New 2018

Civilittee

اللجنة الأكاديمية للهندسة المدنية

سلايدات

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Earth Materials & Excavation

Earth Materials

Classifying Earth Materials

- Rock: continuous mass of solid mineral material
  - Generally, the strongest, most stable of earth materials on which a building can be founded.
  - Strength varies with mineral content and physical structure
- Soil: any earth material that is particulate
  - Characteristics and suitability for foundation support vary with particle size and shape, mineral content, and sensitivity to moisture content

Soils Classified by Size

- ***Boulder:*** Individual particle of soil is too big to lift with one hand or requires two hands to lift
- ***Cobble:*** Can be lifted in one hand (takes the whole hand to lift a particle)
- ***Coarse-grained soils***
  - ***Gravel***: Individual particles can be lifted between thumb and forefinger
  - ***Sand***: particles individual soil particles can be seen but are too small to be picked up individually
- ***Fine-grained soils:*** individual particles are too small to see with naked eye
  - ***Silt***: roughly spherical in shape
  - ***Clay***: very small, plate-shaped particles and smaller than silt particles

- **Organic Soils**

- Peat, topsoil and other soils with organic content
  - Generally weak, unstable, and not suited for supported building foundations

Soil Properties I

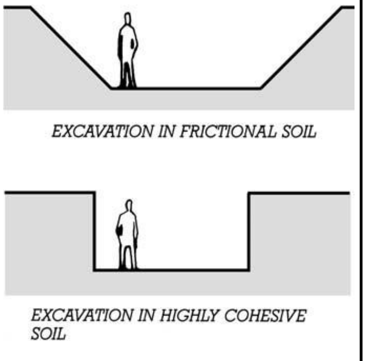
- Coarse-grained Soils (gravel, sand)
  - Don’t stick together when wet; *cohesionless* (Frictional)
  - When unconfined, have little strength
  - Structural properties little affected by moisture content
  - Free-draining; best at draining water away from foundations and substructures

Soil Properties II

- Fine-grained soils (silt, clay)
  - Smaller particle size, less free draining
  - When wet, may be subject to liquefaction during seismic events
  - Drainage characteristics vary
  - Varying degrees of cohesiveness (tendency to stick together)

Soil Properties III

- Clays
  - Particles so small that electrostatic forces cause particles to stick together; *cohesive* soil
  - Structural properties vary greatly with moisture content and mineral composition
  - Some are highly expansive when wetted
  - Some are virtually impervious to water



Soil Particle Grading

- *Well graded* soil: Coarsegrained soils consisting of particles of all sizes (*poorly sorted)*
- *Well sorted* soil: limited range of particle sizes; most void space, most free draining (*poorly graded*)

Soil for Building Foundations

Generally, coarse-grained soils are more desirable for supporting building foundations than fine-grained soils

- Tend to have greater loadbearing capacity
- Tend to be more stable, and to react less to changes in moisture content.
- Rock is generally the best material on which to found a building.

Presumptive Soil Loadbearing Capacity

Generally, the larger the particle size, the greater the bearing capacity of the soil.

TABLE 1804.2
ALLOWABLE FOUNDATION AND LATERAL PRESSURE

CLASS OF MATERIALS	ALLOWABLE FOUNDATION PRESSURE (psf)[d]	LATERAL BEARING (psf/f below natural grade)[d]	LATERAL SLIDING: Coefficient of friction[a]	LATERAL SLIDING: Resistance (psf)[b]
1. Crystalline bedrock	12,000	1,200	0.70	—
2. Sedimentary and foliated rock	4,000	400	0.35	—
3. Sandy gravel and/or gravel (GW and GP)	3,000	200	0.35	—
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel (SW, SP, SM, SC, GM and GC)	2,000	150	0.25	—
5. Clay, sandy clay, silty clay, clayey silt, silt and sandy silt (CL, ML, MH and CH)	1,500[c]	100	—	130

For SI: 1 pound per square foot = 0.0479 kPa, 1 pound per square foot per foot = 0.157 kPa/m.
a. Coefficient to be multiplied by the dead load.
b. Lateral sliding resistance value to be multiplied by the contact area, as limited by Section 1804.3.
c. Where the building official determines that in-place soils with an allowable bearing capacity of less than 1,500 psf are likely to be present at the site, the allowable bearing capacity shall be determined by a soils investigation.
d. An increase of one-third is permitted when using the alternate load combinations in Section 1605.3.2 that include wind or earthquake loads.

EXCAVATION

Excavation

At least some *excavation is required* for every building:

– To remove organic topsoil because it is unsuitable for supporting buildings

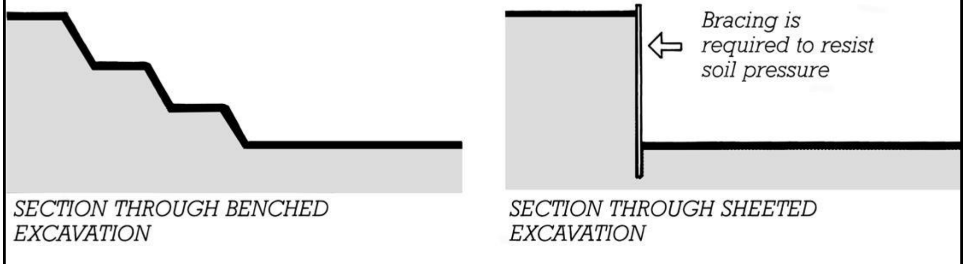
– To place the footings at a depth where soil of the appropriate bearing capacity is available.

– To add one or more levels of basement space to a building (for additional habitable rooms, for parking, or for mechanical equipment and storage)

– To place the footings out of reach of water and wind erosion, and to place the footings below the level to which the ground freezes in winter (frost line) in colder climates

Excavation Support

Sloped or benched excavation is less expensive than sheeted excavation, but requires a site without nearby property lines, adjacent structures, or other limits on excavation.



Excavation Support II

Excavation support can take many forms, depending on the qualities of the soil, depth of excavation, equipment and preferences of the contractor, proximity of surrounding buildings, and level of the water table

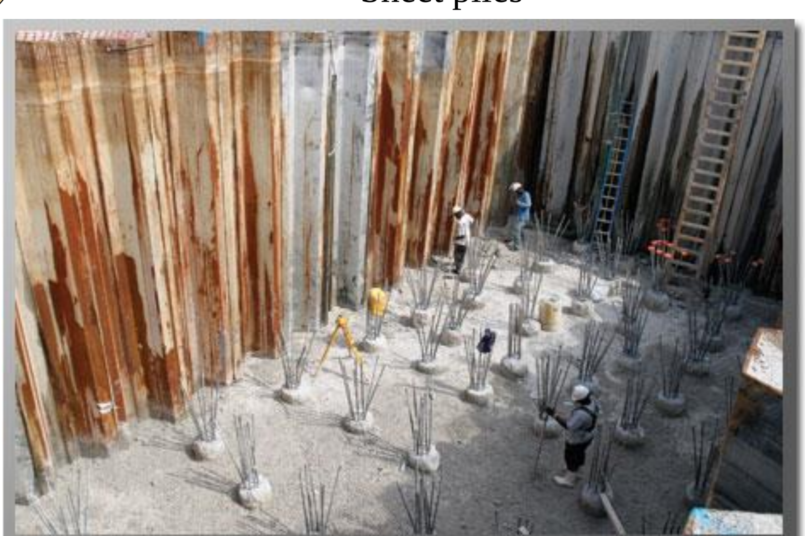
- **Shoring**
  - Soldier beams and lagging
  - Sheet piling.
  - Shotcrete

Excavation Support III

Solider beams and lagging

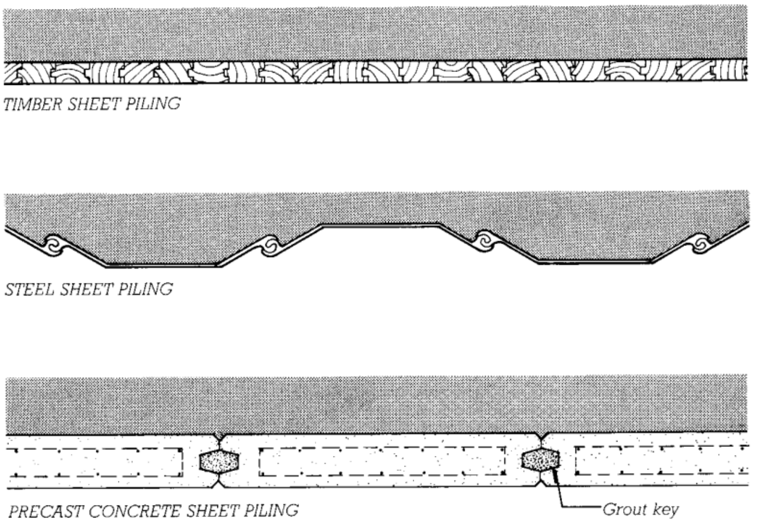
Excavation Support IV

Sheet piles



Excavation Support V

Sheet piles



Excavation Support VI

- Pneumatically applied concrete (shotcrete): excavation proceeds first and then the sloped sides are reinforced with a relatively stiff concrete mixture sprayed directly from a hose onto the soil.

Excavation Support VII

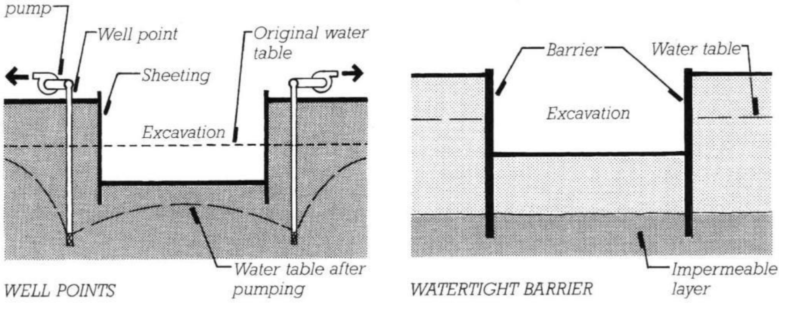
Slope support consisting of soldier beams and shotcrete braced by rakers, followed by waterproofing and cast in place concrete foundation wall

Excavation Support VIII

Soil mixed slope support, with soldier beams, walers, and tie backs

Dewatering I

- Simple: pump water from pits (*sumps)* in the excavation
- Higher volumes of water: use *well points* or *barrier wall*



Dewatering II

- Well points, header pipe, and dewatering pump

Foundations

Foundations

- The function of a foundation is to transfer the structural loads reliably from a building into the ground.
- A building foundation must support different kinds of loads:
  - Dead load
  - Live loads
  - Rain and snow loads
  - Wind loads
  - Seismic loads
  - Loads caused by soil and hydrostatic pressure

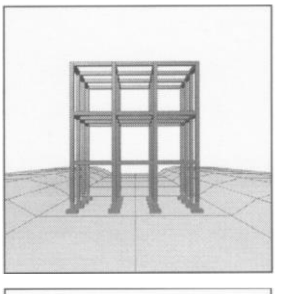
Foundation Requirements

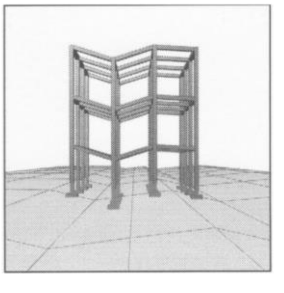
- Must transmit building loads to the rock or soil on which it rests
- Must not fail, resulting in building collapse
- Must not settle so much as to damage structure or impair function
- Must be economically and technically feasible, and without adverse affects on surrounding structures

July 2004 SAI building collapse, Manila, due to faulty foundation

Foundation Settlement

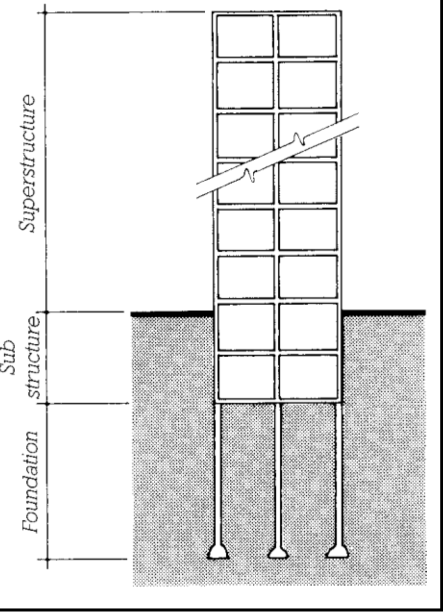
- All foundations settle to some extent as the earth materials around and beneath them adjust to the loads of the building
- Uniform settlement: May disrupt building services where they enter building, or damage elements, such as stairs and walks, at the building/site interface
- Differential settlement: May cause damage to finishes, cladding, and other components where building becomes distorted.





Building Components

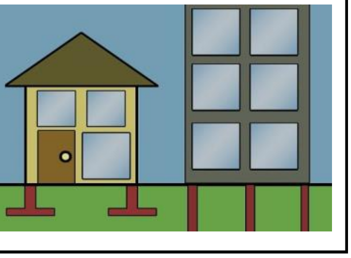
- Buildings consist of three major parts:
  - Superstructure: The aboveground portion of the building
  - The substructure, which is the habitable below-ground portion;
  - Foundations: The components of the building that transfer its loads into the soil



Types of Foundations I

Two basic types of foundations:

1. **Shallow foundations:** Transfer the load to the earth at the base of the column or wall of the substructure.
2. **Deep foundations (either piles or caissons):** penetrate through upper layers of incompetent soil in order to transfer the load to competent bearing soil or rock deeper within the earth.

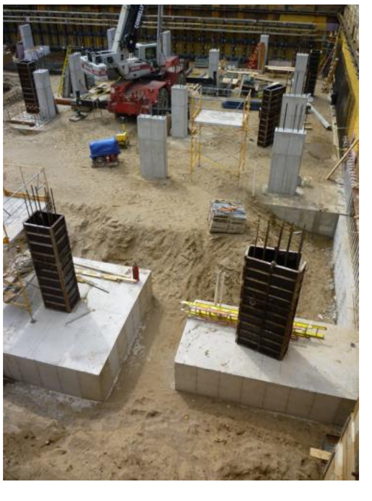


Types of Foundations II

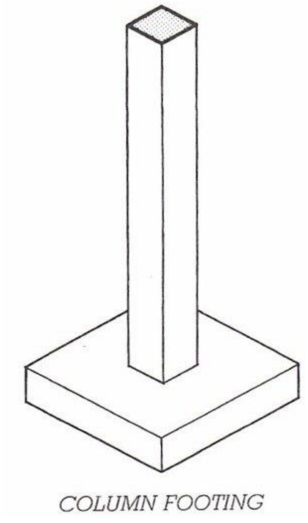
- The primary factors that affect the choice of a foundation type for a building:
  - Subsurface soil and groundwater conditions
  - Structural requirements, including foundation loads, building configurations, and depth
- Secondary factors:
  - Construction methods
  - Environmental factors
  - Building codes and regulations
  - Proximity of adjacent property and potential impacts on that property
  - Time available for construction
  - Construction risks

Shallow Foundations

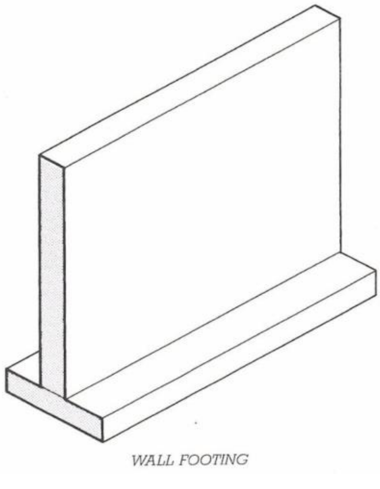
- Column Footing
- Wall Footing (Strip Footing)
- Combined footing and cantilevered footing
- Mat or Raft foundation
- Floating Foundation



Column Footing

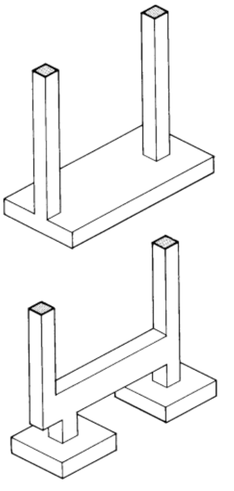


Wall Footing (Strip Footing)



Combined and Cantilevered Footing

- Used when columns are on the border of a property line.
- By combining the foundation for the column against the property line, at the left, with the foundation for the next interior column to the right in a single structural unit, a balanced footing design can be achieved.

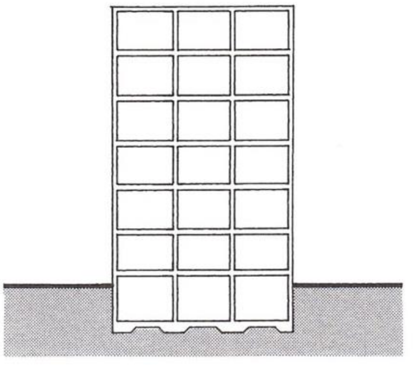


Mat or Raft Foundation

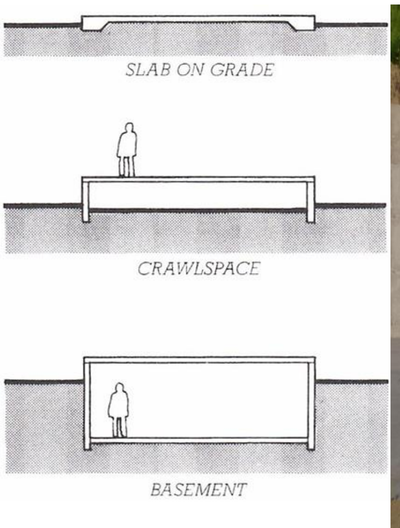
- Used when the allowable bearing capacity of the soil is low in relation to the weight of the building
- Mats for very tall buildings may be 6 feet (1.8 m) thick or more and are heavily reinforced

Floating Foundation

- Balances the weight of soil removed with the weight of building to be constructed
- The load on the remaining soil is little changed.

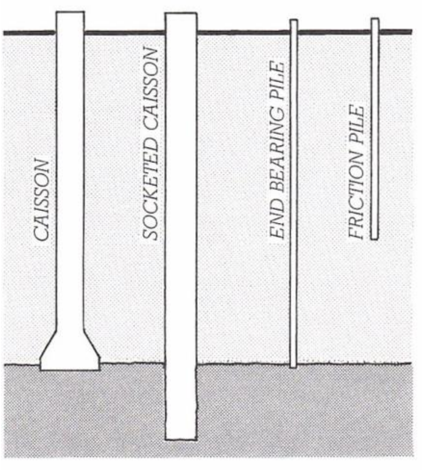


Slab on Grade, Crawlspace, and Basement



Deep Foundations

- Where the soils directly below the building substructure are weak or unstable, deep foundations transmit building loads to deeper, more competent, soils.
- Caissons: Concrete cylinders poured into drilled holes
- Piles: driven into the earth.



Piers (caissons): Drilled into earth

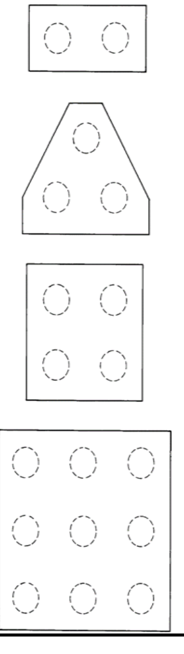
- Steel reinforcing is being lowered into the drilled hole. Once the reinforcing is positioned, concrete will be poured.

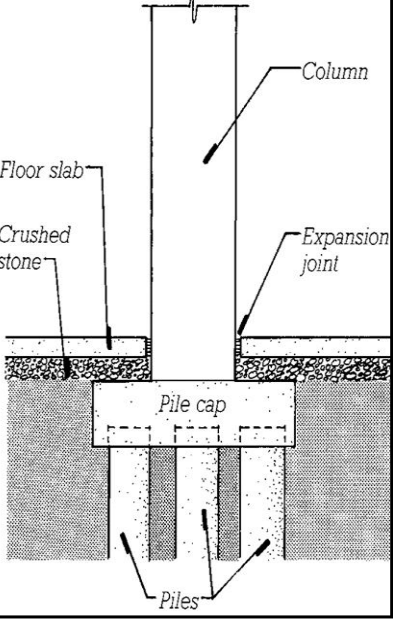
Piles: Driven into Earth

- A pile is distinguished from a caisson by being forcibly driven into the earth rather than drilled and poured
- May be made of steel, wood, or precast concrete (pictured here)

Piles

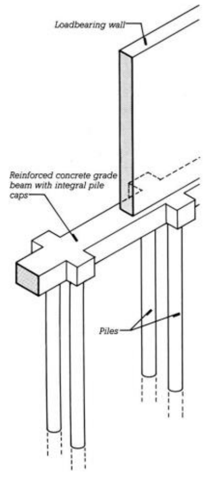
- Right: An elevation view of a pile cap, column, and floor slab.
- Left: Clusters of two, three, four, and nine piles with their concrete caps, viewed from above.





Piles and Grade Beam

- Pile caps share loads among clustered piles.
- A grade beam spans between the piles to provide continuous support for the wall above.



Drilled Piers and Grade Beams

- Reinforcing bars project from the tops of completed drilled piers. Gravel is being deposited between the piers, to form a base for concrete grade beams which will span between the piers.

Waterproofing & Drainage

To ensure a substructure’s resistance to water entry, two approaches are used:
Drainage: draws groundwater away from a foundation, reducing the volume and pressure of water acting on the foundation’s walls and slabs.
Waterproofing. Acts as a barrier, stopping water that reaches the foundation from passing though to the interior.

Dampproofing & Waterproofing I

- Dampproofing : The spray of asphaltic layer on the foundation or basement wall.
  - Less expensive and less resistant to water passage than true waterproofing, and used where groundwater conditions are mild or waterproofing requirements are not critical

Dampproofing & Waterproofing II

- Waterproofing: Materials are resistant to hydrostatic pressure.
  - Includes a sprayed sealer that is covered with a membrane that waterproofs the wall.
  - It can prevent the passage of water even under conditions of hydrostatic pressure
  - Waterproof membranes are most commonly formulated from plastics, asphalt compounds, or synthetic rubbers

Drainage I

- Drainage mat and free-draining backfill material allow ground water to flow away from the substructure.
- The machine in the foreground is used to compact the fill material as it is placed in *lifts* roughly 6 inches deep at a time.

Drainage II

- Perforated piping conducts water away from the substructure.
- Filter fabric "socks" cover the piping to prevent soil particles from accumulating in and eventually clogging the pipes.
- The upturned elbow will be connected to a cleanout fitting at grade that permits future snaking of the piping to remove blockages if needed.

Concrete Construction,
(Cement and Concrete)

Concrete Advantages

- The raw ingredients for its manufacture are readily available in almost every part of the globe
- Concrete can be made into buildings with tools ranging from a primitive shovel to a computerized precasting plant
- Concrete does not rot or burn
- It is relatively low in cost
- It can be used for every building purpose, from simple pavings to sturdy structural frames to handsome exterior claddings and interior finishes.

History I

- Romans were the inventors of concrete construction.
  - Earliest concrete, 300 BC
  - *Pozzolanic ash:* Volcanic ash originally found at Pozzuoli, Italy; high in silica and alumina content
  - When pozzolanic ash was mixed with lime, water, sand, and rock, the resulting mixture would harden to an unusually strong material, even when fully submerged under water.

- Hydraulic cement: Cement that when hardened, is not water soluble

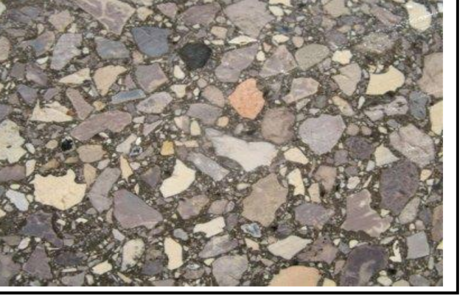
History II

- **Modern Concrete**
  - Knowledge of hydraulic cements is lost with the fall of the Roman Empire.
  - Hydraulic cements are rediscovered in the latter part of the18th century in England.
  - 1824: Joseph Aspdin patents *Portland Cement,* an artificial hydraulic cement made from a finely ground mixture of limestone and clay. This name for hydraulic cement remains in use to today.
  - The embedding of steel reinforcing in concrete, to increase concrete's tensile strength and resilience, is the other key component of modern concrete.
    - Steel reinforced concrete first appears in the 1850's.

Concrete Ingredients

- **Fine aggregate** (sand)
- **Coarse aggregate** (gravel): Coarse and fine aggregate provide the structural mass of the concrete and constitute the majority of the concrete volume.
- **Portland cement**: Cement binds the aggregate.
- **Water**: Water is necessary for the chemical hydration of the cement and the hardening of the concrete.

In the finished concrete, aggregate particles are surrounded by the cement and bound into a solid mass.

