

SECTION 1

BUILDING ELEMENTS

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STRUCTURE

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INTRODUCTION

A well-designed structure is essential for building design. Structural elements that affect interior design include both the substructure and the superstructure. The substructure is the underlying structure that forms the foundation of a building. The superstructure is the vertical extension of a building above the foundation. It includes the building shell—its exterior framework of walls and roof—as well as the aboveground structural system.

A building's interior space is given its primary form by the building's structure and its shell. A basic understanding of a building's structural system is fundamental to the design of an interior space and is critical when changes to interior structural elements or loads are contemplated. Respect for the logic and aesthetics of structural design produces building interiors that belong to the building, rather than being an ephemeral decoration. Working with a building's structure supports the reuse of materials and decreases waste, both cornerstones of sustainable design.

In architecture, the geometric elements of point, line, plane, and volume become columns, beams, walls, floors, and roofs. The endpoints of a linear column define a point in space. A pair of columns supporting a beam outlines the edges of a transparent plane. An opaque wall is a plane that separates adjacent spaces. A floor establishes the boundaries of an area. A roof shelters the volume of space below it.

The scope of the discussion of substructural elements in this chapter is limited to foundations, subgrade enclosures, and slabs on grade that may be visible in the interior and that interact with interior construction and finishes. Wall foundations are introduced for buildings without basements and where a limited load is supported by firm soil. Deep pile foundations are also addressed here. Subgrade enclosures are presented in this chapter, both as a means of supporting a floor and resisting soil pressures, and as interior surfaces that may be exposed or covered with finish materials. Both joints and finishes for slabs on grade are also included.

The information on the building's superstructure begins with an introduction to the basic terminology and considerations for seismic design. The basic types of structures rising from the foundation are introduced, including concrete, wood and steel framing, and masonry structures. Floor construction, as distinct from floor finishes, is covered for wood, concrete, and metal floors. Roof construction types and framing are also introduced, with the emphasis on the shaping of interior space and the implications for interior finishing. Stairs are included here as well, with information on building code and accessibility regulations. Detailed explanations and drawings of handrails, balustrades, and guards are provided. Interior ramp information includes accessible ramps, ramp handrails, and sloping lecture hall floors.

The basic building blocks in Chapter 1—foundations, structural framing, floor and roof construction, and stairs and ramps—set the stage for the design of interior spaces and provide the underpinnings for interior finishes and furnishings. Whether a building is new or old, a basic understanding of its structural vocabulary supports the development of its interior design.

SUBSTRUCTURE

FOUNDATIONS

WALL FOUNDATIONS

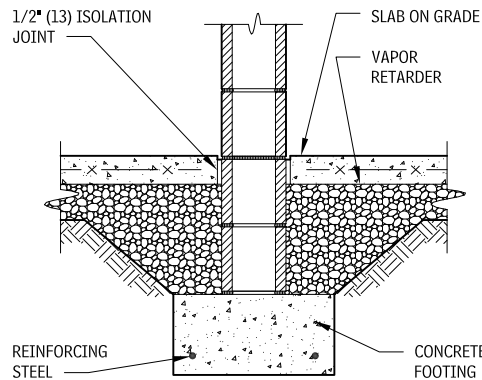
Foundation walls are used where basements are not required and where firm soil is adequate to support a limited load. The excavation typically is to below frost depth or as required by the geotechnical engineer. The wall thickness is usually 8 in. (203 mm) but may be thicker to support thicker walls. Minimal amounts of reinforcing steel are required to limit cracking. Reinforcing requirements may increase as the height of the building wall increases.

In colder climates, insulation on the inside face of the foundation and under the slab helps to minimize the cold penetration to the interior.

Generally, an isolation joint is provided at the slab-wall interface to allow the slab and grade wall to settle independently.

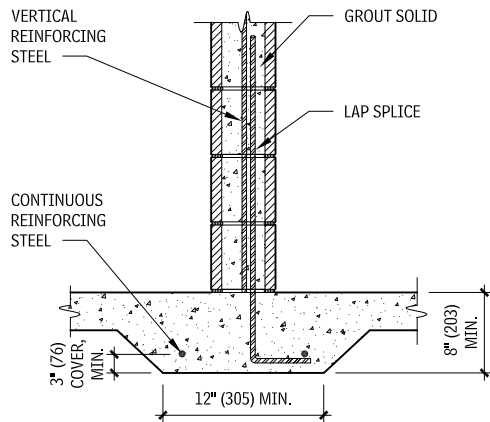
Standard foundation walls may be constructed using concrete, masonry units, or wood. Wood in direct contact with masonry materials should be pressure treated or naturally decay resistant.

INTERIOR LOAD-BEARING CMU FOUNDATION WALL 1.1



Source: Based on *NCMA Annotated Design and Construction Details for Concrete Masonry*, Figure 3E.8. Courtesy of National Concrete Masonry Association.

INTERIOR NON-LOAD-BEARING WALL 1.2



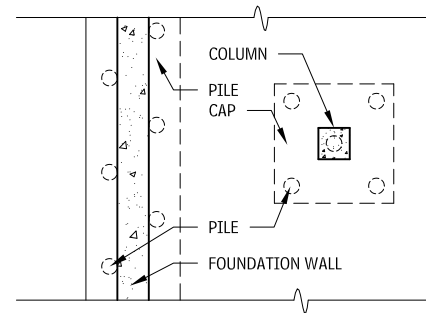
Source: Based on *NCMA Annotated Design and Construction Details for Concrete Masonry*, Figure 8B.2. Courtesy of National Concrete Masonry Association.

PILE FOUNDATIONS

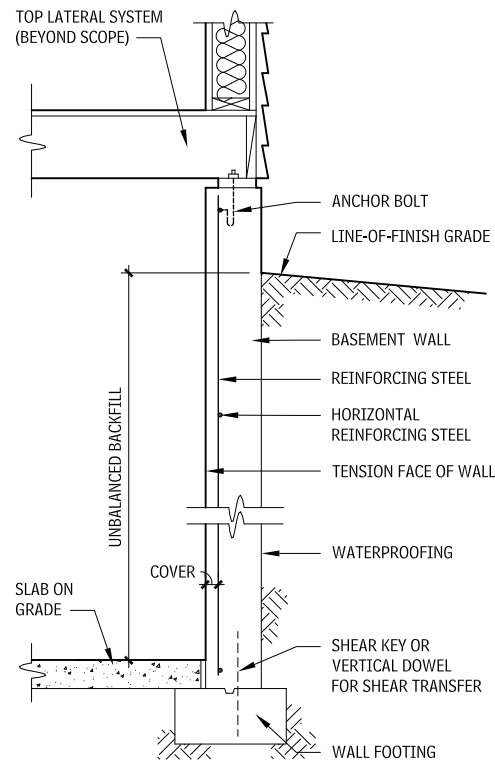
When the soil near the surface is not suitable to support the building loads, it is sometimes necessary to support the structure on deep foundations. Deep foundations come in several types and, depending on the soil conditions, may include driven piles, bored piles, or caissons.

Typically, more than one deep foundation element is required to resist gravity and lateral loads. In order to distribute the loads from the single point column to the multiple foundation elements, a pile cap is required. Pile caps are thick reinforced concrete blocks that distribute the load from the column to the foundations.

INDIVIDUAL PILE CAPS—PLAN 1.3



CONCRETE BASEMENT WALLS 1.5



RESIDENTIAL CONSTRUCTION

Source: Based on *ACI 332, Requirements for Residential Concrete Construction and Commentary*, Figure R7.1. Reprinted with permission of the American Concrete Institute.

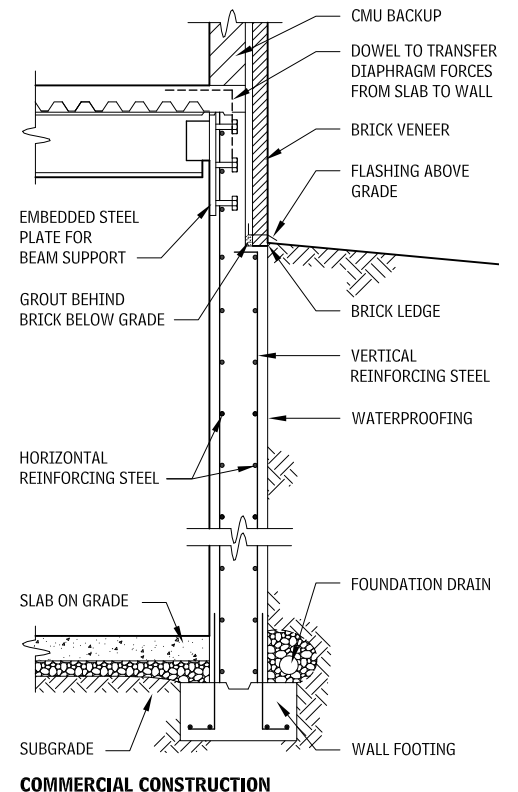
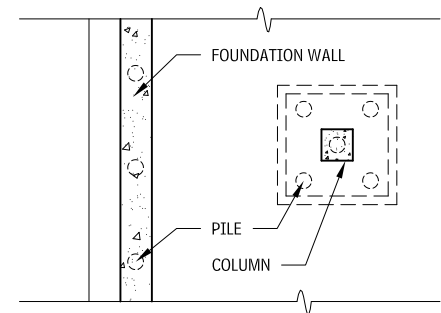
SUBGRADE ENCLOSURES

BASEMENT WALLS

CONCRETE BASEMENT WALLS

Concrete basement walls may be either cast in place or precast. Cast-in-place concrete basement walls provide a cost-effective means of supporting a floor and resisting soil pressures, and are used in both commercial and residential construction. Forms are easily placed in the excavation on the footings. Reinforcing steel is placed within the wall formwork. Depending on the soil and groundwater conditions, dampproofing and waterproofing may be

MAT OR COMBINED FOOTING PILE CAPS—PLAN 1.4



COMMERCIAL CONSTRUCTION

required on the basement walls prior to backfilling. Keeping wall heights uniform, as well as reducing the number of penetrations and maintaining a simple plan configuration, will help reduce the final cost of the wall.

Precast concrete basement walls enable basement construction in less time than conventional cast-in-place concrete. Precast concrete construction also permits the use of concrete admixtures that focus on ultimate strength, rather than cure time and temperature. Precast concrete manufacturers are able to produce mixes that cure to 5,000 psi, which is stronger than concrete unit masonry or cast-in-place concrete walls. Additionally, better control of the concrete mixture and curing environment allows the use of low water/cement ratios, which results in a dense material that reduces water penetration.

MASONRY BASEMENT WALLS

Masonry walls have long served as foundations for structures. Today, most masonry basement walls consist of a single wythe of solid or hollow concrete masonry units, depending on the required bearing capacity. The walls are reinforced as necessary to resist lateral loads.

Basement walls should protect against heat and cold, insect infestation (particularly termites), fire, and penetration of water and soil gases.

If radon is a major concern, the top course of the masonry and the course of masonry at or below the slab should be constructed of solid units or fully grouted hollow units. Using a foundation drain to collect and drain condensation moisture from basements should be avoided in areas where soil gas entry is a concern.

Architectural masonry units may be used to improve the appearance of the wall. Masonry units with architectural finishes facing the interior can be used for economical construction of finished basement space.

Masonry easily accommodates any floor plan, and returns and corners increase the structural performance of the wall for lateral load resistance.

TREATED WOOD BASEMENT WALLS

The construction of treated wood foundations and basements is similar to the construction of standard wood light-frame walls except for two factors:

- The wood used is pressure treated with wood preservatives.
- The extra loading and stress requirements caused by below-grade conditions must be accommodated in the design and detailing of the fasteners, connections, blocking, and wall corners.

Treated wood foundations require good drainage to maintain dry basements and crawl spaces, with additional provisions beyond those that are standard with masonry or concrete foundations. Benefits of a treated wood foundation include:

- Accommodates standard 2-by construction
- Can be erected in any weather and where site access is difficult for other methods
- Accommodates high R-value thermal insulation in deep wall cavities without loss of interior space
- Easily accepts wiring and finishing

Lumber and plywood used in treated wood foundations must be grade stamped for foundation use. These are typically pressure treated with chromated copper arsenate (CCA), which is a chemical wood preservative containing chromium, copper, and arsenic. It has been used to pressure-treat lumber since the 1940s and has been used for the majority of wood in outdoor residential settings since the 1970s. Pressure-treated wood containing CCA is no longer being produced for use in most residential settings, including decks and playsets.

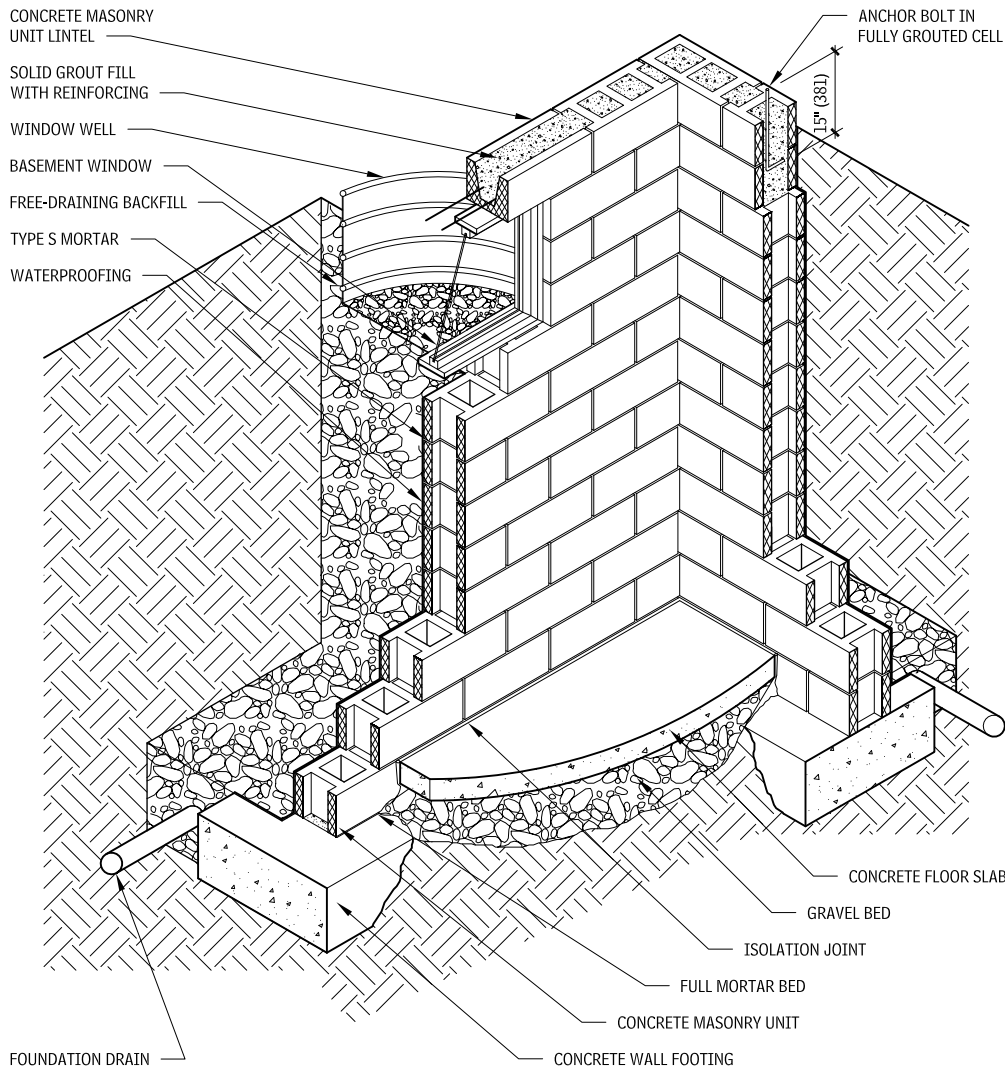
There are several arsenic-free wood pressure treatment alternatives to CCA available on the market, as well as several building material alternatives to pressure-treated wood. Alternatives include alkaline copper quaternary (ACQ), borates, copper azole, cyproconazole, and propiconazole. The U.S. Forest Service provides a list of wood preservative alternatives.

Treated wood products used in foundation construction are required to contain more preservatives than treated wood used in fencing, decking, and similar applications. Skin contact and prolonged or frequent inhalation of sawdust when handling or working with any pressure-treated wood product should be avoided.

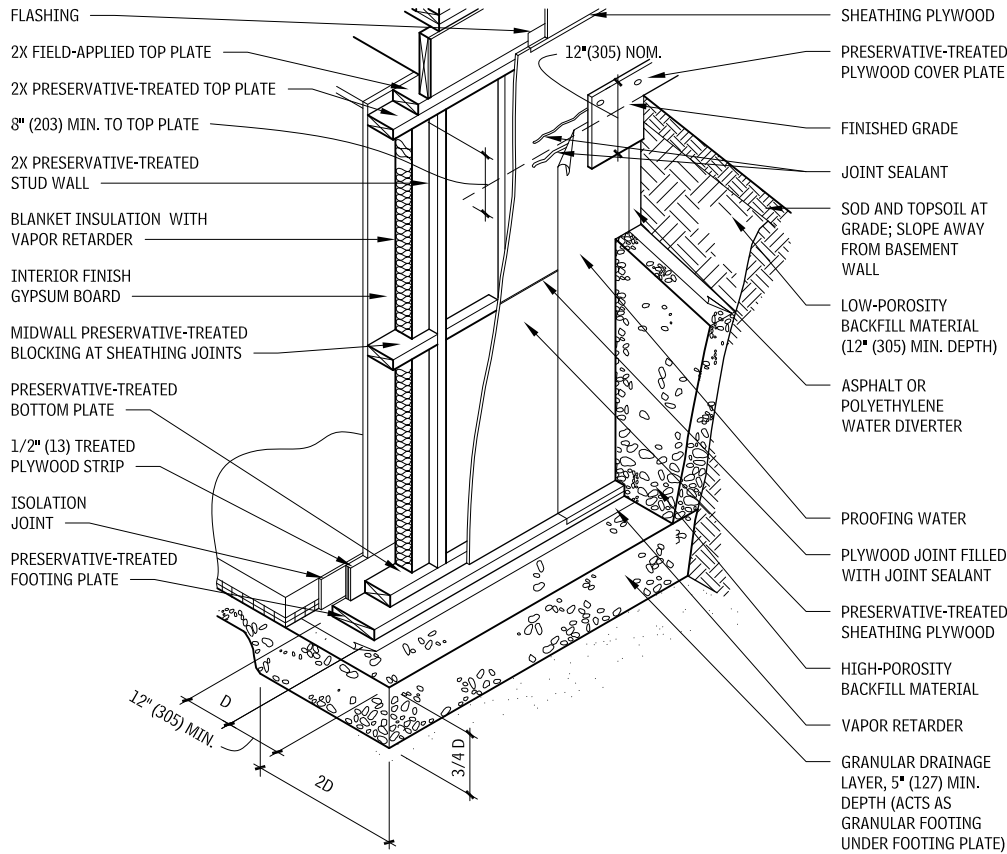
The following guidelines apply to lumber and plywood used in treated wood foundations:

- Codes generally call for hot-dipped, galvanized fasteners above grade and stainless steel fasteners below grade.
- Consult applicable building codes and code officials for requirements and design guidelines.
- The vertical and horizontal edge-to-edge joints of all plywood panels used in these systems should be sealed with a suitable sealant.
- Correct materials and details of construction are very important for treated wood foundations. Most problems with treated wood foundations can be traced to improper installation by inexperienced workers.

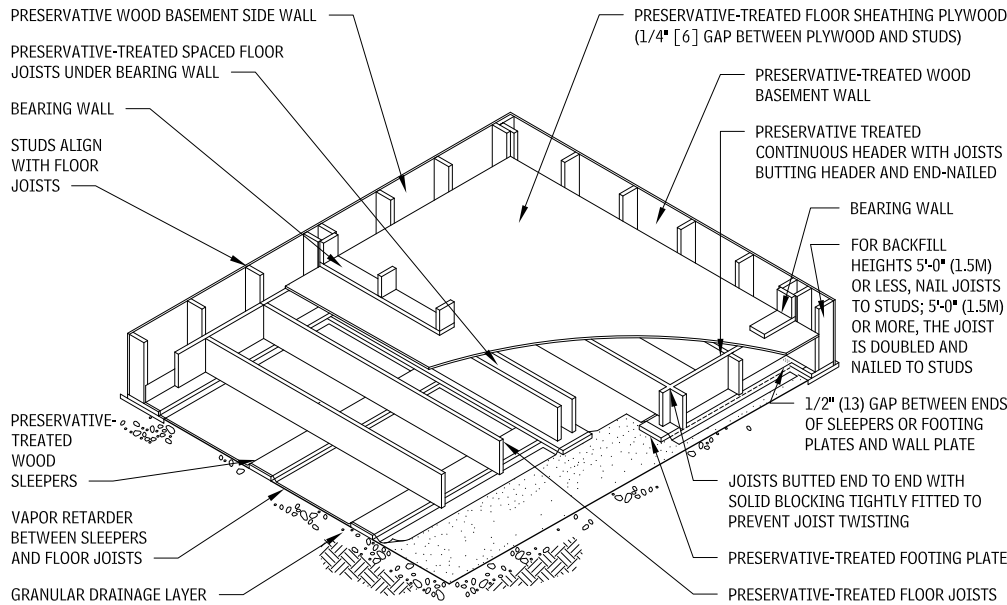
TYPICAL MASONRY BASEMENT WALL
1.6



TYPICAL TREATED WOOD BASEMENT WALLS
1.7



WOOD SLEEPER FLOOR SYSTEM
1.8



SUBGRADE ENCLOSURE WALL INTERIOR FINISH

BASEMENT WALL DAMPPROOFING

Dampproofing is generally provided to reduce or prohibit the absorption of condensation and high humidity into below-grade concrete or masonry and to reduce the likelihood of water not under a head of pressure from moving through or up the construction. Dampproofing is not watertight and will not perform to the same levels as waterproofing, and so should not be used in applications that require waterproofing.

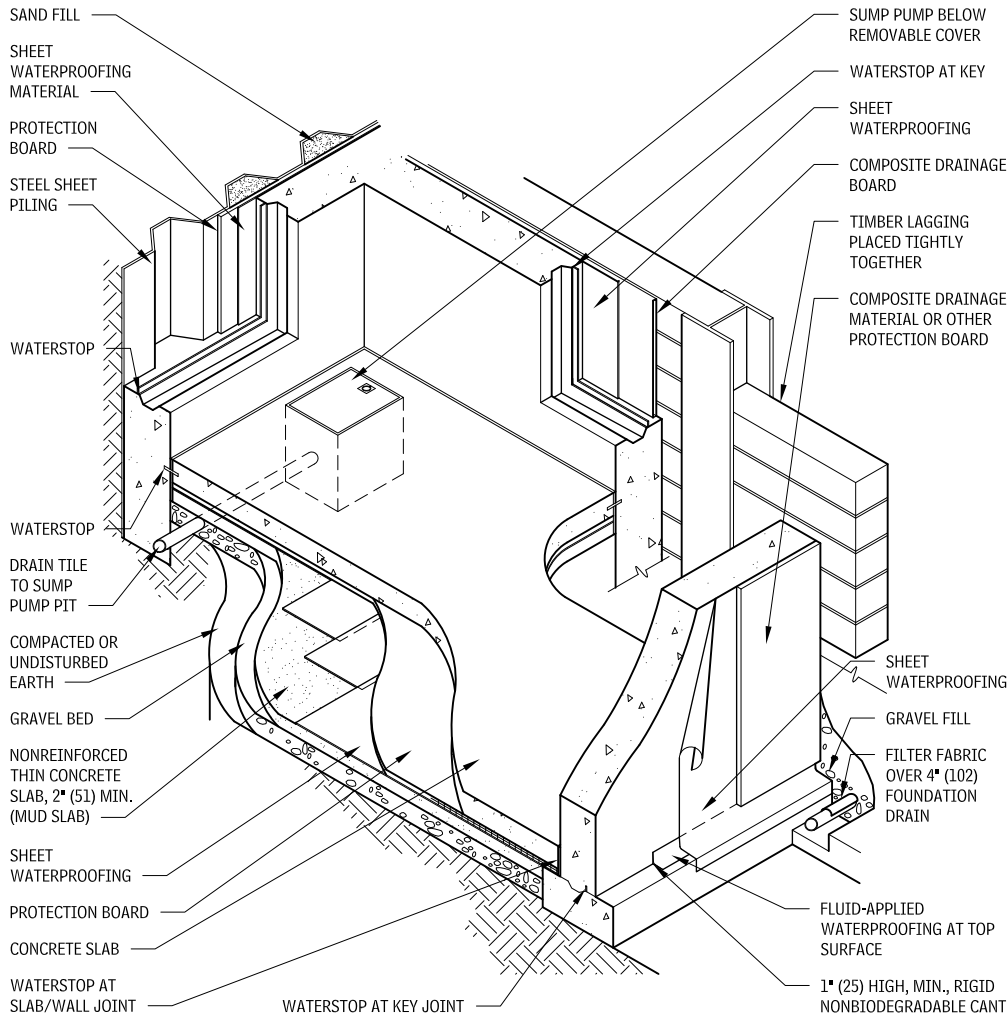
In addition to its use to resist water intrusion through a wall, dampproofing has historically been utilized to prevent water intrusion into concrete or masonry below grade, as a means to limit or eliminate a condition called *rising damp*, in which moisture is absorbed into the subgrade construction and travels upward by capillary action to drier materials such as masonry or wood. Water infiltration of this type can lead to rotting of wood, efflorescence of masonry, or freeze-thaw masonry damage, as well as corrosion of unprotected or improperly protected materials such as light-gauge steel framing. This may not only be a problem at exterior walls, but can also be problematic at foundations and piers (especially crawl spaces) and within the building interior if there are unfavorable water conditions.

