-cement ratio should range from 0.45 to 0.60.

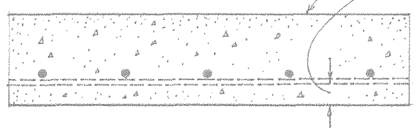


* 1 psi = 6.89 kPa

Concrete is normally specified according to the compressive strength it will develop within 28 days after placement (7 days for high-early-strength concrete).

- Slump test is a method for determining the consistency and workability of freshly mixed concrete by measuring the slump of a test specimen, expressed as the vertical settling, in inches, of a specimen after it has been placed in a slump cone, tamped in a prescribed manner, and the cone is lifted.
- Compression test for determining the compressive strength of a concrete batch uses a hydraulic press to measure the maximum load a test cylinder 6" (150) ø and 12" (305) high can support in axial compression before fracturing.





Reinforced concrete slab

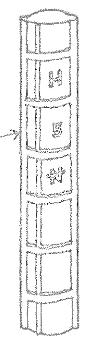
3/4" (19) minimum for #5 bars and smaller; 1-1/2" (38) minimum when exposed to weather; 2" (51) minimum for #6 bars and larger

- Reinforcing steel must be protected by the surrounding concrete against corrosion and fire. Minimum requirements for cover and spacing are specified by the American Concrete Institute (ACI) *Building Code Requirements for Reinforced Concrete* according to the concrete's exposure, and the size of the coarse aggregate and steel used.
- For minimum coverage of steel reinforcement in other concrete members, see 3.08 for spread footings, 4.04 for concrete beams, 5.04 for concrete columns, and 5.06 for concrete walls.

Steel Reinforcement

Because concrete is relatively weak in tension, reinforcement consisting of steel bars, strands, or wires is required to absorb tensile, shearing, and sometimes the compressive stresses in a concrete member or structure. Steel reinforcement is also required to tie vertical and horizontal elements, reinforce the edges around openings, minimize shrinkage cracking, and control thermal expansion and contraction. All reinforcement should be designed by a qualified structural engineer.

- Reinforcing bars are steel sections hot-rolled with ribs or other deformations for better mechanical bonding to concrete. The bar number refers to its diameter in eighths of an inch—for example, a #5 bar is 5/8" (16) in diameter.
- Welded wire fabric consists of a grid of steel wires or bars welded together at all points of intersection. The fabric is typically used to provide temperature reinforcement for slabs but the heavier gauges can also be used to reinforce concrete walls. The fabric is designated by the size of the grid in inches followed by a number indicating the wire gauge or cross-sectional area; see 3.18 for typical sizes.



ASTM Standard Reinforcing Bars

Bar Size	Nominal Dimensions		
	Diameter inches (mm)	Cross-Sectional Area sq. in. (mm²)	Weight plf (N/m)
#3	0.375 (10)	0.11 (71)	0.38 (5.5)
#4	0.50 (13)	0.20 (129)	0.67 (9.7)
#5	0.625 (16)	0.31 (200)	1.04 (15.2)
#6	0.75 (19)	0.44 (284)	1.50 (21.9)
#7	0.875 (22)	0.60 (387)	2.04 (29.8)
#8	1.00 (25)	0.79 (510)	2.67 (39.0)
#9	1.125 (29)	1.00 (645)	3.40 (49.6)
#10	1.25 (32)	1.27 (819)	4.30 (62.8)