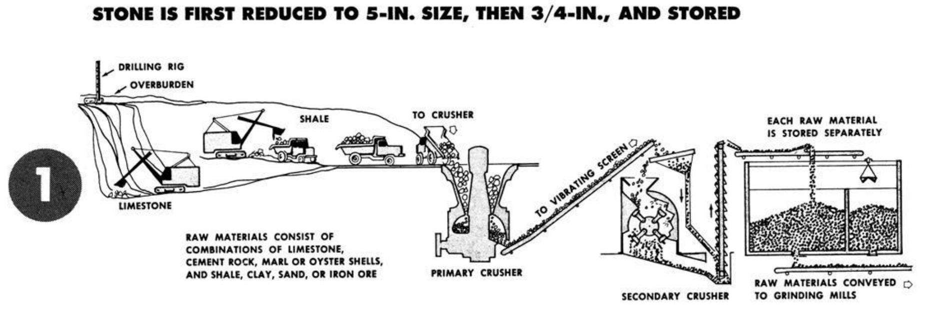


Portland Cement I

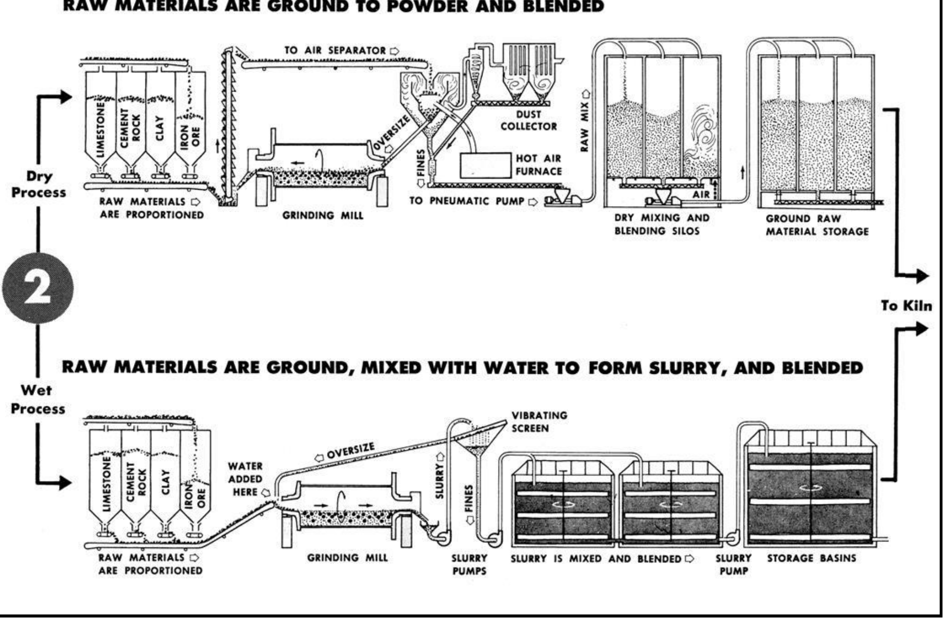
- Primary ingredient: Calcium silicates
- Lesser amounts of compounds of aluminum, iron, and magnesium
- Raw materials can be extracted from a variety of sources depending on the location, such as limestone, chalk, marl, marble, clays, shales, industrial waste materials, iron ore, bauxite, and others.
- Materials are crushed, ground, proportioned and blended into a very fine powder.
- The blended materials are burn in a high-temperature, rotating kiln (1400-1650^{o}C), creating *clinker.*

Portland Cement II

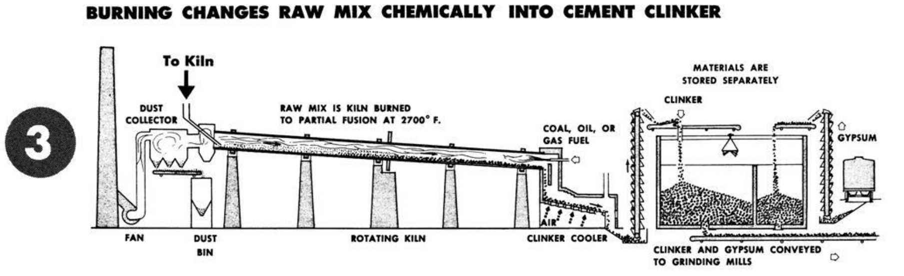
- The clinker is cooled and ground to a fine powder (finer than flour).
- Small quantities of gypsum are added to adjust the cement's setting rate (retardant).
- This finished powder, Portland cement, is either packaged in bags or shipped in bulk.



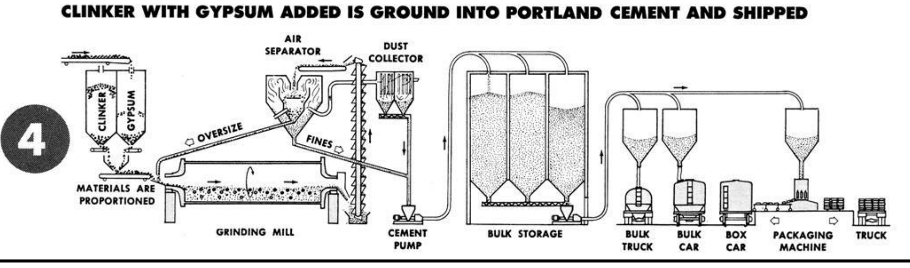
Portland Cement III



Portland Cement IV



The cement kiln is gently sloped, so that as it rotates, the cement ingredients travel down the slope at a controlled rate.



Portland Cement V

Cement clinker after emerging from the cement kiln

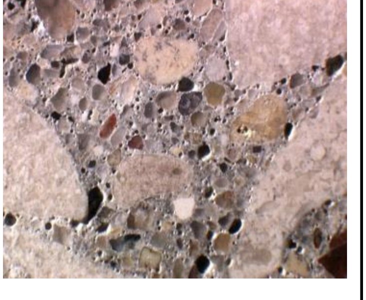
ASTM C150 Cement Types

- *Type I:* General purpose
- *Types II* and *Type V:* For concrete in contact with soils or water with high sulfate concentrations
- *Type III:* For cold weather construction, concrete precast in plants, accelerated construction schedules
- *Type IV:* For massive structures, such as dams, where the heat generated during hydration must be limited to avoid excessive temperatures

ASTM C150	Description
Type I	Normal
Type IA	Normal, air entraining
Type II	Moderate resistance to sulfate attack
Type IIA	Moderate resistance to sulfate attack, air entraining
Type III	High early strength
Type IIIA	High early strength, air entraining
Type IV	Low heat of hydration
Type V	High resistance to sulfate attack

Air-Entraining Cement I

- Ingredients added to the cement generate microscopic air bubbles during concrete mixing that create small, distributed voids in the finished concrete.



  - Typically, air content is in the range of 2 to 8 percent of the total concrete volume
  - Air entraining reduces concrete strength, unless the proportions of other ingredients in the concrete mix are adjusted to compensate.

Air-Entraining Cement II

- Air-entrained concrete:
  - Has greater resistance to freeze-thaw damage. It is use for concrete exposed to wet, freezing conditions
  - Has improved workability during placement of the concrete
- Most air-entrained concrete is made with admixtures added separately to the concrete mix rather than with air-entraining cements
  - Separate admixtures allow greater control over amount and quality of air entraining in the final concrete

Portland Cement and Carbon Dioxide Emissions

- Cement production is a significant source of emissions of carbon dioxide (CO_2), a greenhouse gas.
  - The burning of fuel to heat the cement kiln generates CO_2.
  - The chemical conversion of limestone (calcium carbonate) within the kiln releases additional large quantities of CO_2.
  - In total, manufacturing 1000 pounds of portland cement generates on average roughly 900 pounds of carbon dioxide.

Simplified chemistry of the cement kiln:

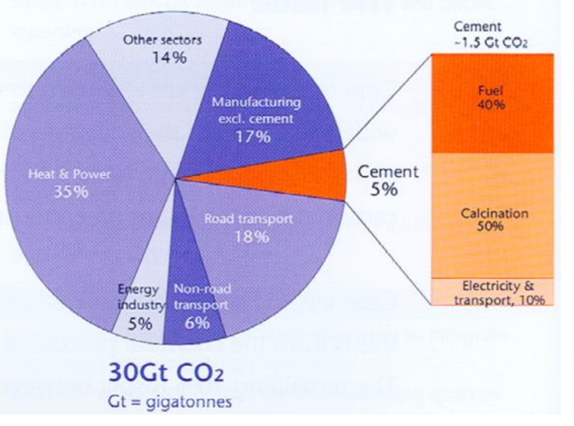
Limestone + silica (2700 deg F) = portland cement + carbon dioxide

$$5CaCO_3 + 2SiO_2 \rightarrow (3CaO, SiO_2)(2CaO, SiO_2) + 5CO_2$$

Portland Cement and Carbon Dioxide Emissions

- Cement production accounts for approximately 5 percent of worldwide CO_2 emissions

Worldwide CO_2 emissions from cement production



White Portland Cement

- Produced by controlling the quantities of certain minerals, such as oxides of iron and manganese, found in the ingredients of cement, that contribute to cement's usual gray color.
  - Used for architectural applications to produce concrete that is lighter and more uniform in color or, when combined with other coloring agents, to enhance the appearance of colored concrete.

Aggregates I

- Coarse and fine aggregate make up 60 to 80 percent of the total concrete volume.
- Most aggregate comes from natural sand and gravel deposits or is made from crushed rock.
- Artificial aggregates may come from:
  - Blast furnace slag
  - Fly ash
  - Recycled concrete
  - Thermally treated clay, shale, and other minerals

Aggregates II

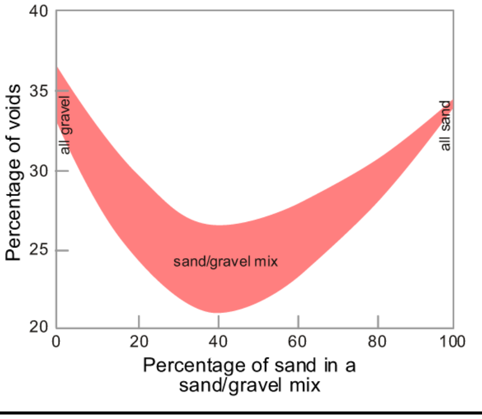
- Strength of concrete is heavily dependent on the quality of the aggregates:
  - Porosity
  - Size distribution (Grading)
  - Moisture absorption
  - Shape and surface texture
  - Strength, elasticity, density, soundness
  - Contamination or detrimental substances

Aggregate Size Distribution I

- Grading: Distribution of aggregate particle sizes
  - Generally, a lower percentage of void space between particles results in a stronger concrete that requires less cement.
  - When identically-sized particles are closely packed, the void space remaining between particles is approximately 30 to 35 percent of the total volume.
  - To reduce void volume, a graded range of aggregates varying in size is used so that smaller particles fill the spaces between larger particles and a denser packing is achieved.

Aggregate Size Distribution II

- Aggregate grading also affects workability of wet concrete. An optimum balance of characteristics is achieved in concrete mixes with void volumes somewhat greater than the least possible.



Maximum Aggregate Size I

- Generally, with larger aggregates, less cement is required in the concrete mix.
  - Reducing the quantity of cement reduces cost, since cement is the most expensive ingredient in the mix.
- The largest aggregate must fit comfortably between reinforcing bars and within the overall thickness of the concrete. Largest aggregate size should not exceed:
  - 1/5 distance between form faces
  - 3/4 of the space between reinforcing bars
  - 1/3 the depth of a slab

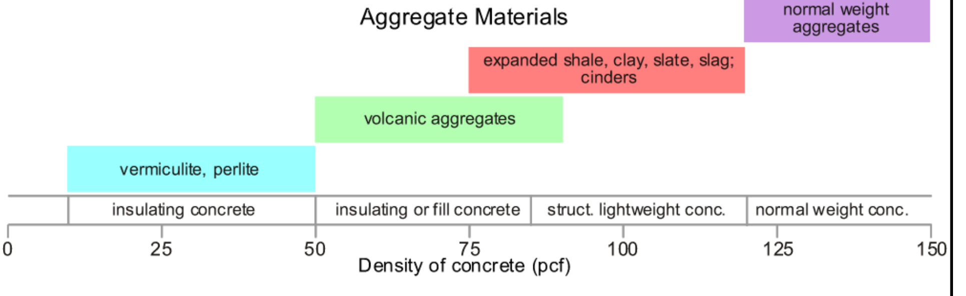
Maximum Aggregate Size II

- Common maximum aggregate size for concrete used in buildings ranges from 3/8 to 1-1/2 in. (19-mm or 38-mm)

Lightweight Aggregates I

- Used to make lighter-weight concrete
- *Structural lightweight concrete:*
  - Roughly 80 percent or less of the weight of ordinary concrete
  - Reduced structure weight saves costs
  - Lower thermal conductivity increases resistance to building fires
- *Nonstructural lightweight concrete:*
  - Roughly 60 percent or less of the weight of ordinary concrete
  - Insulating roof toppings
  - Fill material

Lightweight Aggregates II



- Expanded shale, clay, slate, slag: Minerals or industrial waste products thermally treated such that they expand and take on a less dense, cellular structure
- Cinders and other volcanic rocks: Naturally occurring light-weight volcanic materials
- Vermiculate: Thermally expanded mica
- Perlite: Thermally expanded volcanic glass

Water

- Water is an essential ingredient in concrete, that combines chemically with the cement as the concrete hardens.
- Water must be free of contaminants.
  – Water that is potable is acceptable for use in making concrete.
- The quantity of water in the concrete mix must be controlled as closely as any other ingredient:
  – Adding unneeded water dilutes the cement paste, weakening the hardened concrete.

Admixtures I

- **Admixtures:** Other ingredients in the concrete mix used to alter or improve concrete properties in various ways:
  – Air-entraining
  – Water-reducing
  – Cure accelerating or retarding
  – Workability modifying
  – Shrinkage-reducing
  – Corrosion inhibiting
  – Freeze protecting (for cold weather concreting)
  – Coloring

Admixtures II

- Example: High-strength concrete for very tall buildings:
  - Supplementary cementitious materials (SCMs), for greater strength
  - Water reducers, to increase concrete strength while maintaining workability
  - Admixtures to improve pumpability
  - Retarding admixtures, to allow adequate time for placing

Supplementary Cementitious Materials (SCM) I

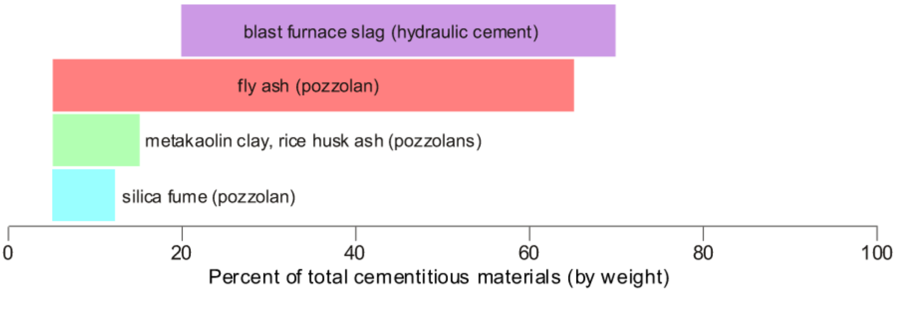
- Materials added to concrete as a partial substitute for portland cement to achieve various benefits:
  - Increased concrete strength and durability
  - Higher early strength
  - Improved workability of wet concrete
  - Reduced concrete drying shrinkage
  - Reduced reliance on Portland cement

Supplementary Cementitious Materials (SCM) II

- *Pozzolans:* Materials that react with hydration byproducts in wet concrete to form additional hydraulic cementing compounds
  - Pozzolans require the presence of a other cementing ingredients with which to react. They are not, on their own, hydraulic cements.
- *Hydraulic cements:* Materials with inherent hydraulic cementing properties
  - Hydraulic cements do not require the presence of other cementing materials with which to react so as to function as hydraulic cement.

Supplementary Cementitious Materials (SCM) III

- Over half of all North American concrete includes SCMs in the mix.
- Use of SCMs can reduce the embodied energy of finished concrete by as much as one-third.
- Use of industrial waste SCMs diverts these materials from landfills.



Making and Placing Concrete

Content

- Concrete Quality
- Concrete Strength
- Water-Cement Ratio
- Mixing Concrete
- Testing Concrete
- Placing Concrete
- Consolidating Concrete
- Curing Concrete
- Formwork

Concrete Quality I

- Workability: Ease of placing, consolidating, and finishing wet concrete
- Structural properties when hardened: Strength, stiffness, durability
- Many other important properties:
  - Rate of early strength gain
  - Degree of shrinkage during curing
  - Flatness, for slabs and paving
  - Surface hardness, for industrial slabs
  - Porosity
  - Density
  - Surface appearance, for architectural concrete

Concrete Quality II

- Resistance to freeze/thaw and weather, for exterior concrete
- Water tightness, for dams, tanks, exterior walls

Concrete Quality III

- The rules for making high-quality concrete:
  - Use clean, sound ingredients
  - Mix ingredients in the correct proportions;
  - Handle the wet concrete properly to avoid segregating its ingredients
  - Cure the concrete carefully under controlled conditions

Concrete Strength I

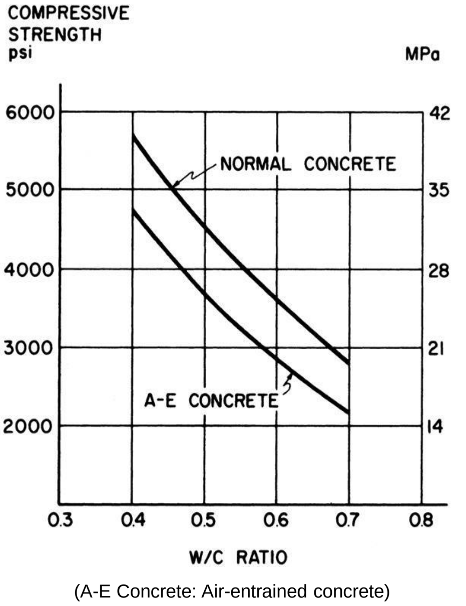
- Concrete strength varies with design of the concrete mix.
- Normal strength concrete
  - Up to 6000 psi (421.8 kg/cm^2) compressive strength
  - Made with conventional ingredients
- High-strength concrete
  - Greater than 6000 psi to roughly 20,000 psi (421.8-1406 kg/cm^2)
  - Supplementary cementitious materials are required to reach higher strengths
  - Lower water content is required for higher strength
    - Water reducing admixtures or high-range water reducing admixtures (superplasticizers) are used to improve workability.

Concrete Strength II

- Specially formulated, ultra-high performance concretes: have compressive strengths as high as 30,000 psi. (2109 kg/cm^2)
- Why use higher-strength concrete:
  - Reduce column dimensions in tall buildings
  - Achieve higher earlier strength, allowing construction to proceed more quickly
  - Satisfy more strict structural requirements
- The *water-cement ratio* (*w/c ratio*) is the most important determinant of concrete strength.

Water-Cement Ratio

- Lowering the proportion of water to cement:
  - Increases concrete strength and durability
  - Decreases workability
  - Increases cost
- W/C ratio is measured by weight, not volume.
- When supplementary cementitious materials are added to the mix, the ratio is measured as the *water-cementitious materials ratio.*



(A-E Concrete: Air-entrained concrete)

Mixing Concrete

- Most concrete is prepared at batch plants and delivered to the construction site in *transit-mix (ready mix) trucks*.
- The concrete ingredients are mixed in the rotating drum of the truck so that the concrete is ready to pour on arrival at the construction site.
- Smaller batches of concrete may be prepared on site by hand or with the aid of portable power mixers.

Testing Concrete I

- **Slump Test:**
  - – The slump test provides a rough measure of the workability of concrete while wet.
  - – Concrete is placed into a conical cylinder; the cylinder is removed, and the loss in height of the concrete mass is measured.
    - Concrete with too low slump may be difficult to place.
    - Concrete with too high slump may have had too much water added.
  - – Slump tests are performed on batches of concrete as they arrive on the concrete site.

Testing Concrete II

- **Slump Test:**
  - Specified maximum slump is usually in the range of 3 to 5 inches.

Testing Concrete III

- **Strength Test Cylinders**
  - Test cylinders may be cast from each batch of concrete delivered to the construction site.
    - The most common cylinder size is 6 in. diameter x 12 in. high.
    - Concrete is placed in a cylindrical mold and consolidated to eliminate voids.
  - Cylinders are returned to the laboratory, cured under controlled conditions, and then strength-tested at appropriate times. Test results for laboratory-cured cylinders verify the quality of the concrete as delivered to the site.

Testing Concrete IV

- **Strength Test Cylinders**
  - Cylinders can also be cured on site in conditions similar to that for the cast concrete. Results from these tests can be used to determine when it is safe to remove formwork or subject cast concrete to construction loads.

Test cylinders prepared and labeled on site.

Laboratory cylinder testing apparatus

Placing Concrete I

- Avoid delays, during which concrete can stiffen and become difficult to place.
  - Depending on conditions, concrete can be placed up to 90 minutes after mixing commences.
- Concrete that does stiffen can have water added prior to placing, provided that:
  - Maximum w/c ratio is not exceeded
  - Maximum slump is not exceeded
  - Agitation limits are not exceeded

Placing Concrete II

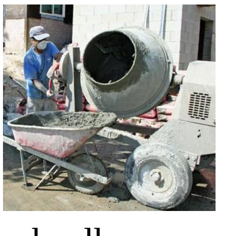
- Concrete may be placed on site :
  - Directly from the discharge chute of a transit-mix truck,
  - Wheelbarrows,
  - Power buggies,
  - Crane-lifted buckets *(right),*
  - Conveyor belts,
  - Concrete pumps

Placing Concrete III

Concrete pump

Concrete buggy

Conveyor belt



wheelbarrow

Placing Concrete IV

- *Segregation,* separation of large aggregate from the finer portions of the mix, must be avoided.
  - Place concrete as close to final position as possible.
  - Do not push concrete over large horizontal distances.
  - Avoid dropping concrete from high heights or discharging against obstacles (use *drop chutes* if needed).
  - Avoid excessive vibration

Consolidating Concrete I

- Consolidation (Compaction): The elimination of voids and air pockets within the concrete pour.
  - Consolidation is especially critical with stiff concrete mixes or when concrete is placed around densely packed reinforcing arrays
  - Over-consolidation must be avoided, as it can lead to segregation of aggregate
- Consolidation methods:
  - Hand *rodding* or *tamping*
  - *Screeding*
  - Internal vibration
  - External vibration

Consolidating Concrete II

Screeding

Internal vibration

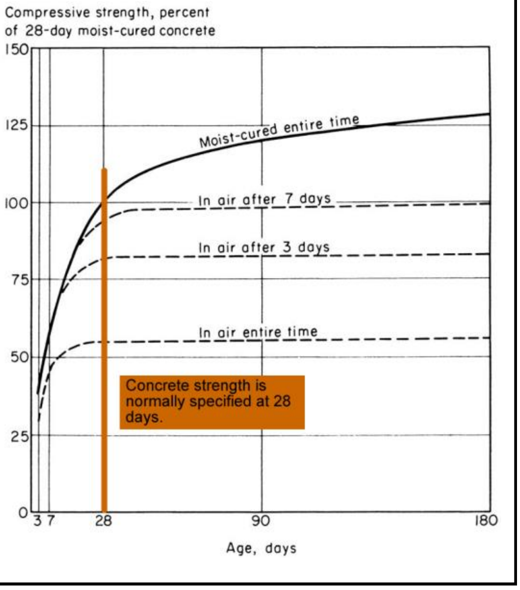
External Rotary Vibrators

Curing Concrete I

- Concrete hardens by *hydration (* the chemical bonding of water and cement
  - If concrete dries out prematurely, the hydration process stops and maximum strength is not achieved
  - Hydration, along with increasing strength and durability, can continue for a very long time, even years. Concrete strength is normally specified at 28 days
- In very hot or cold weather, steps may be taken to moderate the temperature of the concrete, such as pre-heating of ingredients, adding water as ice, or the use of retarders or accelerators to adjust cure rate.

Curing Concrete II

- Exposed surfaces of newly poured concrete must be protected from evaporation and drying.
  - Concrete may be regularly misted,
  - Covered with moisture-retaining materials, or
  - Treated with a chemical surface sealer (curing compound)



Formwork I

- *Formwork:* usually temporary, to hold freshly poured concrete in the desired shape until the concrete achieves sufficient strength to support itself.
- Formwork also frequently helps to protect newly poured concrete from drying too quickly.

Formwork II

- Formwork must be strong and stiff enough to support the weight and fluid pressure of the concrete.
- In conventional concrete construction, formwork can account for half or more of total concrete construction costs.
- Formwork is usually made of braced panels of wood, metal, or plastic.
- Form release compounds: Oils, waxes, or plastic coatings applied to formwork surfaces to prevent adhesion of the formwork to the concrete and ease formwork removal.

Sitecasting vs. Precasting

- Precasting:
  - A process in which concrete is cast into reusable forms at an industrial plant.
  - Rigid, fully cured structural units from the plant are then transported to the job site
- Sitecasting,
  - Also called cast-in-place construction,
  - A process in which concrete is poured into forms that are erected on the job site.

Concrete Framing: Slab on Grade

Casting a Concrete Slab on Grade

- **Concrete Slabs**
- **Subgrade Preparation**
- **Drainage Layer**
- **Slab Edges**
- **Vapor Retarder (Moisture Barrier)**
- **Reinforcing**
- **Pouring the Concrete**
- **Finishing the Concrete**
- **Controlling Cracking**

Concrete Slabs

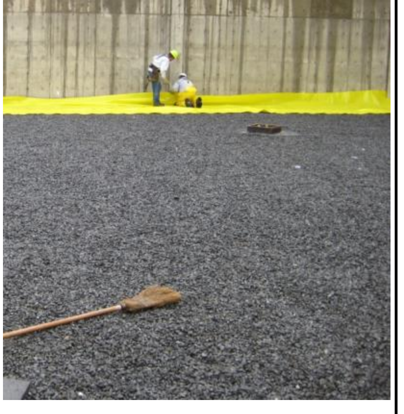
- ***Slab On Grade****:* A concrete surface, lying upon, and continuously supported by, the ground beneath
- ***Suspended or Structural Concrete Slab****:* A concrete slab that spans between intermediate lines or points of support

Subgrade Preparation

- Site is cleared and grubbed if necessary.
- Organic top soil is removed.
- Subsoil, or *subgrade*, is excavated to required depth.
- Subgrade is graded level and compacted to the required density.
- If the subsoil is too soft or unstable, it is over-excavated and replaced with more competent material.
- *Proof rolling:* A heavy roller or loaded dump truck makes multiple passes over the subgrade *(right*). Areas that are revealed to be soft or unstable are corrected.