Dampproofing is most often a spray-, roller-, or brush-applied bituminous material (asphalt), but may include cementitious and sheet materials. Fluid-applied and cementitious applications have little capability to bridge across cracks or discontinuities of a concrete or masonry wall, and have a very limited capability to accept movement.

BASEMENT WALL VERTICAL WATERPROOFING

Generally, waterproofing will be necessary if a head of water is expected against the basement wall or under the slab. Types of waterproofing used on the exterior of foundations include built-up bituminous, sheet, fluid applied, cementitious and reactive, and bentonite. Special negative-side coatings on the interior face of a foundation wall, such as metallic oxide, are recommended only when the exterior is not accessible. When waterproofing materials are placed on top of the structural slab, a protective cover, such as another concrete slab, is required.

WATERPROOFING APPLICATIONS AT BASEMENT CONDITIONS
1.9



BASEMENT THERMAL INSULATION

Insulation requirements are proportional to heating loads. The foundation is often underinsulated and can be a major source of heat loss. The desirable insulation level depends on the use of the basement space, basement temperature, and insulation levels in the rest of the building. Exterior insulation keeps the wall warm and eliminates condensation and thermal bridges. As seasonal basement temperature decreases, losses to it from the superstructure increase, and basement ceiling R-values should increase.

Insulation sheet types used for foundations include:

- Expanded polystyrene, also known as *bead board*
- Extruded polystyrene, a sheet material that is also used as masonry cavity wall insulation
- Expanded or cellular glass, also known as *stink board* because of the sulfur that is trapped within the closed cell-glass structure

It should be noted that these insulation sheets can also be used as a very effective protection board for waterproofing.

SLABS ON GRADE

Factors to consider in the design and construction of all concrete slabs on grade include the intended use of the slab or slab section, the condition and preparation of a uniform subgrade, the quality of the concrete, the adequacy of structural capacity, the type and spacing of joints, the finishing, the curing, and the application of special surfaces.

Wear resistance is directly related to the condition of the top portion of the concrete slab. Surface hardness and abrasion resistance may be provided by special additives or hardeners to the surface. The quality of the overall concrete slab will be enhanced by the proper water-to-cement ratio, reasonable slump limits, and well-graded aggregates with the maximum size of the coarse aggregate as large as placing will permit.

Reinforcement in concrete slabs is unnecessary where frequent joint spacings are used. Where less frequent spacings are used, reinforcement is placed in the slab, at or above mid-depth (generally one-third down from the top surface), to act as crack control. Common contraction joint spacing is 15 to 25 ft (4.6 to 7.2 m), depending on the thickness of the slab and the construction type. Strip placement, rather than checkerboard placement of slabs, is recommended for large areas.

CONCRETE SLAB JOINTS

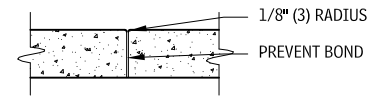
Construction joints facilitate the concrete pouring process. Expansion and contraction joints are installed to accommodate building movement.

- *Construction joints* between two successive placements of concrete are often keyed or doweled to provide lateral stability across the joint.
- *Expansion joints* between two parts of a building or structure permit thermal or moisture expansion to occur without damage to either part. Expansion joints also serve as isolation joints and control joints.

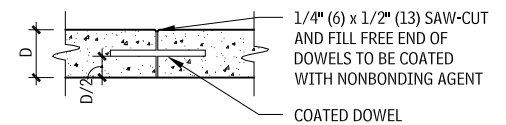
- *Isolation joints* separate two sections of a structure to allow differential movement or settlement between the slab and fixed parts of the building such as columns, walls, and machinery bases.
- *Control joints* are continuous grooves or separations formed, sawed, or tooled in concrete to form a plane of weakness and thus regulate the location and amount of cracking resulting from drying shrinkage or thermal stresses.
- *Contraction joints* between two parts of a structure are designed to compensate for the contraction of either part.

TYPICAL JOINT DETAILS

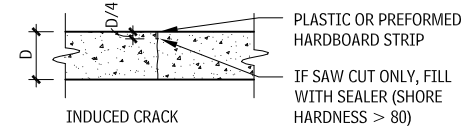
1.10



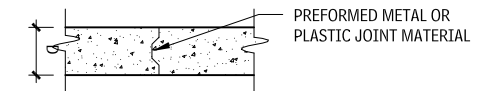
BUTT JOINT CONSTRUCTION JOINT



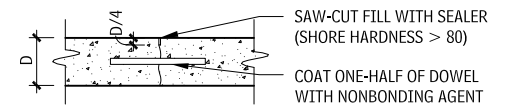
BUTT-TYPE CONSTRUCTION JOINT WITH DOWELS



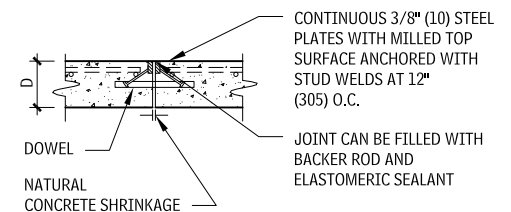
SAWED OR PREMOLDED CONTRACTION JOINT



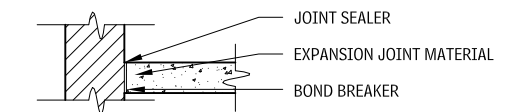
TONGUE-AND-GROOVE JOINT



CONTRACTION JOINT WITH DOWELS



TYPICAL ARMORED CONSTRUCTION JOINT DETAIL



ISOLATION JOINT

Source: American Concrete Institute, www.concrete.org.

8 STRUCTURE SUPERSTRUCTURE

Saw-cut control joints should be made as early as is practical after finishing the slab and should be filled in areas with wet conditions, hygienic and dust control requirements, or considerable traffic by hard-wheel vehicles such as forklifts.

Expect some cracking in concrete construction. Generally, cracking is controlled with joints and reinforcement. However, not all cracks indicate errors or performance problems, and not all cracks need to be repaired.

CONCRETE SLAB FINISHES

Concrete floor slabs are monolithically finished as a general procedure by floating and troweling to a smooth and dense top finish. ACI 302 provides specific guidance for appropriate finishing procedures to control the achievable floor flatness. ACI 302, ACI 360, and ACI 117 provide guidance for flatness selection and the techniques by which flatness and levelness are produced and measured. Floor finish tolerance is measured by placing a freestanding 10-ft (3 m) straightedge on the slab surface or by the F-Number system, which is preferable.

Special finishes are available to improve appearance as well as surface properties. These include sprinkled (shake) finishes or high-strength toppings, either as monolithic or as separate two-stage floor surfaces.

When propagation of water vapor is undesirable, a waterproof vapor barrier, with permeance not to exceed 0.20 perms, can be used.

Floor hardening agents are applied to reduce dusting and increase hardness slightly at the surface.

PROTECTIVE COATINGS AND SEALERS 1.11

FINISH	USE
Cementitious acrylic polymeric coating	Aesthetic treatment
Two-component epoxy coating	Protects damp or underwater surfaces
Solvent-based aliphatic urethane coating	Resists graffiti, chemicals, abrasion
Epoxy coal tar-based coating	Waterproof; resists corrosion
Coal tar-modified epoxy resin coating	Nonskid waterproof surface membrane
Water-based epoxy coating	Chemical and abrasion resistance for interiors
Vinyl ester-based coating	High chemical resistance
Aliphatic urethane coating	Chemical and abrasion resistance
Solvent-based acrylic methacrylate copolymer sealer	Reduces water penetration
Silane/siloxane sealer penetrating water repellent	Protects from deicers and freeze/thaw damage

SUPERSTRUCTURE

The structural system of a building is designed and constructed to support the loads applied to the building and to transmit them safely to the ground without damage to the building. Some structural systems are based on a single material, such as heavy timber structures. Others combine more than one material. A building may have more than one structural system. What appears to be a structural material may actually be only an exterior facing material.

Structural elements visible within interior spaces include supports such as columns, horizontal structural elements such as beams and trusses as well as horizontal floor and ceiling planes, and load-bearing interior walls.

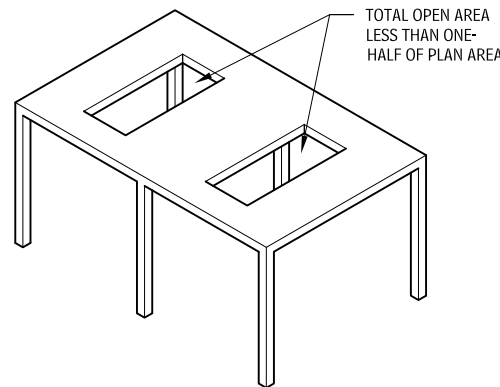
When working with structural elements, it is important to remember that changes in one part of the structure result in changes in loads carried by other parts. Respect the structural properties of the materials involved, and use caution tempered by understanding. It is wise to avoid major structural changes where possible; they are expensive and may be complex.

SEISMIC CONSIDERATIONS

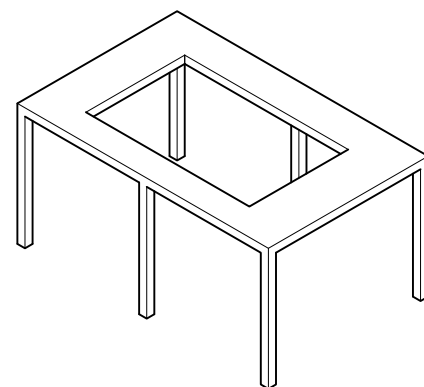
A *load path* is the path seismic forces take from the roof to the foundation of a structure. Typically, the load travels from the diaphragms through connections to the vertical lateral force-resisting elements and on to the foundation by way of additional connections. This path should be direct and uninterrupted. Seismic design begins with, and codes require, the establishment of a continuous load path.

The seismic-resistant framing system selected for a structure must meet both architectural and seismic design requirements. Although most buildings can be made seismic resistant, some architectural configurations interrupt the load path or otherwise interfere with the seismic design process. Inappropriate design choices increase construction costs and make the seismic restraint system less effective.

DIAPHRAGM DISCONTINUITIES—PREFERRED 1.12



DIAPHRAGM DISCONTINUITIES—DISCOURAGED 1.13



SUPERSTRUCTURE FRAMING

CONCRETE FRAMING

Concrete is either cast in place, where it will be used by a concrete mixer or agitator truck, or precast off-site under factory-controlled conditions. Concrete used for construction is usually reinforced with steel reinforcing bars or with welded wire fabric.

PRECAST CONCRETE FRAME

Precast concrete frame systems are ideal for highly repetitive structural frames such as parking garages and multiple residences (hotels, apartments, dormitories). Precast concrete members can be precast structural concrete or precast architectural concrete in exposed locations.

Detailing of connections for both aesthetics and to protect embedded steel members from corrosion is crucial. Typically, welded or bolted connections are grouted after final adjustment and anchorage.

Using shear walls in both directions is the most common method to resist lateral loads. Stair and elevator cores and dwelling unit separations may also serve as shear walls.

Precast concrete structural elements are cast and steam-cured off-site, transported to the site, and set in place with cranes. They may be reinforced or prestressed for extra strength or reduced thickness.

Precast, prestressed concrete structural elements include:

- *Solid flat slab*: plank used for short spans and uniformly distributed loads
- *Hollow-core slab*: plank with hollow cores that reduce weight; used for uniformly distributed loads over medium to long spans
- *Single and double tees*: T-shaped plank with a single or double stem and broad, flat slab
- *Ledger beam*: beam with projecting ledges to support the ends of joists or slabs; L or inverted T shapes

Precast concrete wall panels are used for bearing walls that support site-cast concrete floors or steel floor and roof systems. They are usually 8 ft (2.4 m) wide but are available up to 12 ft (3.7 m) wide.

Contributor:
Richard Eisner, FAIA, Governor's Office of Emergency Services, Oakland, California.

Precast concrete columns are commonly produced to support these approximate areas:

- A 10 by 10 in. (254 by 254 mm) column supports 2,000 sq ft (186 sq m).
- A 12 by 12 in. (305 by 305 mm) column supports 2,750 sq ft (255 sq m).
- A 16 by 16 in. (406 by 406 mm) column supports 4,500 sq ft (418 sq m).

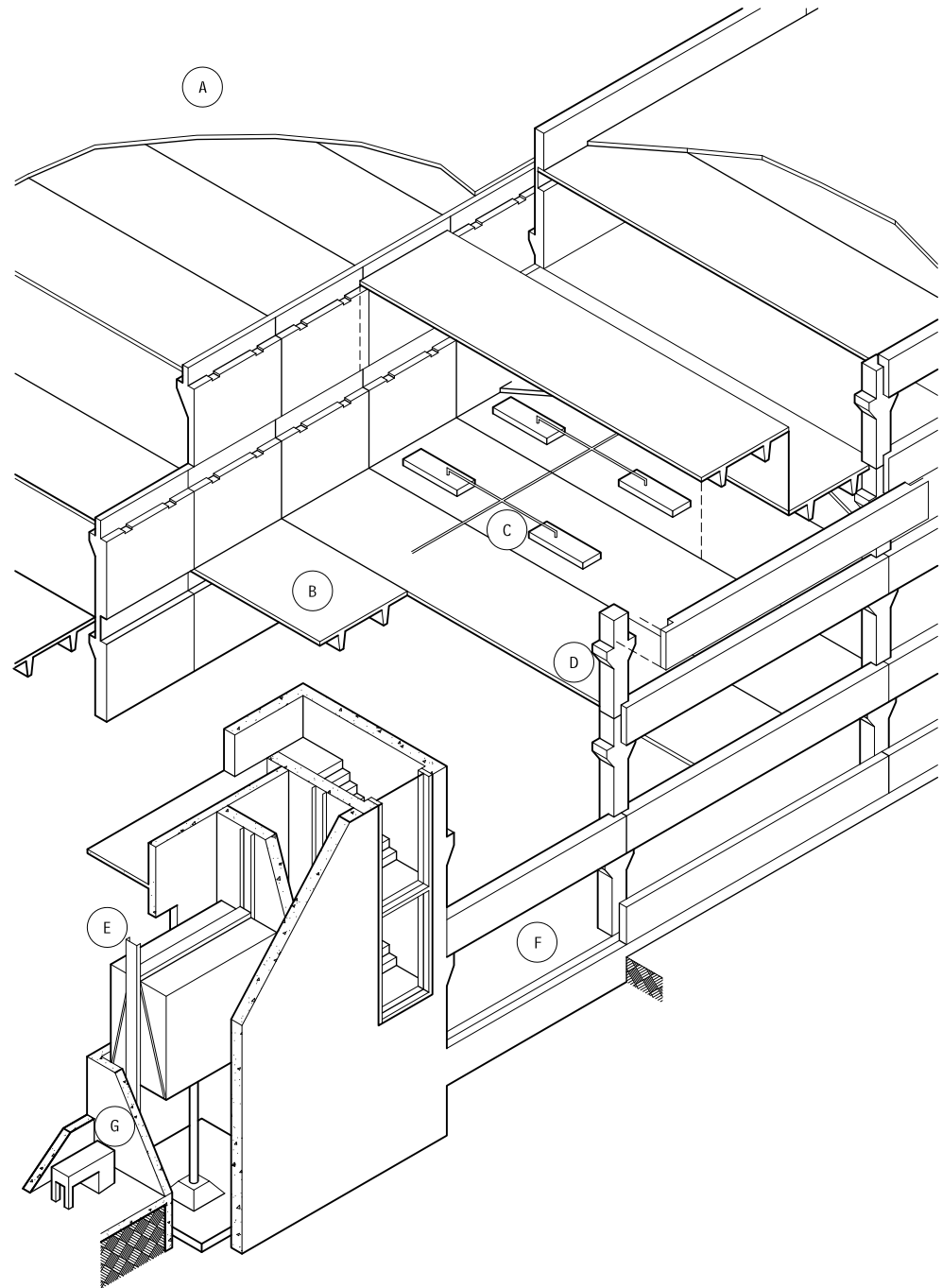
Precast concrete components are usually pretensioned. Pretensioning is a method of prestressing concrete in which steel tendons are stretched prior to placement of the concrete and maintained in tension until the concrete is cured. The external tension on the tendons is then released to compress the concrete. The example in Figure 1.14 employs prestressed columns, inverted T-girders, ledger girders, and double-T joists, all of the same length and design. Once the floor and roof Ts are set, the surface is covered with a thin concrete topping that provides the finished, weather-exposed surface and a horizontal structural diaphragm. The precast components are fabricated off-site and lifted into place by crane. Various finished surfaces are possible, and the unity of materials presents an opportunity for natural visible integration of elements. Thin brick or tile can also be used as a surface material.

Double-T joists are generally 8 or 12 ft (2.4 or 3.7 m) wide, at a depth of 18 to 36 in. (457 to 914 mm), depending on the spanning requirements. Spans of 60 ft (18.3 m) are considered maximum, due to the constraints of shipping and lifting the pieces, but longer spans and deeper sections are possible. It is advantageous to use as many similar elements as possible; that is, floors, inverted T-girders, and columns should all be of the same length and design. Off-site precasting can conserve time and materials for concrete forming, and on-site erection time is considerably faster than cast-in-place construction. A cast-in-place core provides lateral stability to the frame. Adding final finishes and installation hardware to prestressed components before erection helps reduce on-site construction time. Temporary shoring and bracing may be required during construction, particularly until the toppings have cured to service strength (if the structure is composite). Lifting loops are generally embedded in the precast pieces and then covered with the topping or cut off after installation.

Holes or sleeves can be cast in the stems and flanges of the Ts, to allow for passage of conduit and piping. These holes and openings can be as great as one-third of the stem's total depth but must avoid the reinforcing tendons; openings toward the top of the stem in midspan and toward the bottom at the ends are most common. Preplanning of all openings is essential to minimize sitework and to realize the inherent economies of the system. Ts may be notched at the ends to permit passage of conduit along girders or bearing walls. Also, channels can be formed by chamfering mated edges of adjacent Ts at the upper surface, setting the conduit, and pouring a concrete topping slab.

Most typical interior elements are not needed because of the open-air nature of the building type; however, all elements provided are attached directly to the exposed structure. In parking garages, the depth of the structural Ts and concerns for minimizing floor-to-ceiling height present special challenges for the integration of lighting and signs.

PRECAST CONCRETE FRAME
1.14



LEGEND

- A Concrete topping as floor finish
- B Prestressed, precast concrete double-T
- C Fluorescent light fixtures attached to structure
- D Prestressed, precast concrete columns and spandrel beams
- E Cast-in-place concrete vertical circulation
- F Slab on grade, with cast-in-place concrete piles
- G Elevator equipment for hydraulic elevator

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland, based on
Richard D. Rush, AIA, *The Building Systems Integration Handbook* (John
Wiley & Sons, 1986).

FLAT-PLATE CONCRETE

Flat-plate concrete construction combines cast-in-place concrete columns with two-way concrete slab plates of uniform thickness. Two-way flat-plate concrete floors are among the simplest concrete structures for reinforcing, formwork, and detailing. Exterior precast concrete plates can be attached on lower floors, even with flat-plate shoring still in place, while concrete is being poured for upper floor columns and plates. When crane hoists are used to lift concrete buckets or large equipment, a hole is generally left in a section of each plate to allow for passage of the hoist; this hole is filled later, when large components have been moved and concrete pouring is complete.

Flat-plate concrete construction permits more stories to be fitted into a given building height than any other system. This is because its floor structure has minimum thickness, especially when post-tensioned.

Flat-plate construction is typically used for low- to medium-rise construction because of the costs and difficulties associated with placement of materials and labor in higher buildings. It is especially applicable to apartments, hotels, and dormitories, in which no suspended ceiling is required. Story height can be minimized in these applications by using the undersides of the slabs as finished ceiling.

Cast-in-place concrete slabs are classified by whether they have steel reinforcing running in one, two, or three directions. The reinforcing pattern affects how the slabs carry the stresses created by loads to other structural members or the ground. Slabs are usually cast with their supporting beams. Some slabs are made of closely spaced concrete joists supported by parallel beams, giving them the strength for longer spans and heavier loads.

For the exterior envelope, precast concrete panels can be attached to the exterior on lower floors, even with flat-plate shoring still in place, while concrete is being poured for upper-floor columns and plates. Window framing elements and glazing are installed after the spandrels have been set.

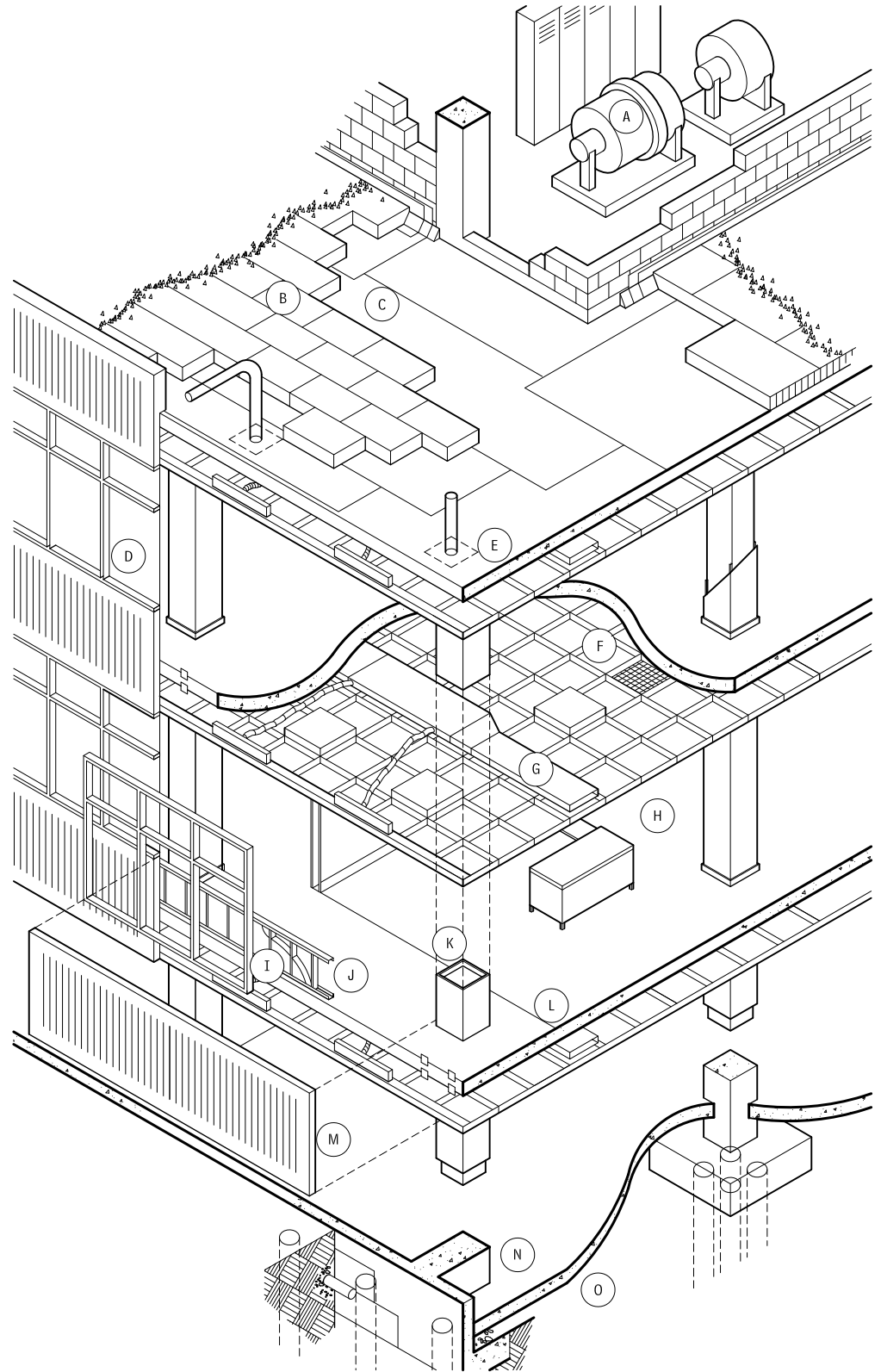
Flat-plate construction usually has a central core for vertical circulation and services. The central core also permits consolidation of vertical service risers, increasing fire protection by reducing or eliminating through-floor penetrations in office areas. A centralized core permits relatively uniform, short horizontal runs for power, plumbing, lighting, and mechanical systems.

Workstations in unpartitioned interior offices can be serviced unobtrusively by ceiling-height power and communications poles, in furred-out areas around columns, and in corridor partition walls. Office workstations require daylight exposure and views. Because the central core is farthest from perimeter zones, usable floor area in the perimeter can be maximized. On constrained urban sites, the central core may be moved against an unfenestrated wall and still retain this advantage.