Drainage Layer (Capillary Break)

- A layer of crushed rock or gravel, usually 4 inches deep, is placed over the subgrade.
- This rock material is *well sorted* (comprised of particles mostly uniform in size), that may range from approximately ¾-inch to 1½-inch in diameter.
- This layer drains water easily and discourages moisture in the ground from rising up to the concrete slab through capillary action.
- This layer also provides a structurally sound base for the concrete slab to follow.

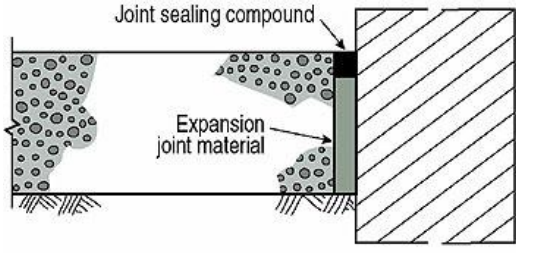


Slab Edges I

- Edge forms: Strips of wood or metal are placed to contain the concrete pour at the slab edges.
- Forms are held in place by stakes of wood or metal rebar, or other bracing.
- The tops of the forms are set level with the top the slab, to act as guides in later finishing operations.

Slab Edges II

- Isolation or expansion joints: Where slabs adjoin walls, columns, or other elements, compressible joint material is placed to create an isolation joint or expansion joint.
- Isolation joints allow unrestrained expansion and contraction of the slab, as well as differential settling between the slab and the adjoining elements.



Vapor Retarder (Moisture Barrier) I

- A heavy plastic sheet or other impervious material may be laid over the drainage layer.
- This layer provides the slab with additional protection against subgrade moisture and is particularly important when the slab will be covered with moisture-sensitive finishes.
- Vapor retarders are used only with interior slabs, not with exterior slabs.

Tape (blue in this photo) is used to seal laps in the vapor retarder sheets.

Vapor Retarder (Moisture Barrier) II

- Vapor retarder materials must be durable enough to resist being punctured or torn during subsequent construction operations, such as laying reinforcing steel or pouring the concrete.
- Penetrations and tears in the in the vapor retarder are sealed tightly to maintain a continuous barrier.
- In cases of extreme ground water conditions, the moisture barrier may be replaced with a heavier, more impervious waterproofing membrane.

Reinforcing

- A grid of reinforcing bars or sheets of welded wire reinforcing (WWF) is usually placed.
- Reinforcing improves a slab's resistance to cracking due to:
  - Concrete shrinkage during curing
  - Effects of thermal expansion and contraction
  - Concentrated stresses
  - Differential settlement

Pouring the Concrete I

- Concrete is placed by any of a number of methods, depending on the size of the pour and ease of access to the slab.
  - Pumping
  - Wheel barrow
- Concrete should be placed as close as possible to its final destination.
- Pushing concrete along the ground can cause segregation of large and small particles in the concrete mix, leading to a lack of uniform density and uneven finish qualities in the completed slab.

Pouring the Concrete II

- If the reinforcing has not been set on bolsters or other supports, it must be lifted into approximately the middle depth of the slab as the concrete is poured.

Reinforcing bar indicated by arrow has just been lifted off the gravel base into the middle of the concrete pour.

Finishing the Concrete I

- **Striking off or screeding**: A wood plank or metal straightedge is drawn across the surface of the freshly poured concrete, using an end-to-end sawing motion.
- A bulge of concrete is maintained in front of the screed, to fill low spots as the screed progresses.
- Striking off establishes the elevation of the upper slab surface.

In this photo, note the use of the edge form to guide the screed.

Finishing the Concrete II

- ***Floating:*** Immediately after screeding, floating is performed to consolidate and smooth the slab surface.
- *Right*: A *bull float* is drawn back and forth over the slab.

Finishing the Concrete III

- A darby is used to float areas of the slab that can be reached without the long arm of the bull float.

- Where a rough finish is acceptable, no further operations may be required.

Finishing the Concrete IV

- Further finishing operations depend on the type of final finish required for the slab.
  - When required, further finishing steps begin after the concrete has been allowed to stiffen, and free water that rises to the surface, called bleed water, has evaporated.
  - Edgers and groovers are used to create neatly formed, well-consolidated edges and joints in the slab surface.

Finishing the Concrete V

- Floating may be performed a second time, to further consolidate and densify the surface of the slab.
- Floats are made of wood or metal with a slightly rough surface. The floating operation leaves the slab with a lightly textured surface.
- Floating may be done by hand, or with power machinery

Finishing the Concrete VI

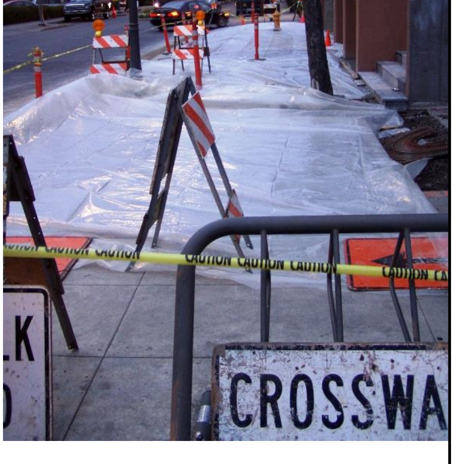
- ***Troweling***: For a smoother finish, the slab is troweled immediately after floating.
  - Trowels are made of smooth-surfaced steel or other metal. Troweling may performed by hand or with power-operated machinery.

Finishing the Concrete VII

- ***Broom Finish**:* A stiff broom is drawn across the slab surface to create a striated, slip resistant texture (*bottom*)
- ***Restraightening**:* After each floating or troweling operation, a long straightedge may be drawn over the slab surface to reduce minor undulations
- ***Shake-On Hardeners**:* Dry powders may be floated into the slab surface to create a harder, more durable surface
- ***Laser Screeds**:* Laser-guided power screeds can be used to finish slabs to more precise flatness and levelness requirements.

Curing the Concrete

- To ensure proper curing of the concrete, freshly poured slabs must be kept damp for at least the first week.
- Slabs are especially vulnerable to premature drying because of their relatively large exposed surface area:
  - Cover slab with impervious plastic sheets
  - Cover slab with absorbent, dampened straw, sawdust, or burlap.
  - Coat slab with a liquid-applied *curing compound,* that dries to form a clear moisture barrier.



Controlling Cracking I

- Relatively thin, lightly reinforced concrete slabs on grade are especially prone to cracking, especially as the concrete shrinks during curing.

Controlling Cracking II

- *Control joint* or *contraction joint:* A partial-depth joint or groove that creates a natural plane of weakness in the slab.
- Control joints encourage shrinkage cracking to occur in an organized, visually acceptable manner.

- *Right:* Control joints may be saw-cut into a slab after the slab has partially hardened.
- Control joints can also be formed during slab finishing operations using hand tools called groovers.

Controlling Cracking III

- Control joints need to extend at least ¼ the depth the slab to be effective.
- As a rule of thumb, control joints should be spaced from 24 to 30 times the depth of the slab. (E.g., for a 4-inch slab, joints should be spaced no more than 8 to 10 feet in both directions.)

Controlling Cracking IV

- *Expansion joint* or *isolation joint:* Expansion and isolation joints are full-depth separations between slab sections, that allow full freedom of movement between sections.
  - Reinforcing is also interrupted across expansion joints. (Across control joints, reinforcing is usually uninterrupted.)

A diamond-shaped section of slab around a column is bordered by an isolation joint separating it from the surrounding slab on grade.

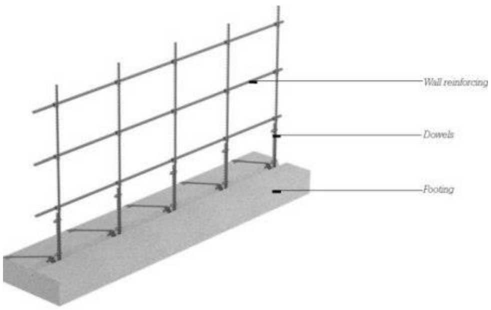
Concrete Framing Systems - Walls and Columns

Casting a Concrete Wall

- Wall Footing
- Reinforcing
- Wall Forms
- Pouring Concrete
- Finishing the Concrete
- Controlling Cracking
- Insulating Concrete Forms (ICF)
- Tilt-Up Construction

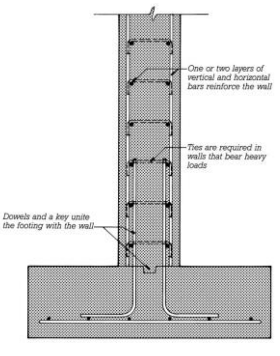
Wall Footing

- Concrete walls are most commonly cast over concrete strip footings.
- The steel reinforcing projecting from the footing will overlap with reinforcing in the wall, to structurally tie the two elements.



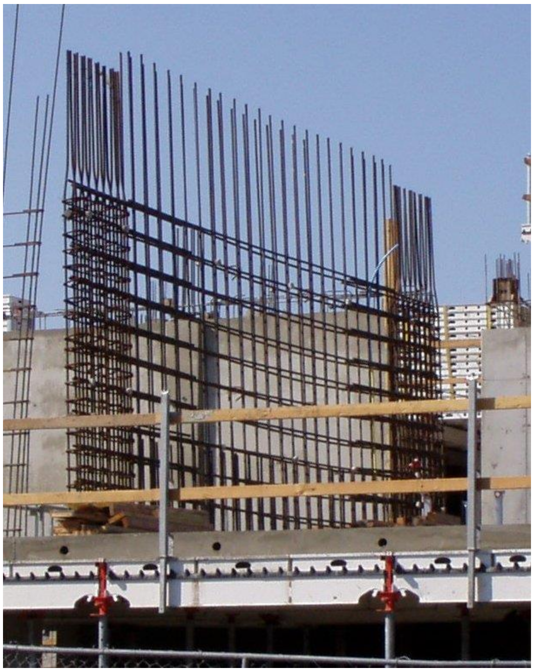
Wall Reinforcing I

- The size, spacing, and arrangement of reinforcing bars varies with the structural requirements of the wall.
- Typically, reinforcing is placed in one or two layers of vertical and horizontal reinforcing bars.



Wall Reinforcing II

- Reinforcing for a concrete shear wall (designed to resist lateral forces such as wind or earthquake), consisting of two layers of vertical and horizontal bars.
- The wall is reinforced more heavily at either end, where it must resist greater stresses.



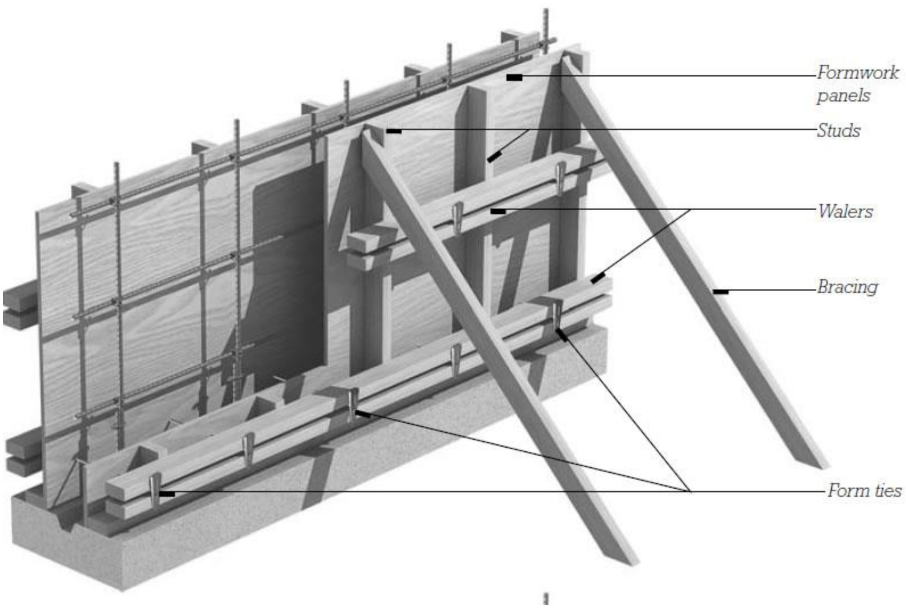
Wall Reinforcing III

- Heavy reinforcing at the base of concrete shear walls for a large, multistory building

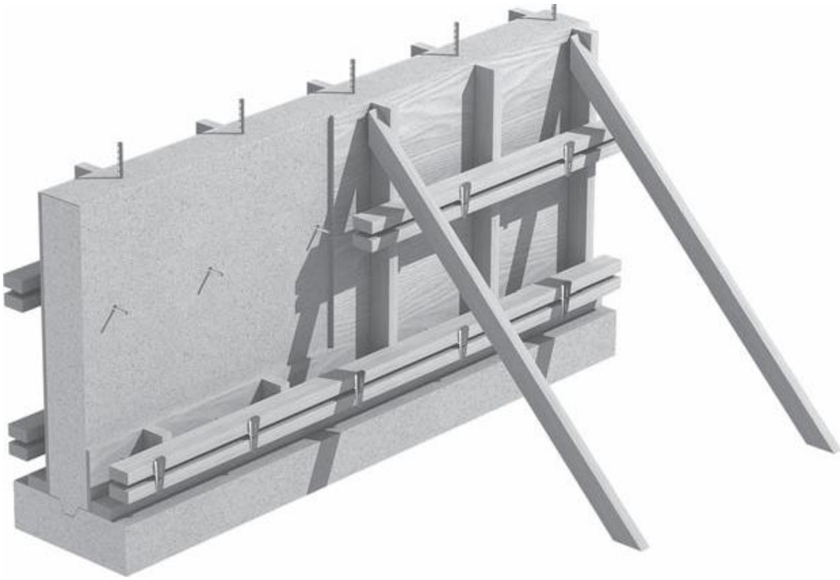
Wall Forms I

- Sheets of plywood form the faces of the concrete. They are supported by vertical wood studs.
- The studs are supported against the pressure of the wet concrete by horizontal walers.
- The walers are supported by steel rod ties that pass through holes in the plywood to the walers on the other side.
- The ties also act as spreaders to maintain a spacing between the plywood walls that is equal to the desired thickness of the wall.
- Diagonal braces keep the whole assembly plumb and straight.

Wall Forms II

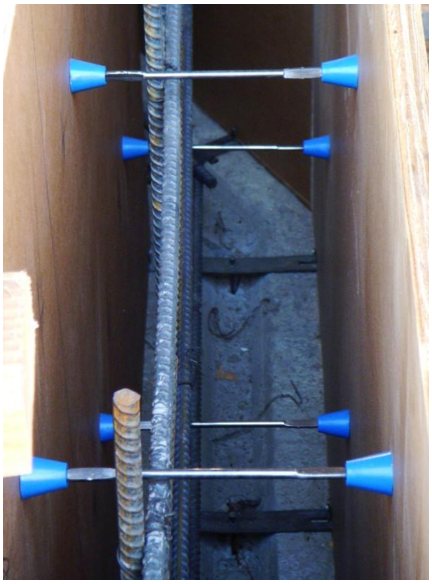


Wall Forms III



Wall Forms IV

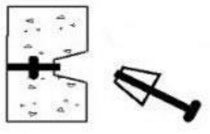
- *Form ties*, hold the forms in position and resist the outward pressure of the concrete when it is placed.
- The plastic cones prevent the formwork from sliding along the ties, and form a neat, conical hole in the finished surface of the concrete



Wall Forms V

- Form ties can be made from steel rods (*left*), straps (*right*), wire, fiberglass, or other plastics.

- After the wall is cast and the forms removed, the protruding ends of the metal ties are broken off and the plastic cones removed.



Wall Forms VI

- The remaining holes in the concrete may be left open, filled with mortar *(picture),* or plugged with some other material.
- If the broken end of a metal form tie rod is not covered, rust staining may result as the end of the tie gradually corrodes
- Fiberglass form tie rods may be used without plastic cones. The protruding ends of the rods are simply ground off flush with the face of the concrete, becoming virtually unnoticeable to the untrained eye

Wall Forms VII

- Wall forms must be constructed sufficiently stiff to resist the fluid pressures of the freshly poured concrete.
- *Right:* A proprietary, modular wall form system, that can be easily raised and reused as wall construction proceeds upwards.
- Note the temporary scaffolding integrated into the form system, providing workers with access to the top of the wall.

Wall Forms VIII

- Heavy, braced formwork for a large, free-standing concrete wall.

Wall Forms IX

- Self-climbing formwork relies on hydraulic jacks to climb the concrete core structure as it is constructed.

Pouring Concrete

- Concrete is placed in the wall by a large crane-mounted bucket or by a concrete pump and hose
- It is consolidated by vibrating or hammering on the sides of the formwork.
- The top of the wall is struck off level
- The top of the wall is covered to limit water loss, and the wall is left to cure.
- After several days, the formwork may be stripped. Curing should continue for at least one week.

Finishing the Concrete I

- A residential concrete foundation wall with the formwork stripped.
- Without special efforts, the form panels and ties leave strong patterns on the wall surface.

Finishing the Concrete II

- A concrete foundation wall with blockouts to create openings in the wall for passage of building services.

Finishing the Concrete III

- Rough boards were used to line the inside of the wall forms, creating a *board form* finish on the cast wall.

Finishing the Concrete IV

- Poor quality formwork construction leads to defects in the concrete wall that do not become evident until the formwork is removed.

Finishing the Concrete V

- Incomplete consolidation leads to a *rock pocket* in the concrete wall.
- Note the exposed reinforcing bar.
- Unsound concrete will be removed and the area patched.

Casting a Concrete Wall

- The process of casting a concrete wall:
  - –Vertical reinforcing bars are wired to the dowels that project from the footing, and horizontal bars are wired to the vertical bars.
  - –The formwork is erected.
  - –The concrete is poured, consolidated, and cured
  - –The wedges that secure the walers to the form ties are driven out and the formwork is pulled off the concrete. The projecting ends of the form ties are broken off.
  - –If required, major defects in the wall surface caused by defects in the formwork, inadequate filling of the forms with concrete, or poor consolidation of the concrete can be repaired at this time

Controlling Cracking

- Like slabs, concrete walls are susceptible to cracking due to concrete shrinkage during curing, thermal stresses, and other effects.
  - Vertical control joints, spaced at 24 to 30 times the thickness of the wall, can be formed in the wall to organize and conceal shrinkage cracks.
  - Full-depth expansion joints can also be inserted at larger spacings, if required.

Shrinkage cracks in a concrete retaining wall highlighted by moisture migrating through the joints.

Insulating Concrete Forms (ICF)

- Concrete forms made from rigid plastic foam blocks or other lightweight insulating materials are easy to erect.
- The forms become a permanent part of the structure, creating a more energy efficient wall in comparison to conventional concrete construction.

Tilt-Up Construction

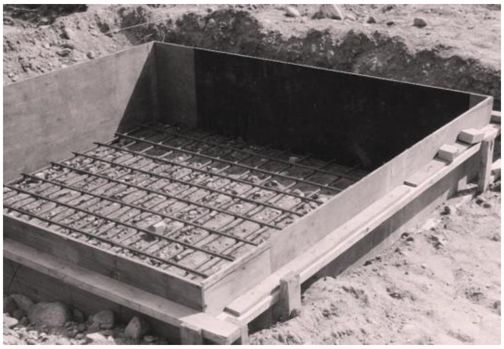
- Concrete wall panels are poured lying flat, much like a slab on grade.
- Once the panels have gained sufficient strength, they are lifted into final position.
- Tilt-up construction significantly reduces formwork costs, which can account for 50 per cent or more of the cost of conventional concrete construction.

Casting a Concrete Column

- Column Footing
- Column Reinforcing
- Column Forms
- Pouring Concrete
- Finishing the Concrete

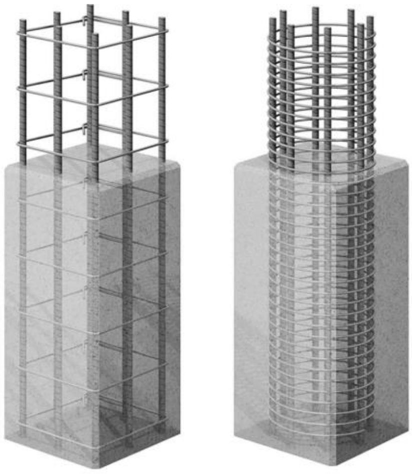
Column Footings I

- Columns may rest on isolated footings, pile caps, caissons, or enlarged portions of strip footings.
- *Picture:* The lower layer of reinforcing has been placed for an isolated footing. Additional reinforcing, including vertical dowels that will project out of the footing and overlap with vertical reinforcing bars in the column, will be added next.



Column Reinforcing I

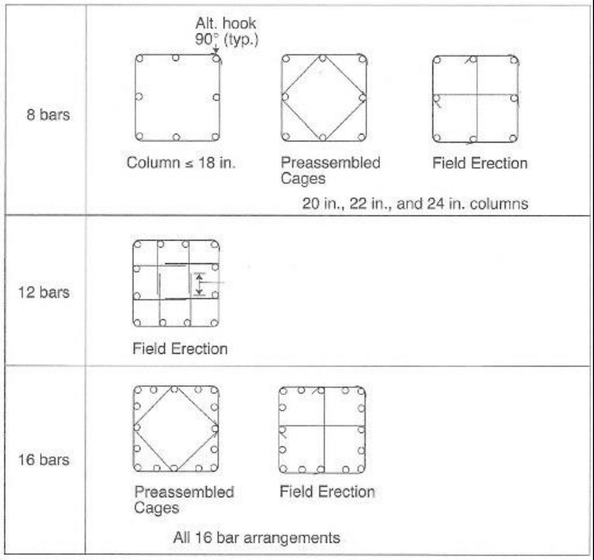
- Vertical reinforcing bars increase the column's load carrying capacity and give it resistance to bending forces generated by lateral forces on the building structure or by connected beams.
- Ties, lighter in weight, wrap around the vertical bars to resist outward buckling of the bars.
- Ties also increase a column's resistance to extreme cyclical seismic loads.



Spiral reinforcement, *right*, is more expensive and produces stronger columns than those reinforced with conventional ties.

Column Reinforcing II

- The arrangement of ties varies with the quantity and arrangement of vertical bars.



Column Reinforcing III

- *Right:* Vertical bars in a rectangular column are arranged 3 deep and 4 wide.
- Ties wrap around and cross through the vertical bar array .

Column Reinforcing IV

- Vertical bars are bent inward at the top, so as to nest with the next section of reinforcing as construction proceeds upward.
- The length of the overlapping portions of reinforcing are sufficient to fully transfer stresses from one set of bars to the next.

Column Reinforcing V

- Prefabricated column reinforcing stacked on site, ready to be lifted into position.

Column Forms

- Column forms may be square, rectangular, or round.
- The column form may be a rectangular box of plywood or composite panels, a cylindrical steel or plastic tube bolted together in halves so that it can later be removed
- Unless the column is unusually wide, no form ties are required.

Pouring Concrete

- Pouring Concrete
  - Concrete is deposited into the column form by any number of means.
  - The concrete is vibrated or otherwise consolidated as needed as it is placed.
  - *Right:* A concrete bucket lifted by a construction crane is used to deliver concrete to the column form.

Finishing the Concrete

- A partially-completed concrete column with the formwork recently removed.

Concrete Framing Systems- Floors and Roofs

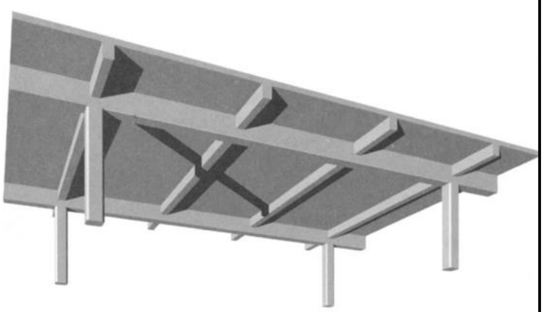
Floor and Roof Framing Systems

- One-way Floor and Roof Framing Systems
  - One-Way Solid Slab
  - One-Way Concrete Joist (Rib Slab
  - Wide-Module Concrete Joist System
- Two-way Floor and Roof Framing Systems
  - Two-Way Solid Slab
  - Two-Way Flat Slab
  - Two-Way Flat Plate
  - Two-Way Waffle Slab

One-Way Solid Slab I

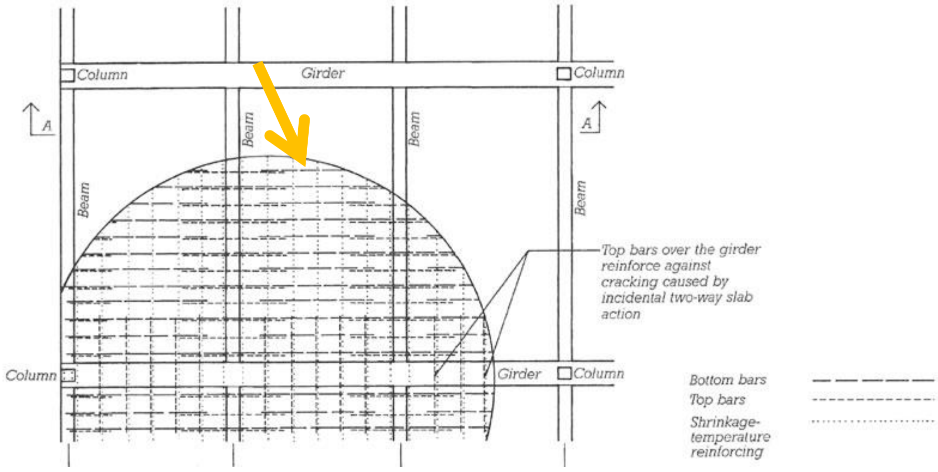
- A system of beams support a slab. The slab is reinforced to span in one direction only.
  - Girders (deeper beams) span between columns.
  - Beams (shallower) span from girder to girder.
  - The slab spans between the beams.