LEGEND

- A Elevator equipment in penthouse
- B Rigid insulation and ballast
- C Protected roof membrane
- D Window assembly
- E Cast-in-place concrete flat plate
- F Suspended acoustical tile
- G Ducts with diffusers suspended from structure in ceiling plenum
- H Power and communications supplied to furniture by overhead poles or undercarpet flat cable
- I Batt insulation
- J Gypsum board and metal stud assembly
- K Cast-in-place concrete column
- L Carpeting
- M Precast concrete spandrel panels
- N Slab on grade and concrete pile foundation
- O Waterproofing and protective board at foundation, with vapor barrier under slab

**FLAT-PLATE CONCRETE
1.15**



Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland, based on
Richard D. Rush, AIA, *The Building Systems Integration Handbook* (John
Wiley & Sons, 1986).

POSTTENSIONED CONCRETE WITH INFILL PANELS

Posttensioning is a method of reinforcing concrete by stretching steel reinforcing tendons after placement and curing of the concrete structure. This prestressing reduces or eliminates tensile stresses on the concrete under use loading and strengthens the slab without increasing its thickness or adding the dead loads introduced by additional steel reinforcing rods. Posttensioning is useful when slab thickness is important to economical or functional design aspects or when concentrated live loads are high and the building height must be kept to a minimum. It is also effective when project conditions require minimal floor-to-floor heights but maximum ceiling heights with generous space above the ceilings.

Posttensioned concrete construction is virtually identical to flat-plate concrete construction. The major difference lies in the thickness of the concrete slab, which is slightly reduced in this type of construction.

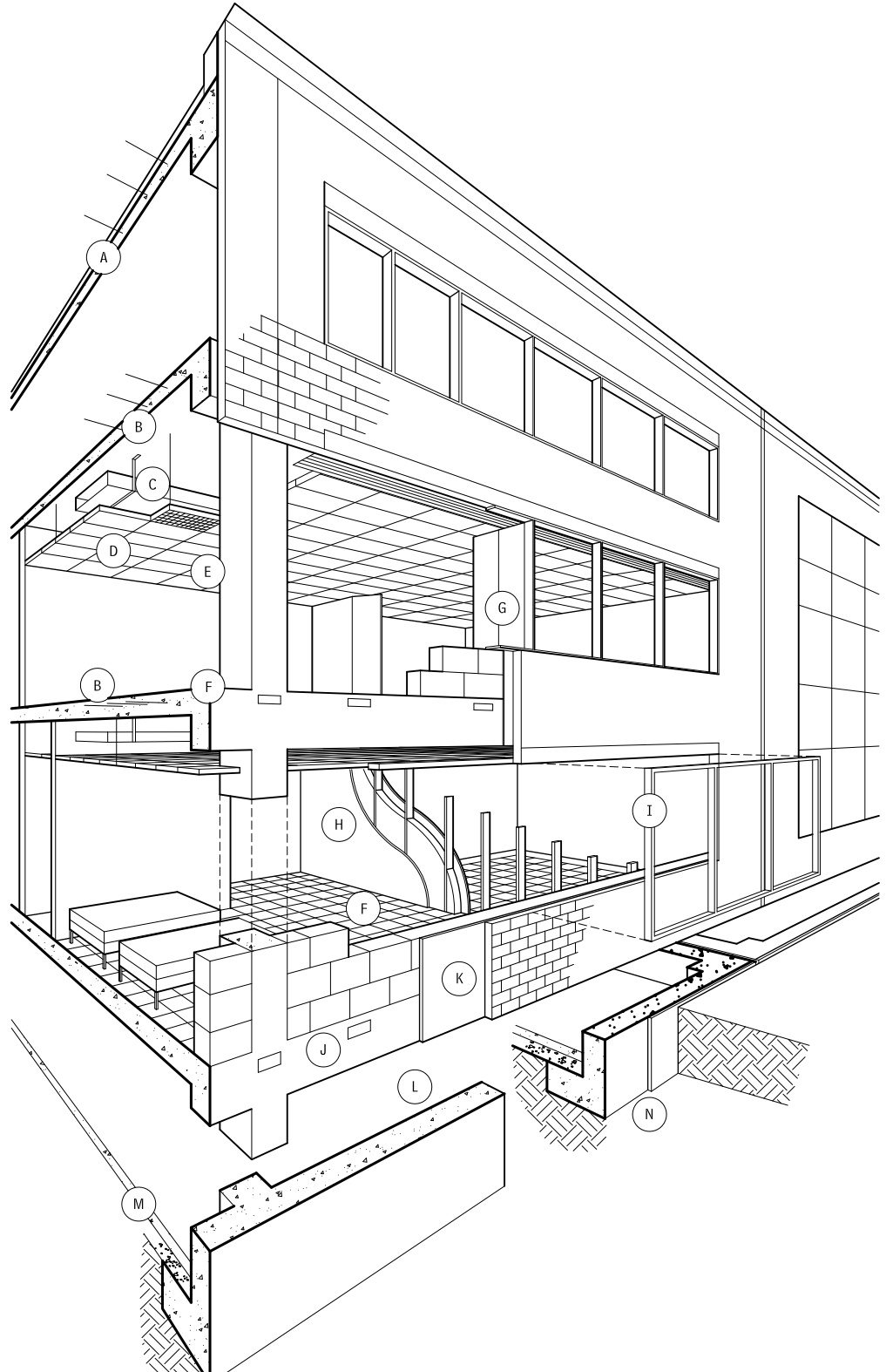
Posttensioning employs a highly sensitive integration of the compressive strength of concrete with the tensile strength of steel. Plastic-sheathed high-strength steel tendons are cast in the slab and, after curing, are placed into tubes, anchored, and jacked into tension from one end. After stresses are applied, the tendon channels may be grouted to bond the tendons to the slab. For lengths that are greater than 100 ft (30.5 m), stresses must be applied simultaneously from two ends.

Integration of mechanical services is influenced greatly by the positioning of tendons, which controls the locations of through-slab penetrations. Posttensioning permits the use of shallower beams and slabs, reducing the overall building height and permitting longer spans with thinner structural members. Alterations and demolition can be difficult due to potential forces latent in posttensioned tendons. A suspended ceiling provides space for distribution of internal services but tends to be used only for overhead lighting and ductwork.

The building skin rests on the concrete frame by means of steel shelf angles attached to spandrel beams. The structure is quite rigid and less subject to movement and creep, allowing use of masonry infill for the envelope.

Mechanical systems hidden in ceiling plenums can be accessed through removable panels. This system is optimal for additions to hospitals and other medical facilities, which often require floor-to-floor heights that match those of the existing structure. Although contemporary standards for servicing and mechanical equipment require deeper interstitial spaces than are found in many older buildings, the shallower slabs and beams of posttensioned concrete construction can conserve such space.

POSTTENSIONED CONCRETE 1.16



LEGEND

- A Built-up roofing or single-ply membrane on rigid insulation
- B Concrete slab with reinforcing steel bars
- C Ducts with diffusers, suspended from structure in ceiling plenum
- D Fluorescent light fixture in ceiling
- E Suspended acoustical tile ceiling
- F Resilient floor
- G Operable partitions
- H Metal stud and gypsum wallboard assembly
- I Window assembly
- J Concrete
- K Brick and concrete masonry with rigid insulation
- L Slab on grade and concrete foundation
- M Vapor barrier under slab
- N Waterproofing and protective board at foundation

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland, based on
Richard D. Rush, AIA, *The Building Systems Integration Handbook* (John Wiley & Sons, 1986).

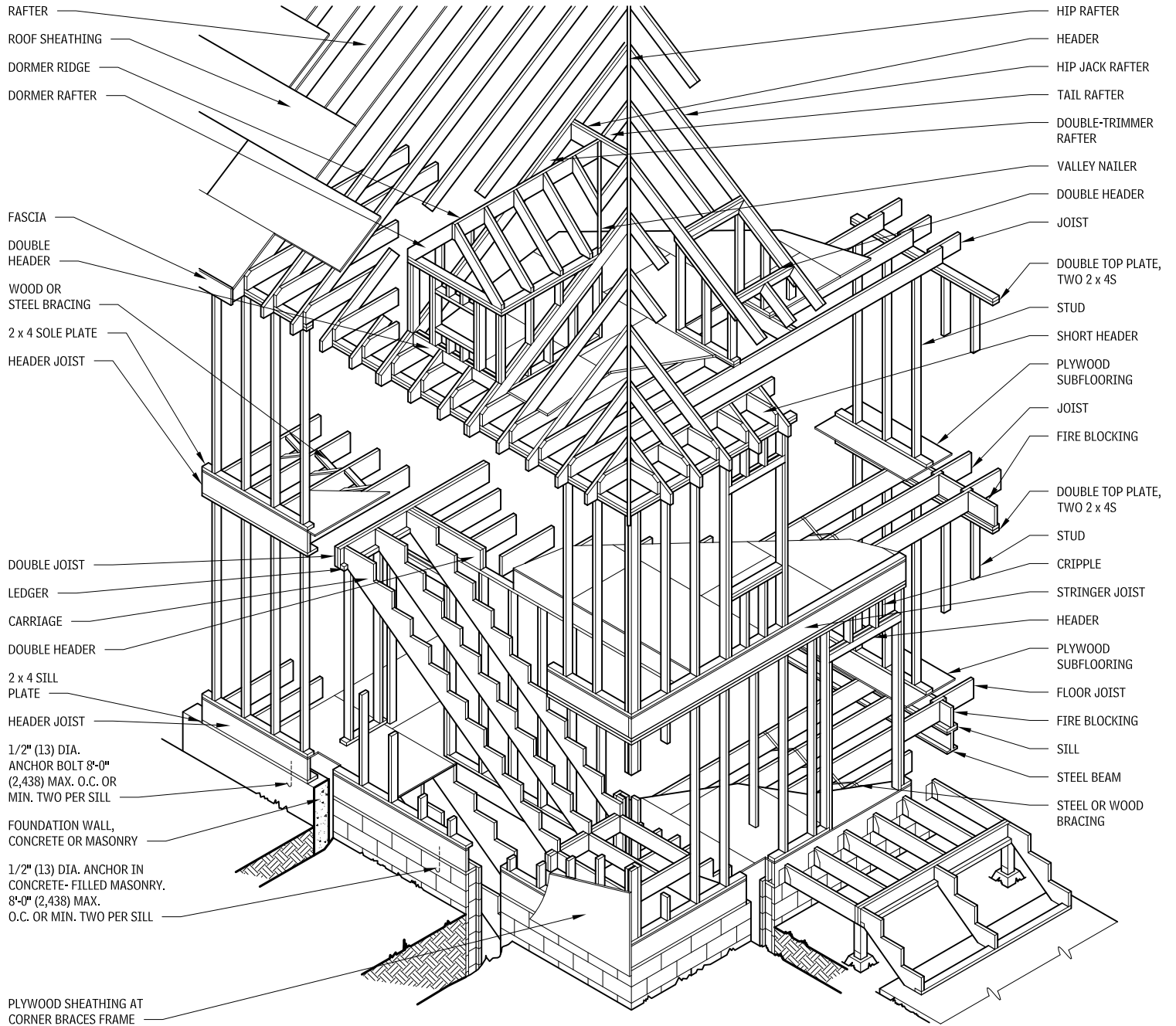
WOOD FRAMING

The superstructure of a light-frame building encloses interior spaces and carries loads to the ground. Many wood structures originally designed as family homes find new lives as commercial buildings. Codes for residential and commercial buildings have different requirements that must be considered.

Light wood frame construction consists of dimensional lumber that is uniformly cut. Heavy-timber construction uses beams cut from large trees. Spaced beams made with blocking and open spaces to reduce weight and laminated beams made from pieces of wood glued together are also used in wood frame construction. Light-gauge steel framing is often used in building interiors with existing wood framing.

PLATFORM FRAMING

1.17



WOOD TRUSSES

Prefabricated floor and roof trusses are built at the factory to engineering specifications. Laminated wood trusses consist of smaller pieces of wood glued together into large trusses. Open-web wood trusses allow threading of wiring, piping, and ductwork without on-site drilling or cutting.

Roof trusses come in a variety of shapes and sizes. The top chords serve as roof rafters, and the bottom chords act as ceiling joists.

WOOD COLUMNS

Wood columns may be solid wood or built out of wood pieces either solidly glue laminated or mechanically fastened together.

Spaced wood columns are made of multiple structural members with blocking and spaces inside.

WESTERN OR PLATFORM FRAMING

The most common type of wood framing is western or platform framing. Before any of the superstructure is erected, the first-floor framing and subflooring is put down, making a platform on which the walls and partitions can be assembled and tilted into place. Because floor framing and wall frames do not interlock, adequate sheathing must act as bracing and provide the necessary lateral resistance. Where required for additional stiffness or bracing, metal strapping or 1 × 4s may be let into the outer face of studs at 45° angles, secured at top and bottom and to studs. The process is repeated for each story of the building.

Bridging may be omitted when flooring is nailed adequately to the joists. However, where the nominal depth-to-thickness ratio of the joists exceeds 6, bridging would be installed at 8-ft (2.4-m) intervals.

Contributor:
Timothy B. McDonald, Washington, DC.

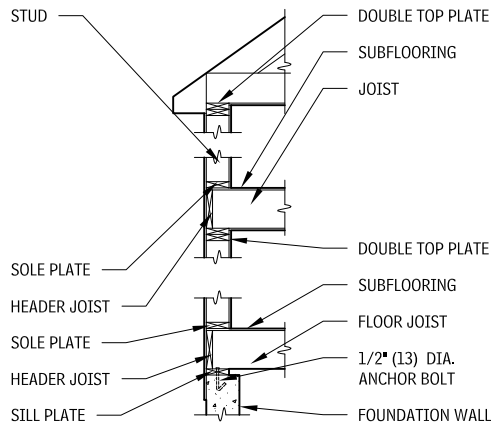
Building codes may allow omission of bridging under certain conditions. Steel bridging is available. Some types do not require nails. Bridging between wood joists is not required for spans up to 15 ft (4.6 m) and joist depths up to 12 in. (305 mm). Bridging increases the likelihood of floors squeaking, if the subfloor is not glued to the joists. Bridging between floor trusses should not block transverse duct runs.

Roof framing may be level, I-joist, or trusses. Floor joists may be any of the following types of beams: heavy timber, laminated veneer lumber (LVL), parallel strand lumber (PSL), glue laminated, built up, flitch, or box.

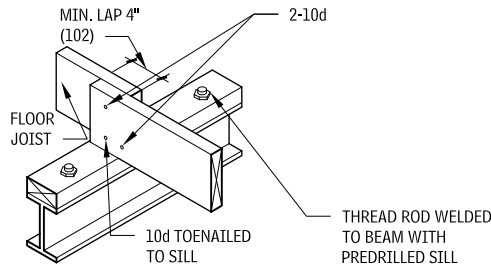
For firestopping, all concealed spaces in the framing, with the exception of areas around flues and chimneys, are to be fitted with 2-in. (51-mm) blocking arranged to prevent drafts between spaces.

Platform framing has essentially replaced balloon framing. Balloon framing with studs continuous from wood sill to top plate is rarely used, except in special locations, such as in two-story spaces, at parapets, and in similar situations where a structural cantilever of the wall is required.

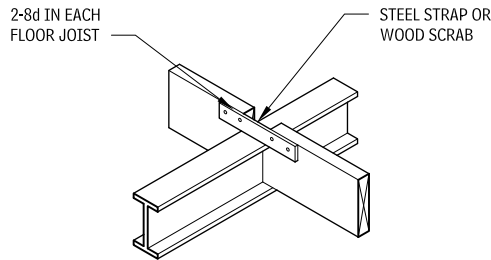
PLATFORM FRAMING—SECTION 1.18



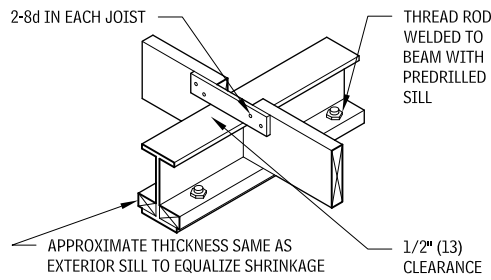
WOOD JOISTS SUPPORTED ON STEEL BEAM 1.19



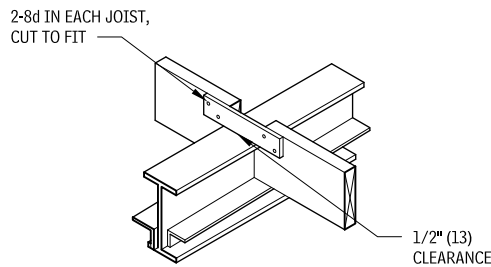
LAPPED OVER WOOD SILL



ON LOWER FLANGE



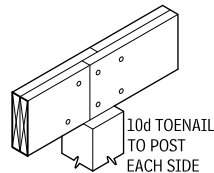
ON WOOD LEDGER



ON STEEL ANGLES

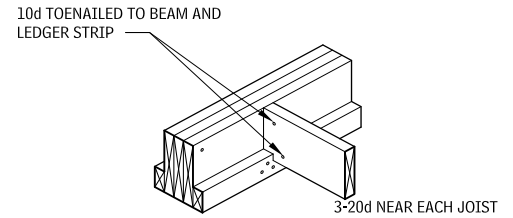
BEAMS 1.21

2-10d EACH END ON ONE SIDE; OTHERS STAGGER 16" (406) APART

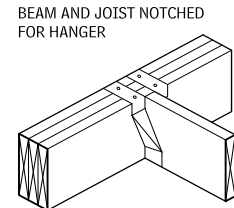


TWO-PIECE BUILT-UP BEAM

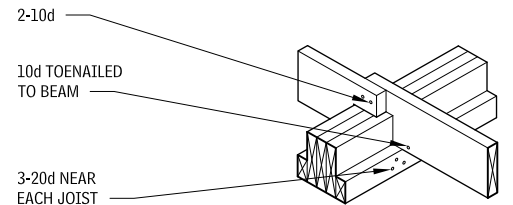
WOOD JOISTS SUPPORTED ON WOOD BEAM 1.20



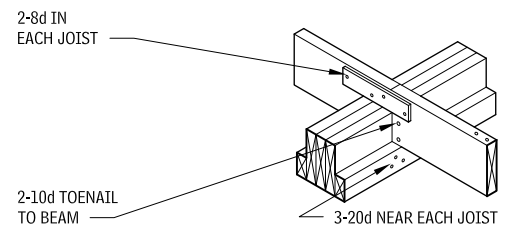
JOIST NOTCHED OVER LEDGER STRIP



JOIST IN JOIST HANGER

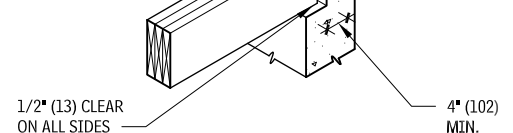


OVERLAPPING JOISTS NOTCHED OVER BEAM



JOISTS NOTCHED OVER BEAM

2-20d AT END OF EACH PIECE, EACH SIDE; OTHERS STAGGERED 32" (813) APART

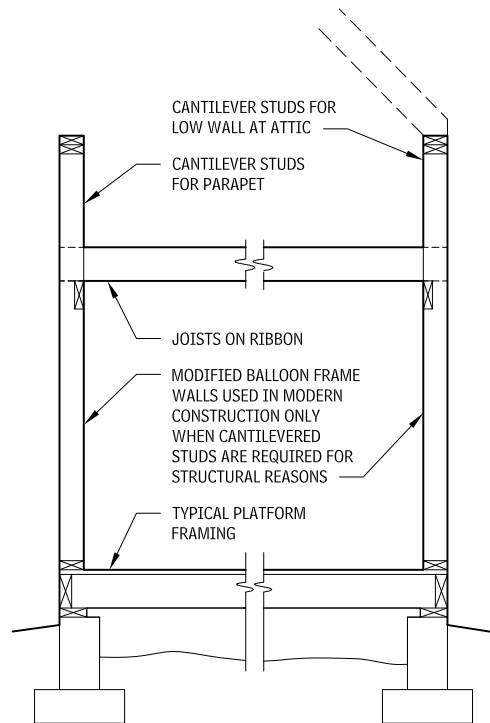


THREE-PIECE BUILT-UP BEAM

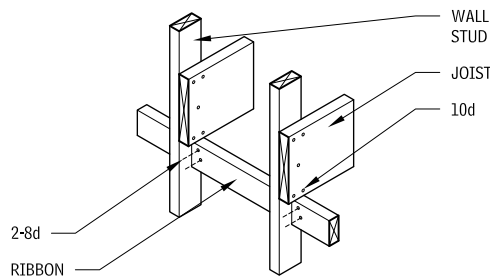
Contributors:
Timothy B. McDonald, Washington, DC.
Joseph A. Wilkes, Wilkes and Faulkner, Washington, DC.

BALLOON FRAMING

BALLOON FRAMING
1.22



JOISTS BEARING ON RIBBON
1.23

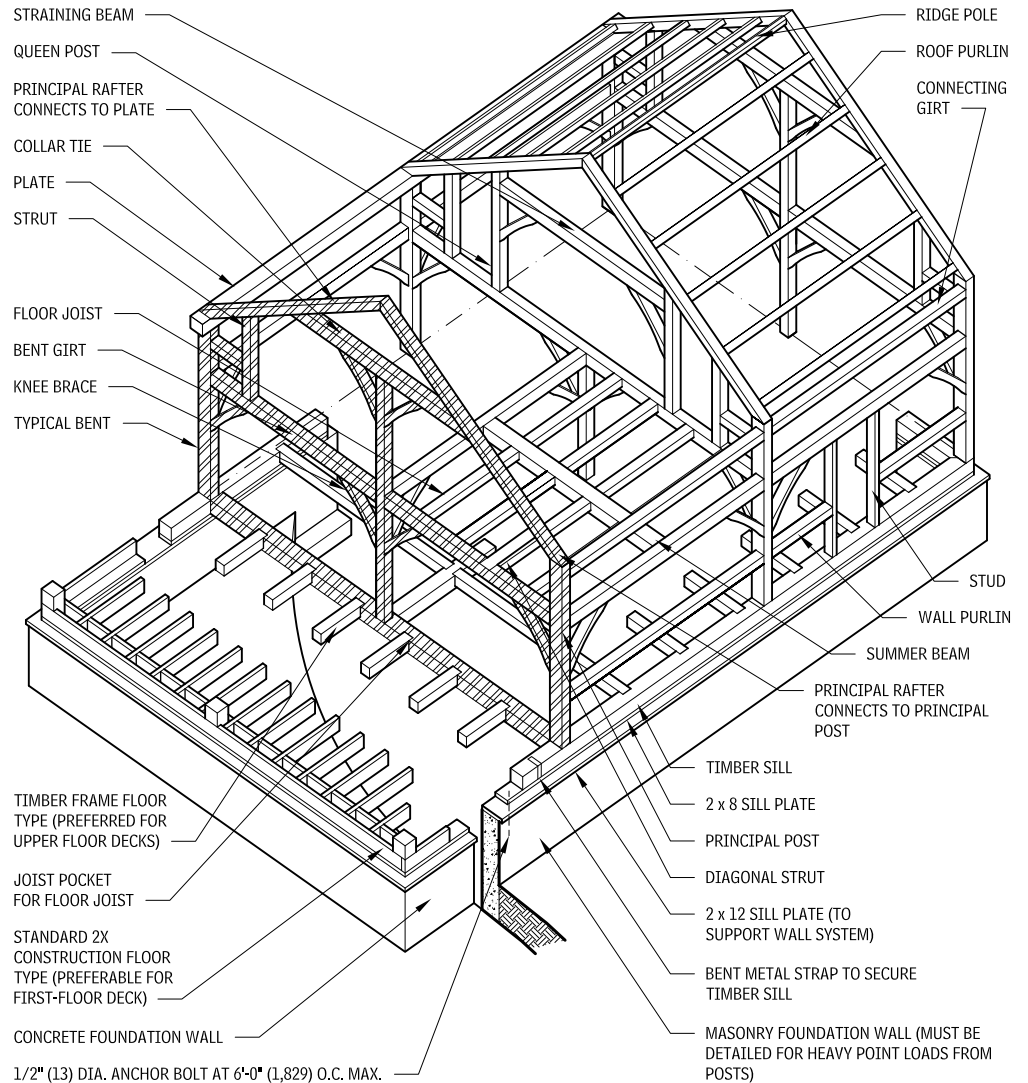


HEAVY-TIMBER CONSTRUCTION

Heavy-timber construction is characterized by large, exposed timber columns, beams, and other structural members, joined together by traditional pegged mortise and tenon or similar joints. Heavy timber uses rectangular solid wood framing members that are nominally a minimum of 5 in. (127 mm) in both dimensions. Heavy-timber fabricated timber frame modules are called *bents*. Bents run perpendicular to the ridge, and include the primary columns, beams, girders, rafters, and knee braces. Bents are typically spaced 10 to 16 ft (3 to 4.9 m) on center. Note that alternate framing methods running parallel to the ridge, or utilizing systems similar in concept to platform framing, are available from some timber framers. Knee braces typically provide bracing against lateral loads.

Heavy-timber structures are typically enclosed with stressed-skin insulated panels, leaving the frame totally exposed on the interior. Heavy-timber construction is being updated with modern materials such as glue-laminated members and proprietary concealed metal connections.

TYPICAL TIMBER FRAME SHOWING TWO ROOF AND FLOOR TYPES
1.24



GLUE-LAMINATED CONSTRUCTION

The term *glue laminated (glulam)* refers to an engineered, stress-rated product made of wood laminations bonded with adhesives, with the grain approximately parallel lengthwise. Laminated pieces can be end-joined to form any length, be glued edge to edge to make wider pieces, or be composed of bent pieces curved during the laminating process.

STANDARD DEPTHS

Dimension lumber surfaced to 1-1/2 in. (38 mm) is used to laminate straight members and members that have a curvature within the bending radius limitations for the species. Boards surfaced to 3/4 in. (19 mm) are recommended for laminating curved members when the bending radius is too short to permit the use of dimension lumber, provided that the bending radius limitations for the species are observed. Other lamination thicknesses may be used to meet special requirements.

STANDARD WIDTHS
1.25

NOMINAL WIDTH	NET FINISHED WIDTH
3" (76)	2-1/8" (54)
4" (102)	3-1/8" (3" for southern pine) (79, 76)
6" (152)	5-1/8" (5" for southern pine) (130, 127)
8" (203)	6-3/4" (171)
10" (254)	8-3/4" (8-1/2" for southern pine) (222, 216)
12" (305)	10-3/4" (10-1/2" for southern pine) (273, 267)
14" (356)	12-1/4" (309)
16" (406)	14-1/4" (362)

NOTE

1.24 Hatched members represent components of a typical bent.

Contributors:
Tedd Benson and Ben Brungraber, PhD, PE, Benson Woodworking Co., Inc., Alstead, New Hampshire.
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

CONNECTION DESIGN

The design of connections for glue-laminated construction is similar to the design of connections for dimension lumber. Since glue-laminated members often are much larger than dimension lumber, and the loads transferred are larger, the effect of increased size should be taken into account in the design of connections. In addition to being designed for strength to transfer loads, connections also should be designed to avoid splitting of the member, as well as to accommodate swelling and shrinking of the wood.

FIRE SAFETY

Similar in nature to those of heavy timber, the self-insulating qualities of glue-laminated construction cause the members to burn slowly. Good structural details, elimination of concealed spaces, and use of vertical fireblocking contribute to its fire resistance and ability to retain its strength longer than unprotected metals.

Therefore, building codes generally classify glue-laminated construction as heavy-timber construction if certain minimum dimensional requirements are met. Codes also allow for calculation of one-hour fire ratings for exposed glue-laminated members.

Fire-retardant treatments should generally not be applied to glue-laminated members because they do not substantially increase their fire resistance. In considering fire-retardant treatment, it is essential to investigate the following:

- Reduction of strength related to type and penetration of treatment
- Compatibility of treatment and adhesive
- Use of special gluing methods
- Difficulty of application
- Effect on wood color and fabrication process

Some fire-retarding treatments may discolor wood, accelerate corrosion of metal fasteners, or alter the structural properties of the wood.

POST AND BEAM CONSTRUCTION

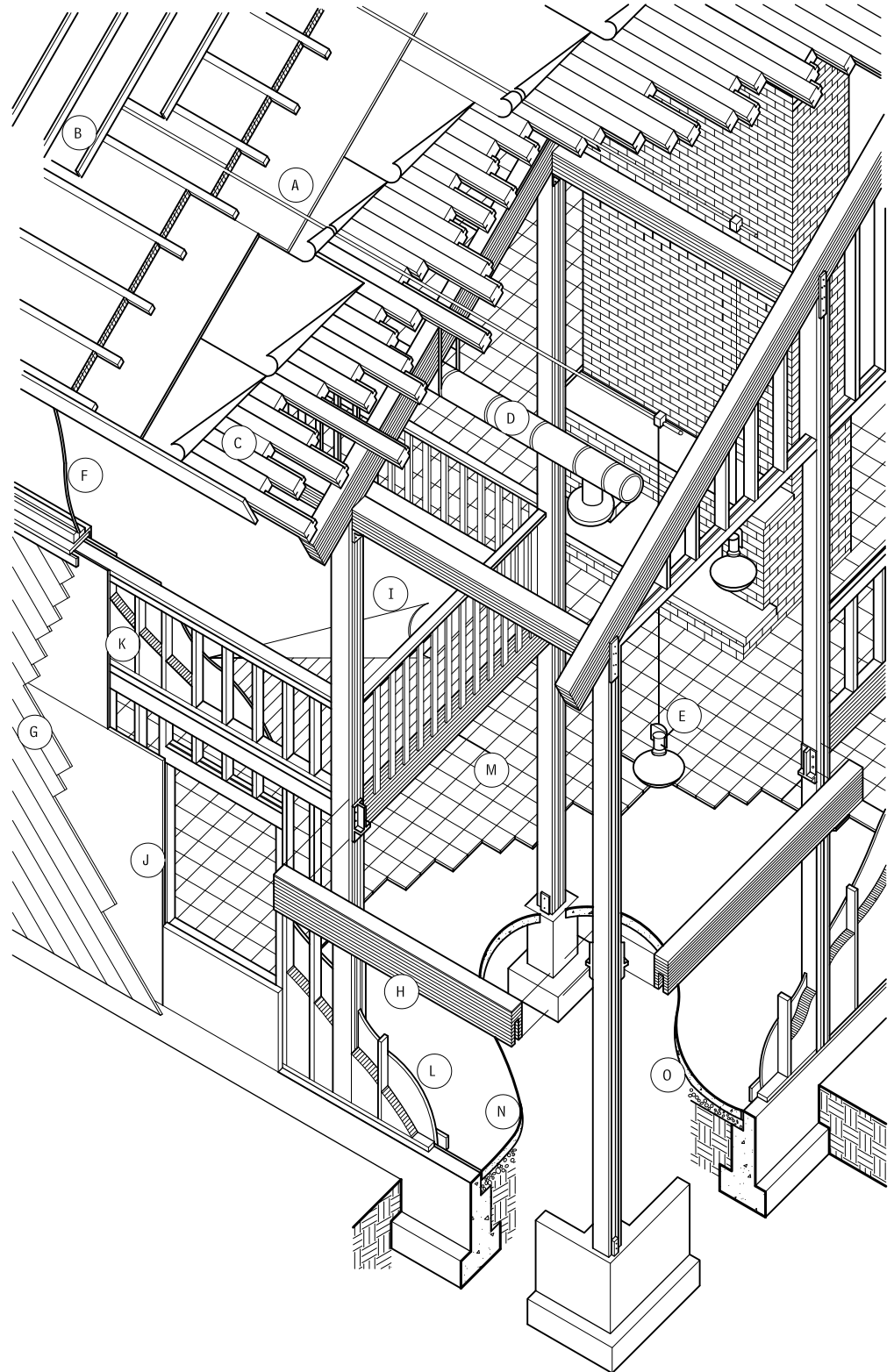
Although used historically for larger buildings, post and beam construction is now generally confined to buildings of three stories or fewer. Its main advantages are simplicity of elements and details, combined with the potential for visual integration and bold structural and architectural forms.

Structure and interior are unified in post and beam construction. Because the structural elements in this system are exposed to view, as are portions of the mechanical system, care is required in the visual integration of these components and in the design and appearance of hardware used to join the wood members. Certain parts of the mechanical system can be concealed within interior partitions and exterior walls. The sizing of structural members and joinery details may be influenced more by considerations of visual proportion and appearance than strictly by the loading and stress conditions involved.

LEGEND

- A Rigid conduits run through decking
- B Roof deck covered with roofing felt moisture barrier; rigid insulation board between sleepers. Standing seam metal roof over sleepers
- C Plywood sheathing and wood roof, laminated tongue-and-groove decking, nominally 2-1/4 in. (.57) thick, laid over the beams
- D Air supply and return ducts
- E Lighting fixtures
- F Window assembly
- G Wood siding
- H Heavy glue-laminated wood beams
- I Carpeting
- J Exposed wood frame and plywood sheathing
- K Wood stud framing
- L Drywall
- M Clay tile flooring
- N Slab on grade and concrete foundation
- O Vapor barrier under slab

**LAMINATED WOOD POST AND BEAM
1.26**



NOTES

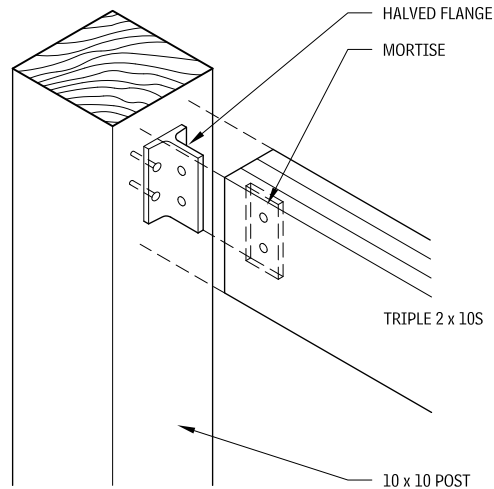
- 1.26a. The underside of the laminated tongue-and-groove decking is exposed to interior view and should be specified for appearance grade.
- b. A vapor barrier is placed toward the occupied side, and the voids are filled with batt or rigid insulation.
- c. The exterior is sheathed in plywood and finished with diagonal wood siding.
- d. Kitchens, lavatories, and other areas requiring both odor removal equipment and greater amounts of fresh air are separated by walls and covered by suspended or furred ceilings.

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland, based on Richard D. Rush, AIA, *The Building Systems Integration Handbook* (John Wiley & Sons, 1986).

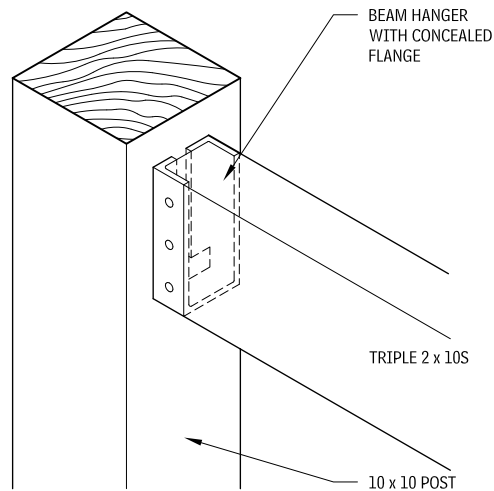
Considerable flexibility is available in selecting structural modules and bay sizes in heavy-timber construction by varying the depth of beams and increasing the thickness of decking to span between beams. Columns are frequently oversized to give an appropriate appearance. If sized only to carry the loads transferred from above, they may appear too spindly in proportion to other framing elements.

Glue-laminated beams, columns, and decking are generally preferred over dimensioned saw-cut lumber because appearance is easier to specify and ensure. A variety of custom shapes, sizes, and presawn joints can be obtained in glue-laminated pieces, and they are drier and more resistant to twisting, checking, and shrinkage. All pieces should remain factory-wrapped until in place and out of the weather, as rain and snow will stain them.

POST AND BEAM CONNECTIONS 1.27

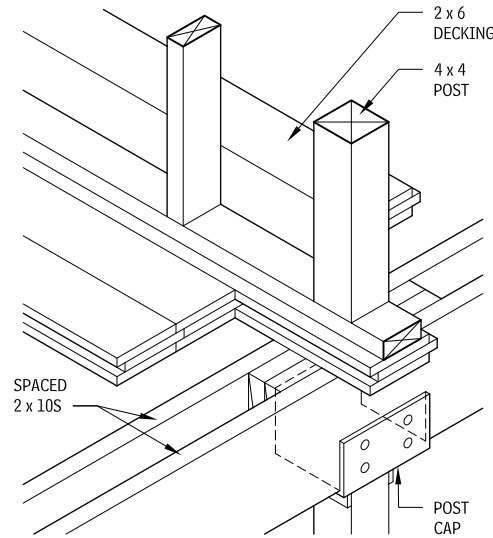


BEAM AND COLUMN CONNECTION



BEAM HANGER CONNECTION

SPACED BEAM BEARING ON INTERIOR COLUMN 1.28



MILL CONSTRUCTION

Mill construction uses a combination of fire-resistant brick walls with heavy-timber interior construction. It is characterized by large open floor spaces and daylight streaming through large windows. Although this type of construction is rarely used today, many of these buildings still stand, and have been converted into office spaces, housing and studios for artists, and museums.

STEEL FRAMING

Iron and steel, and their alloys, are usually the most cost-effective metal choices for structural applications. Steel is a ferrous metal. Nonferrous metals contain little or no iron, generally have good corrosion resistance, and are nonmagnetic. Nonferrous metals include copper and aluminum. Desirable properties of different metals can often be combined by mixing metals together to form alloys.

Iron that contains no trace of carbon is soft, ductile, and easily worked, but it rusts in a relatively short time and is susceptible to corrosion by most acids. Higher carbon content increases metal strength and hardness but reduces iron's ductility and weldability.

METALS 1.29

FERROUS (CONTAIN IRON)	NONFERROUS (CONTAIN LITTLE OR NO IRON)
Steel	Copper
Stainless steel	Aluminum
Iron	Tin
	Magnesium
	Bronze and brass
	Lead
	Zinc
	Titanium

TYPES OF IRON

Many iron types are manufactured for specific applications.

- *Gray irons*: high in carbon and silicon content; rather brittle; excellent for damping (absorbing) vibrations. Applications include decorative shapes, such as fences and posts, gratings, and stair components.
- *Malleable iron*: low-carbon white iron is cast, reheated, and slowly cooled, or annealed, to improve its workability. Used for applications that require great toughness and high ductility.

- *Ductile iron*: made by adding magnesium to molten iron shortly before the metal is poured into molds, increasing ductility. Ductile iron is less brittle, stiffer, stronger, and more shock resistant than gray iron.
- *ADI castings*: ductile castings made using a special austempering heat-treating process; they rival or surpass certain alloy steel castings in tensile and yield strengths.
- *White-iron castings*: extremely hard and brittle; used primarily in industrial machinery parts that experience high wear and require abrasion resistance.
- *High-alloy irons*: gray, ductile, or white irons with an alloy content of 3% to more than 30%.
- *Wrought iron*: made from iron ore that is heated until it is soft but not melted; relatively soft, corrosion and fatigue resistant, and easily worked. Ideal for railings, grilles, fences, screens, and various types of ornamental work; commercially available in bars, rods, tubing, sheets, and plates.
- *Cast iron*: contains a large amount of carbon; so hard and brittle that it cannot be worked and must be cast into molds. Relatively corrosion resistant. Used for plumbing drainage pipes and ornamental rails for exterior applications.

TYPES OF STEEL

Steel comprises the various alloys of iron and carbon. More than 90% of the steel manufactured into finished products is carbon steel.

- *Carbon steel*: a higher carbon content increases metal strength and hardness but reduces its ductility and weldability. Reasonably strong but poor resistance to corrosion. Used in structural shapes such as welded fabrications or castings, metal studs and joists, fasteners, wall grilles, and ceiling suspension systems.
- *Galvanized steel*: application of zinc to the surface of carbon steel or steel alloys to prevent corrosion; either *hot dipped* or *electroplated*.
- *High-strength, low-alloy (HSLA) steels*: better corrosion resistance than carbon steels; chosen when weight is a consideration and higher strength is specified.

The most commonly used framing systems for steel construction include open-web steel joists, rigid frames, framed tubes, braced cores, space frames, and moment-resisting frames. Following are characteristics and principles to keep in mind when working with structural steel framing:

- The high strength of steel provides for economical construction of relatively large structural bays.
- Major framing elements are typically W-shaped sections or round, square, and rectangular hollow structural sections. Angles or channels may be used for architectural expression.
- Building codes require protection of the steel from fire, except for small or low-rise structures in some low-hazard occupancies.
- Horizontal loads from wind and seismic events must be resisted, typically by diagonal bracing, moment connections, or shear walls.
- Shear walls, typically around shafts for stairs, ducts, and elevators, can be an effective lateral load design option. Shear walls can be constructed of steel plate, concrete, or reinforced concrete masonry units (CMUs). Minimize openings in shear walls for doors and services.
- The floor or roof deck typically is designed to act as a diaphragm to transmit loads to the lateral restraint elements.
- Open-web steel joists may be used within a main frame of structural steel for economy.

For more information, refer to the *AISC Manual of Steel Construction*.

OPEN-WEB STEEL JOISTS

Steel construction with open-web joists and bearing walls yields buildings that have relatively large interior clear spans and flexible interior layouts. The open webbing of the joist provides a light-weight structure that is easily penetrated by mechanical systems. The bottom chords of the joists are used for suspension of interior finishes, lighting fixtures, and air diffusers in finished areas, although they may be left uncovered.

Open-web steel joists are usually covered by 2-1/2 to 3 in. (64 to 76 mm) of concrete on steel decking. Concrete thickness may be increased to accommodate electrical conduit or electrical/communications raceways. Precast concrete, gypsum planks, or plywood can also be used for the floor system.

Ceiling supports can be suspended from or mounted directly to the bottom chords of joists, although suspended systems are recommended because of dimensional variations in actual joist depths.

FABRICATED FIREPROOFED STEEL COLUMNS

Fabricated fireproofed steel columns (*lally columns*) are structural units that consist of load-bearing steel columns filled with concrete. This creates a column with increased load-bearing capacity in a space no larger than a standard column. Lally columns have fire-resistant characteristics when a layer of fireproofing material encases the structural column. Fire ratings typically range from two to four hours.

ARCHITECTURALLY EXPOSED STRUCTURAL STEEL FRAMING

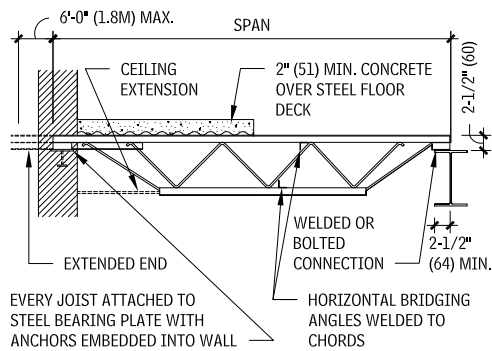
The characteristics and principles to keep in mind when working with *architecturally exposed structural steel* (AESS) include the following:

- AESS is structural steel superstructure, supporting all or portions of a building, which is left exposed in the finished work. Through layout and detailing, AESS is meant to contribute to the architectural expression.

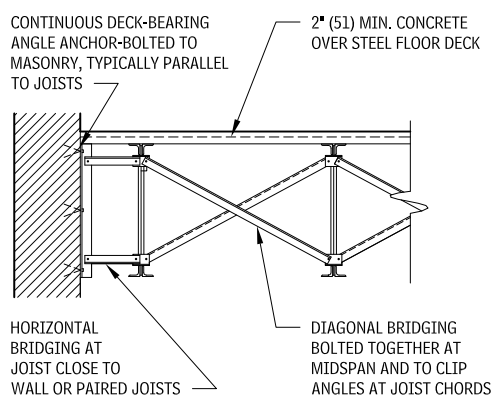
- The challenge to successful use of AESS is to clearly specify and detail the level of quality required, which is substantially beyond the requirements for normal structural steel. Primary areas of concern include the quality of finish of the individual members, the quality of the methods of joining members together (particularly of welds), and the tolerances of the finished work.
- AESS frequently incorporates a variety of tension members fabricated of stainless steel and proprietary fittings.
- AESS may need special fire protection, such as intumescent coatings or deluge sprinkler systems.
- For economy, it is worthwhile to carefully identify which portions of the AESS will be viewed in close proximity versus those that are farther away. Locate defects, welds, and connections on the side of assembly away from view.

Refer to the May 2003 supplement to *Modern Steel Construction* for an explanation of how to specify AESS.

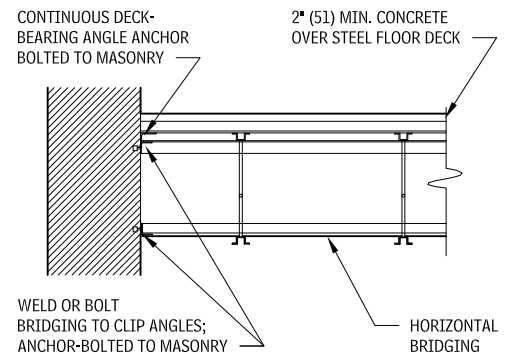
SECTION THROUGH JOIST BEARING 1.30



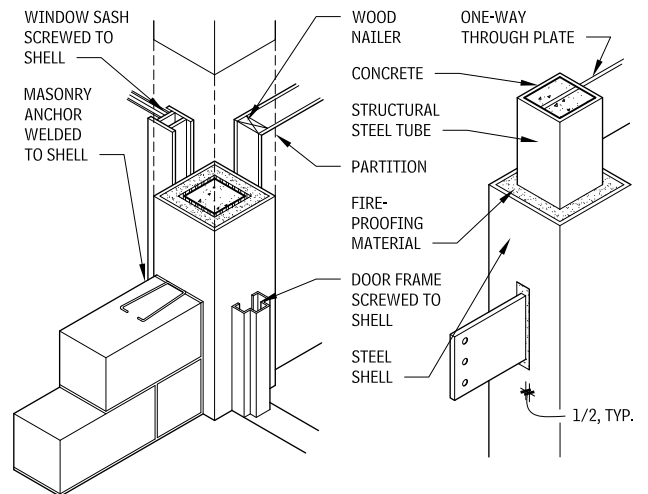
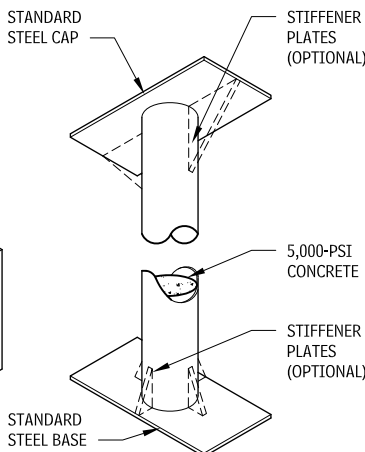
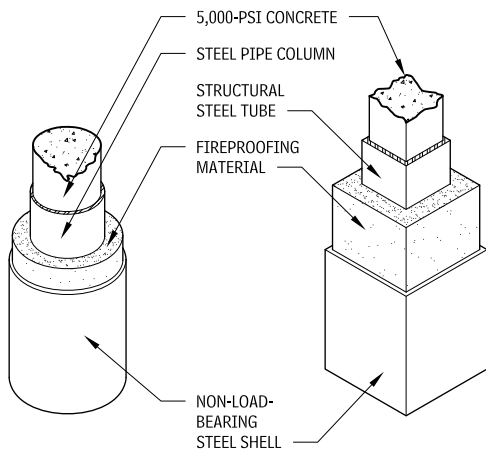
SECTION THROUGH LONG-SPAN STEEL JOISTS 1.31



SECTION THROUGH STEEL JOIST 1.32



FABRICATED FIREPROOFED STEEL COLUMNS 1.33



FIREPROOF COLUMNS

TYPICAL COLUMN BASE AND CAP

ATTACHMENTS TO STEEL COLUMN COVER

BEAM CONNECTIONS

STEEL FRAME WITH CURTAIN WALL

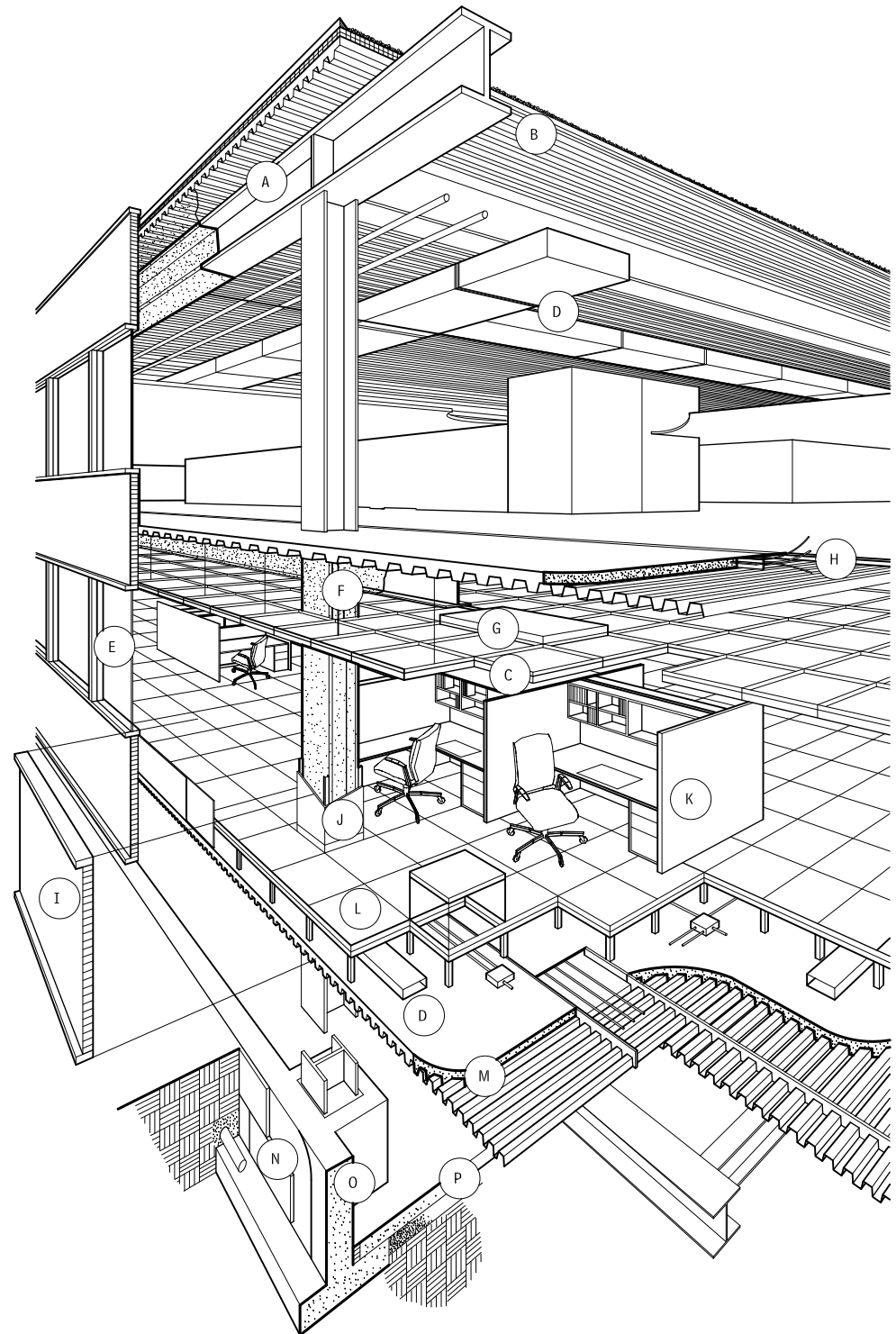
Steel frame and curtain wall construction allows for off-site fabrication of frame and envelope components, easy shipping to the site, and rapid assembly at the site. The steel and concrete in the floors are designed to act as a composite diaphragm, providing a thin, lightweight structural element with or without an access floor. The access floor is advantageous in office environments that need especially flexible interior layouts. This system keeps all wires and cables in the space below the finish floor (generally not less than 4 in. [102 mm] deep) and out of wall cavities. Although access floors may add to overall floor-to-floor heights, the access floor conceals the most visually obtrusive distribution elements.