- Depending on beam and column arrangements, this system can be designed for a wide range of load conditions.
- Forming for girders and beams makes this system more expensive than many other systems.



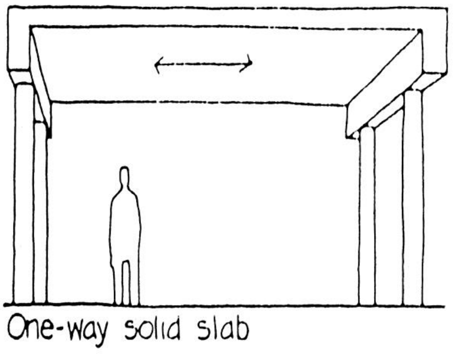
One-Way Solid Slab II

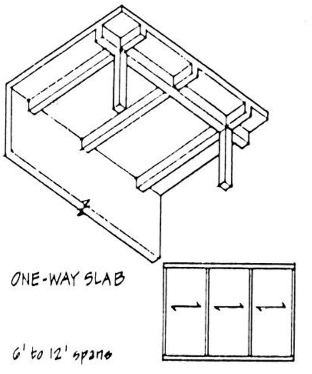
- Principal slab reinforcing (top and bottom bars in the diagram below) spans in only one direction, from beam to beam.



One-Way Solid Slab III

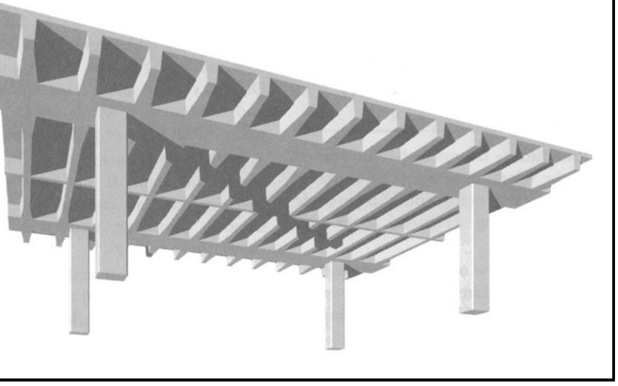
- One- way slab is used with short span range from 1.80-3.60 m .
- Rectangular shaped slab (w : L = 1: 3) also appropriate to use one-way slab system.





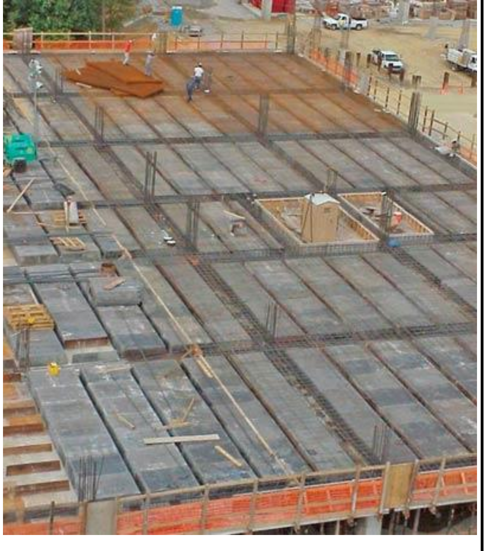
One-Way Concrete Joist (Rib Slab) I

- A system of beams and slender, closely-space ribs support a one-way slab.
  - Beams span between columns.
  - Joists (ribs) span from beam to beam.
  - The slab spans between the joists.
- Greater spans are possible than with solid slab.
- Modular, prefabricated form systems help to keep this system economical.

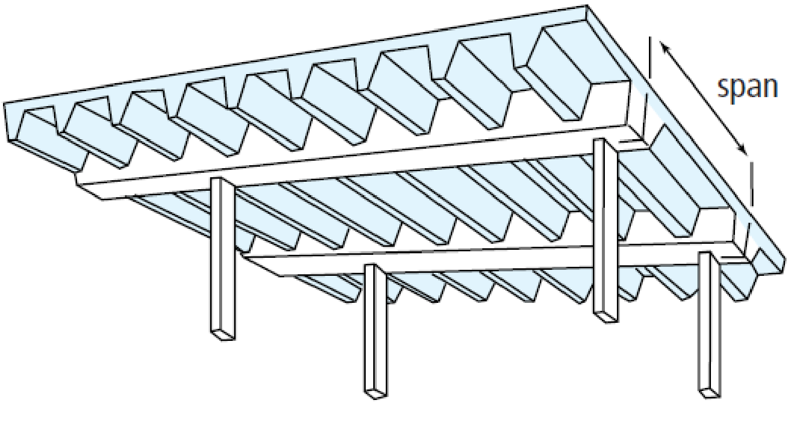


One-Way Concrete Joist (Rib Slab) II

- In one-way joist systems, the bottoms of the beams and joists are all on the same plane, simplifying formwork construction.
- A simple, level surface is formed on site. Next, prefabricated metal or fiberglass *joist pans* are placed on this surface to form the system of beams and ribs.

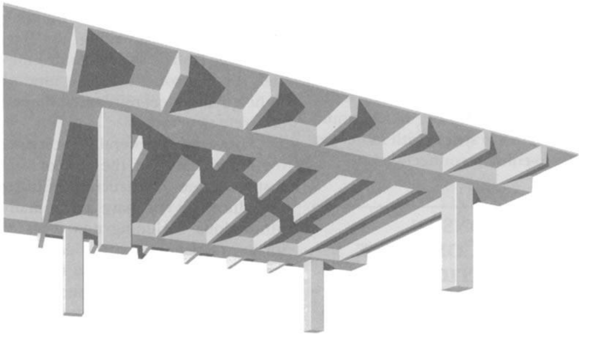


One-Way Concrete Joist (Rib Slab) III



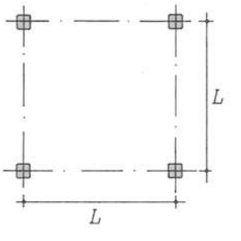
Wide-Module Concrete Joist System

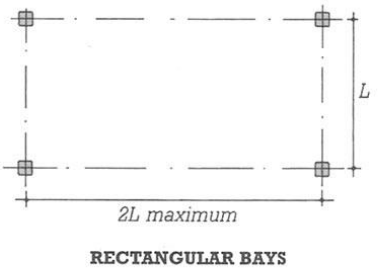
- Like one-way joist, but ribs are spaced 4 to 6 feet rather than 20 to 30 inches.
- A thicker slab is required to span the greater distance between ribs (useful when greater thickness is required for greater fire resistance).
- Also called "skip-joist" system.



Two-Way Framing Systems

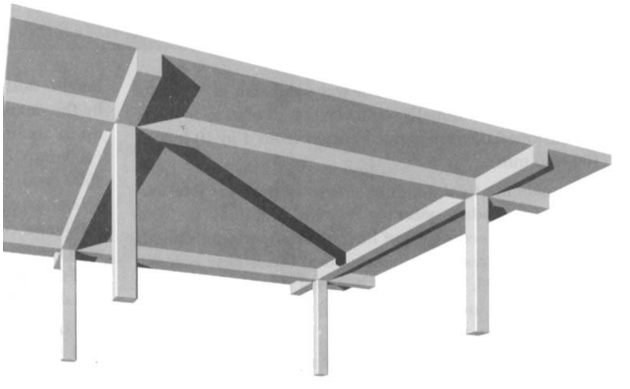
- A two-way slab is reinforced so that it spans structurally in both directions
- Two-way slabs are more structurally efficient than one-way slabs of the same thickness.
- Two-way slabs must span roughly the same distance in both directions. As the layout of slab supports becomes increasingly rectangular in proportion, the efficiency of the two-way slab decreases.
- In contrast, one-way slab systems are more suitable for column and beam layouts that create rectangular bays.





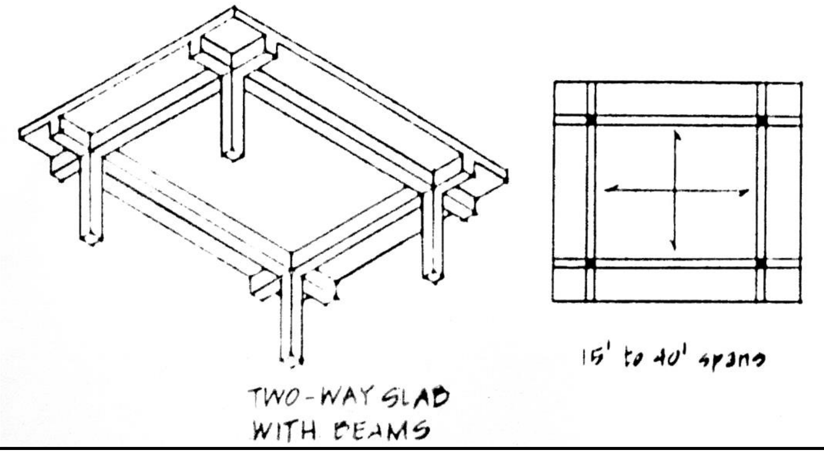
Two-Way Solid Slab I

- A system of beams supports a two-way slab.
- Forming of the beam systems tends to make this system more expensive than other two-way slab systems.



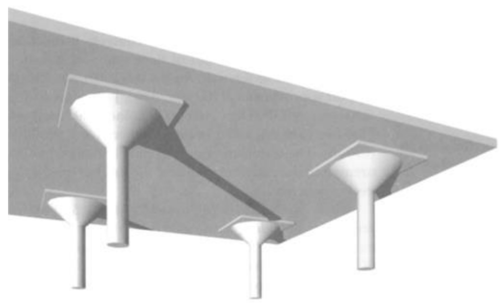
Two-Way Solid Slab II

- Two-way slab is used with long span (4.5-12 m.) and heavy loads, or when high lateral force resistance is required.



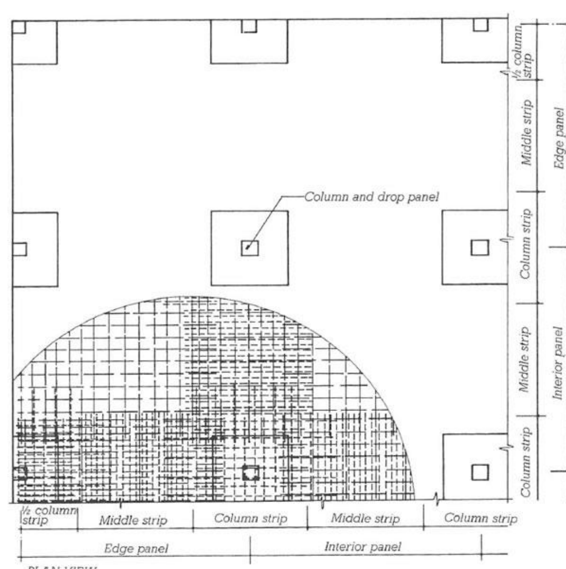
Two-Way Flat Slab I

- A two-way reinforced slab is supported by columns without beams.
- The flat slab system includes added structure where columns meet slabs:
  - *Mushroom capitals:* Conical widening toward the top of the column
  - *Drop panels:* Thickening of the slab around the column
- This added structure allows the system to carry heavier loads



Two-Way Flat Slab II

- Between columns, more heavily-reinforced *column strips* act like shallow beams within the depth of the slab.
- Between column strips, *middle strips* are reinforced for two-way slab action.



Two-Way Flat Slab III

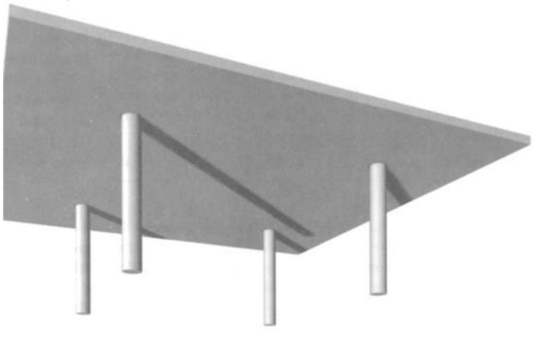
Two-Way Flat Slab

- A two-way flat slab with dropped panels, but no column capitals.
- The extra structure around the column/slab juncture prevents the columns from "punching through" the slab.

Two-Way Flat Plate I

- Like the flat slab, a two-way reinforced slab is supported by columns without beams.
- There are no column capitals or drop panels in the flat plate system.
- Additional reinforcing within the depth of the slab at the column/slab junction is used to increase strength in that area.

- Flat plate systems are best suited to lighter loads than flat slab systems. The simplified formwork also makes them less expensive to construct.



Two-Way Flat Plate II

- A cross-shaped array of shear studs (with orange heads in the photo) provides additional strength at the column/slab junction of a two-way flat plate system.
- The green cables are posttensioning strands

Two-Way Flat Plate III

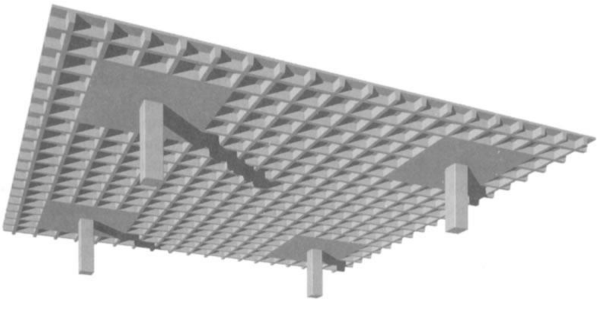
- The absence of forming for beams, column capitals, or drop panels shows this to be a two-way flat plate system

Two-Way Flat Plate IV

- Two-way flat plate construction in a residential tower
- Two-way flat plate is one of the thinnest of floor framing systems available in any structural material, an economy that is compounded in multi-story construction.
- Note the *reshoring* (yellow clad columns) in use underneath the upper two slabs. When the formwork is removed, reshoring is inserted to provide support for the slabs until the concrete gains additional strength.

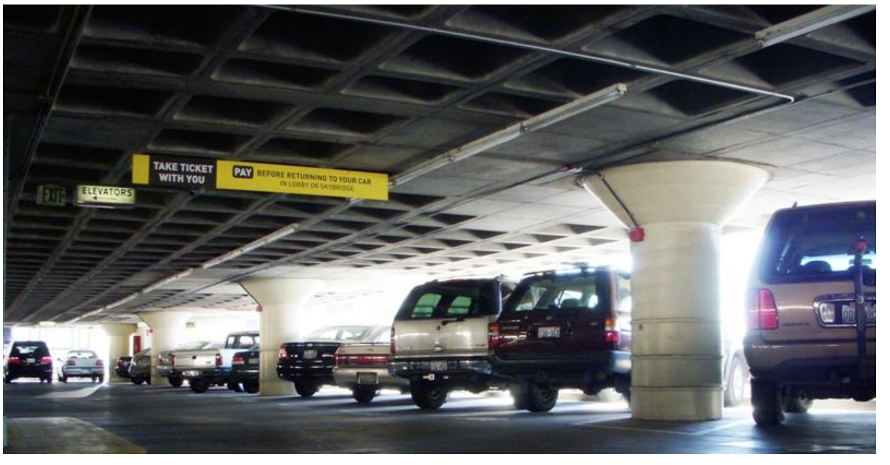
Two-Way Waffle Slab I

- It is a two-way concrete joist slab
- Similar to one-way joist, but with a two-way system of ribs
- Constructed with prefabricated *domes* that simply formwork construction.
- Around the columns, domes are filled solid to create *heads* that strengthen the column/slab connection, like drop panels in flat slab construction.



Two-Way Waffle Slab II

- A concrete waffle-slab parking garage. Note the expanded solid heads and mushroom column capitals, creating a stronger column/slab connection.



Reinforcing Concrete

The Concept of Reinforcing

- Concrete has no useful tensile strength—ability to resist pulling forces.
- Steel bars or wires are laid into concrete along lines of tension, to provide resistance to these forces

Material	Working Strength in Tension[a]	Working Strength in Compression[a]	Density	Modulus of Elasticity
Wood (framing lumber)	300–1000 psi 2.1–6.9 MPa	600–1700 psi 4.1–12 MPa	30 pcf 480 kg/m^3	1,000,000– 1,900,000 psi 6900–13,000 MPa
Brick masonry (including mortar, unreinforced)	0	250–1300 psi 1.7–9.0 MPa	120 pcf 1900 kg/m^3	700,000– 3,700,000 psi 4800–25,000 MPa
Structural steel	24,000–43,000 psi 170–300 MPa	24,000–43,000 psi 170–300 MPa	490 pcf 7800 kg/m^3	29,000,000 psi 200,000 MPa
Concrete (unreinforced)	0	1000–4000 psi 6.9–28 MPa	145 pcf 2300 kg/m^3	3,000,000– 4,500,000 psi 21,000–31,000 MPa

[a]Allowable stress or approximate maximum stress under normal loading conditions.

Reinforcing Concrete

- Steel and concrete work well together.
  - The two materials have similar rates of thermal expansion/contraction.
  - The alkaline chemistry of the concrete protects the steel from corrosion.
  - The two materials bond well, allowing them to work as a single structural composite.

Steel Reinforcing Bars (Rebar)

- The most common concrete reinforcing material
- Rebar are hot-rolled steel, deformed with surface ridges so as to better bond with concrete
- Bar sizes are numbered, with numbers generally corresponding to the diameter of the bar
- Bars are made with steel grades of varying strength
- Higher strength bars are used to reduce *rebar congestion,* where reinforcing becomes crowded and concrete placement becomes more difficult
  - Use of higher strength steel allows for bars smaller in diameter or with greater spacing

Welded Wire Reinforcing

- Welded wire reinforcing (WWR) or welded wire fabric (WWF): Prefabricated, welded grids of reinforcing bars or wires
- Especially common for concrete slab reinforcing

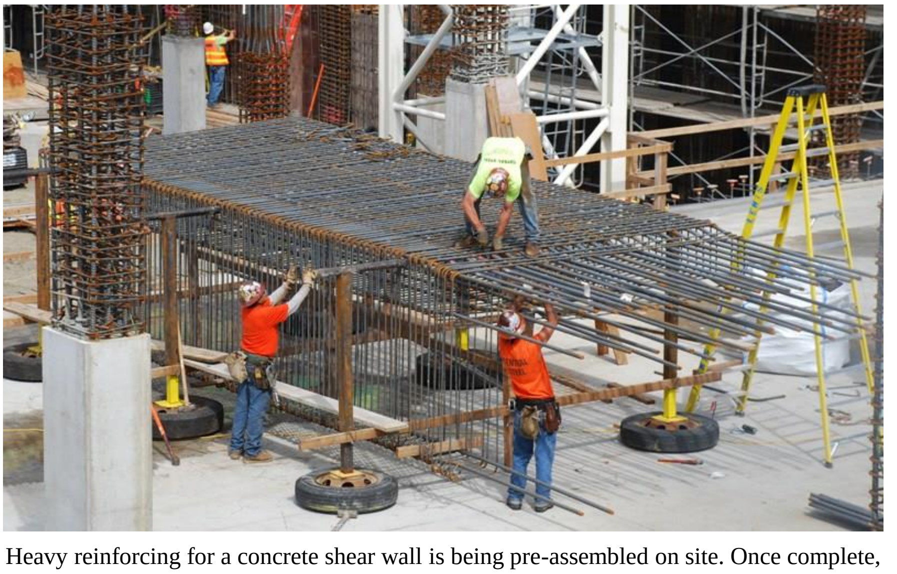
Reinforcing Fabrication and Erection I

- Concrete reinforcing requirements are shown on the structural drawings.
- A reinforcing fabricator prepares shop drawings that are reviewed by the structural engineer.
- Reinforcing is cut to length, bent as needed, and possibly partially assembled before being transported to the construction site.
- Fabrication continues on site. Eventually reinforcing is assembled in its final configuration.
- After inspection by the engineer, concrete may be poured.

Reinforcing Fabrication and Erection II

Shop-fabricated spiral reinforcing, for drilled concrete piers (Caissons.

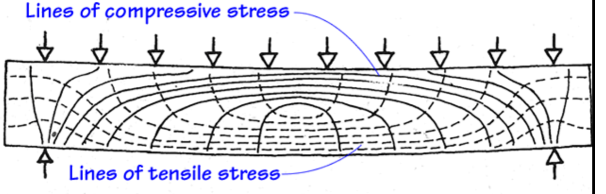
Reinforcing Fabrication and Erection III



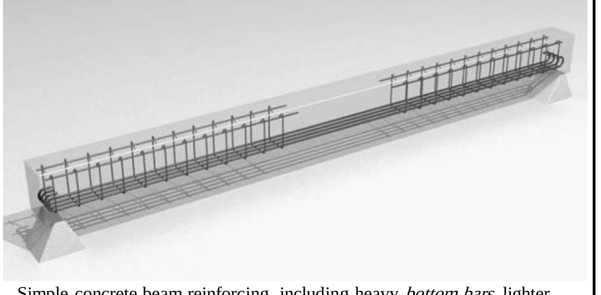
Heavy reinforcing for a concrete shear wall is being pre-assembled on site. Once complete, the assembly will be lifted into place by a construction crane

Reinforcing a Simple Beam

- *Top:* In a simply supported beam, the greatest tension forces occur at the bottom middle of the beam.
- Where tension forces cross compression forces closer to the beam ends, shear forces also occur.
- *Bottom:* The placement of reinforcing in a concrete beam approximates the lines of tension, but is simplified to reduce fabrication costs.



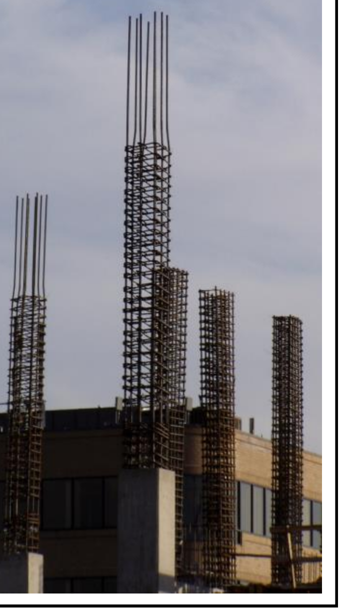
Theoretical lines of tension and compression in a simple beam.



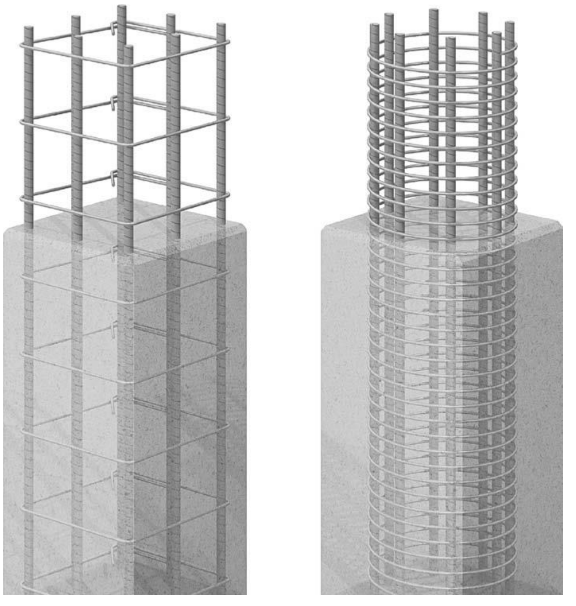
Simple concrete beam reinforcing, including heavy *bottom bars*, lighter *top bars*, and U-shaped *shear stirrups*

Reinforcing a Column I

- Vertical or column bars: Larger-diameter bars placed vertically in the column
  - The vertical bars add to the strength of the column in compression, and resist tensile forces that are introduced from wind or seismic forces, or from connections to beams
- Ties or spirals: Wrap around the vertical bars
  - Ties prevent the vertical bars from buckling outward



Reinforcing a Column II

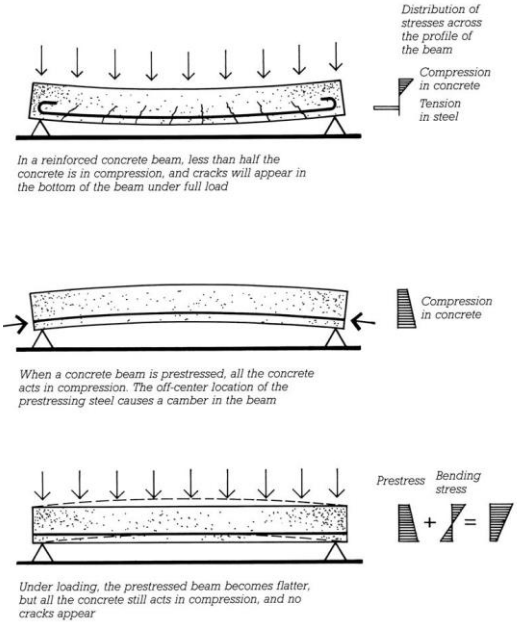


Fibrous Reinforcing

- Fibrous reinforcing: Short fibers of glass, steel, or polypropylene, added to the concrete mix
- Microfiber reinforcing: Relatively low amounts of fibers, to aid concrete in resisting plastic shrinkage cracking that occurs during early curing
- Macrofiber reinforcing: Greater concentrations of fibers, that also resist longer-term cracking due to drying and thermal stresses
- Steel fiber reinforcing also increases the durability of the concrete surface

Prestressing I

- Applying an initial compressive stress to a concrete member, so as to improve its structural efficiency.
- High-strength steel strands are stretched tightly and then restrained by the concrete, putting the concrete into initial compression.
- When normal service loads are added, the concrete in prestressed members is subject to less tensile force.
- Prestressed members are typically more slender and lighter than comparable conventionally reinforced members.



Prestressing II

- ***Pretensioning:*** Steel strands are tensioned before concrete is cast. This requires heavy abutments to restrain the strands and is normally only done with concrete in precasting plants, but not on the construction site.

- ***Posttensioning:*** Steel strands are tensioned after concrete has been cast and reached adequate strength. Concrete cast on the construction site can be posttensioned.

Plastering

Plaster

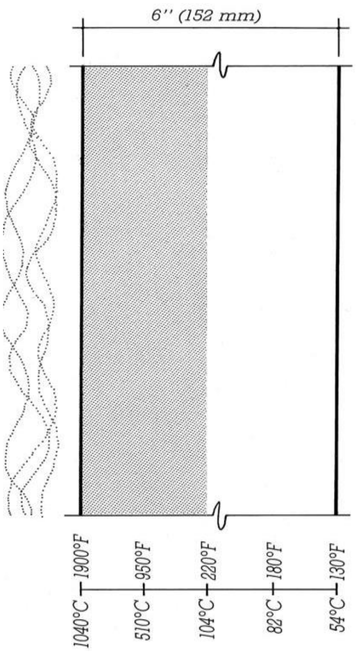
- Plaster: a building material used for coating walls and ceilings.
  - Plaster is a **generic term that refers to any number of cement** like substances applied to a surface in a paste form which hardens
- Plaster can be applied directly to solid surface or any group of bases known as lath
- <u>Common plaster material types:</u>
  - Gypsum
  - Lime
  - Portland cement

Plaster – Gypsum

- Gypsum plaster is made from gypsum which is abundant in nature (crystalline hydrous calcium sulfate)
  - The calcined gypsum, ground to a fine white powder, is known as plaster of Paris
  - When plaster of Paris is mixed with water, it rehydrates and recrystallizes rapidly to return to its original solid state. As it hardens, it gives off heat and expands slightly.
- Gypsum's disadvantage:
  - Solubility in water

- Gypsum's advantages
  - Inexpensive
  - Durability and light weight
  - It resists the passage of sound better than most materials
  - Highly workable
  - It has a very fine grain
  - Highly resistant to the passage of fire
  - Can be fashioned into surfaces that range from smooth to heavily textured
  - Gypsum plaster is very resistant to cracking.

The Effect of Fire on Gypsum: After 2- hour exposure to fire, less than half of the gypsum on the side toward the fire, shown here by shading, has calcined. The portions of the gypsum to the right of the line of calcination remain at temperatures below the boiling point of water.



- For use in construction, calcined gypsum is carefully formulated with various admixtures to control its setting time and other properties.
- Gypsum plaster is made by mixing the appropriate dry plaster formulation with water and an aggregate, either fine sand or a lightweight aggregate such as perlite
- Two Categories of Gypsum plasters:
  - Base-coat plasters
  - Finish-coat plasters

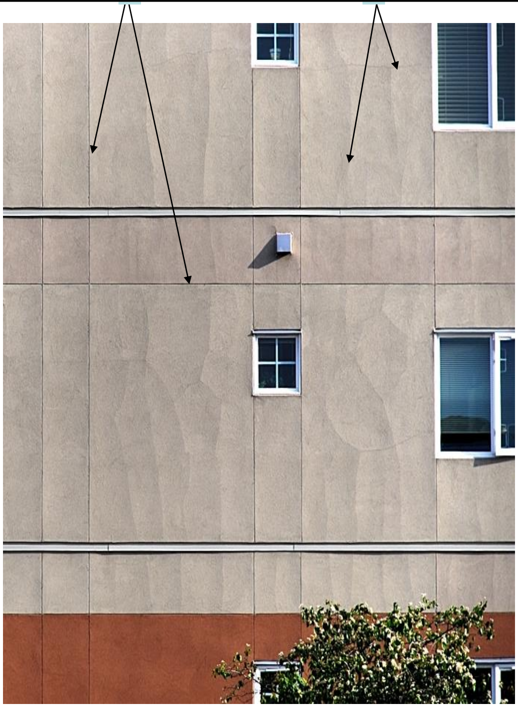
- Base-coat plasters used for the underlying preparatory coats of a plaster application
  - Mixed with aggregate, chopped wood fibers, or lightweight aggregate (perlite or vermiculite)
- Finish-coat plasters are a blend of gypsum and lime

Spray Application of Gypsum Plaster to Gypsum Lath

Portland Cement Plasters

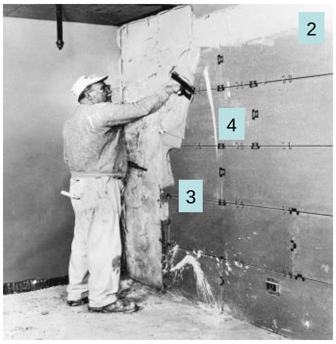
- Portland cement-lime plaster also known as stucco is similar to masonry mortar
- Used where plaster is subjected to moisture
  - Exterior wall surfaces, kitchens, and shower rooms
- It is less workable than gypsum plaster.
  - it is not as easy to apply and finish.
- It shrinks and therefore needs control joints frequently to regulate cracking
- Curing reaction same as that of concrete and is very slow relative to that of gypsum plaster

- Exterior Portland cement lime plaster (stucco).
- Late afternoon sun, striking the plaster surface at a steep angle highlights shrinkage cracking (1) in the plaster.
- Like concrete, Portland cement plaster shrinks during curing. Even with the generous placement of surface control joints (2) seen here, significant additional shrinkage cracking (1) has occurred.



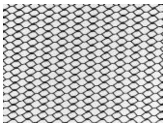
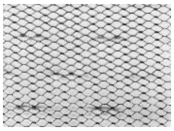
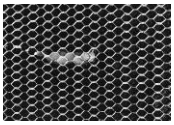
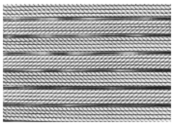
Plaster – Application

- Plaster can be applied either by machine (1) or by hand (2).
  - Machine application is essentially a spraying process
  - Hand application is done with
    - Hawk to hold small quantity of plaster (3)
    - Trowel to apply plaster to surface (4)
    - Darby to level the surface



Plaster – Lathing – Metal Lath

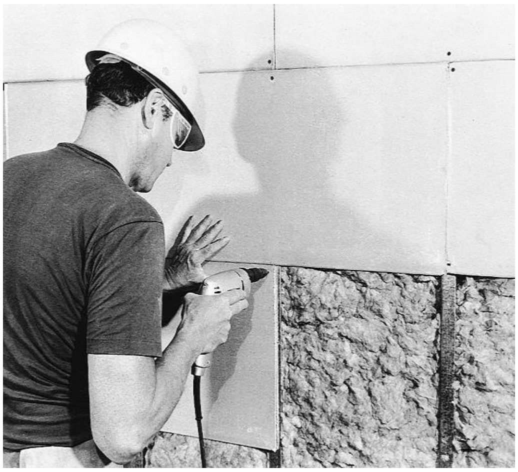
- Lath is the base to which plaster is applied
- Most lath today is expanded metal or preformed gypsum boards.
- Person who applies lath and trim accessories is called lather
- Expanded metal lath is made from thin sheets of galvanized steel that are cut and stretched to produce a mesh of diamond-shaped openings
  – Applied using ties of steel wire, self-drilling, self-tapping screws, lathing nails

Plaster – Lathing – Gypsum Lath

- Gypsum lath is made in gypsum board sheets
  – 16x48 inches (406x1220mm) 3/8 inch (9.5mm) thick
  - Consists of sheets of hardened gypsum plaster faced with outer layers of a special absorbent paper
  - Attaches using metal clips or screws
  - Portland cement stucco will not bond to gypsum lath

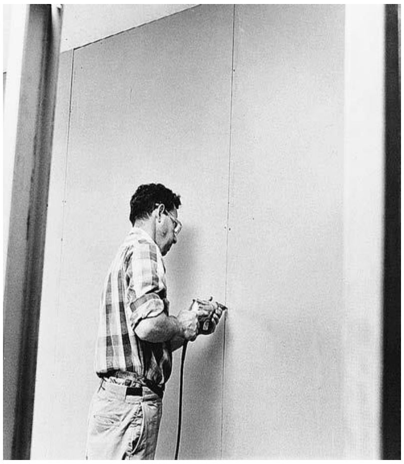
Gypsum Lath Attached to Steel Studs



Plaster – Lathing – Veneer Plaster Base

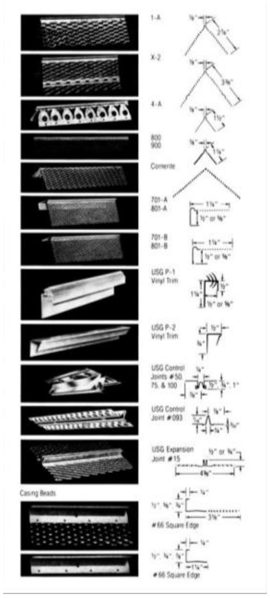
- Veneer plaster base or gypsum veneer base is a paper-faced gypsum board
  - Sheets are 4 feet (1220mm) wide by 8 to 14 feet long (2440-4270 mm)
  - Thickness of sheets ½ inch or 5/8 inch (13-16mm)
  - Can be screwed, nailed

Installing veneer plaster base with a screw gun



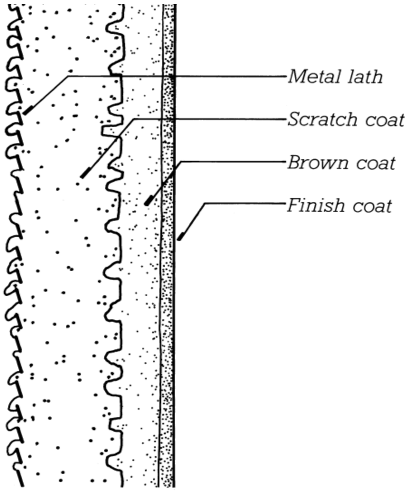
Plaster – Lathing

- Various lathing trim accessories and control joint accessories are available
  - Various lathing trim accessories are used at the edges of a plaster surface to make a neat, durable edge or corner
  - Trim accessories are referred to as grounds when they are used to gauge the proper thickness and plane of plaster
  - Lathing Trim accessories can be galvanized steel, aluminum or plastic

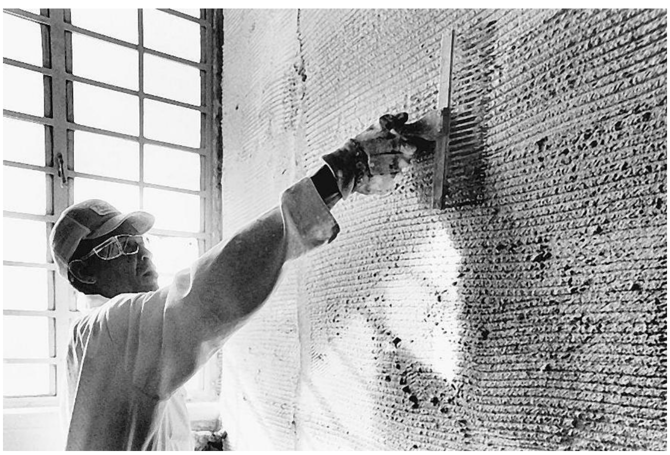


Plaster Over Expanded Metal Lath

- Plaster is applied over expanded metal lath in three coats
  - Scratch coat:
    - Troweled on roughly.
    - This first coat is scratched while still wet to create a rough surface to which the second coat can bond mechanically



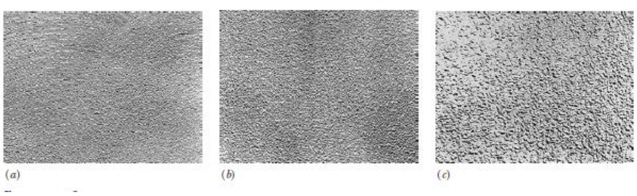
Scratch coat:



- Brown coat:
  - The purpose of the brown coat is to build strength and thickness and to present a level surface for the application of the finish coat.
  - The level surface is produced by drawing a long straightedge across the surfaces of the grounds (the edge beads, corner beads, and control joints) to strike off the wet plaster.
  - On large, uninterrupted plaster surfaces, intermittent spots or strips of plaster, are leveled up to the grounds in advance of brown coat plastering to serve as intermediate reference points for setting the thickness of the plaster during the striking-off operation.

- Finish coat:
  - The finish coat is very thin application of finish-coat plaster, about 1/16 inch (1.5 mm) thick. It may be troweled smooth or worked into any desired texture

A sponge-faced float can be used to create various rough surface textures on plaster.



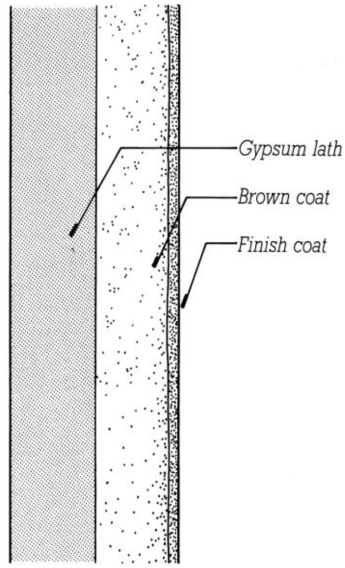
a-Float, b-Spray, c-Texture

- The total thickness of the plaster that results from this three coat process, as measured from the face of the lath, is about 5/8 inch (16 mm).
- Three-coat work over metal lath is the premium-quality plaster system, extremely strong and resistant to fire.
- The only disadvantage of three-coat plaster work is its cost, which can be attributed largely to the labor involved in applying the lath and the three separate coats of plaster

- Gypsum plaster over metal lath, with a unique, textured finish.

Plaster Over Gypsum Lath

- Because gypsum lath is sufficiently rigid, two coats would be sufficient (brown coat and finish coat)
- Gypsum lath is more economical than metal lath because of speed of installation
- Total thickness of plaster applied over gypsum lath is ½ inch (13mm)



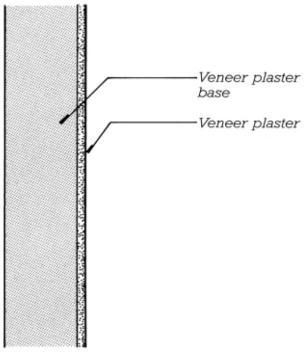
Plaster Over Masonry

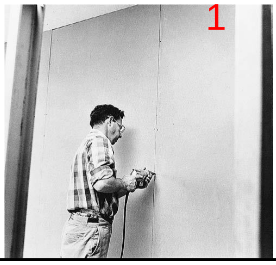
- Before applying plaster directly over concrete or masonry walls they should be dampened thoroughly in advance of plastering
- Bonding agent may have to be applied to smooth masonry surfaces to ensure good adhesion
- Number of coats will be dependent on the degree of unevenness of the masonry surface
- For best work three coats totaling 5/8 inch (16mm) should be applied but two coats are sufficient

- Application of Plaster Over Masonry – Joints Are Visible and Will Require Additional Coats

Veneer Plaster

- Veneer plaster system is the least expensive
- Veneer lath is applied first (1)
- Veneer base creates very flat surfaces that can be finished with a formulated dense gypsum plaster applied in one or two coats 1/6-1/8 inch (2-3mm) in total thickness

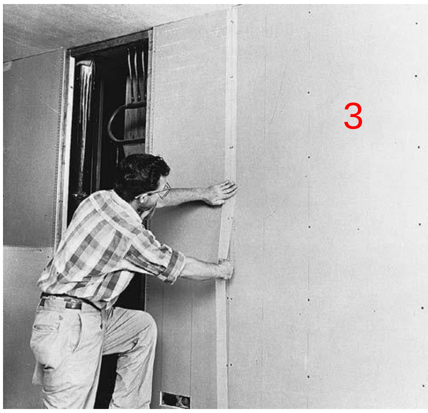




Installing veneer plaster base with a screw gun

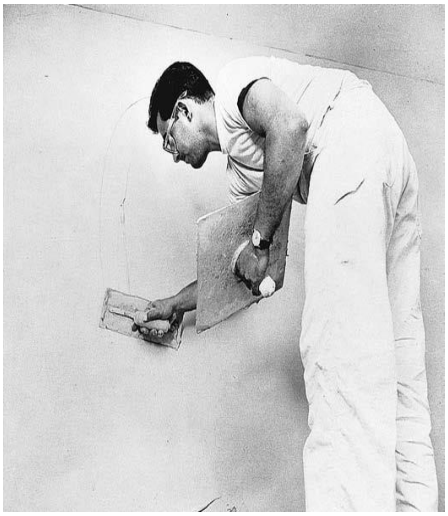
- Corner beads (2) and reinforcing tape are applied 3)

Stapling a corner bead to veneer plaster base to create a straight, durable corner.



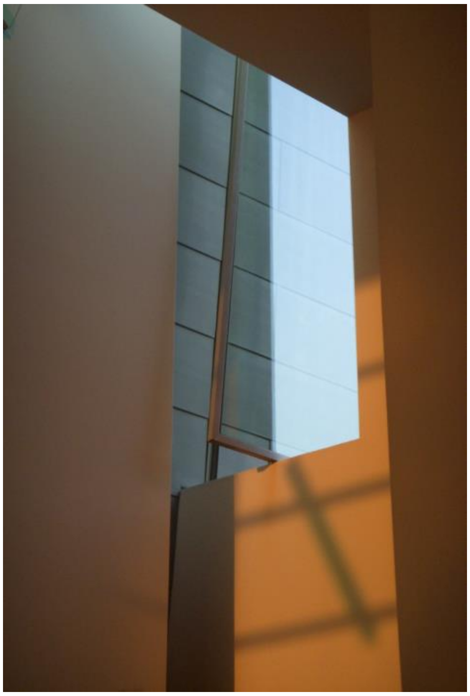
Reinforcing the panel joints of veneer plaster base with a self-adhesive glass fiber mesh tape

- A single coat is applied in a double-back process in which a thin coat is followed immediately by a skim coat that is finish troweled to the desired texture.
- The plaster dries rapidly and is ready for painting the following day



Applying veneer plaster with a hawk and trowel

- Veneer plaster walls illuminate by warm, afternoon sunlight.



Wall and Partition Facings

Wall and Partition Facings I

Ceramic tile facings

- Ceramic tile facings are often added to the walls for reasons of appearance, durability, sanitation, or moisture resistance
- In a thickset or mortar bed application, tile is applied to a base of Portland cement mortar.
- Tiles can be mounted with adhesive to tile backing boards (thin-set). Tile backing boards are most frequently made of fiber-reinforced lightweight cement or glass-mat faced water-resistant gypsum board

Wall and Partition Facings II

Ceramic tile facings

After the tiles have become fully adhered, a cementitious grout of any desired color is wiped into the tile joints with a rubber-faced trowel.

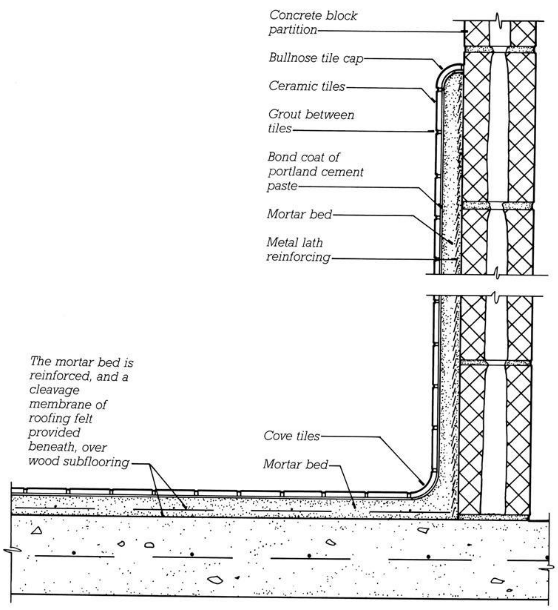
Thin-set compounds and grouts formulated with epoxies may also be used for tiling applications where greater strength, impact resistance, or chemical resistance is required.

In showers, steam rooms, and other wet locations, a waterproofing membrane should be added to the tile assembly to prevent water from seeping through the tile and into the wall behind.

Wall and Partition Facings III

Thickset ceramic tile installation:

Thickset mortar beds for wall tiling are typically ¾ to 1 inch (19–25 mm) thick, while those for floors are typically 1¼ to 2 inches (32–50 mm) thick.



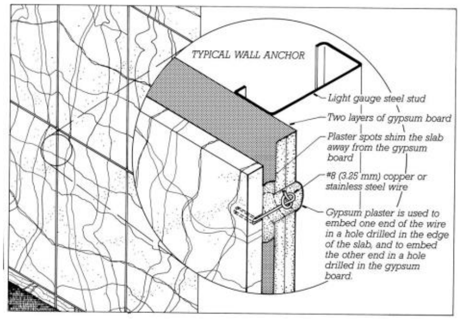
Wall and Partition Facings IV

Stone

Facings of granite, limestone, marble or slate are used in public areas of building

Wood

Wood paneling may be used in limited quantities in fire-resistant buildings. They are mounted on backing of plaster or gypsum board to retain the fire-resistive qualities of the partition.



Marble Wall

Manufactured stone wall

Teak wood wall panels

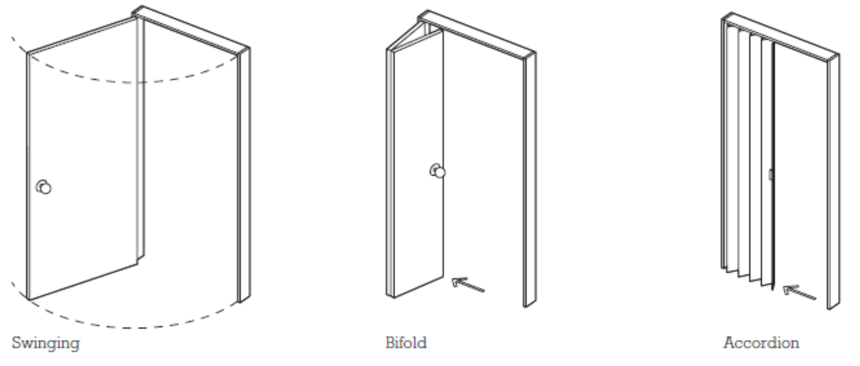
Doors

Door Categories I

- Exterior doors
  - Weather resistance is an important criteria
- Interior doors
  - Passage of sound and fire are important criteria
- Types of Exterior doors:
  - Solid entrance doors, doors with glass, screen doors, storm doors, vehicular doors for residential garages and industrial use, revolving doors.
  - Most common are swinging doors

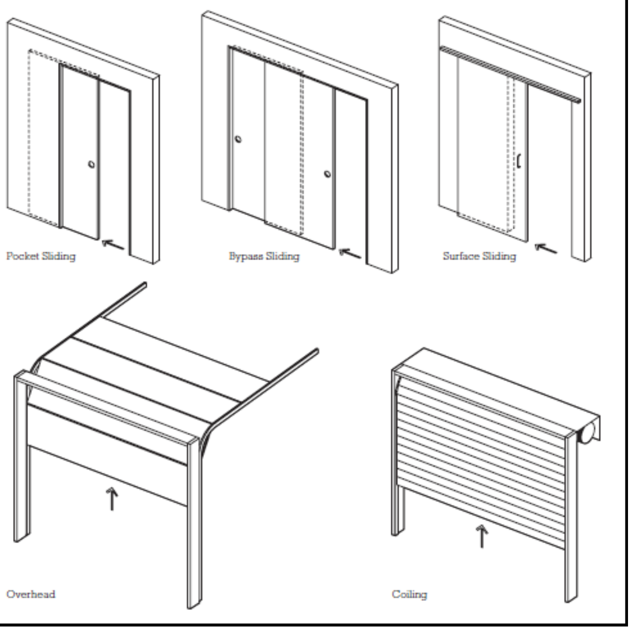
Door Categories II

- Modes of door operations
  - Swinging, bifold, accordian, sliding, overhead, coiling



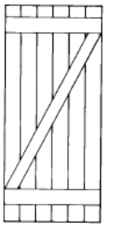
Door Categories III

- Sliding, overhead, coiling

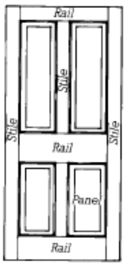


Wood Doors I

- Plank doors:
  - In simple buildings, primitive doors made of planks and Z-bracing were once common.
  - Subject to problems of moisture expansion and contraction
- Stile-and-rail doors
  - Popular in higher-quality buildings
  - May be made of solid wood or of wood composite materials with veneered faces and edges.