Core shear walls add rigidity to the frame; the composite action of structural steel framing and a steel and concrete floor diaphragm result in relatively long, uninterrupted clear spans with smaller depth of construction. Heights can range from 1 to more than 100 stories. The corrugated steel deck becomes a working surface as soon as it is placed and provides formwork for concrete topping.

The envelope is structurally independent of the steel frame, providing flexibility in weight, size, and configuration of the envelope system. Curtain wall units preassembled at the factory must be designed with shipping, storage, installation, and general handling in mind, emphasizing protection from damage at all stages.

Mechanical systems, hidden in floor or ceiling plenums or both, can be accessed through removable panels in ceiling or floor systems. A suspended ceiling provides space for the distribution of internal services, but it tends to be used principally for overhead lighting and ductwork.

Structural/electrified floors and access floor systems keep all wires and cables in the space below the finish floor, which are easily accessible by removing floor panels. This allows for a high degree of flexibility in the interior environment. Buildup of static electricity and the ensuing risk of equipment damage and shocks must be considered. Access floors are not suited to situations involving heavy point loads or shifting heavy equipment. Stringerless systems are among the most flexible and least costly varieties, but they lack the stability of fully gridded systems and depend on perimeter walls for restraint. Use of access floors to create an air plenum, requiring tight and uniform joints between access panels, may hinder access to wires, cables, and pipes; ductwork in floor plenums may eliminate the advantages of access floors by blocking the path for wiring, cables, and pipes.

STEEL FRAME WITH CURTAIN WALL
1.34**LEGEND**

- A Steel decking welded to frame
- B Built-up roofing or single-ply membrane on rigid insulation
- C Suspended acoustical tile
- D Ducts with diffusers, either suspended from structure in ceiling plenum or placed in floor plenum beneath access floor
- E Curtain wall units
- F Steel with welded and bolted connections
- G Fluorescent light fixture in ceiling
- H Electrical wires and cables placed in concrete floor
- I Insulated spandrel panels
- J Gypsum wallboard
- K Systems furniture
- L Carpeted access floor system
- M Steel decking welded to primary frame members, with cast-in-place concrete topping
- N Waterproofing and protective board with foundation drain
- O Slab on grade with concrete foundation
- P Vapor barrier under slab

Contributor:

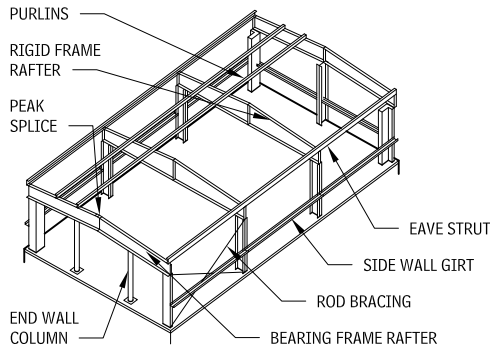
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland, based on Richard D. Rush, AIA, *The Building Systems Integration Handbook* (John Wiley & Sons, 1986).

RIGID FRAMES

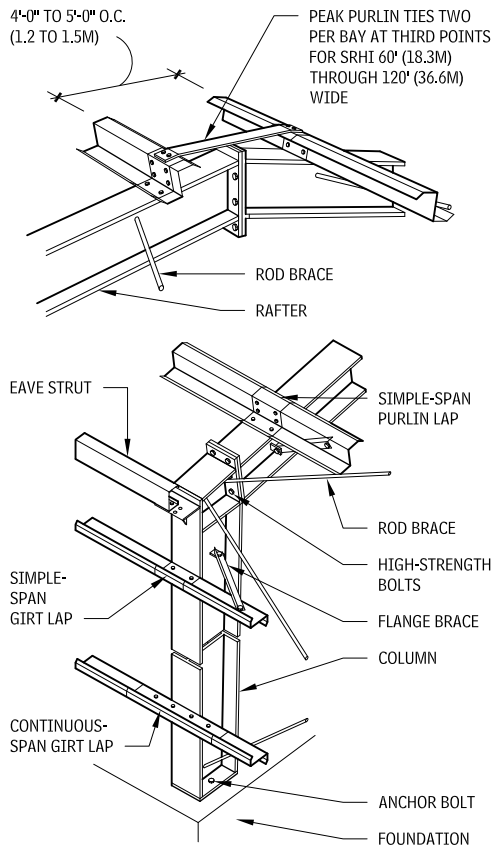
Rigid frame construction combines columns and a beam or girder welded together to make a rigid connection. Such a frame can carry vertical loads and resist horizontal forces, either wind or seismic. Rigid frame buildings are usually single story. The roofs are generally sloped, usually at least 1 in 12.

Because they span fairly long distances relatively cheaply—widths range between 30 and 130 ft (9.1 and 39.6 m)—rigid frame structures are used for recreational buildings; warehouses; light industrial buildings; and commercial buildings, such as supermarkets, automobile dealer showrooms, and garages. Bay sizes are usually 20 to 24 ft (6 to 7.3 m) but may be extended to 30 ft (9.1 m). The roof profile is most often configured as a symmetrical gable, but such a profile is not a structural necessity. Some manufacturers offer precast concrete and masonry siding. Pre-engineered buildings most often use rigid frames for roof and wall supports.

RIGID STEEL FRAME 1.35



RIGID STEEL FRAME DETAILS 1.36

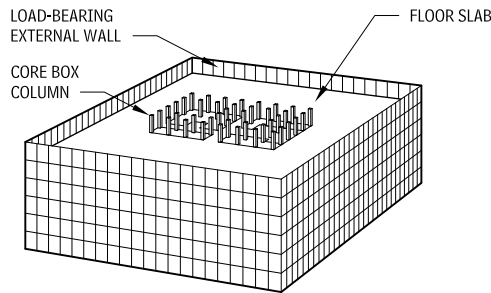


FRAMED STEEL TUBE

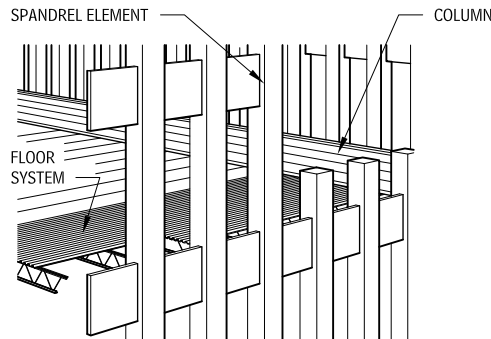
In the framed tube system, structural steel members form the load-bearing exterior perimeter wall; this wall is designed so the entire building becomes, in effect, a structural steel tube. The tubular strength is achieved in two ways: The exterior columns are spaced closely together (perhaps 6 ft [1.8 m] on center) and connected to spandrel beams, and the structure is stiffened by the floors to form a torsionally rigid tube. The spandrel beams are generally very deep, in units of feet as opposed to inches. The columns and spandrel beams are welded together to create a moment-resisting connection. Often this system is referred to as a *pierced tube*, the pierced areas being the window openings.

The framed tube system is most economical for very tall buildings. The World Trade Center towers in New York were framed tube construction. The Sears Tower in Chicago is the most conspicuous existing example of this construction system. Systems like that of the Sears Tower, a combination of nine framed tubes in a 3 × 3 array, are sometimes called *bundled tubes*.

FRAMED STEEL TUBE 1.37



PERIMETER FRAMED TUBE WALL DETAIL 1.38

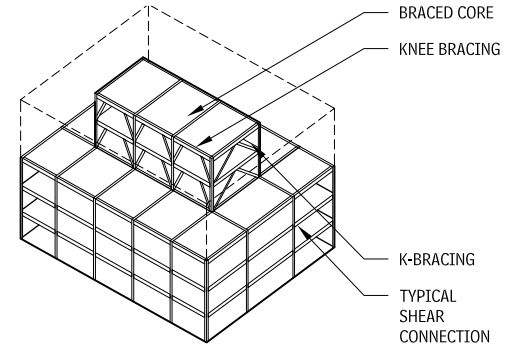


BRACED CORE

In the braced core system, walls around elevator shafts and stairwells are designed to act as vertical trusses that cantilever up from the foundation. The chords of each truss are building columns; the floor beams act as ties. Diagonals placed in a K-pattern (occasionally in an X-pattern) complete the truss. A system employing knee braces is used in seismic areas because of its greater capability to dissipate earthquake energy. Braced core systems can be used efficiently in single-story buildings as well as in buildings over 50 stories.

Braced frames are cost effective, but disrupt the floor plan if not carefully located around typical core elements such as stairs, shafts, and toilet rooms. Bracing typically is provided by angles or W-shapes as well as hollow structural shapes. Rods and cables may be used for architectural expression.

BRACED CORE 1.39



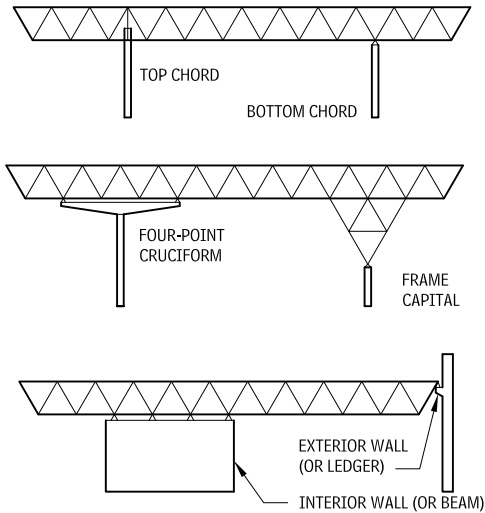
SPACE FRAMES

A space frame is a three-dimensional truss with linear members that form a series of triangulated polyhedrons. It can be seen as a plane of constant depth that can sustain fairly long spans and varied spatial configurations. The prime attributes of space frame structural systems are their light weight; their inherent rigidity; their wide variety of form, size, and span; and their compatible interaction with other building support systems, primarily HVAC. Most systems are designed for specific applications, and a structural engineer with space frame experience should always be consulted. Manufacturers can provide the full range of capabilities—loading, spans, shapes, specific details—for their products. Standardized systems in 4- and 5-ft (1.2- and 1.5-m) modules are available.

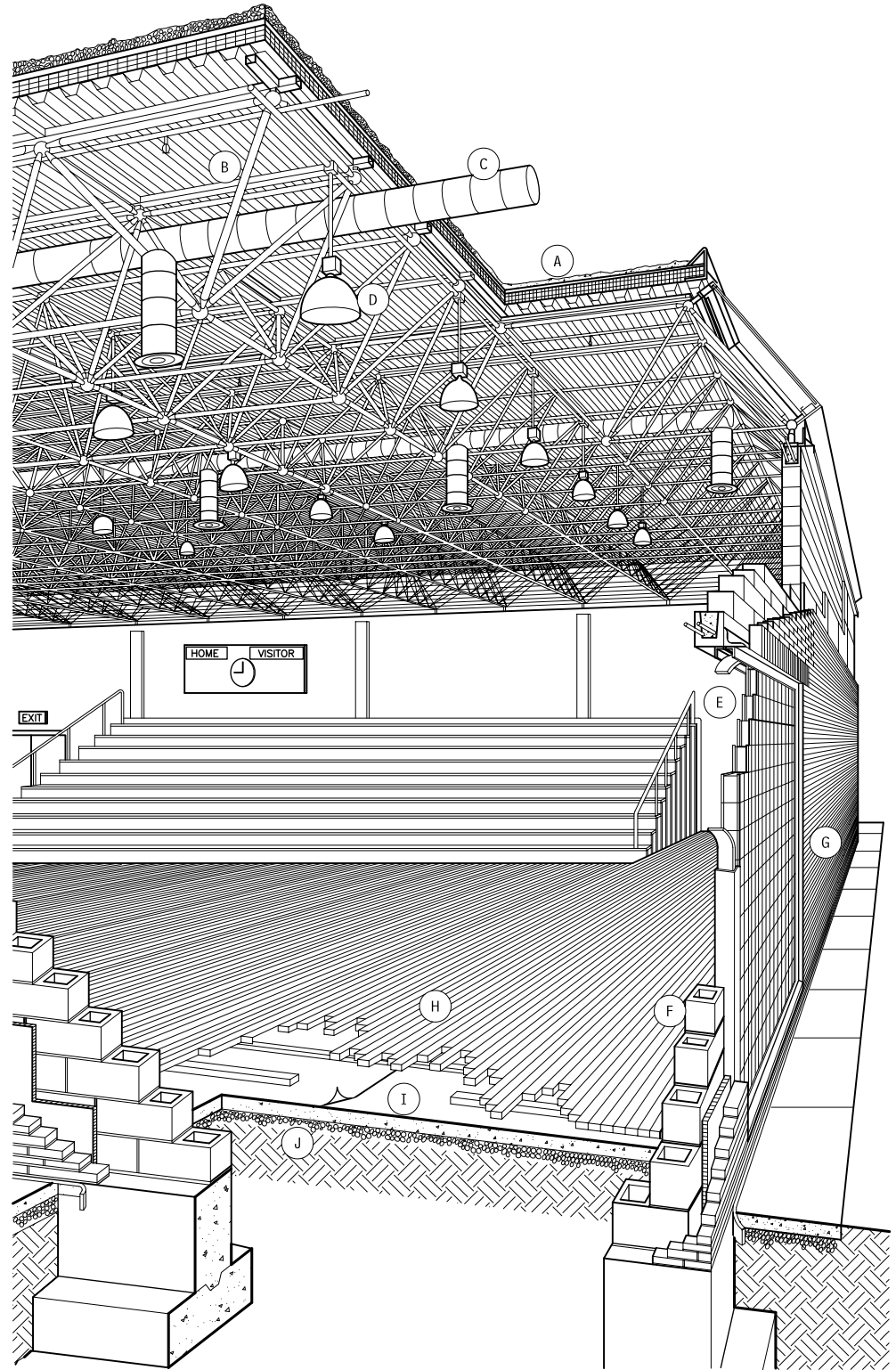
Metal space frames are classified as noncombustible construction and can usually be exposed when 20 ft (6 m) above the floor. However, an automatic fire-extinguishing system or a fire-rated ceiling may be required.

SPACE FRAME SUPPORT TYPES

1.41



SPACE FRAME
1.40



LEGEND

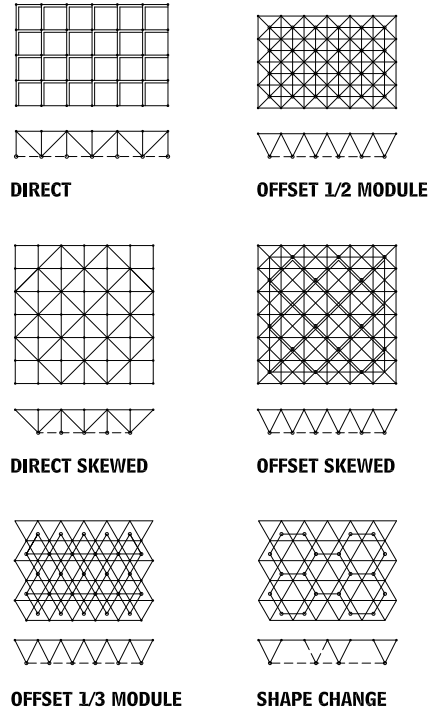
- A Built-up roofing and rigid insulation
- B Space frame and metal deck
- C Ducts suspended from hubs of the frame
- D Light fixtures
- E Glass block panel
- F Concrete masonry unit (CMU) bearing wall
- G Brick veneer and rigid insulation
- H Wood flooring
- I Slab on grade and concrete foundation
- J Vapor barrier

Contributor:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland, based on
Richard D. Rush, AIA, *The Building Systems Integration Handbook* (John
Wiley & Sons, 1986).

COMMON SPACE FRAME PATTERNS

Many proprietary systems are available for specific applications and budgets.

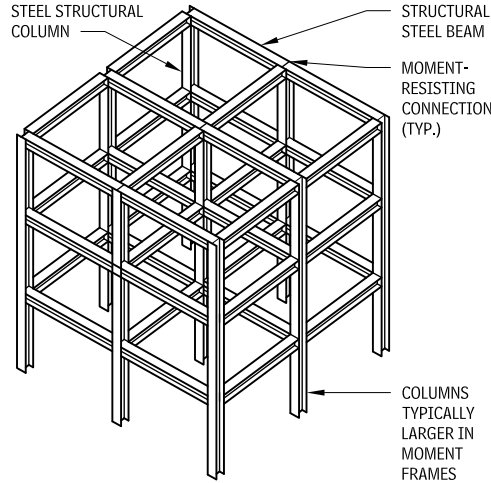
COMMON SPACE FRAME PATTERNS 1.42



MOMENT-RESISTING FRAME

A moment-resisting frame's lateral stability and resistance to wind and seismic forces depend on a fixed connection of beams and columns. A moment-resisting connection is achieved when the top and bottom flanges of each beam are welded to the flanges of the connecting columns with full-depth welds. By directly welding the beam web to the column flange, the beam's horizontal reaction to wind forces is transferred to the column. (A connection using web angles and high-strength bolts is also permitted.) The building's floors are designed to act as diaphragms that connect all of the columns and beams, enabling the building to react as a unit.

MOMENT-RESISTING FRAME 1.43



Moment frames allow maximum floor plan flexibility, but typically increase the weight and cost of the structural steel framing.

Moment-resisting frames are uneconomical in tall steel buildings because the larger lateral forces in such buildings can be handled more efficiently by diagonal members, as found in braced frames. To save costs, often the upper stories of a braced frame building use moment-resisting beam-column connections to resist wind loads.

LIGHTWEIGHT STEEL FRAMING

Lightweight steel frame bearing wall construction is often used in low-rise commercial and residential buildings. The long-term performance of lightweight steel framing in structures over three stories is a concern. To date, its use in medium- and high-rise buildings has been mainly for exterior partitions or as nonbearing backup for exterior veneers.

Speed of construction, noncombustibility, and relative light weight are key advantages of this system. The space between studs eases insulation and accommodates piping and electrical distribution. Because the framing can be completed independent of the masonry veneer, the interior is out of the weather quickly and can be finished while the exterior brick veneer is being laid. In nonresidential construction, which is likely to have fewer bracing walls and longer vertical spans and horizontal runs, added cold-formed bridging or bracing to the frame increases lateral stability. This can also be accomplished by decreasing the stud spacing or increasing the stud gauge.

The lightweight cold-formed steel members are load bearing, and beams, columns, channels, headers, and other elements can be built up from standard steel shapes and sections. The frame's rigidity depends on cross-bracing, the distance from exterior corner to exterior corner, and the type and layout of fasteners used. Sheathing both sides of the frame also provides some lateral stability. Steel studs used for masonry backup should be cross-braced with steel straps. Horizontal and diagonal bracing increases the frame's rigidity. Welded connections are stronger than self-tapping screws. The positioning and types of fasteners for affixing both interior and exterior sheathing should be carefully specified, because these factors significantly affect lateral stability.

Cold-rolled steel framing is detailed and fastened quite differently from wood framing, so special noncarpentry tools and equipment are required. The advantages of cold-formed steel framing include its light weight, dimensional stability, speed and ease of assembly, resistance to moisture and decay, and, in some cases, readier availability than wood framing members. Also, steel framing members are frequently made from recycled scrap and can be endlessly recycled.

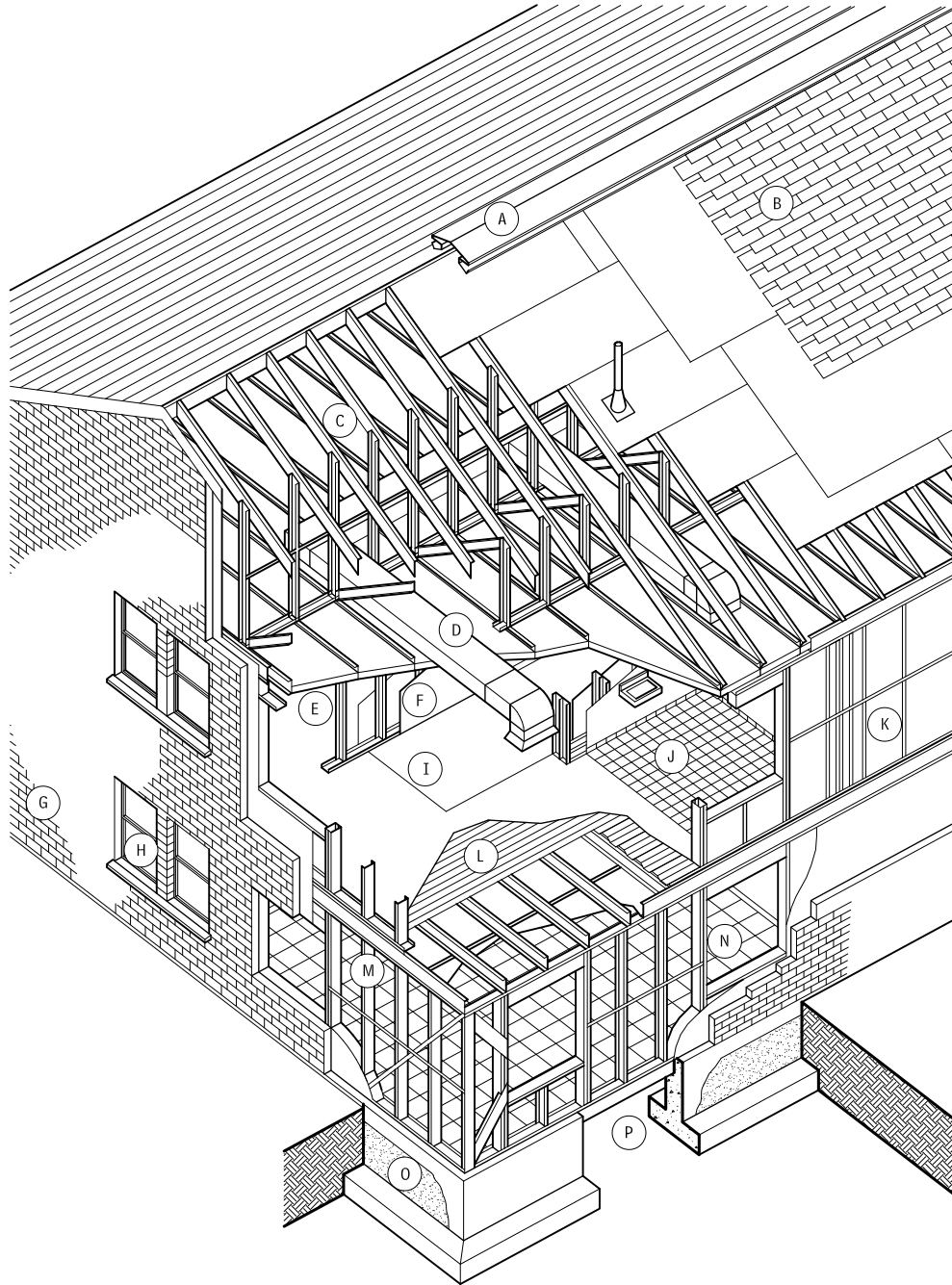
Deflection in lightweight steel frame construction can be several times greater than deflection in exterior masonry veneer; such differentials must be accommodated in anchoring details or be overcome by adding structural rigidity to the wall frame. The masonry ties that anchor the veneer to the steel frame should permit free and independent movement of the two materials. Where the veneer depends on the steel frame for lateral stability, anchors should be flexible and should not resist shear; wire ties that allow independent movement are recommended. The framing design and method of fastening windows and doors should account for the differences in movement. In general, fenestration components should be attached to either the framing or the veneer, but not attached rigidly to both. When filled with batt insulation and fully sheathed, the lightweight steel frame wall is thermally isolated from the single wythe of masonry veneer. This results in greater differential thermal movement in the veneer than would occur with solid double-wythe masonry construction; the interior heat is not transferred as readily to the exterior masonry.