Z-BRACE



FOUR PANEL

Wood Doors II

- Flush doors
  - Have captured the majority of the market (easier to manufacture and less costly)
  - Solid core (wood blocks or wood composite material):

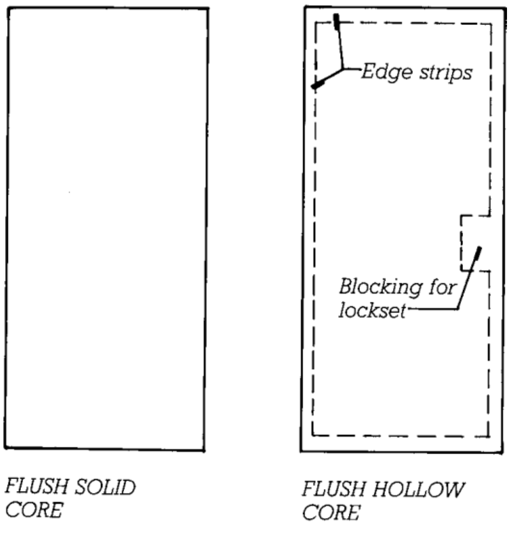
    For exterior use in small buildings, and for both exterior and interior use in institutional and commercial buildings,
  - Hollow core:

    For interior uses in residential

    Consist of two veneered wood faces that are bonded to a concealed grid of interior spacers made of paperboard or wood.

Wood Doors III

- Flush doors
  - Solid mineral core: Qualifies them as fire doors

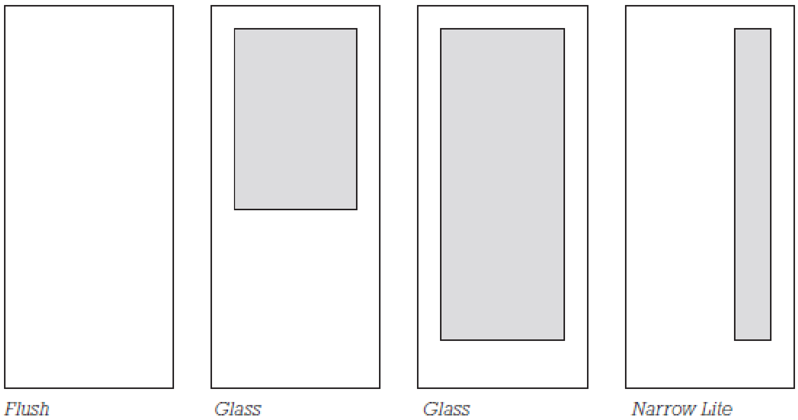


Wood Doors IV

- Wood fiber composite material doors:
  - A relatively recent development
  - A door made of wood fiber composite material that is pressed into the shape of a stile-and-rail door.
  - Usually, the faces of the door may be given an artificial wood grain texture or faced with real wood veneer.

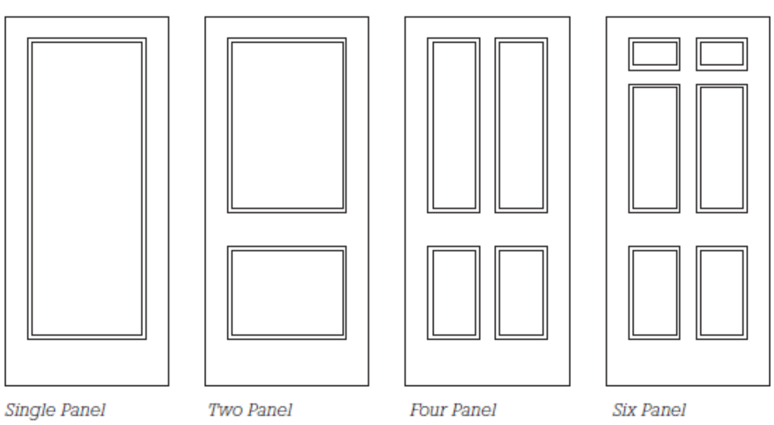
Wood Doors V

- Typical Configurations for Wood Doors



Wood Doors VI

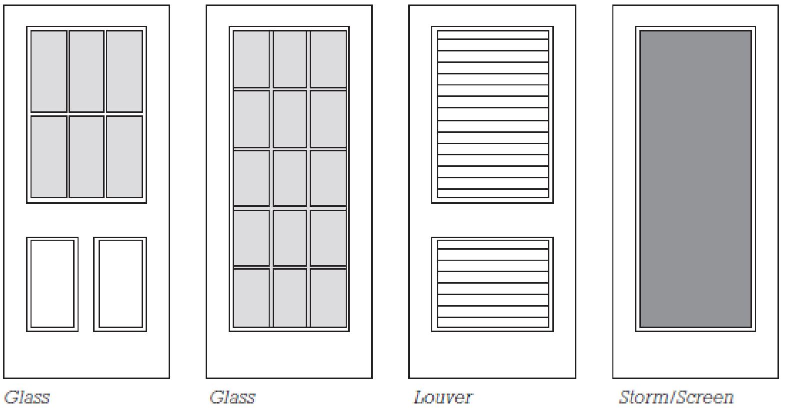
- Typical Configurations for Wood Doors



- Stile-and-Rail Doors

Wood Doors VII

- Typical Configurations for Wood Doors



Exterior Residential Doors I

- Wood panel or solid-core doors:
  - Excellent for exterior residential use if properly installed and finished
- Pressed sheet metal doors & molded plastic doors
  - Popular alternatives to wood exterior residential doors.
  - Usually embossed to resemble wood stile-and-rail doors,
  - Their cores are filled with insulating plastic foam, making their thermal performance superior to that of wood doors.

Exterior Residential Doors II

- Pressed sheet metal doors & molded plastic doors
  - They are often furnished prehung, meaning that they are already mounted on hinges in a surrounding frame, complete with weatherstripping, ready to install by merely nailing the frame into the wall.
  - The major disadvantage of metal and plastic exterior doors is that they do not have the satisfying appearance, feel, or sound of a wood door.

Exterior Residential Doors III

Safety (Security) Doors

Exterior Residential Doors IV

- Residential entrance doors almost always swing inward and are mounted on the interior side of the door frame.
  - This makes them less vulnerable to thieves who would remove hinge pins or use a thin blade to push back the latch to gain entrance.
  - In cold climates, it also prevents snow that may accumulate against the door from preventing the door from opening.

Exterior Residential Doors V

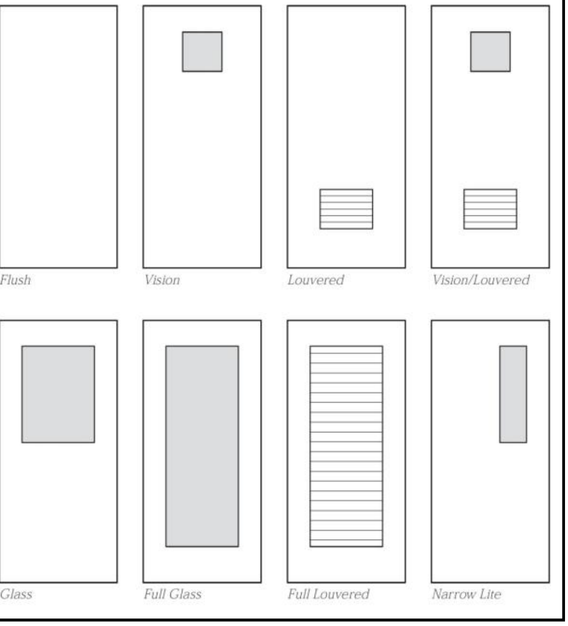
- Storm door:
  - Used to improve wintertime thermal performance of entrance doors
  - Mounted on the outside of the frame of the entrance doors, swinging outward.
  - The storm door usually includes at least one large panel of tempered glass.
- Screen door : (In summer)
  - A combination door, which has easily interchangeable screen and storm panels, is more convenient than separate screen and storm doors.

Steel Doors I

- Flush doors with painted sheet steel are the most common type in nonresidential buildings
  - Hollow core for economy, interior steel doors
  - Solid core Steel doors are required for exterior use and in situations that demand increased fire resistance, more rugged construction, or better acoustical privacy between rooms.
- Steel doors and frames are commonly manufactured and specified according to Steel Door Institute's (standard steel doors) and Hollow Metal Manufacturer's Standards (custom steel doors)

Steel Doors II

- Typical Configurations for Steel Doors



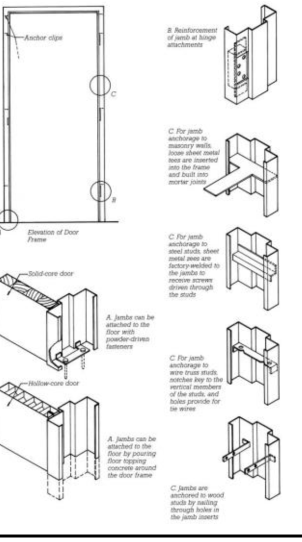
Steel Doors- Frames I

- Metal doors and most nonresidential wood doors are usually hinged to hollow steel door frames
  - Wood and aluminum frames may be used
  - Different types of anchors are available to mount to different frames
  - Where hollow metal door frames are installed within masonry walls, they may be filled with cementitious grout to improve sound deadening and to make the door frame more resistant to tampering or forced entry

Steel Doors- Frames II

- A steel flush door and hollow metal frame, in a concrete masonry exterior wall

- Details of Hollow Steel Door Frames



Fire Doors I

- Fire doors have a noncombustible mineral core and are rated according to the period of time for which they are able to resist specified time and temperature conditions
- In general, doors within fire-resistance-rated walls must themselves also be fire rated.
- Glass used in fire doors must itself be fire rated so that it will not break and fall out of the opening for a specified length of time when exposed to the heat of fire. The maximum size of glass may also be restricted, depending on the fire classification of the door and the properties of the particular type of glass used.

Fire Doors II

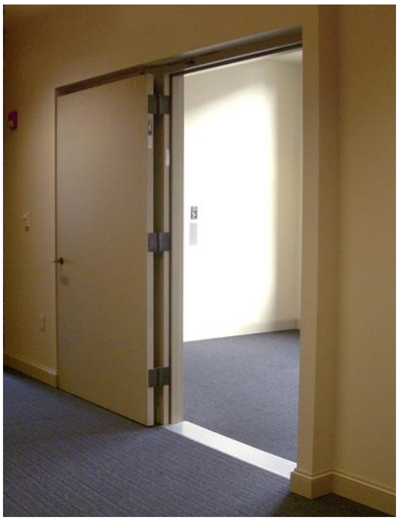
TABLE 715.4
FIRE DOOR AND FIRE SHUTTER FIRE PROTECTION RATINGS

TYPE OF ASSEMBLY	REQUIRED ASSEMBLY RATING (hours)	MINIMUM FIRE DOOR AND FIRE SHUTTER ASSEMBLY RATING (hours)
Fire walls and fire barriers having a required fire-resistance rating greater than 1 hour	4	3
	3	3[a]
	2	$1^1/_2$
	$1^1/_2$	$1^1/_2$
Fire barriers having a required fire-resistance rating of 1 hour:		
Shaft, exit enclosure and exit passageway walls	1	1
Other fire barriers	1	$^3/_4$
Fire partitions:		
Corridor walls	1	$^1/_3$ [b]
	0.5	$^1/_3$ [b]
Other fire partitions	1	$^3/_4$
	0.5	$^1/_3$
Exterior walls	3	$1^1/_2$
	2	$1^1/_2$
	1	$^3/_4$
Smoke barriers	1	$^1/_3$ [b]

a. Two doors, each with a fire protection rating of $1^1/_2$ hours, installed on opposite sides of the same opening in a fire wall, shall be deemed equivalent in fire protection rating to one 3-hour fire door.
b. For testing requirements, see Section 715.4.3.

Fire Doors III

- The fire test label, required for all fire doors, can be seen affixed to the edge of the door below the uppermost hinge



Hardware

- Custom Fabricated Door Hardware

Fenestration Testing and Standards I

- The designer's task in selecting windows, doors, and skylights is facilitated by testing programs that allow objective comparisons of the performance requirements of products of different types and from different manufacturers.
  - Structural Performance and Resistance to Wind and Rain
  - Thermal Performance
  - Impact Resistance
  - Blast Resistance

Structural Performance and Resistance to Wind and Rain

- Specifications establish minimum requirements for air leakage, water penetration, structural strength, operating force, and forced-entry resistance of aluminum, plastic, and wood-framed windows, doors, and unit skylights.

Thermal Performance I

- The two most important properties included in the standards and directly impact building energy consumption and are regulated by energy codes are:
- Thermal Transmittance (U-Factor)
- Solar Heat Gain Coefficient,.
- U-Factors represent the overall thermal transmittance, or whole product heat loss, of complete window, door, and skylight products. That is, they account for the combined contributions to thermal transmittance of the center of glass, edge of glass, framing, and any other components.

Thermal Performance II

- Other tests include:
- Visible light transmittance
- Air leakage,
- Condensation resistance ratings

Impact Resistance

- Especially important for buildings in hurricane-prone regions.
- Such buildings can be subject to extremely powerful and destructive winds, and glazed openings in such buildings are especially vulnerable. The pressure of high-speed winds can cause glass to break, or it can suck whole lights out of their sashes, whole sashes out of their surrounding frames, or whole frames out of their rough openings.

Projectile damage to a window wall resulting from hurricane force winds

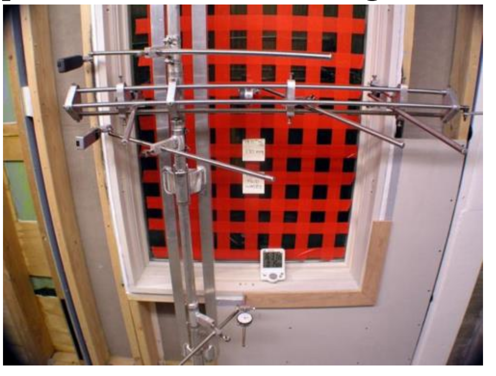
Blast Resistance

In buildings subject to special security requirements, windows, curtain walls, and other glazing systems can be designed for resistance to the force of explosive blasts. Design for blast resistance involves defining the size of the blast and its distance from the glazing system, as well as the glazing system's response to the blast.

Of particular concern is the extent to which glass remains intact in the system or is shattered and dispersed as hazardous fragments. Like impact-resistant glazing, blast-resistant glazing typically relies on laminated glass and reinforced framing and attachment systems.

Window Testing I

- Setting up a laboratory test for window structural strength and resistance to wind pressures
- The metal apparatus is used to measure deflection of the window frame during the test
- The glass is taped to prevent it from shattering



Window Testing II

Window Testing

Setting up a laboratory test for window structural strength and resistance to wind pressures
The metal apparatus is used to measure deflection of the window frame during the test
The glass is taped to prevent it from shattering

Fenestration Performance

Many other issues that need to be taken into account in choosing fenestration

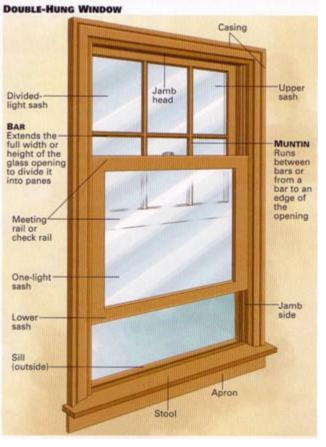
- Fire
- Egress (Emergency escape)
- Accessibility
- Accidental breakage

Doors and Windows

MasterFormat Sections For Windows and Doors

CSI/CSC MasterFormat Sections for Windows and Doors		
08 10 00	DOORS AND FRAMES	
08 11 00	Metal Doors and Frames	
		Hollow Metal Doors and Frames
		Metal Screen and Storm Doors and Frames
08 14 00	Wood Doors	
		Flush Wood Doors
		Clad Wood Doors
		Stile and Rail Wood Doors
08 15 00	Plastic Doors	
08 50 00	WINDOWS	
08 51 00	Metal Windows	
		Aluminum Windows
		Steel Windows
08 52 00	Wood Windows	
08 53 00	Plastic Windows	
08 54 00	Composite Windows	
		Fiberglass Windows
08 60 00	ROOF WINDOWS AND SKYLIGHTS	
08 61 00	Roof Windows	
08 62 00	Unit Skylights	

Windows



Windows

- Window is thought to have originated from "wind-eye"
- Windows have changed from open holes in earliest buildings to an intricate sophisticated mechanism with many layers of control

  - **<u>Layers of control:</u>**

  curtains, shade or blind, sash, glazing, insulating airspace, low-emissivity and other coatings, insect screen, weatherstripping, and perhaps a storm sash or shutters.

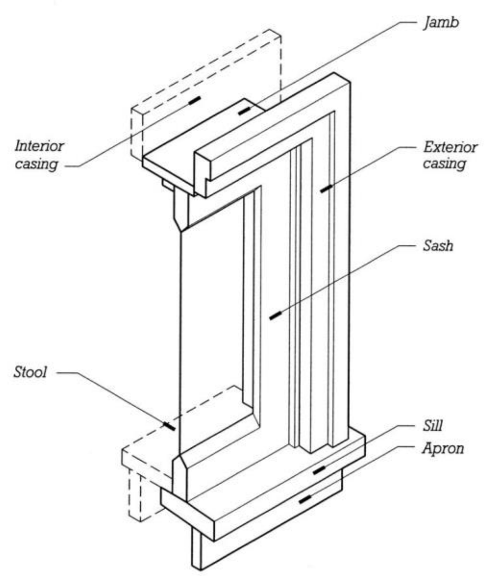
- Windows were formerly made on the construction site by highly skilled carpenters, but today nearly all of them are produced in factories.
  - Higher production efficiency
  - lower cost
  - better quality(the most important).

- Windows must be made to a very high standard of precision if they are to operate easily and maintain a high degree of weather tightness for many years.

- The Prime window is a window made to be installed permanently in a building
- A storm window is a removable auxiliary window that is added seasonally to a prime window to improve its thermal performance.
- Combination window includes operable and fixed portions in addition to insect screening
- Replacement windows install in existing openings

Window Terminology

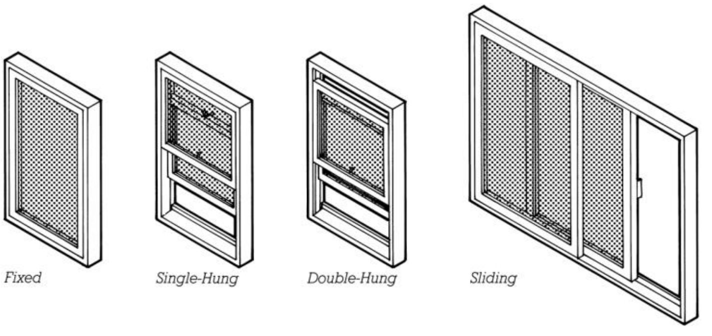
- The top of window frame is called head jamb or simply head, the two verticals are called side jambs or jambs and the bottom portion is called a sill. Casings, stools and aprons provide the finishing



Types of Windows

- Fixed windows
  - Least expensive and least likely to leak air or water because they have no operable components.
- Hung windows
  - Maybe single hung or double hung depending on one or two moving sashes
  - The sashes slide up and down in tracks that are part of the window frame.
  - Sashes were hung by counterweights in the past but now use springs

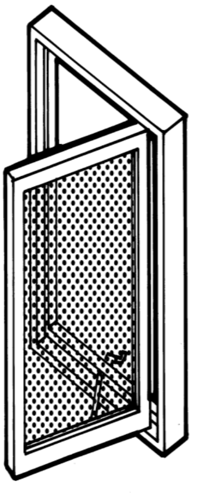
- Sliding windows
  - Essentially like a single hung window on the side
  - Inherently stable operable windows because of tracks
  - Can be designed in many sizes



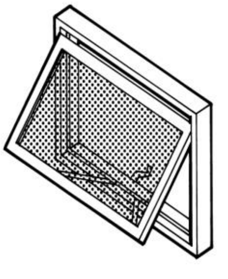
- Projected windows
  - Includes casement, awning, hopper, tilt/turn and inswinging windows
  - All projected windows have sashes that rotate outward or inward from their frames and therefore must have enough structural stiffness to resist wind loads while being supported only at two corners.
  - Many projected windows can be opened to full area unlike windows with sliding sashes

    No window with sashes that slide can be opened to more than half of its total area

- Casement windows
  - Assist in catching passing breezes and inducing ventilation through the building.
  - Generally narrow in width but can be joined to one another or with fixed windows to fill wider openings

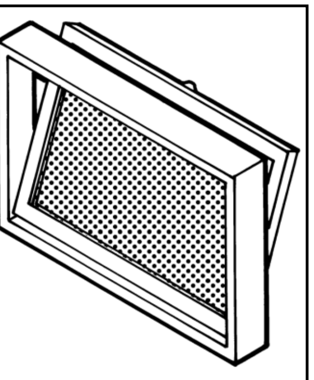

Casement

- Awning windows
  - Can be broad but not usually tall
  - Can protect an open window from water during rainstorms
  - Lend themselves to building block approach when designing window walls


Awning


Awning and Fixed Window Creating a Patterned Wall of Glass

- Hopper windows
  - More common in commercial buildings than in residential
  - They are inswinging
  - Admit little or no rainwater if left open during a rainstorm

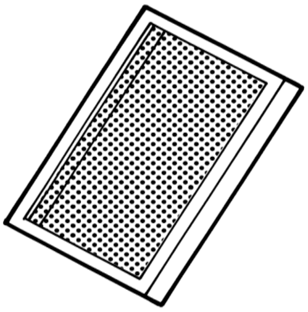


Hopper

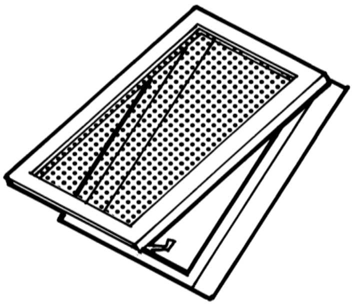
- Tilt/Turn windows
  - Have elaborate but concealed hardware that allows window to be operated as either a casement or a hopper

- Types of windows and airtightness
  - Projected windows have pliable rubber weatherstripping (unlike brush type) that seals by compression providing good air tightness
  - Single-hung, double-hung, and sliding windows generally must rely on brush type weatherstripping because it does not exert as much friction against a sliding sash as rubber does.
  - Brush type materials do not seal as tightly as compression weatherstripping, and they are also subject to more wear than rubber weatherstripping over the life of the window.

- Windows in roofs
  - Windows in roofs are flashed for water tightness
  - They may be fixed – skylights
  - They may be operable – roof windows



Skylight

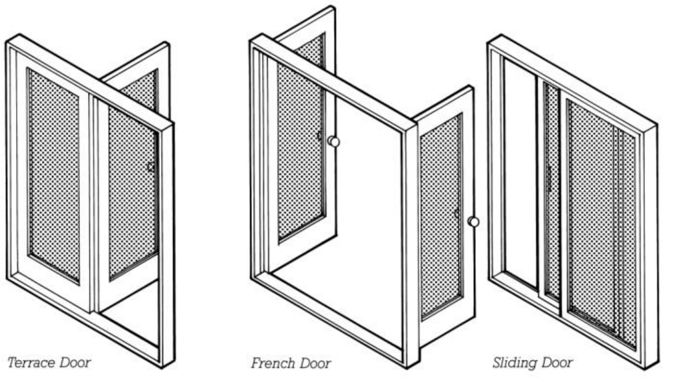


Roof Window

Glass Doors

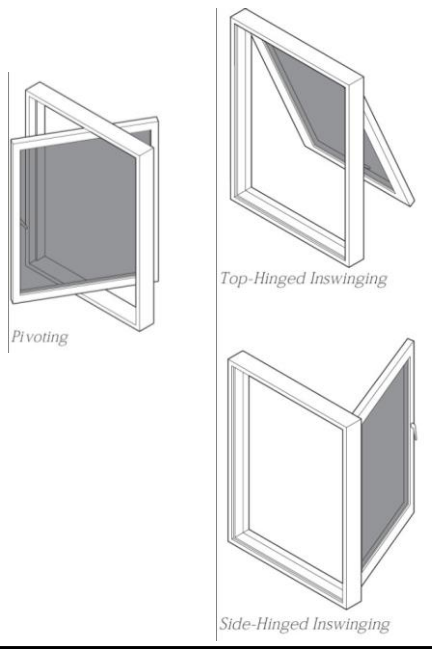
- Large glass doors may slide on tracks or swing open on hinges
- French doors
  - Open fully and are more welcoming than sliding doors
  - Not easy to regulate air into the room because it can't be kept partially open
  - Prone to more air leakage
- Sliding doors
  - Can be partially opened to regulate air
  - Can only open half its area

- Terrace doors
  - Half leaf can swing open



Types of Windows- Larger Buildings

- Horizontally and vertically Pivoting windows
- Side-hinged inswinging windows
- Top-hinged inswinging windows
- Allows for inside washing of exterior glass surface
- Devices limit amount of opening to reduce damage



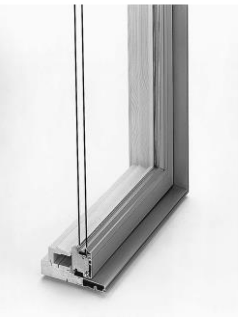
- A commercial horizontal strip window system

Window Frames

- Wood
  - Tradition frame material for housing
  - Fairly good thermal insulator
  - Low coefficient of thermal expansion
  - Easily worked and consistently strong (if free of knots)
  - Wood shrinks and swells with changing moisture content
  - Requires repainting every few years and is subject to decay
  - Wood frame windows can be clad with aluminum or vinyl (on the exterior side)

- Double Hung Wood Frame Windows

- Wood Windows – Double Hung and Triangular

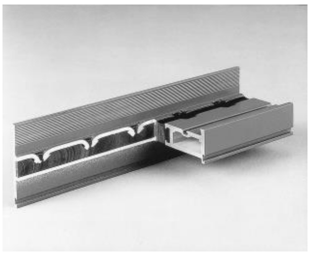


- Aluminum Clad Wood Framed Window

- Aluminum
  - Strong, easy to form and join
  - Less vulnerable to moisture damage
  - Attractive profiles and colors
  - Durable factory finishes (anodized or permanently coated)
  - Aluminum conducts heat so rapidly (Require thermal breaks to reduce heat flow)
  - More costly
  - Mostly common in large buildings

- Aluminum

- Cutaway Section of Thermal Break



- Aluminum Double Hung and Sliding Window

- Commercial grade aluminum windows

- Plastic
  - Becoming more common
  - Do not need painting
  - Provide good thermal resistance
  - Not as stiff or strong as other materials
  - Have high coefficient of thermal expansion
  - PVC is the most common plastic used

Cutaway Sections of Plastic Framed Windows

- GFRP – Glass Fiber Reinforced Plastic
  - Frequently referred to as fiberglass windows
  - GFRP frame sections are produced by a process called pultrusion
  - Strong, stiff and relatively low in thermal expansion
  - More expensive
  - The thermal performance of both PVC and GRFP window frames can be enhanced with foam insulation injected into the hollow spaces within the frame sections.

- Steel

  Main advantage is strength which permits sashes to be slender than other materials

  Corrosion is a problem so frames would need to be coated or painted

  More thermally conductive than wood and plastic but less than aluminum

Steel Frame Results in Narrow Sight Lines

- Steel

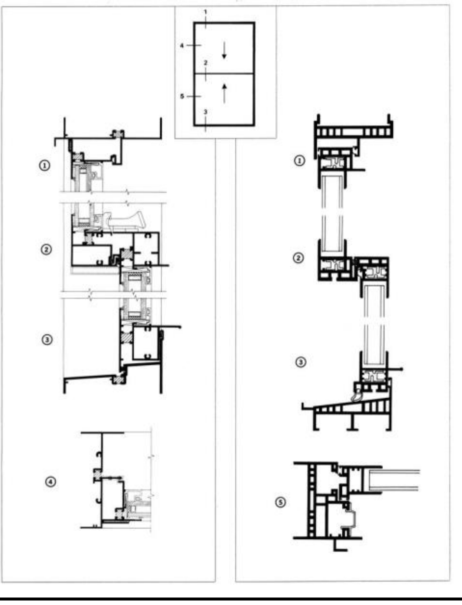
- Hot Rolled Steel Window Frame Sections

- Cutaway of Steel Framed Window

Muntins

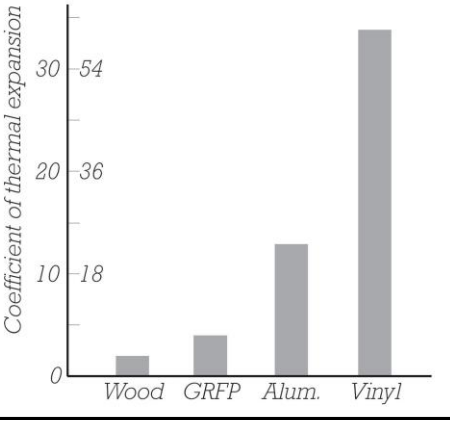
Glass in windows is divided into small sections within each sash by muntins (thin wooden bars in which the glass was mounted within each sash)
It was necessary when large sizes of glass were not common but is more decorative now

Window Frames- Comparisons



- Single Hung Aluminum Framed Window (left) Compared to PVC Plastic Framed Window (right)
- The comparatively thick sections of plastic are indicative of the greater stiffness of aluminum as a material.

- Coefficient of Thermal Expansion:
  Vinyl expands 15 times as much as wood, 8 times as much as GFRP, and 3 times as much as aluminum.



- Window Frames- Comparisons III

- Thermal Performance: Impact of Window Frame to Overall U Values of Windows

	Overall U-Factor[a]		
Window Frame	**Single-Glazed**	**Double-Glazed, Clear**	**Double-Glazed, Low-e, Argon Gas**
Aluminum, without thermal break	1.2 *6.8*	0.76 *4.3*	0.60 *3.4*
Thermal break aluminum	1.0 *5.7*	0.63 *3.6*	0.48 *2.7*
Steel	0.92 *5.2*	0.55 *3.1*	0.41 *32.3*
Wood, clad wood, vinyl	0.84 *4.8*	0.49 *2.8*	0.35 *2.0*
GFRP	0.65 *3.7*	0.44 *2.5*	0.27 *1.5*

[a]U-factor: Btu/ft^2-hr-^{o}F followed by *W/m^2-^{o}K.*

Glazing

Sealed double glazing or single glazing with storm windows is the minimum acceptable glazing under most building codes

More than 90 percent of all residential windows sold today in North America have two or more layers of glass.

Double glazing with a low-emissivity (low-e) coating on one glass surface performs at least as well as triple glazing.

Single glazing is acceptable only in the mildest climates because of its low resistance to heat flow and the likelihood that moisture will condense on its interior surface in cool weather.

With fire-rated glazing such as wired glass, shown here, a steel window can be fire rated

Installing Windows I

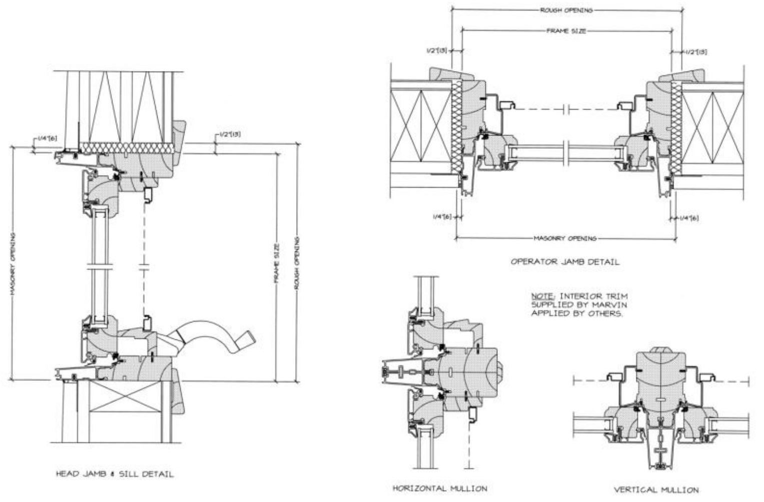
- Designers need to ensure to provide rough openings or masonry openings for the windows
- The rough opening height and width are the dimensions of the hole that must be left in a framed wall for installation of the window. They are slightly larger than the corresponding outside dimensions of the window unit itself

  To allow the installer to locate and level the unit accurately and

  To ensure that the window unit is isolated from structural stresses within the wall system.

- The masonry opening dimensions indicate the size of the hole that must be provided if the window is mounted in a masonry wall
- Details need to be considered to flash openings carefully before the window is installed in order to avoid later problems with leakage of water or air
- Attachments/Anchoring of windows to the frame need to be taken into account. The window manufacturer's recommendations should be followed in each case.

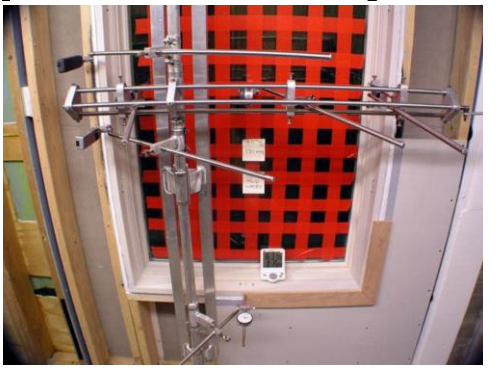
- Manufacturer’s Catalog Details Showing Rough Opening & Trim Requirements



- Aluminum-clad, wood windows being installed into a rough opening constructed of thin steel sections and plywood

Window Testing

- Setting up a laboratory test for window structural strength and resistance to wind pressures
- The metal apparatus is used to measure deflection of the window frame during the test
- The glass is taped to prevent it from shattering



Window Testing

Setting up a laboratory test for window structural strength and resistance to wind pressures
The metal apparatus is used to measure deflection of the window frame during the test
The glass is taped to prevent it from shattering

Selecting Interior Finishes

Installation of Interior Finishes

- The installation of interior finish materials (ceilings, walls, partitions, floors, casework, finish carpentry) cannot proceed at full speed until:
  - **The roof and exterior walls of a building are complete**
    - The roof and walls are needed to shelter the moisture-sensitive finish materials.
  - **Mechanical and electrical services have been installed**
    - The mechanical and electrical services generally must be covered by the interior finish materials, and thus must precede them

Installation of Mechanical and Electrical Services

- **Sequence of installation of services**
  - Waste lines and water supply lines
  - Pipes for automatic sprinklers
  - HVAC – boilers, chillers, pumps, fans, piping, and ductwork
  - Electrical, communication and control wiring
  - Elevators and escalators are installed in the structural openings
  - provided for them.

- The vertical runs of (ducts, pipes, wires, and elevators) through a multistory building are made through vertical shafts whose sizes and locations were determined at the time the building was designed.

- Horizontal runs are located below floors in ceilings or above ceilings in raised floors.
- Some services are concealed in structure.
- Distribution equipment for electrical and communications wiring is housed in special rooms or closets.

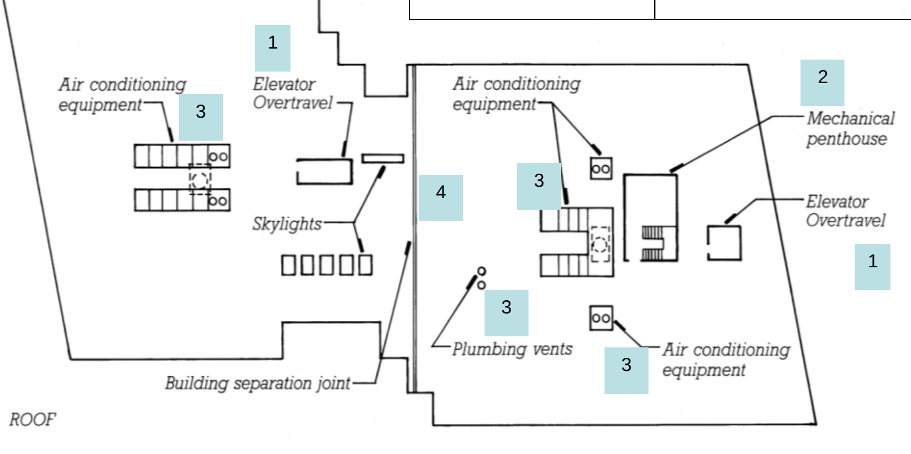
✓ **F**an rooms are often provided on each floor for air handling machinery.

In a large multistory building, space is set aside, usually at a basement or subbasement level, for pumps, boilers, chillers, electrical transformers, and other heavy equipment.

In very tall buildings, one or two entire intermediate floors may be set aside for mechanical equipment, and the building is zoned vertically into groups of floors that can be reached by ducts and pipes that run up and down from each of the mechanical floors.

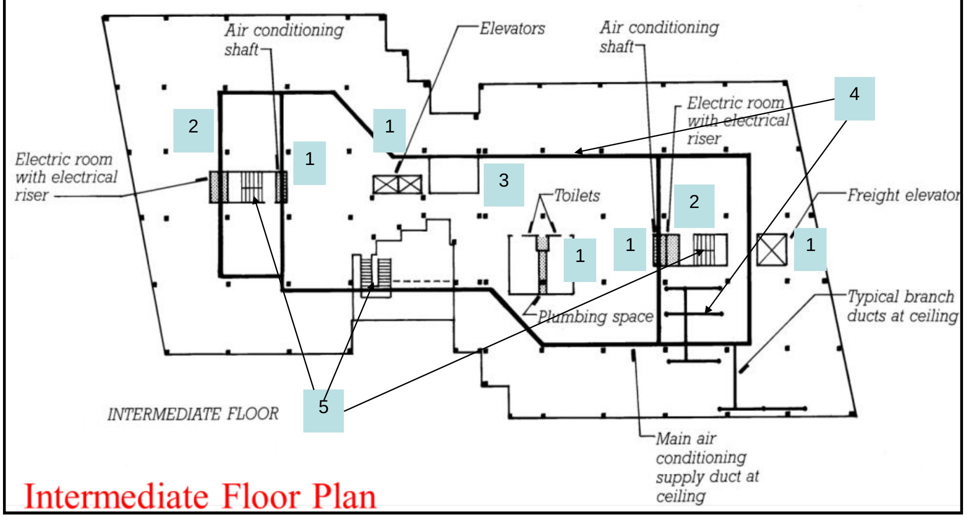
10 - 5

1. Service space for elevator room	**3. Location of possible vertical shafts below**
2. **Mechanical equipment located on roof**	**4. Location of horizontal building expansion joints**



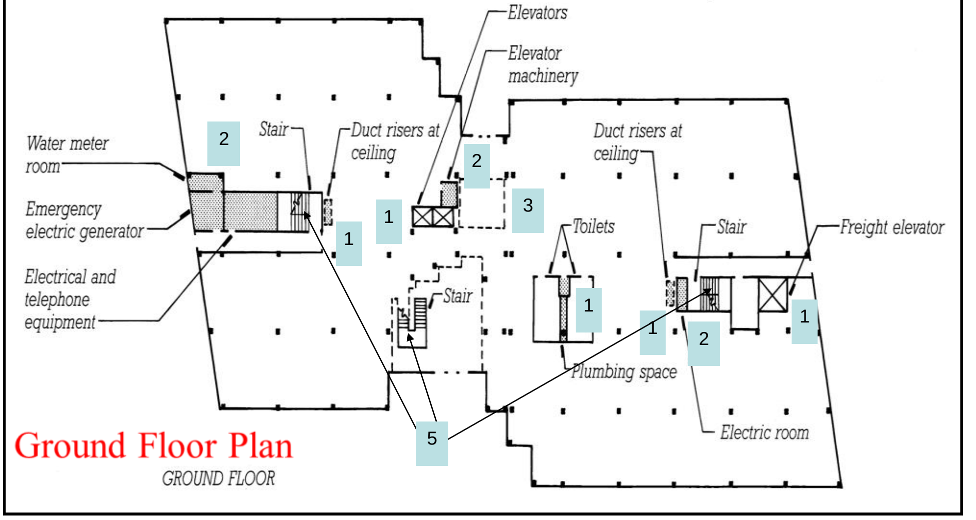
Roof Plan

1.Vertical Shafts for M/E
2. Rooms on each floor with vertical shafts
3. Double columns at expansion joints
4. Horizontal distribution of services
5. Other vertical shafts/spaces such as stairways



Intermediate Floor Plan

1. Vertical Shafts for M/E
2. M/E rooms on ground floor
3. Double columns at expansion joints
4. Horizontal distribution of services not shown
5. Other vertical shafts/spaces such as stairways



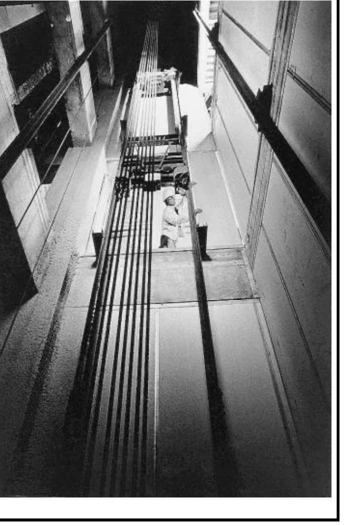
Ground Floor Plan

Sequence of Interior Finish Operations

- **Finishing Shafts**

Interior finishing operations follow a carefully ordered sequence

  – The first finish items to be installed are usually hanger wires for suspended ceilings and full-height partitions and enclosures especially those around mechanical, electrical and elevator shafts, equipment rooms and stairs



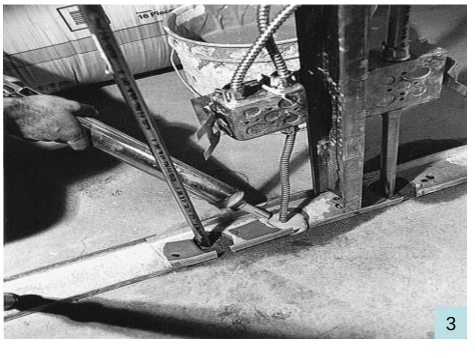
- **Installing Firestopping**

  – Firestopping is inserted around pipes, conduits and ducts where they penetrate floors and fire-rated walls.

  – Firestopping may consist of applying safing material first followed by mastic, or in very small openings just applying mastic

(1) Within a plumbing wall, a layer of safing insulation is cut to fit and inserted by hand into a large slab opening around a cast iron waste pipe

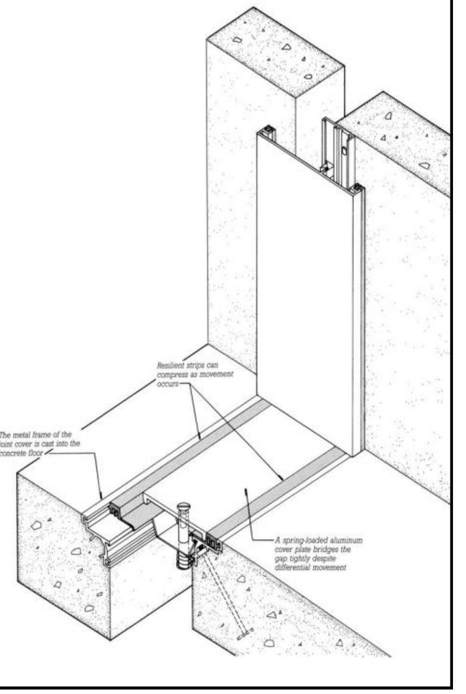
2. Then a mastic firestopping compound is applied over the safing to make the opening airtight



(3) Applying firestopping compound around an electrical conduit at the base of a partition.

Installing Joint Covers

- The full height partition enclosures, firestopping, joint covers and safing around the perimeters of the floors constitute a very important system for keeping fire from spreading through the building



- Installing Joint Covers
  - Building separation/expansion joint covers at the floor, wall, and ceiling.

Sequence of Interior Finish Operations

Interior Finishing

- After the horizontal distribution system is installed the suspended ceiling is installed
- This is followed by framing for wall partition and wall finishing including locating outlets
- The floor finishing is applied last when all trades have completed work to prevent damage

Selecting Interior Finish Systems

- Functional parameters in selecting interior finishes:
  1. Appearance
  2. Durability and Maintenance
  3. Acoustic Criteria
  4. Fire Criteria – Combustibility
  5. Fire Criteria – Fire Resistance
  6. Relationship to M/E Services
  7. Changeability
  8. Cost
  9. Toxic Emissions from Interior Materials

Appearance

- A major function of interior finish components is to make the interior of the building look neat and clean
- By covering the rougher and less organized portions of the framing, insulation, vapor retarder, electrical wiring, ductwork, and piping.
- Interior finishes represent designer's concept of interior space with respect to space, light, color, pattern and texture
- Reflections from interior finish material affect sense of illumination
- Light originates from windows and electric lighting fixtures and is propagated by successive reflections off the interior surfaces of the building.

- Lighter-colored materials raise interior levels of illumination; darker colors and heavier textures result in a darker interior.
- Flooring and wall finishes can be used to give a sense of affluence and appropriateness to the desired occupancy
- Deep carpets and rich, polished marbles in muted tones may be chosen to give an air of prosperity to a corporate lobby
- Brightly colored surfaces to create a happy atmosphere in a day care center

Durability and Maintenance

- Wear and tear in relation to the use of the building must be considered
- Highly durable finishes generally cost more than shorter-lived ones and are not always required
- Areas with intense traffic need to be designed with properly wearing surfaces
- Long-wearing materials are essential for a courthouse, a transportation terminal, a recreation building, or a retail store
- In a private office or an apartment . more economical finishes are usually adequate.

- Water resistance of finishes should be considered in appropriate places
- kitchens, bathrooms, and entrance lobbies
- In areas such as hospitals finishes should be used that do not trap dirt and that can be easily cleaned and disinfected
- Ability to carry out routine maintenance and the associated costs should be considered in selecting interior finishes
- How often will each surface be cleaned, with what type of equipment, and how much this will add to the cost of owning the building?

Acoustic Criteria

- Interior finish materials can affect:
- Noise levels
- Quality of listening conditions
- Levels of acoustic privacy
- Absorptive and reflective surfaces need to be carefully selected to control and manage sound within space
- In noisy environments, absorptive surfaces can decrease the noise intensity to a tolerable level
- In lecture rooms, classrooms, meeting rooms, theaters, acoustically reflective and absorptive surfaces must be proportioned and placed so as to create optimum hearing conditions

Acoustic Criteria

- Acoustic isolation properties of partitions need to be considered to reduce air borne noise transmission between spaces.
- Sound Transmission Class (STC) rating of partitions is a property most commonly used to distinguish walls for sound isolation
- Acoustic privacy between rooms, is created by partitions that are both heavy and airtight.
- The acoustic isolation properties of lighter-weight partitions can be enhanced by partition details that damp the transmission of sound vibrations (resilient mountings on one of the partition surfaces and sound-absorbing materials in the interior cavity of the partition (mineral wool)

- Openings in a wall with STC rating may breach the sound isolation
- If the rooms on both sides are served by a common air duct that also acts incidentally as a conduit for sound, or if the partition reaches only to a lightweight, porous suspended ceiling that allows sound to pass over the top of the partition
- If cracks around the edges of a partition are not completely sealed, a loosely fitted door or even an unsealed electric outlet is inserted into the partition.

- Impact noise needs to be considered to reduce structure borne sound transmission.
- M/E services need to be isolated and resilient material need to be used for the purpose.
- Impact isolation class (IIC) is a property used for this purpose
- Impact noise transmission can be reduced by floor details that rely on soft materials that do not transmit vibration readily (carpeting, soft underlayment boards, or resilient underlayment matting)

Fire Criteria – Combustibility

- Surface burning characteristics of interior finishes are governed by code requirements. Different measures are used to select materials based on combustibility
  - Flame spread rating which indicates the rapidity with which fire can spread across the surface of a given material (Steiner Tunnel Test)
    - Materials are assigned a class of A, B or C based on testing with A being better than B or C
    - Class A materials are those with flame-spread ratings between 0 and 25, Class B between 26 and 75, and Class C between 76 and 200. (The scale of flame-spread numbers is established by assigning a value of 0 to cement-asbestos board and 100 to a Red oak board.)

  - Smoke developed rating which classifies material according to the amount of smoke given off when it burns (Steiner Tunnel Test)
    - For all three classes, the smoke-developed rating may not exceed 450. Materials with higher smoke-developed ratings are not permitted to be used inside buildings, because smoke, not heat or flame, is the primary killer in building fires
  - Room fire growth contribution testing is used for very flammable materials (e.g. textile or vinyl coverings)
    - It measures the material's potential to add fuel to an incipient fire.

- Minimum critical radiant flux exposure is used to test the combustibility of some flooring materials to be used in exists, corridors and areas connected to these spaces. Materials are divided into Class I or II with the former being better
  - The purpose of this test is to ensure that flooring materials in essential parts of the egress system cannot be easily ignited by the radiant heat of fire and hot gases in adjacent spaces.
  - Some traditional flooring materials, including solid wood, resilient materials, and terrazzo, which have historically demonstrated satisfactory resistance to ignition during building fires, are not required to meet this test standard.

- Pill test may be used to test flooring material to test the hazard from burning cigarettes
  - Evaluates the material's susceptibility for flame spread when exposed to a burning tablet intended to simulate a dropped lit cigarette, match, or similar hazard.

Fire Criteria – Fire Resistance

- Fire resistance of assemblies and structural elements refers to the ability to resist the passage of fire from one side to the other
- Building code regulates the fire resistance of assemblies and structural members by requiring a certain fire resistance rating
- Fire resistance ratings are determined by testing where assemblies are subject to fire in a furnace
- The tested assemblies are required to:
  - Not develop any openings to permit the passage of flame or hot gases

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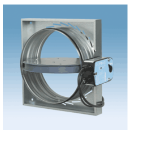
  - Insulate sufficiently against the heat of fire to prevent temperature rise on the other side of the fire
  - Pass a test called the hose stream test
- Openings in assemblies with fire resistance rating must also be protected
  - Doors must be rated although with a lower rating
  - Ducts must be equipped with dampers
  - Penetrations for pipes and conduits must be closed tightly with fire-resistive material



Relationship to M/E Services

– Depending on whether M/E services are concealed or not will impact the manner in which finishes are completed
– If M/E needs to be concealed then access openings will need to be provided for servicing at various locations
– If M/E are not be concealed and left exposed then the services should be organized visually and a high standard of workmanship should be specified

Changeability

– Interior finishes should adapt to need for change base on occupancies
– In a concert hall, a mosque/church, or a hotel major changes will be infrequent so fixed unchangeable partitions with more luxurious finishes would be appropriate
– In a rental office building or a retail shopping mall changes will be frequent and lighting and partitions should be designed to allow for such changes.
– Less expensive material that can be disposed may be used or more expensive material which can be reused may be used

Cost

- The cost of interior finish systems may be measured in two different ways
- First cost is the installed cost and is of paramount importance when construction budget is tight or the expected life of the building is short
- Life-cycle cost is a cost that take into account the expected lifetime of the finish system cost, maintenance cost, fuel cost, replacement cost , inflation and time value of money in addition to first cost.