Prepunched holes in the studs provide easy routing of plumbing and electrical lines. Most codes require the use of electrical conduit or sheathing of the prepunched stud opening to avoid stripping the insulation as wires are drawn through.

Interior gypsum board applied to steel studs, along with exterior sheathing, provides additional lateral bracing.

22 STRUCTURE SUPERSTRUCTURE

LIGHTWEIGHT STEEL FRAME AND BRICK VENEER 1.44



LEGEND

- A Ridge flashing
- B Shingles and roofing felt
- C Metal roof frame (C-stud brace, -rafter, -channel, -joist)
- D Ducts with diffusers
- E Suspended acoustical tile
- F Gypsum board
- G Brick veneer
- H Window assembly
- I Carpet
- J Ceramic floor tile
- K Batt insulation
- L Metal floor frame (C-joint), steel deck, and concrete topping
- M C-stud assembly, wiring threaded through wall assembly
- N Resilient floor tile
- O Dampproofing
- P Slab on grade with concrete foundation

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Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland, based on
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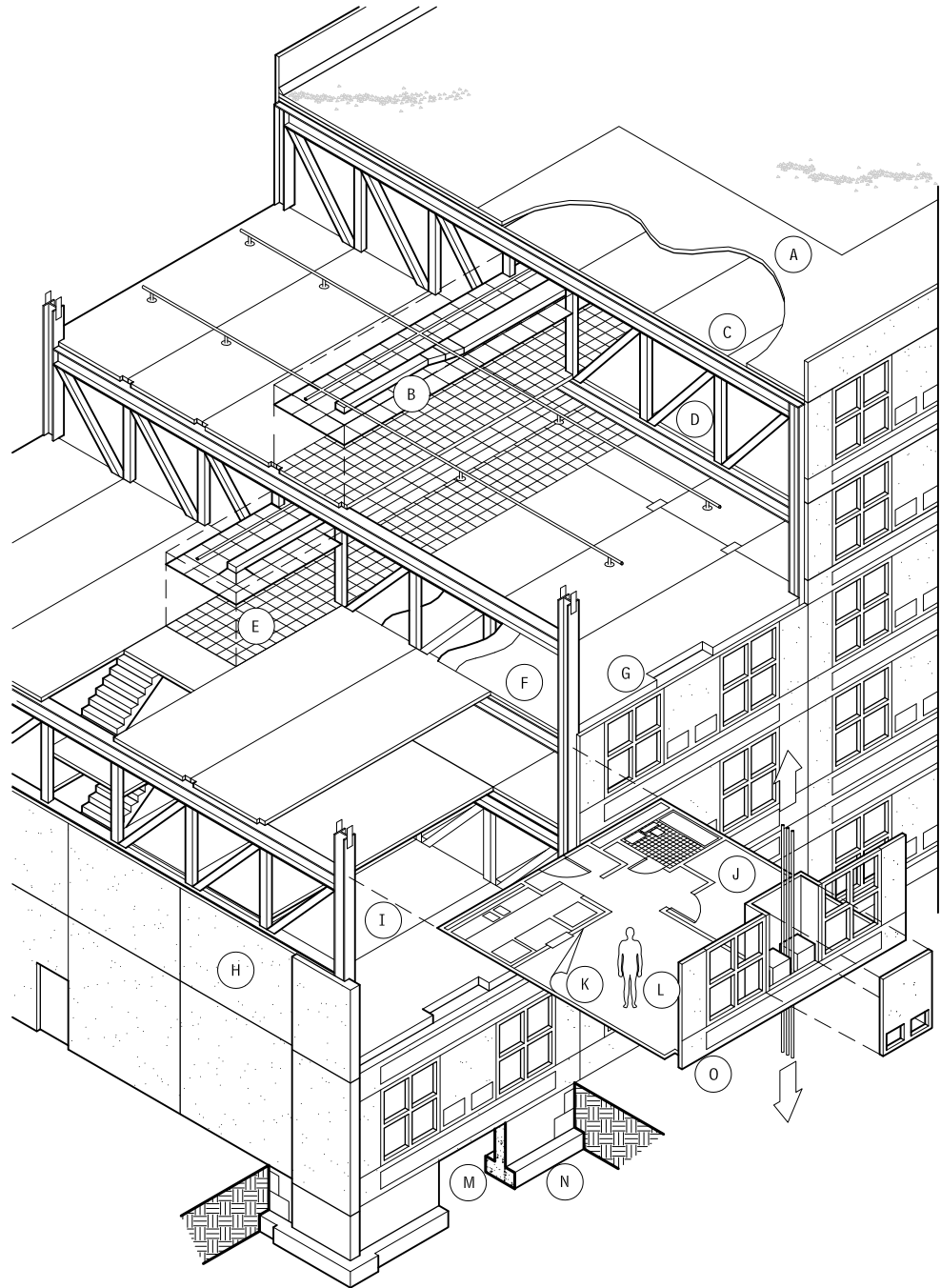
STAGGERED STEEL TRUSS

Staggered truss construction is most often used for double-loaded residential-type occupancies, including hotels, high-rise apartments, nursing homes, and hospitals. This system is best suited to multiunit residential or hotel buildings of 7 to 30 stories. Such building types usually have highly repetitive floor plans and can benefit from systems that integrate objectives regarding structure, interior unit separations, fire compartmentalization, and acoustical privacy. The system is not generally considered economical for low-rise buildings due to the manufacturing costs of the jigs for the trusses and the forms for the spandrel precasting. The system easily allows for long structural bays, permitting a high degree of flexibility in unit interiors. The ground floor is free of trusses and interior columns and thus is suitable for parking or retail commercial use. The system's light weight reduces foundation size.

Floor-height Pratt trusses are placed atop every other column in a staggered pattern, strengthening the structural system while reducing the overall weight; precast hollow-core concrete planks serve as the floor without a topping slab, allowing for bays of approximately 60 by 60 ft (18.3 by 18.3 m), twice the truss spacing. A fire-resistant membrane, such as drywall, is usually added to each side of a truss to provide protection; these walls also serve to divide individual units. Lower floors in this system can be finished and trimmed while upper-level structural members are still being laid; the structure becomes rigid as soon as the precast exterior wall panels are installed. Precast concrete wall members act as an envelope system as well as a structural system.

Because the Pratt-type trusses extend from floor to ceiling, with openings for corridors and elevator doors only, horizontal running of pipes, wiring, and ductwork can be difficult. For this reason, separate unit-by-unit heating and air-conditioning systems are often preferable. Also, unitary HVAC systems offer economic and maintenance advantages in multifamily residential construction. Utilities are typically fed upward through chases and risers on outer walls, with service or supply units placed to either side on each floor; end wall stair enclosures are also used for this purpose. Most sprinkler systems are laid out in this fashion as well. The smooth surface of concrete deck planks can provide interior ceiling finishes, if desired.

**STAGGERED STEEL TRUSS
1.45**



LEGEND

- | | |
|--|--|
| <ul style="list-style-type: none"> A Rigid insulation under single-ply roofing and ballast B Ducts with diffusers, and sprinkler system; underside of concrete planks either painted or covered with acoustical ceiling tile C Precast hollow-core concrete plank deck D Staggered story-high steel trusses E Tile F Gypsum board G Window assembly | <ul style="list-style-type: none"> H Precast shear panels I Steel columns J Conduit fed through vertical chases in outer walls K Joints at floor planks grouted, tops carpeted L Precast exterior wall panels that support floor slabs on both top and bottom chords M Slab on grade with concrete foundation N Vapor barrier with waterproofing with protective board O Precast stiffener beams |
|--|--|

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Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland, based on Richard D. Rush, AIA, *The Building Systems Integration Handbook* (John Wiley & Sons, 1986).

MASONRY STRUCTURES

Masonry construction is composed of building units of natural or manufactured products usually held together with mortar. Masonry bearing walls are usually one-story structures. Roof spans up to 60 ft (18.3 m) can generally be accommodated.

Types of masonry building units include:

- Concrete masonry units (CMUs)
- Brick
- Glass unit masonry
- Stone and cast stone

Masonry units can be assembled into solid walls, cavity walls, or veneered walls. They may be unreinforced or reinforced with metal wall ties or steel reinforcing bars inside grout-filled cavities and joints. Masonry walls are constructed of either solid or hollow masonry units, with joints filled with mortar. Typically, they are constructed in parallel sets to support steel, wood, or concrete spanning systems. It is common for masonry walls to be spanned by open-web steel joists, timber or steel beams, or concrete slabs.

Masonry materials expand and contract with changes in temperature and moisture content. Clay masonry units absorb water and expand. CMUs shrink as they dry after manufacture.

Movement joints are designed to control these changes. Movement joints are located each 100 to 125 ft (30.5 to 38.1 m) along unbroken lengths of masonry walls. They are also placed at changes in wall height or thickness; at columns, pilasters, and wall intersections; and near corners. They are additionally found on both sides of openings greater than 6 ft (1.8 m) wide, and on one side of openings less than 6 ft.

Masonry bearing or shear walls typically have a minimum thickness of 8 in. (203 mm). With reinforcing, this can be reduced to 6 in. (152 mm). Solid 6-in. masonry walls in single-story buildings are limited to 9 ft (2.7 m) in height.

In many applications, single-wythe walls are reinforced. The term *partially reinforced* is erroneous. Reinforcement schedules are designed for a particular application, and all the required reinforcement is necessary. Nonreinforced single-wythe walls are used in interior construction where no loads, including lateral loads, or other forces are anticipated. Consult with the National Concrete Masonry Association and engineers to determine wall construction requirements.

Concrete masonry unit walls are often partially grouted; that is, only the cells or cavities of the wall containing reinforcement are grouted. When walls are partially grouted, special units or construction fabric are used for vertical containment of the grout. Horizontal containment is usually provided by mortaring the webs of the masonry units. When steel placement is frequent, it may become economical or necessary to fully grout the walls.

Structural components of a building using reinforced masonry combine the tensile strength of reinforcement with the compressive strength of the masonry to resist design loads. The benefits of incorporating reinforcement are improved ductility, structural integrity, and resistance to flexural and shear stresses. Reinforced masonry provides economical construction, especially when a high degree of resistance to lateral loads is necessary.

Seismic performance categories A and B require no special provisions. In many instances, the wind loads will govern the minimum reinforcing levels in seismic performance category C and above. For designs in seismic performance category C, vertical reinforcement of at least 0.20 in. (5 mm) in cross-sectional areas must be provided continuously from support to support at each corner, at each side of each opening, and at the ends of walls. Horizontal reinforcement of not less than 0.20 in. (5 mm) must be provided at the bottom and top of all openings and extend not less than 24 in. (610 mm) nor less than 40 bar diameters past the opening. Horizontal reinforcement should be installed continuously at structurally connected roof and floor levels, at the tops of walls, and at the bottom of the wall or at the top of the foundation; maximum spacing is 10 ft (3 m), unless uniformly distributed joint reinforcement is provided.

For designs in seismic performance categories D and E, walls must be reinforced both vertically and horizontally. Requirements in addition to those for seismic performance category C include that spacing cannot exceed 4 ft (1.2 m), except for designs using moment-resisting space frames, where the spacing of principal reinforcement must not exceed 2 ft (0.6 m). Also, the diameter of the reinforcement cannot be less than 3/8 in. (10 mm), except for joint reinforcement. Consult with an engineer and the National Concrete Masonry Association for information on specific project requirements for reinforcing.

MASONRY BEARING WALL WITH STEEL BAR JOIST

Masonry bearing walls and metal joist roofs are among the simplest and easiest to design and build. The relatively low cost of the system makes it attractive for speculative projects, as does the fact that contractors find this method familiar and easy to erect. Retail commercial facilities often require flexibility in lighting, partitioning, and mechanical systems and large expanses of column- and wall-free space; the envelope and structural systems chosen often reflect these demands. The height to which masonry bearing walls can be built without resorting to lateral bracing is limited, so they are used most frequently in one-story structures.

Bearing wall and bar joist roof building systems employ masonry walls bearing on a turndown slab on grade or conventional spread footings. The walls support a roof structure of open-web steel bar joists, through which mechanical distribution systems are threaded.

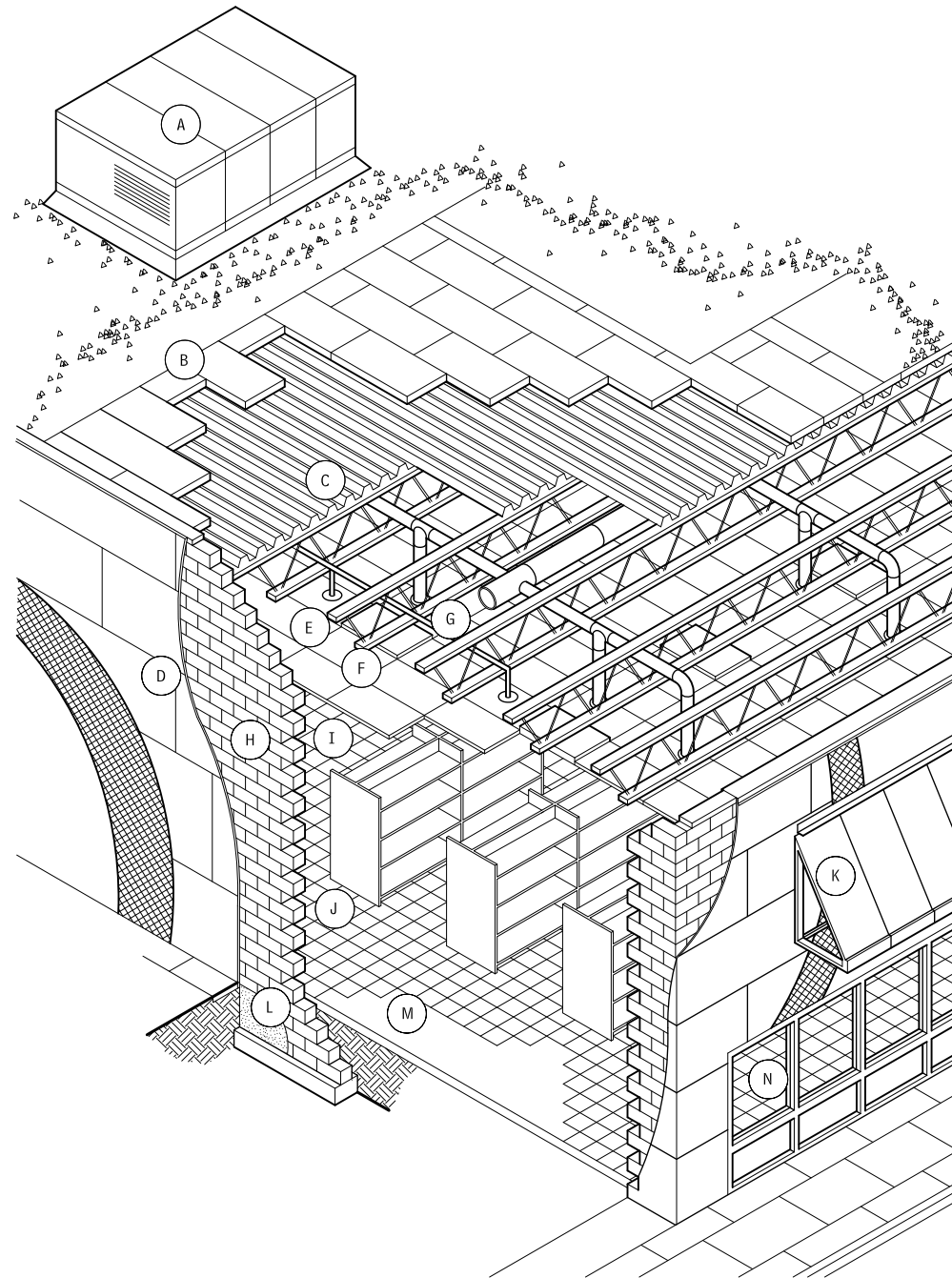
Roof spans up to 60 ft (18 m) can generally be accommodated. The spacing and depth of joists is related to the spanning capability of the roof decking material and the requirements for loads on the roof structure.

Spans for J- and H-series open-web joists generally may not exceed more than 20 times the joist depth, or more than 50 to 60 ft (15.2 to 18 m). Long-span joists are available, as are a wide variety of special shapes. By their nature, open-web joists spaced at even intervals are best suited to relatively light, uniform loads; joists may be doubled or tripled to accommodate heavier, concentrated loads, or they may be combined with other steel framing for roof openings and rooftop mechanical equipment. The roof deck may be precast concrete plank, tongue-and-groove wood decking, or, more commonly, steel decking. Small openings in the roof area can be framed between joists by means of specially designed headers.

Steel open-web joist and bearing wall construction yields buildings that have relatively large interior clear spans and flexible interior layouts. The open webbing of the joists provides a lightweight structure that is easily penetrated by mechanical systems. The bottom chords of the joists are used for suspension of interior finishes, lighting fixtures, and air diffusers in finished areas, although they may be left uncovered. The CMU bearing walls are insulated on the exterior to take better advantage of the wall's thermal mass by placing it toward the occupied side. Long-span open-web steel joist roofs can deflect substantially, and the camber of the joists alone is often not sufficient to maintain the necessary slope to roof drains.

Suspended interior ceilings are nearly always preferred to directly attached interior ceilings. Finished ceilings attached directly to the bottom joist chord are not only difficult to alter but must be designed to accommodate the high degree of deflection the roof assembly will experience. If ductwork is to be housed within the depth of the joist, headers or branches must be fed through the joist webs, perpendicular to the spanning direction.

STEEL BAR JOIST WITH BEARING WALL
1.46



LEGEND

- | | |
|--|---|
| <p>A Rooftop mechanical unit
 B Built-up roofing and rigid insulation
 C Steel decking and open-web steel joists
 D Exterior insulation and finish system (EIFS)
 E Suspended acoustical tile, sprinkler system suspended from structure in ceiling plenum
 F Fluorescent light fixture in ceiling</p> | <p>G Ductwork
 H Concrete masonry bearing wall and concrete footing
 I Glazed interior face on concrete masonry unit (CMU)
 J Resilient tile
 K Canopy assembly
 L Vapor barrier and dampproofing
 M Slab on grade
 N Window assembly</p> |
|--|---|

MASONRY BEARING WALL AND METAL JOIST ROOF

Masonry bearing walls and metal joist roofs are among the simplest and easiest to design and build. The relatively low cost of the system makes it attractive for speculative projects, as does the fact that contractors find this construction method familiar and easy to erect. Retail commercial facilities often require flexibility in lighting, partitioning, and mechanical systems and large expanses of column- and wall-free space; the envelope and structural systems chosen often reflect these demands.

The height to which masonry bearing walls can be built without resorting to lateral bracing is limited, so they are used most frequently in one-story structures. Roof spans up to 60 ft (18.3 m) can generally be accommodated. The spacing and depth of joists is related to the spanning capability of the roof decking material and the requirements for loads on the roof structure.

Bearing wall and bar joist roof building systems employ masonry walls bearing on a turndown slab on grade or conventional spread footings. The walls support a roof structure of open-web steel bar joists, through which mechanical distribution systems are threaded. Spans for J- and H-series open-web joists generally may not exceed more than 20 times the joist depth, or more than 50 to 60 ft (15.2 to 18.3 m). Long-span joists are available, as are a wide variety of special shapes. By their nature, open-web joists spaced at even intervals are best suited to relatively light, uniform loads; joists may be doubled or tripled to accommodate heavier, concentrated loads, or they may be combined with other steel framing for roof openings and rooftop mechanical equipment. The roof deck may be precast concrete plank, tongue-and-groove wood decking, or, more commonly, steel decking. Small openings in the roof area can be framed between joists by means of specially designed headers.

In buildings with masonry bearing walls, each joist should be anchored to the masonry by means of a joist anchor embedded in the masonry. Steel joists can be designed to cantilever beyond the edges of the bearing walls. Continuous horizontal bracing of both top and bottom joist chords is possible with spot-welded connections at each joist and with the ends of the bracing members anchored to a bearing wall; this type of system is well suited to seismic risk zones.

CMU bearing walls are insulated on the exterior to take better advantage of the wall's thermal mass by placing it toward the occupied side. Long-span, open-web steel joist roofs can deflect substantially, and the camber of the joists alone is often not sufficient to maintain the necessary slope to roof drains.

Suspended interior ceilings are nearly always preferred to directly attached interior ceilings. Finished ceilings attached directly to the bottom joist chord are not only difficult to alter but must be designed to accommodate the high degree of deflection the roof assembly will experience.

If ductwork is to be housed within the depth of the joist, headers or branches must be fed through the joist webs, perpendicular to the spanning direction.

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FLOOR CONSTRUCTION**WOOD FLOOR FRAMING**

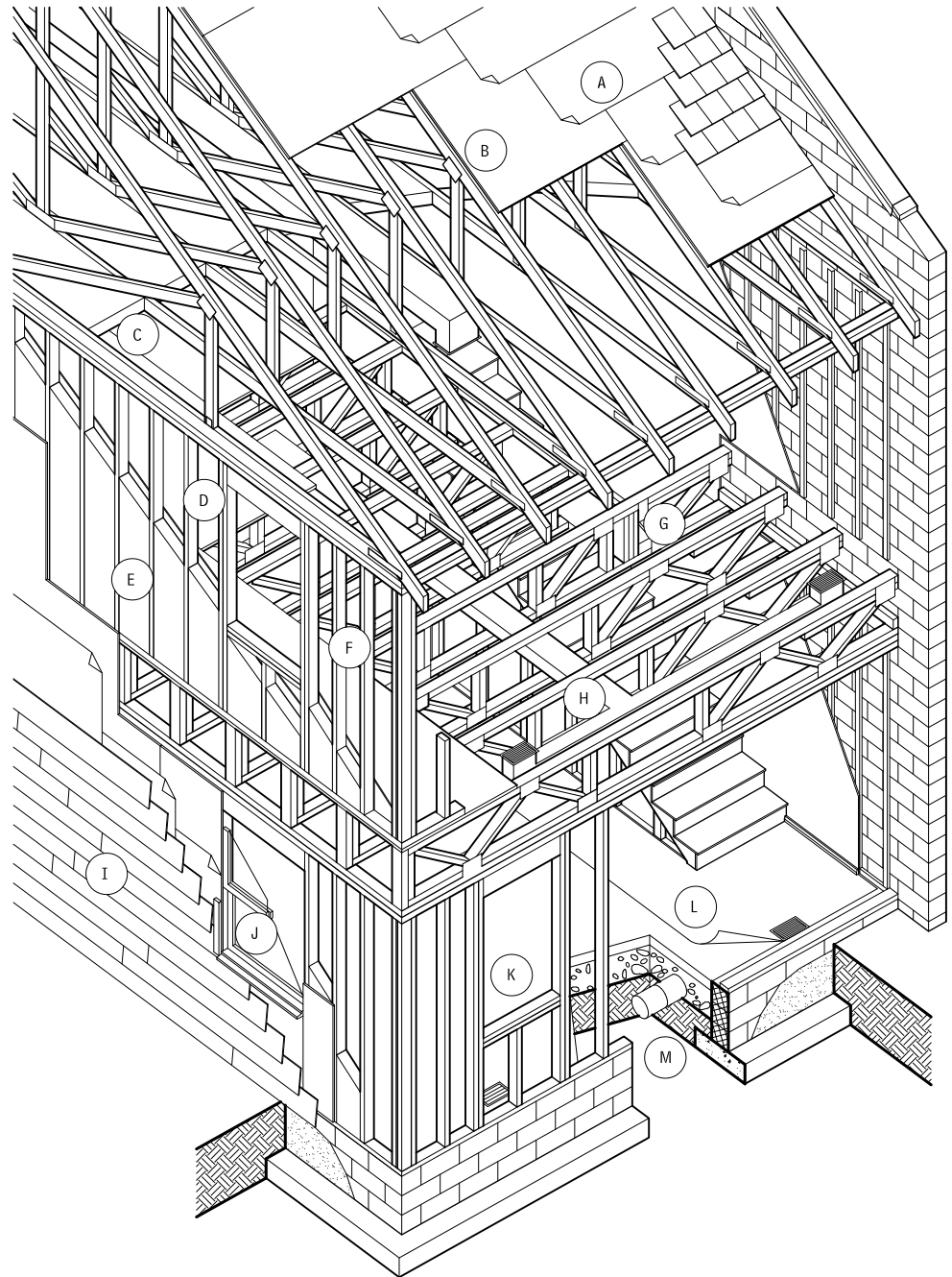
In a standard wood framing system with prefabricated roof and floor trusses and exterior sheathing, the trusses are built at the factory to engineering specifications. The exterior panels act in concert with wall studs as a structural skin and weathering surface. The wood frame system unifies envelope and structure when this external skin acts as a diaphragm over the studs, joists, and rafters. Because trusses are made from commonly available dimension lumber, there is little chance that supply shortages will delay projects.

Bridging between floor trusses may be eliminated, depending on the depth of the truss and the application and rigidity of subflooring and ceiling finishes. When such bridging is used, it should not block possible transverse duct runs.

Open-web trusses allow threading of wiring, piping, and ductwork without on-site drilling or cutting, thus greatly speeding and easing the installation of heating, plumbing, and electrical systems. Open-web wood trusses permit longer clear spans than conventional timber framing, leaving greater flexibility for the location of interior partition walls that need not be load bearing.

Prefabricated roof and floor trusses eliminate much field labor, thus speeding up on-site construction; help ensure dimensional stability; and may eliminate the need for intermediate load-bearing partitions. Longer clear spans are possible with floor trusses than with generally available dimension lumber. The smaller wood components used in prefabricated trusses are more readily available from sustainably grown sources, as opposed to the older-growth trees harvested for larger standard lumber sections.

WOOD ROOF TRUSS AND WOOD FLOOR TRUSS
1.47

**LEGEND**

A Shingles and roofing felt with metal flashing
 B Wood roof truss and plywood sheathing
 C Acoustical tile
 D Wood frame
 E Batt insulation
 F Gypsum board
 G Wood floor truss and plywood subfloor

H Ducts and diffusers
 I Lapped wood siding
 J Window assembly
 K Slab on grade, concrete masonry foundation wall, and concrete footing
 L Carpet
 M Below-slab perimeter ducts

WOOD FLOOR FRAMING MEMBERS
1.48

FRAMING MEMBER TYPE	DESCRIPTION	COMPOSITION [NOMINAL DIMENSIONS]
Dimension lumber	Short span, less than 24'-0" (7.3 m)	Dimensional lumber [2 × 8, 2 × 10, 2 × 12]
Laminated veneer lumber	Short to medium span, 16'-0" to 30'-0" (4.9 to 9.1 m)	1-3/4" (44 mm) thick laminated joists
Wood I-joists	Small to medium span, 20'-0" to 60'-0" (6 to 18.3 m)	Lightweight 3/8" (10 mm) laminated strand lumber, oriented strand board, or plywood web; 1-1/2", 2", or 3" (38, 51, 76 mm) wide laminated veneer lumber or lumber flange
Shop-fabricated wood trusses	Medium span, 40'-0" to 60'-0" (12.2 to 18.3 m)	Trusses [2 × 4], wood chords and webs, steel plate connectors
Metal web wood joists	Medium to long span, 40'-0" to 60'-0" (12.2 to 18.3 m)	Wood chords, 20-gauge steel webs
	Medium to long span, 40'-0" to 60'-0" (12.2 to 18.3 m)	Wood chords, 1" to 1-1/2" (25 to 38 mm) diameter tubing webs, depths to 40'-0" (12.2 m)
	Long to very long, span 60'-0" to 100'-0" (18.3 to 30.4 m)	Double [2 × 6] chords, 2" (51 mm) diameter webs, depth to 63" (1.6 m)

TYPES OF FABRICATED TRUSSES
1.49

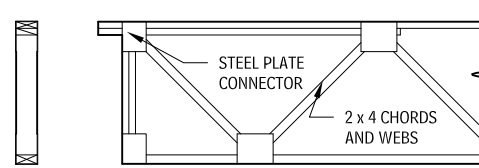
SHORT SPAN, LESS THAN 24' (7.3M)



DIMENSION LUMBER

DIMENSIONAL LUMBER 2 x 8, 2 x 10, 2 x 12

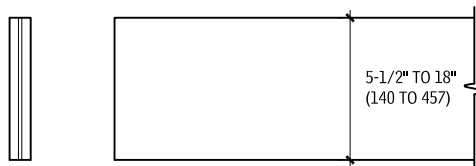
MEDIUM SPAN, 40' TO 60' (12.2 TO 18.3M)



SHOP-FABRICATED WOOD TRUSSES

WOOD CHORDS AND WEBS, STEEL PLATE CONNECTORS

SMALL TO MEDIUM SPAN, 16' TO 30' (4.9 TO 9.1M)



LAMINATED VENEER LUMBER

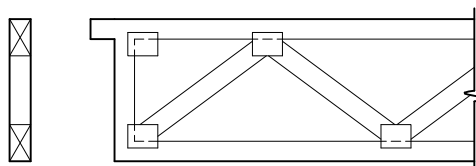
1-3/4" (44) THICK LAMINATED JOISTS

SMALL TO MEDIUM SPAN, 20' TO 60' (6 TO 18.3M)



WOOD I-JOISTS

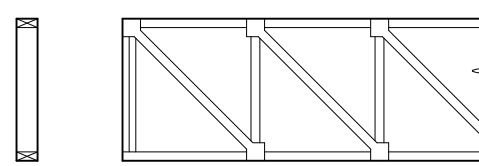
LIGHTWEIGHT 3/8" (10) LAMINATED STRAND LUMBER, OSB, OR PLYWOOD WEB 1-1/2" (38), 2" (51) OR 3" (76) WIDE LVL OR LUMBER FLANGE



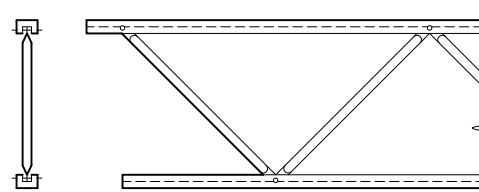
SHOP-FABRICATED WOOD TRUSSES

2 x 4 TRUSSES

MEDIUM TO LONG SPAN, 40' TO 60' (12.2 TO 18.3M)

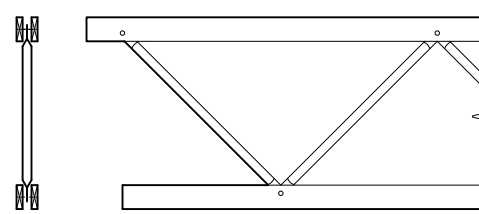


WOOD CHORDS, 20-GA. STEEL MONEX WEBS



WOOD CHORDS, 1" (25) TO 1-1/2" (38) DIA. TUBING WEBS; DEPTHS TO 40" (1,016)

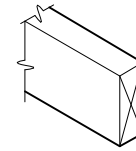
LONG TO VERY LONG SPAN, 60' TO 100' (18.3 TO 30.5M)



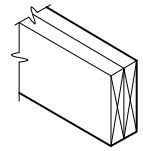
DOUBLE 2 x 6 CHORDS, 2" (51) DIA. WEBS; DEPTHS TO 63" (1,600)

METAL WEB WOOD JOISTS

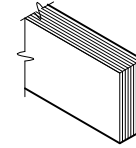
FLOOR FRAMING WOOD BEAMS
1.50



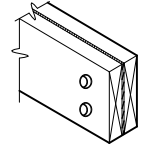
HEAVY-TIMBER BEAM



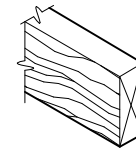
BUILT-UP BEAM



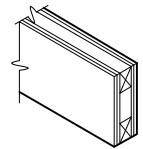
LAMINATED VENEER LUMBER (LVL) BEAM



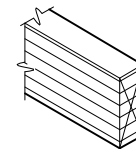
FLITCH BEAM



PARALLEL STRAND LUMBER (PSL) BEAM

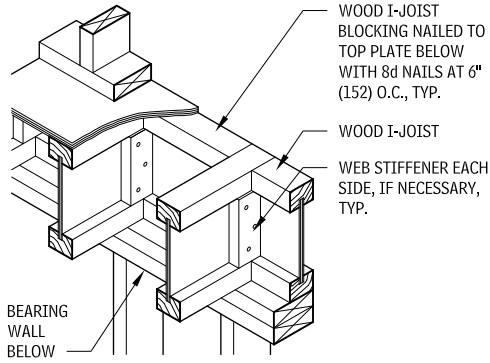


BOX BEAM

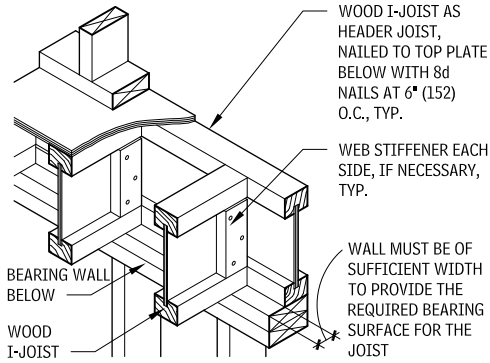


GLUE-LAMINATED BEAM

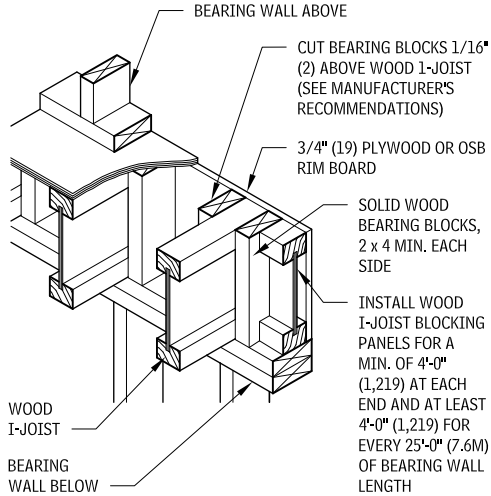
WOOD I-JOIST FLOOR FRAMING DETAILS
1.51



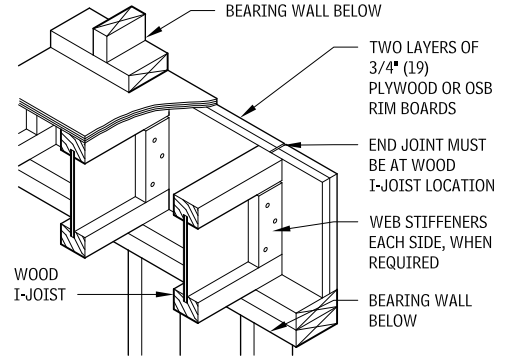
WOOD I-JOIST BLOCKING



WOOD I-JOIST AS HEADER JOIST

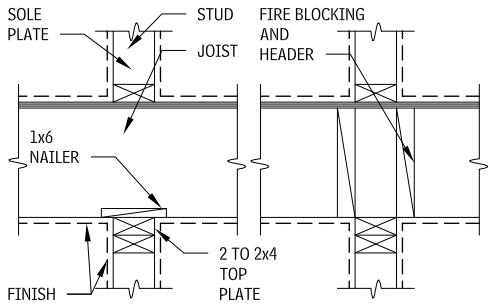


BEARING BLOCKS

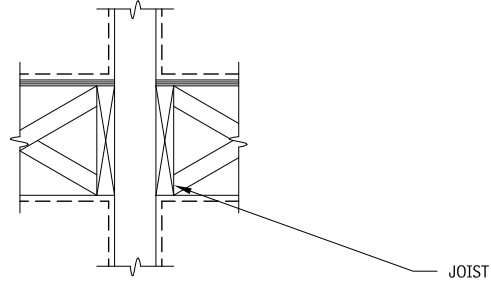


STANDARD 2X RIM BOARDS

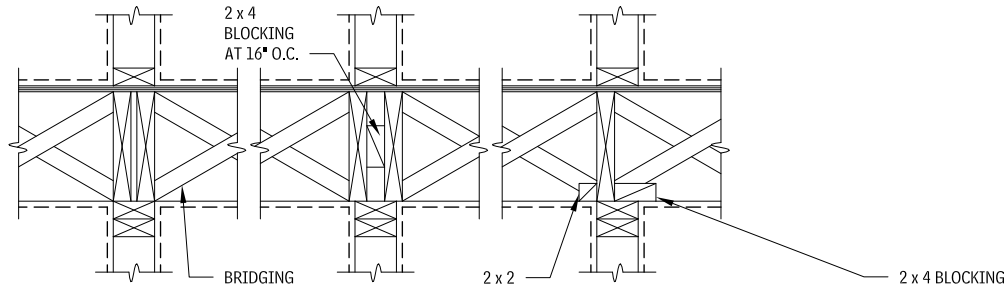
FLOOR DETAILS AT BEARING INTERIOR PARTITIONS
1.52



PARTITIONS PERPENDICULAR TO JOISTS

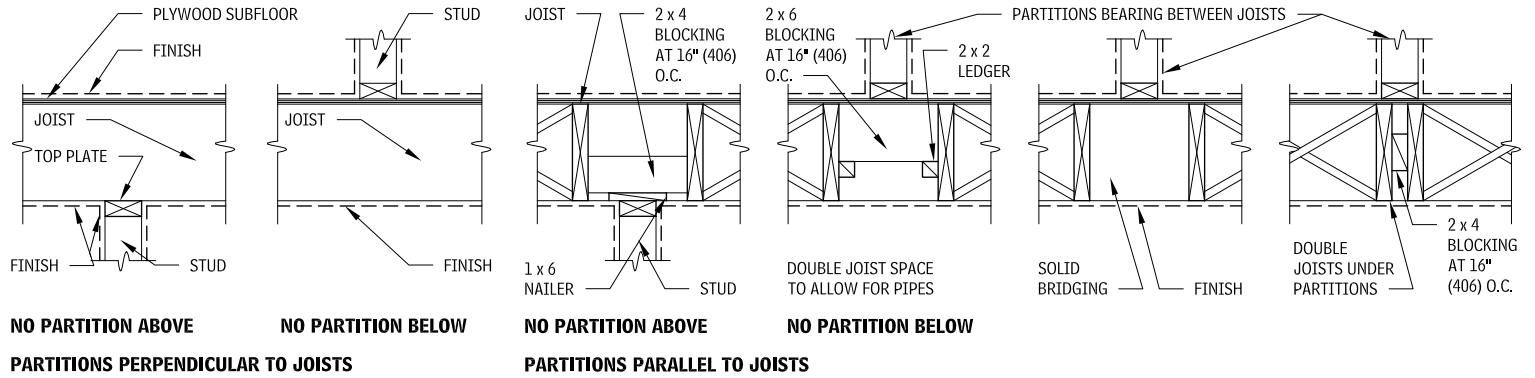


BALLOON AND BRACED

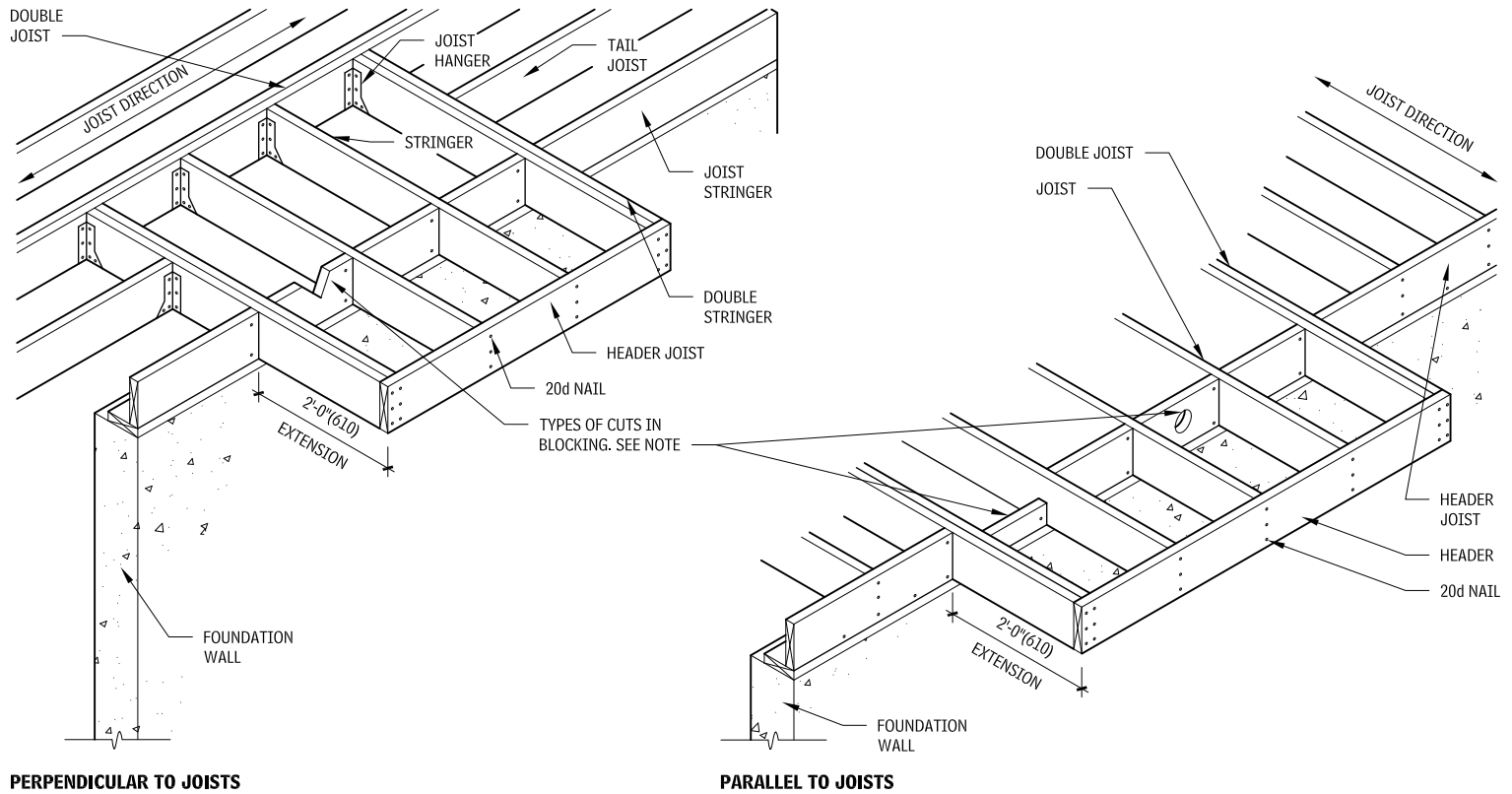


PARTITIONS PARALLEL TO JOISTS

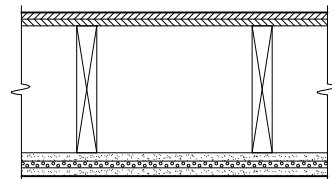
FLOOR DETAILS AT NONBEARING INTERIOR PARTITIONS
1.53



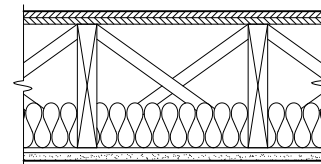
FLOOR CANTILEVERS
1.54



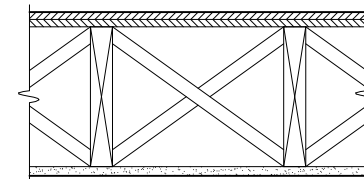
WOOD FRAME FLOOR/CEILING ASSEMBLY—
TWO-HOUR DOUBLE-LAYER RESILIENT
1.55



ONE-HOUR ELECTRIC RADIANT HEAT PANEL
1.56



WOOD FRAME FLOOR/CEILING
1.57



Source: Steven R. Breuer, AIA, LEED AP, lauckgroup, Dallas, Texas.

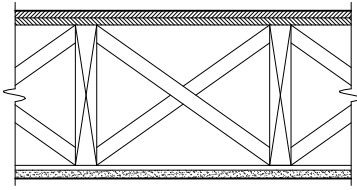
NOTES

- 1.54 a. Any extension greater than 2 ft (610 mm) must be engineered.
- b. If space above is to be heated, insulate between joists and provide cuts in blocking as shown.
- 1.55 a. Base layer 5/8 in. (16 mm) Type X gypsum board applied at right angles to 2 by 10 in. (51 by 254 mm) wood joists with 1 in. (25 mm) Type S gypsum board screws 16 in. (406 mm) on center (O.C.).
- b. Resilient furring channels spaced 24 in. (610 mm) O.C. and nailed through baseboard into and at right angles to joists.
- c. Face layer of 5/8 in. (16 mm) same-type board screwed to furring channel with same-type screws.

- d. Tongue-and-groove subfloor and finish floor.
- 1.56 a. Proprietary Type X gypsum board electrical radiant heating panels (5/8 in. [16 mm]) attached to resilient furring channels spaced 24 in. (610 mm) O.C. installed to 2 by 10 in. (51 by 254 mm) wood joists 16 in. (406 mm) O.C.; 3-1/2 in. (89 mm) glass fiber insulation friction-fit in joist space.
- b. Wood floor of nominal 1 in. (25 mm) tongue and groove or 1/2 in. (13 mm) plywood subfloor and nominal 1 in. (25 mm) tongue and groove or 5/8 in. (16 mm) plywood finish floor.
- 1.57 a. Type X gypsum board or veneer base (5/8 in. [16 mm]) applied to wood joists 16 in. (406 mm) O.C.

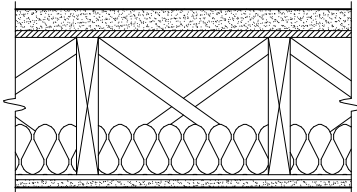
- b. Joists supporting 1 in. (25 mm) nominal wood subfloor and finish floor or 5/8 in. (16 mm) plywood finished floor with long edges tongue and groove and 1/2 in. (13 mm) interior plywood with exterior glue subfloor perpendicular to joists with joints staggered.
- c. Sound Transmission Class (STC) ratings 35 to 39.

WOOD FRAME FLOOR/CEILING WITH RESILIENT CHANNELS
1.58



Source: Steven R. Breuer, AIA, LEED AP, lauckgroup, Dallas, Texas.

WOOD FRAME FLOOR/CEILING WITH GLASS FIBER BATTS
1.59



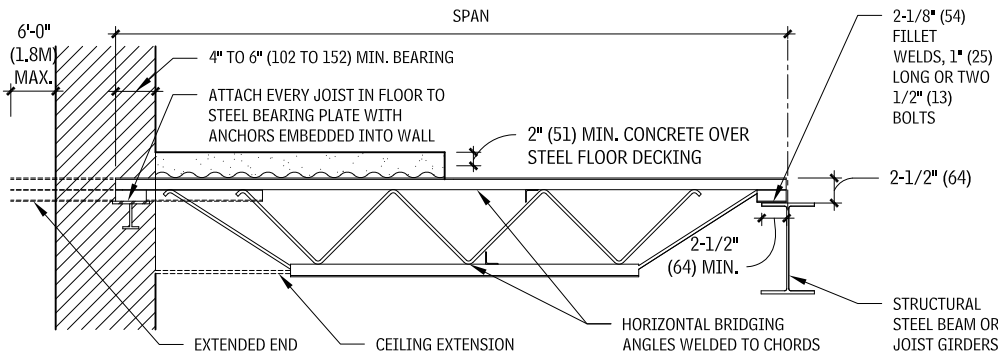
Source: Steven R. Breuer, AIA, LEED AP, lauckgroup, Dallas, Texas.

STEEL JOIST FLOOR FRAMING

Design considerations for steel joist floor framing should include the following:

- Ceiling supports can be suspended from or mounted directly to the bottom chords of joists. Suspended systems are recommended, because of dimensional variations in joist depths.
- Floor joists are usually covered by 2-1/2 to 3 in. (64 to 76 mm) of concrete on steel decking. Concrete thickness may be increased to accommodate electrical conduit or electrical/communications raceways. Precast concrete, gypsum planks, or plywood can also be used for the floor system.
- Objectionable vibrations can occur in open-web joist and 2-1/2 in. (64 mm) concrete slab designs for open floor areas at spans between 20 and 40 ft (6.1 and 12.2 m), in particular at 28 ft (8.5 m). When a floor area cannot have partitions, objectionable vibrations can be prevented or reduced by increasing slab thickness or modifying the joist span. Unsupported framing beams can magnify a vibration problem.
- Small openings between joists in floor or roof systems are framed with angles or channels supported on the adjoining two joists. Larger openings necessitating interruption of joists are framed with steel angle or channel headers.
- It is more difficult to alter joists, add openings, change loading, or apply fireproofing than with structural steel framing.

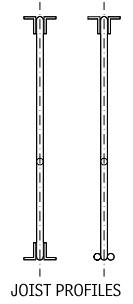
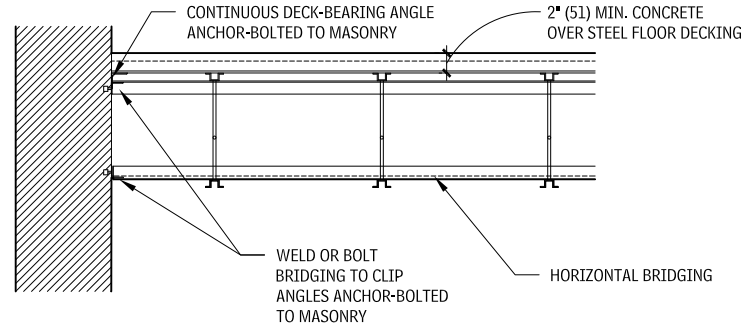
SECTION THROUGH OPEN-WEB STEEL JOIST BEARING
1.60



NOTES

- Type X gypsum board or veneer base 1/2 in. (13 mm) applied to gypsum board resilient furring channels 24 in. (610 mm) O.C. and nailed to wood joists 16 in. (406 mm) O.C.
- Wood joists supporting 1 in. (25 mm) nominal tongue-and-groove wood subfloor and finish floor or 5/8 in. (16 mm) plywood finished floor with long edges tongue and groove and 1/2 in. (13 mm) interior plywood with exterior glue subfloor perpendicular to joists with joints staggered.
- STC ratings 40 to 44.