- Life cycle becomes important for owners who expect to retain ownership over an extended period of time
- Higher first costs may be justifiable if there are savings in life cycle costs

Toxic Emissions from Interior Materials

- Interior materials can contribute negatively to the Indoor Environmental Quality
- Formaldehyde fumes (Many synthetics and wood panel products)
- Fumes from solvents and paints and carpet adhesives
- Fibers of asbestos and glass
- Airborne spores from mildews
- Radon gas
- Construction dust

- There is increasing pressure, both legal and societal, on designers to select interior materials that do not create objectionable odors or endanger the health of building occupants.
- Designers should try to seek data on emissions of pollutants from finish materials (data are becoming increasingly available)
- This is complicated by the fact that data on the toxicity of various indoor air pollutants are inconclusive.
- It is wise to select materials that give off the smallest possible quantities of irritating or unhealthful substances

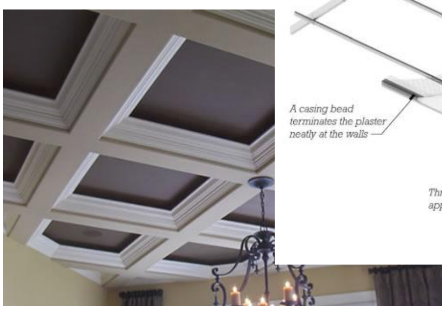
Trends in Interior Finishes

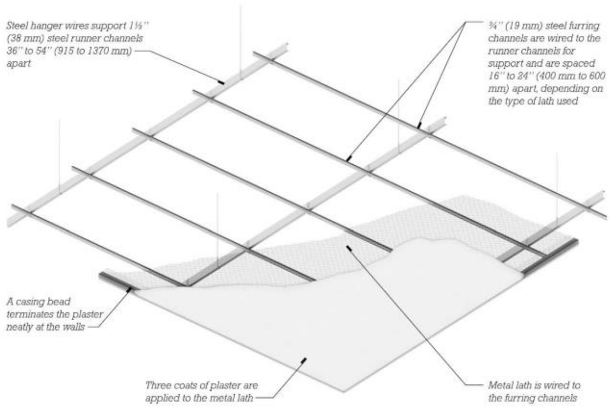
- Change from integral, single-piece system toward a system made of discrete components
  - This is illustrated by partitions made of modular, demountable, relocatable panels away from integral hard to change wall systems
- Change from heavy finish material toward lighter ones
  - Reduction in dead loads
  - Reduction in shipping, handling and installation costs
  - Less effort to move or remove when changes required

Trends in Interior Finishes II

- Change from wet systems to dry systems
- Change to more sustainable systems that have lesser impact on resources
- The trends need to be balanced with aspects of durability, permanence, and quality
  - The traditional finishes are far from obsolete
  - In many situations, the life-cycle costs of traditional finishes compare favorably with those of lighter-weight finishes whose first cost is considerably less

Finish Ceilings





Functions of Finish Ceilings

- Play a part in the visual expression of the room
- Controls diffusion of light and sound in the room
- May play a role in preventing the passage of sound vertically
- Control combustibility and passage of fire
- Part of distribution system for M/E services

Shapes of Finish Ceilings

Shapes of ceiling's finishes include: flat, a series of sloping planes, coffered, or vaulted ceilings

Coffered Ceiling

Vaulted Ceiling

Types of Ceilings

- Exposed Structural and Mechanical Components
- Tightly Attached Ceilings
- Suspended Ceilings
- Interstitial Ceilings

Exposed Structural and Mechanical Components

- This approach offers the advantages of economy and ease of access for maintenance.

- When it is appropriate:
  - Where appearance is not as important
  - Where structure is inherently attractive
  - Where exposed services add aesthetic appeal
- It requires:
  - Care and planning is required when systems are to be left exposed and it may increase cost

- The concrete ceiling in buildings which have little need for mechanical services at the ceiling can be painted and left exposed as finished ceilings

Tightly Attached Ceilings

- Ceilings of different materials may be tightly attached to the underlying structural elements

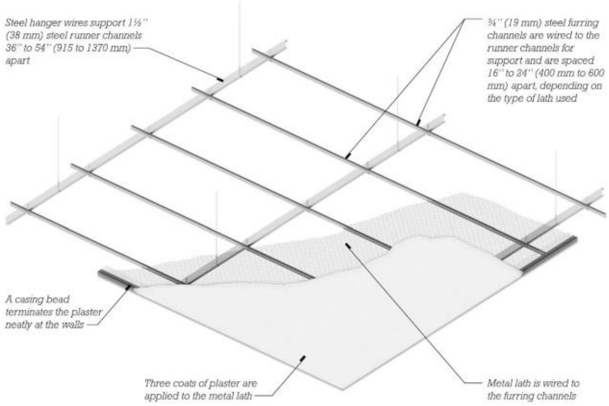
Suspended Ceilings

- Ceiling that is suspended on wires some distance below the floor or roof structure
- Advantages:
  - It can conceal structure (girders, beams, joists) and services in space above called plenum
  - Ceiling can be flat even though the structure may be sloped
  - Lighting fixtures, sprinkler heads, loudspeakers, and fire detection devices may be recessed into the ceiling

  - Ceiling can serve as membrane fire protection for floor structure above
  - Can be made from variety of materials
- The most widely used material for suspended ceilings:
  - Gypsum board
  - Plaster panels
  - Tiles composed of incombustible fibers.

Suspended Gypsum Board and Plaster Ceiling

- Can be framed onto light gauge steel c channels

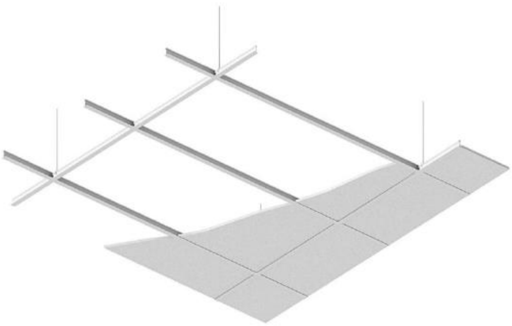


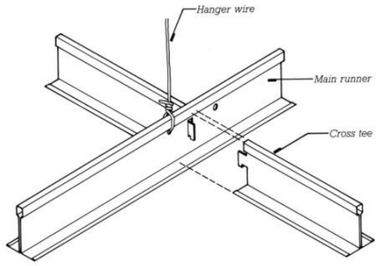
Suspended Plaster Ceiling

Suspended Acoustical Ceilings

- Ceilings made from fibrous materials in the form of lightweight tiles or panels are customarily referred to as acoustical ceilings because most of them are highly absorptive of sound energy,
  - Usually less costly than either plaster or even gypsum board ceilings
  - Acoustical ceilings valuable for reducing noise levels in interior spaces
  - Sound absorption performance is measured as **Noise Reduction Coefficient (NRC**).
  - Materials that produce high NRC ratings allow most sound energy to pass through

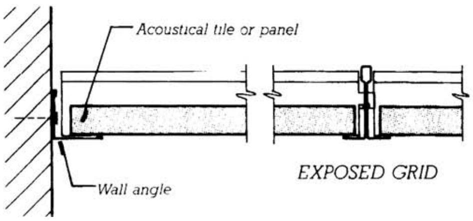
- Most economical type consists of lay-in-panels supported on exposed grid.

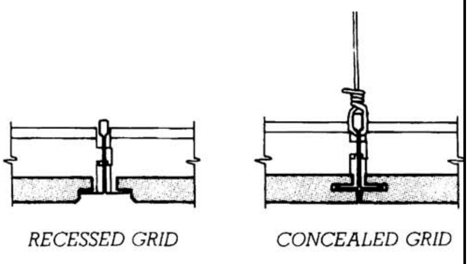




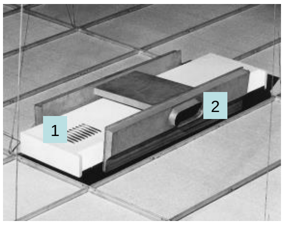
Example of exposed grid lay-in-panels

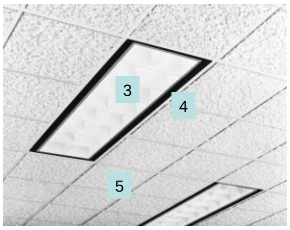
- The grid may be exposed, recessed, or concealed for different visual appearances.





- Integrated Ceiling System
  - View above the ceiling shows light integrated (1) with the distribution boot (2) for conditioned air
  - View from bottom shows light fixture (3) with slot around (4) it through which air is distributed
  - The rough textured acoustical panels are grooved to give a look of smaller square panels (5)





- Another integrated system the air distribution (1) occurs between panels
- Light fixtures (2), loudspeakers (3), and smoke detectors (4) are incorporated simply and unobtrusively
- An example of coffered acoustical ceilings (5) that act as light diffusers in an integrated system

Suspended Ceilings Examples I

Suspended Acoustic Ceilings

Suspended Ceilings Examples II

Suspended Acoustical Ceiling

Expanded Metal Lath Ceiling

Suspended Ceilings Examples III

Suspended Linear Metal Ceiling

Suspended Linear Wood Ceiling

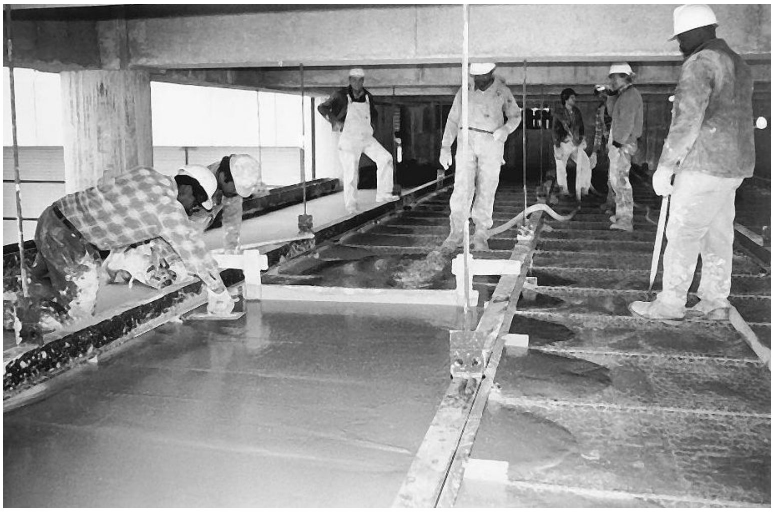
Suspended Fire Resistance Rated Ceilings

- May be made of gypsum, plaster panels and grid systems designed for that purpose
- Penetrations in such membrane ceilings must be detailed to maintain the FRR
  - Lighting fixtures must be backed up with fire-resistive material
  - Air conditioning grills must be isolated from the ducts that feed them by automatic fire dampers
  - Access panels must meet the requirements for fire resistance

Interstitial Ceilings

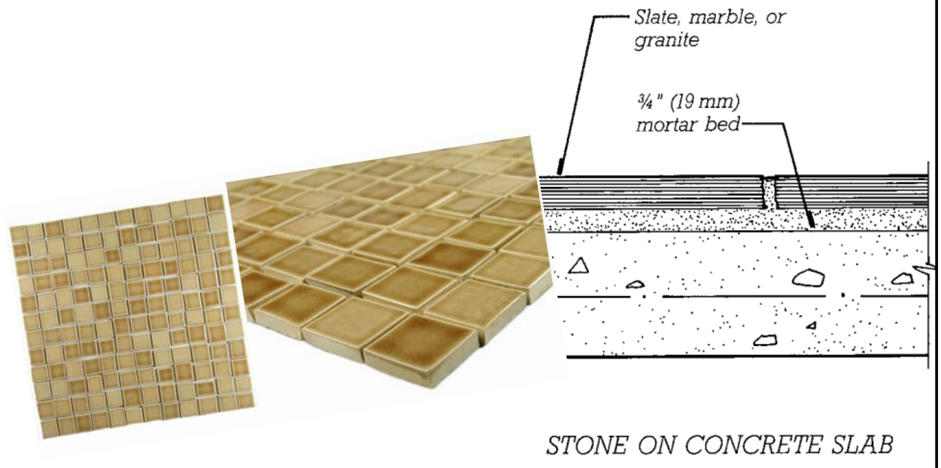
- What?
  - Interstitial ceilings are ceiling spaces that are used for services and that can provide access for servicing them
  - They are suspended at a level to allow for workers to travel freely in a plenum space
  - Must be structured strongly enough to support safely the weight of the workers
  - Usually made of gypsum or lightweight concrete ceilings.

- Interstitial Ceiling Being Completed



- Why?
  - Many laboratory and hospital buildings have extremely elaborate mechanical and electrical systems
- Advantage:
  - Maintenance and updating work on the mechanical and electrical systems of the building can be carried on without interrupting the activities below

Finish Flooring- Hard Flooring Materials



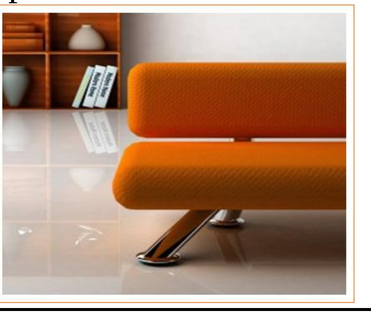
Hard Flooring Materials

- The most desirable types of flooring by designers and building owners
- Types of Hard Flooring Materials
  - Concrete
  - Stone
  - Ceramic Tiles
  - Quarry Tiles
  - Bricks and Brick Pavers
  - Terrazzo

- Advantages:
  - Resistance to wear and moisture
  - Very beautiful and desirable in their colors and patterns
  - Durable
- Disadvantages:
  - Being rigid and unyielding, they are not comfortable to stand on for extended periods of time
  - They contribute to a noisy acoustic environment

Concrete

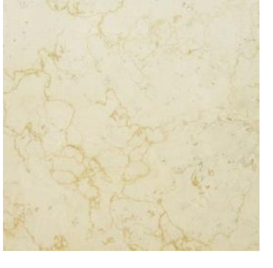
- Can have many different finishes
  - Lightly textured wood coat finish for traction,
  - Smooth, hard, steel trowel finish,
- Color can be added with a colorant admixture, a concrete stain, or a couple of coats of floor paint.

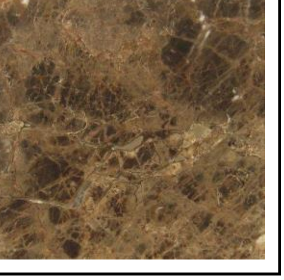


- Advantages:
  - Low initial cost and durability
- Disdvantages:
  - Extremely good workmanship is required to make an acceptable floor finish
  - Unless applied as a finish topping very close to the end of construction, even the best concrete surface is likely to sustain some damage and staining during construction.

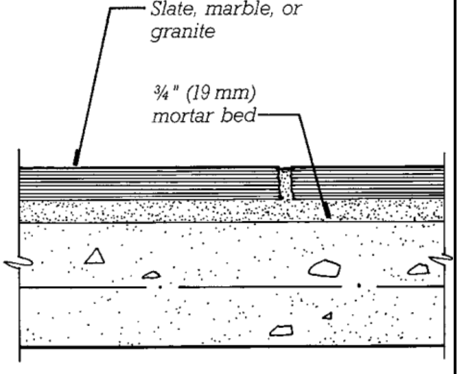
Stone

- Many types of building stone are used as flooring materials
- Surface textures ranging from mirror-polished marble and granite to split-face slate and sandstone

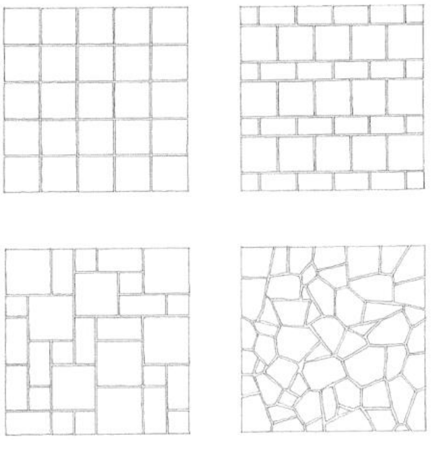




- Installation is a relatively simple but requires highly skilled procedure of bedding the stone pieces in mortar and filling the joints with grout
- Requires multiple applications of a clear sealer coating and periodic maintenance



STONE ON CONCRETE SLAB

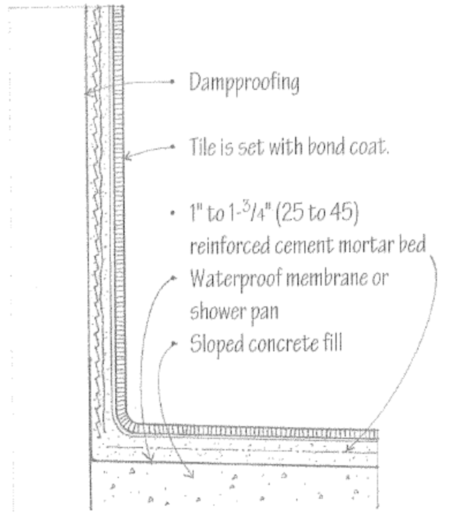


Ceramic Tiles

- Ceramic tiles are relatively small, modular surfacing units made of clay or other ceramic materials.
  - The tiles are fired at very high temperatures
  - They are usually glazed and available in many colors and shapes
  - Durable material, water-resistant, difficult to stain, easy to clean, its colors generally do not fade.

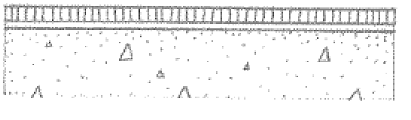
- Ceramic Mosaic Tile
  - To facilitate handling and speed installation, smaller-sized tiles are shipped from the factory with their faces adhered to large backing sheets of plastic mesh or perforated paper, with proper tile spacing.

- Grout color has a significant influence on the appearance of the of tile surfaces,
- As in wall tiling applications, waterproofing membranes may be integrated into floor tile assemblies in wet-use locations.

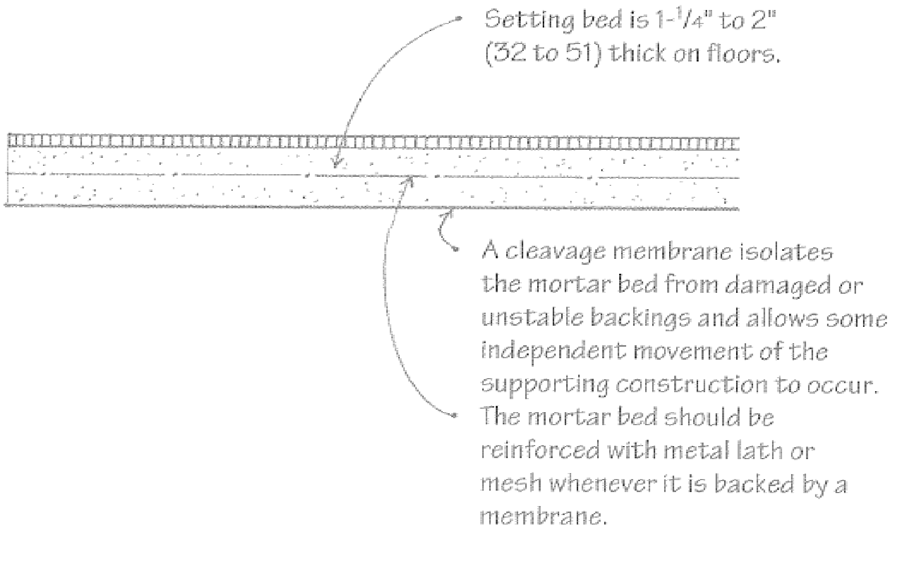


Ceramic Tile Shower

- **Thinset Process**
  - Ceramic tiles are bonded to a continuous, stable backing with a thin coat of latex-portland cement mortar, epoxy mortar, or an organic adhesive
  - Suitable floors for thinset installations include concrete slabs and double wood floors
  - Concrete slabs should be smooth, level, and properly reinforced and cured. A leveling topping can be used if required

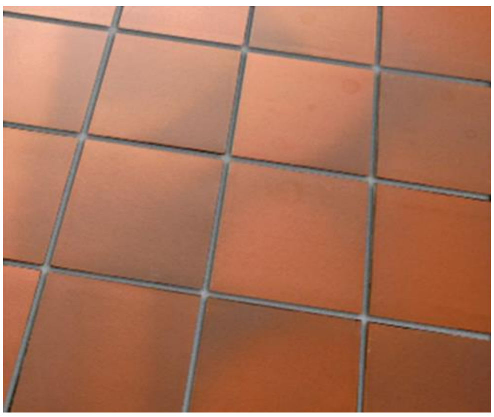


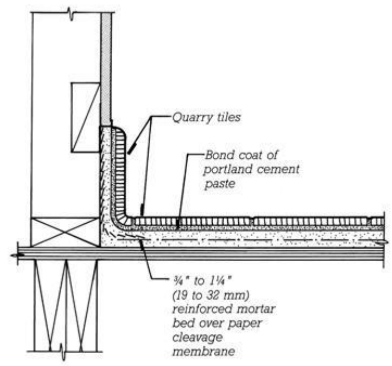
- **Thickset Process**
  - Ceramic tiles are applied over a bed of portland cement mortar.
  - This relatively thick bed allow for accurate slopes and true planes in the finished work
  - The mortar bed is not affected by prolonged contact with water.
  - Suitable floors for this installation include properly reinforced and cured concrete slabs, and structurally sound plywood subflooring



Quarry Tiles

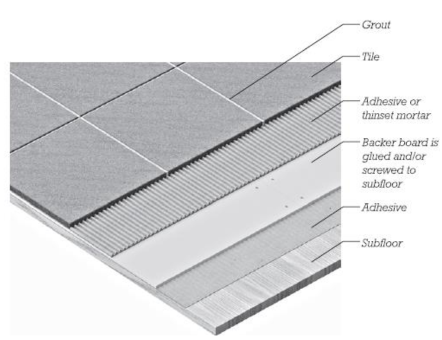
- They are large, unglazed fired clay tiles usually square but also available in other shapes
- Used in floors subjected to heavy-duty loads





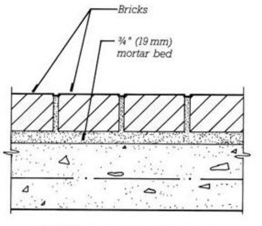
QUARRY TILE ON WOOD SUBFLOOR

- Many colors available
- Usually set in reinforced mortar bed
- May also be thin-set directly to a subfloor of wood panels or tile backer boards



Bricks and Brick Pavers

- Both bricks and half thickness bricks called pavers are used for finish flooring
- Bricks are laid with their largest surface horizontal or on edge
- Decorative joint patterns can be designed



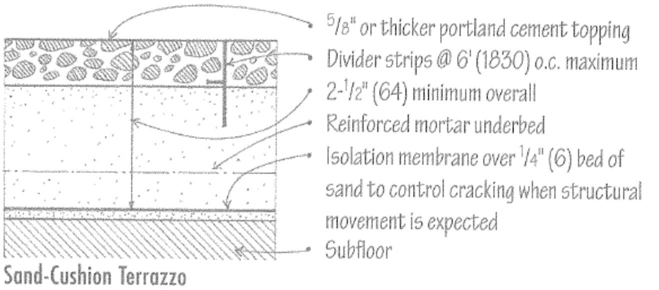
Terrazzo I

- What?
  - A mosaic floor composed of marble or granite chips set in a cementitious matrix or another binding agent and ground and polished when dry.

- Main Advantage:
  - An exceptionally durable flooring
  - Smooth flooring surface
- Manufacturing:
  - Formed in place
  - Factory-made tiles.
  - Precast

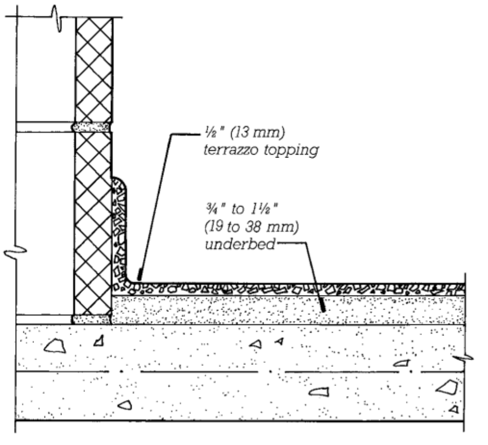
Installation Methods:

- **Sand cushion terrazzo:** Installed over a thin bed of sand that isolates it from the structural floor slab, thus protecting it to some extent from movements in the building frame.



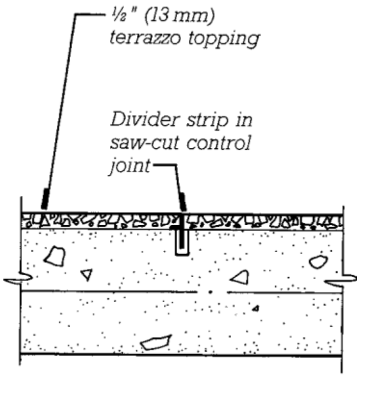
Sand-Cushion Terrazzo

- **Bonded terrazzo**: The sand bed is eliminated to reduce thickness, and for greater economy



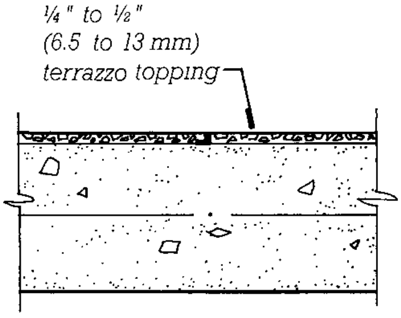
BONDED TERRAZZO

- **Monolithic terrazzo:** both the sand bed and underbed are eliminated.



MONOLITHIC TERRAZZO

- **Thin-set terrazzo:** uses very small stone chips in a mortar that is strengthened with epoxy resins, polyester resins, or polymer-modified cements,



THIN SET TERRAZZO

Glass Tile Flooring