SECTION THROUGH OPEN-WEB STEEL JOISTS
1.61



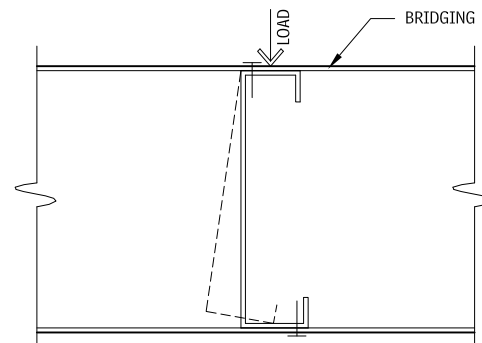
COLD-FORMED METAL FLOOR JOIST FRAMING

Cold-formed steel (CFS) floor framing uses C-shaped members that are cold rolled from a steel sheet. CFS framing is laid out similar to traditional wood joist floor framing. Finishes may be hot-dipped, galvanized coatings or shop primed. Fastening is typically self-drilling, self-tapping screws, or welded.

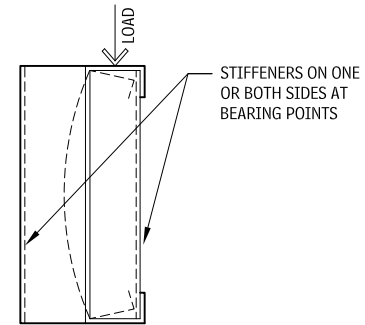
Joists are subject to twisting under load. Bracing of the top and bottom flange is required at approximately one-third points or 6 to 8 ft (1.8 to 2.4 m) on center, depending on the final design. Bridging is typically continuous top and bottom straps with solid blocking at ends, periodically spaced. Structural sheathing or decking may reduce some or all of the bridging.

Point loads at bearing points or from applied loads may cause crushing of the flange or folding of the web. Stiffeners from short lengths of a vertical joist, a sistered joist, or angles attached to the rim track may be required, as determined by final engineering.

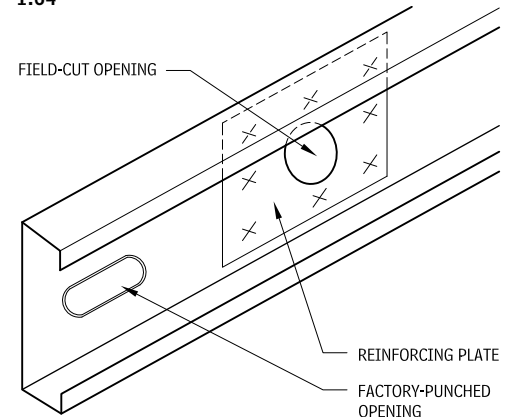
BRIDGING
1.62



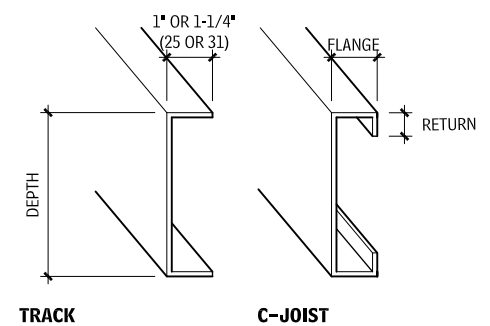
WEB STIFFENERS
1.63



OPENINGS
1.64



COLD-FORMED METAL JOISTS
1.65



- Type X gypsum board or veneer base 1/2 in. (13 mm) applied to resilient furring channels.
- Resilient channels applied 24 in. (610 mm) O.C. to wood joists 16 in. (406 mm) O.C.
- Wood joists support 1/2 in. (13 mm) plywood subfloor and 1-1/2 in. (38 mm) cellular or lightweight concrete over felt; 3-1/2 in. (89 mm) glass fiber batts in joist spaces.
- Sound-tested with carpet and pad over 5/8 in. (16 mm) plywood subfloor.
- STC ratings 60 to 64.

Contributors:
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John Ray Hoke, Jr., FAIA, Washington, DC.

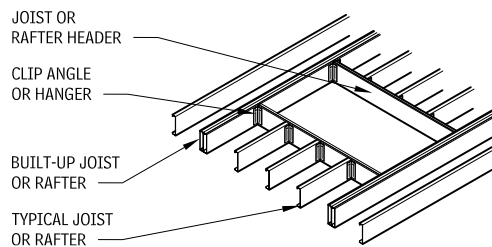
COLD-FORMED METAL JOIST DIMENSIONS
1.66

FLANGE	RETURN	COMMON DEPTHS
1-3/8" (35 mm)	5/16" to 3/8" (8 to 10 mm)	6" (152 mm)
1-5/8" (42 mm)	1/2" to 9/16" (13 to 14 mm)	7-1/4" (184 mm)
2" or 2-1/2" (51 or 64 mm)	9/16" to 11/16" (14 to 17 mm)	8" (203 mm)
3" or 3-1/2" (76 or 89 mm)	1" (25 mm)	9-1/4" (235 mm)
		10" (254 mm)
		11-1/2" (292 mm)
		12" (305 mm)
		14" (356 mm)
		16" (406 mm)

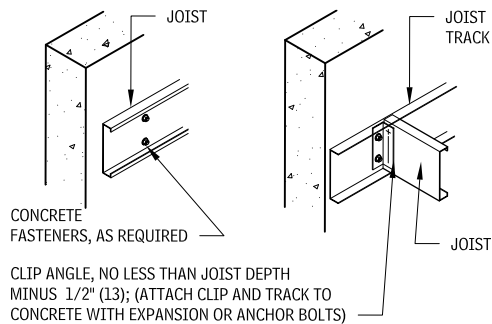
Joists may come factory-punched, with openings of approximately 1-1/2 by 4 in. (38 by 102 mm) on center, though this will vary by manufacturer. Additional openings, generally not larger than half the joist depth, may be added if individually analyzed during final engineering. Reinforcing plates may be required.

For further information, see *Product Technical Information* published by the Steel Stud Manufacturers Association (www.ssma.com).

FRAMING OF FLOOR OPENING
1.67



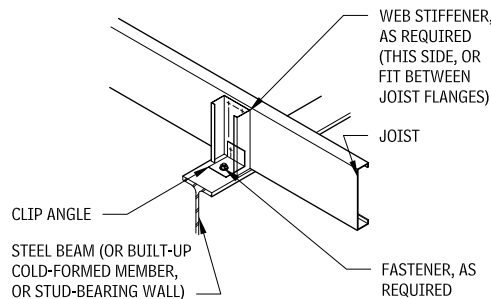
FLOOR JOISTS AT CONTINUOUS WALLS
1.68



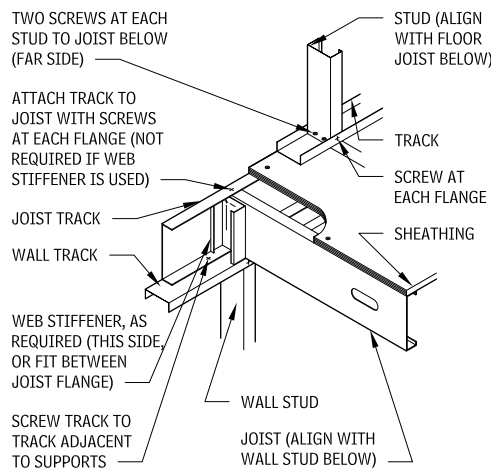
FLOOR JOISTS PARALLEL TO WALL

FLOOR JOIST SUPPORT AT WALL

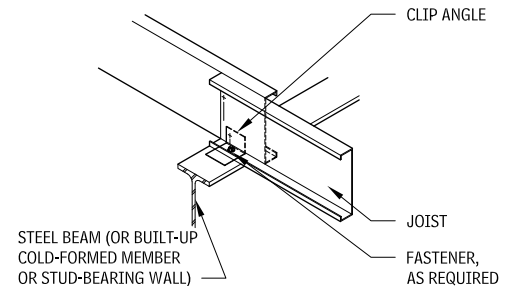
JOISTS OVER BEAM OR BEARING WALL (CONTINUOUS SPAN)
1.69



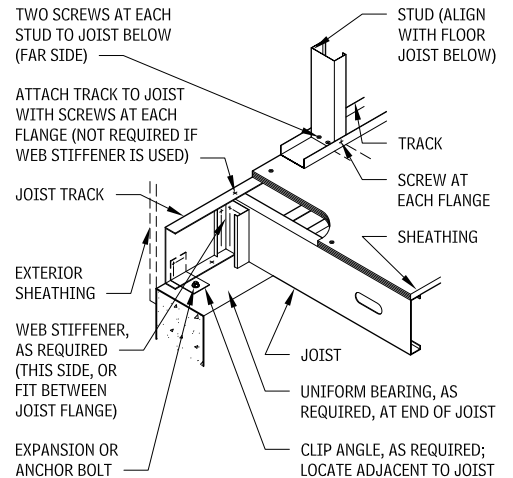
FLOOR FRAMING AT EXTERIOR WALL
1.70



FLOOR JOISTS SUPPORTED BY BEAM OR BEARING WALL (OVERLAPPED)
1.71



FLOOR JOISTS BEARING ON FOUNDATION
1.72



FLOOR DECKS, SLABS, AND TOPPINGS

CONCRETE FLOOR SYSTEMS

The information presented here is intended only as a preliminary design guide. All structural dimensions for slab thickness, beam and joint sizes, and column sizes should be calculated and analyzed for each project by a licensed professional engineer.

Spans shown in the accompanying figures and tables are approximate and are based on use of mild reinforcing steel. For spans greater than 40 ft (12.2 m), consider posttensioning.

Consider embedded items such as conduits and penetrations for ducts and pipes when coordinating a structural system. Concrete floor construction may have less flexibility for locating large duct openings close to beam lines or small penetrations immediately adjacent to columns.

NOTES

- 1.66 Consult the manufacturers for available sizes.
- 1.68 Provide solid blocking and bridging as required.
- 1.69 a. Continuous bridging is required between each joist above a beam. Solid blocking in other spaces may be used in lieu of bridging.
- b. When a bearing wall is above, the studs must align with the joists below.
- c. Web stiffeners are not required when continuous solid blocking is used.
- 1.72 a. Continuous bridging is required between each joist above a beam. Solid blocking in other spaces may be used in lieu of bridging.
- b. When a bearing wall is above, studs must align with joists below.

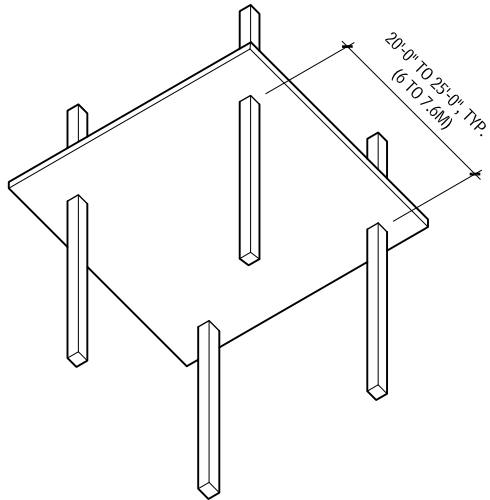
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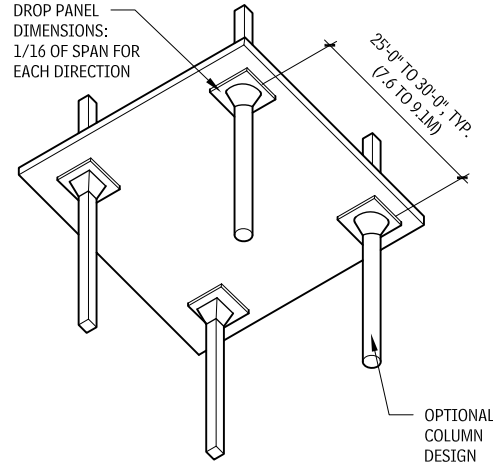
CONCRETE SLABS 1.73

SLAB TYPE	USES	ADVANTAGES	DISADVANTAGES
Flat plate	Moderate spans. Hotels, motels, dormitories, condominiums.	Most economical floor system; has the lowest structural thickness. Inexpensive formwork, ceilings may be exposed, fast erection, flexible column location.	Penetrations for piping and ductwork through slab near columns must be avoided. Spandrel beams may be necessary. Excess concrete for longer spans, low shear capacity, greater deflections.
Flat slab	Buildings supporting very heavy loads. Warehouses, industrial structures, parking structures.	When live loads exceed 150 psf (7.182 Pa), flat slabs are by far the most economical.	Formwork is costly.
Banded slab	High-rise buildings; same use as flat plates if flying forms can be used more than 10 times.	Advantages of a flat plate; permits a longer span in one direction. Resists greater lateral loads in direction of beams. Typically posttensioned, minimum slab thickness.	Must reuse formwork many times to be economical.
Joist slab	Best scheme if slabs are too long for a flat plate and the structure is not exposed. Slab thickness between joints is determined by fire requirements. Most economical if beams are the same depth as the joists. Appropriate building types: schools, offices, churches, hospitals, public and institutional buildings, buildings with moderate loadings and spans.	Minimum concrete and steel; minimum weight, thus reduced column and footing size; long spans in one direction; accommodates poke-through electrical systems.	Unattractive for an exposed ceiling; formwork may cost more than flat plate.
Skip joist slab	Same uses as for joist slabs, especially for longer fire ratings. For large projects, should be less expensive than a joist slab.	Uses less concrete than joist slab; incurs lower steel rebar placing costs; joist space is used for mechanical systems; permits lights and equipment to be recessed between joists.	Similar to joist slab; joists must be designed as beams; forms may require special order.
One-way beam and slab	Parking garages, especially with posttensioning.	Long span in one direction.	Long span of about 60 ft (18.3 m) must be prestressed unless beams are quite deep. Shallow beams will deflect excessively. Beams interfere with mechanical services; more expensive forms than flat plate.
Waffle slab	Prominent buildings with exposed ceiling structure; same types as are suitable for flat slab, but with longer spans.	Longer two-way spans; exposed ceiling pattern; heavy load capacity. Drop panels can be diamond shaped, square, or rectangular.	Formwork costs more and uses more concrete and steel than a joist slab. Column spacing should be multiples of pan spacing to ensure uniformity of drop panels at each column.
Two-way slab and beam	Portions of buildings in which two-way beam framing is needed for other reasons; industrial buildings with heavy concentrated loads.	Long span in two directions; small deflection; can carry concentrated loads.	High cost of formwork and structural interference with mechanical systems.

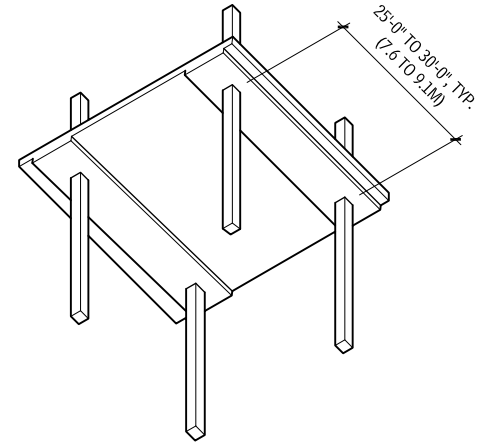
FLAT PLATE
1.74



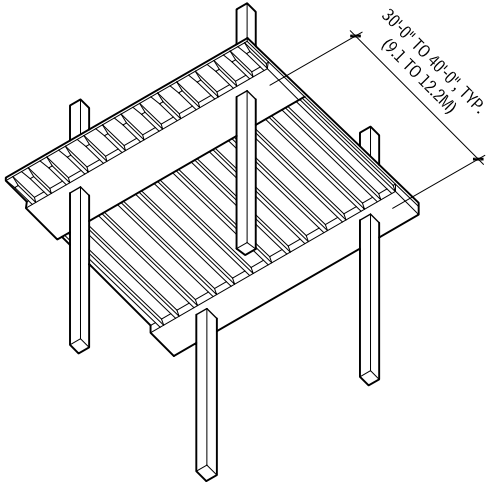
FLAT SLAB
1.75



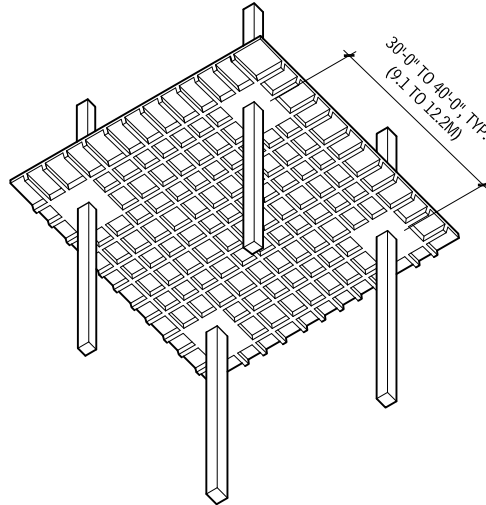
BANDED SLAB
1.76



JOIST SLAB
1.77



WAFFLE SLAB
1.80

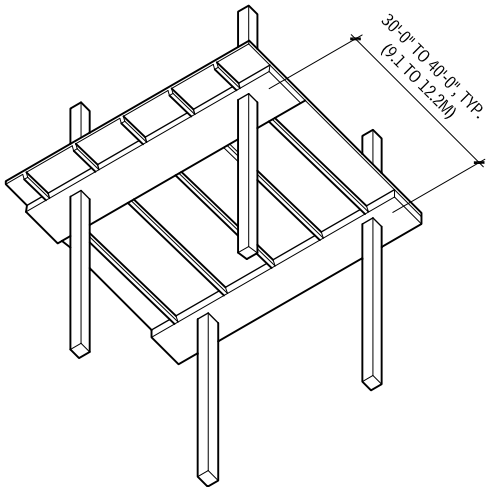


PRECAST CONCRETE DECKS AND SLABS

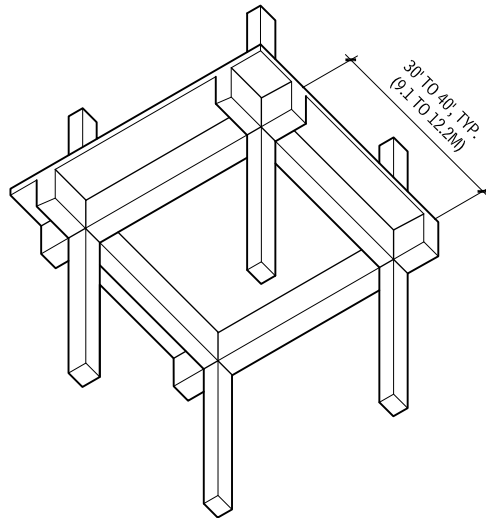
Natural-weight (150 psf) or lightweight concrete (115 psf) is used in standard precast concrete slab construction. Concrete topping is usually normal-weight concrete with a cylinder strength of 3000 psi. All units are prestressed with strand release once the concrete strength is 3500 psi. Strands are available in various sizes, strengths, and placements, according to individual manufacturers.

Camber varies substantially, depending on slab design, span, and loading. Nonstructural components attached to members may be affected by camber variations. Calculations of topping quantities should recognize camber variations. Safe superimposed surface loads include a dead load of 10 psf for topped concrete and 15 psf for topped concrete. The remainder is live load.

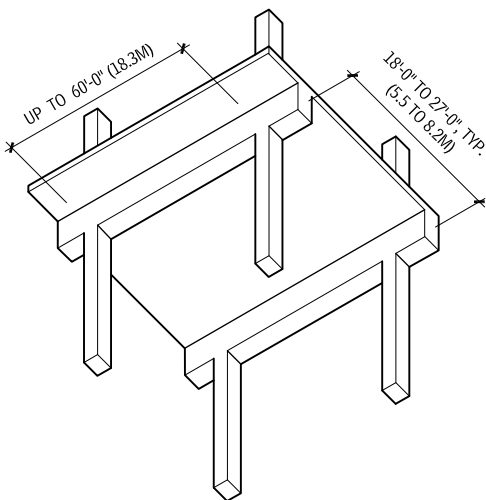
SKIP JOIST SLAB
1.78



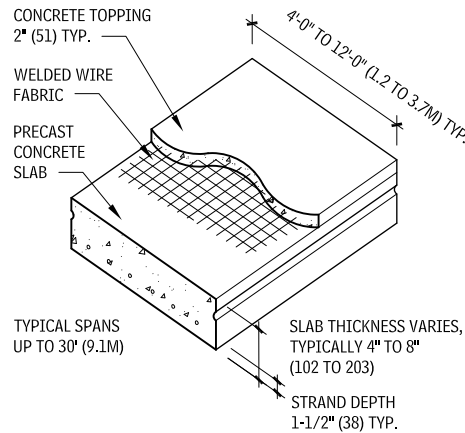
TWO-WAY SLAB AND BEAM
1.81



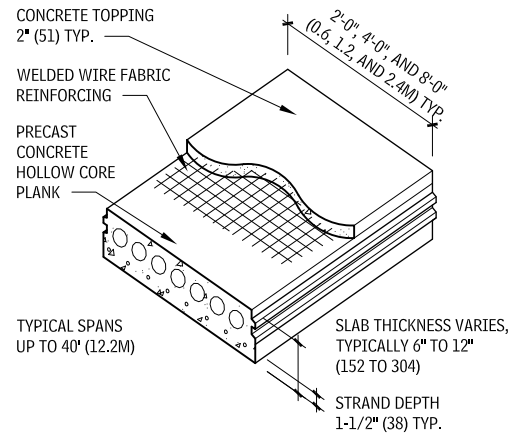
ONE-WAY BEAM AND SLAB
1.79



FLAT DECK MEMBERS
1.82



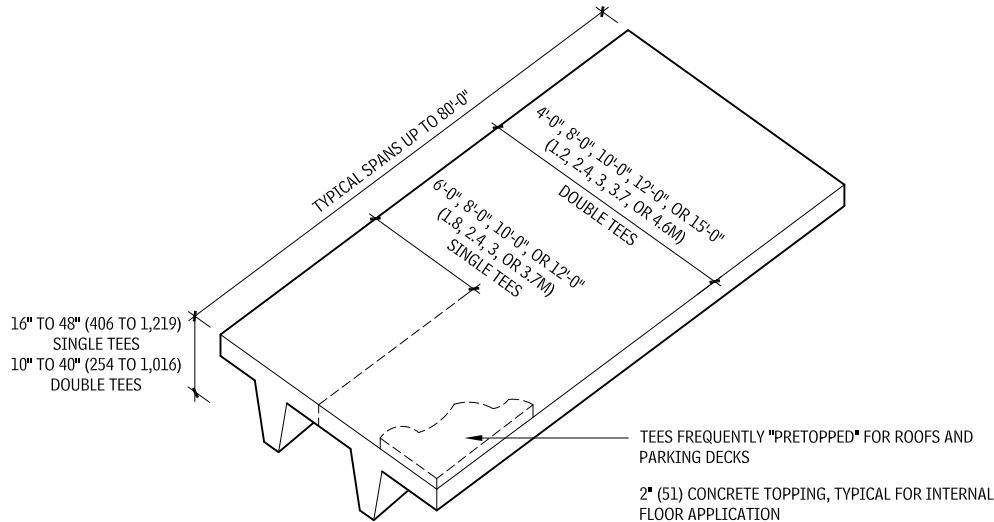
PRECAST CONCRETE SLAB



HOLLOW CORE PLANK

Contributor:
Russell S. Fling, PE, Columbus, Ohio.

SINGLE- OR DOUBLE-TEE MEMBERS
1.83



METAL FLOOR DECKING

When designing with metal decking, two guidelines are important to follow:

- When lightweight concrete is used in the construction, use galvanized deck material.
- In a fire-resistant assembly, ensure that metal components are unprimed.

Consult independent testing laboratory directories for specific fire-rating requirements.

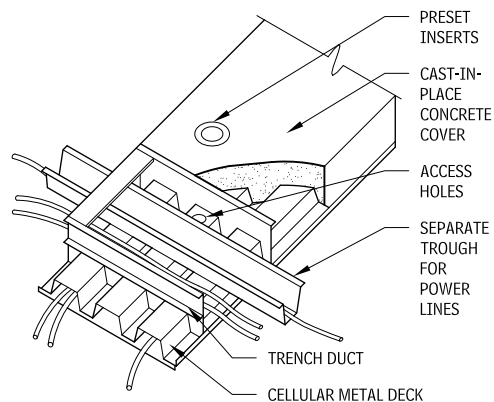
ADVANTAGES OF METAL FLOOR DECKS

- They provide a working platform, eliminating temporary wood planking in high-rise use.
- Composite decks provide positive reinforcement for concrete slabs.
- Both noncomposite and composite decks serve as forms for concrete, eliminating the need for forming and stripping.
- Acoustical treatment is possible.
- Electric raceways may be built into the floor slab.
- Metal floor decking provides economical floor assemblies.

ELECTRICAL TRENCH DUCTS

Electrical raceways may be built into floor slabs by using cellular deck or special units that are blended with plain deck. Two-way distribution is achieved by using trench ducts that sit astride the cellular units at right angles. Using trench ducts with composite

ELECTRICAL TRENCH DUCT
1.84



floor deck may reduce or eliminate entirely the effectiveness of composite action at the trench duct. This is also true for composite action between steel floor beams and concrete fill. Trench duct locations must be taken into account in deciding whether composite action is possible.

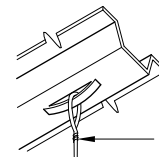
FLOOR DECK ACCESSORIES

A convenient, economical means of supporting lightweight acoustical ceilings is to attach a suspension system to hanger tables at side laps, pierce tabs driven through the deck, or prepunch tabs in the roof deck. Do not use this tab-and-metal deck arrangement to support plaster ceilings, piping, ductwork, electrical equipment, or other heavy loads. Such elements must be suspended directly from structural members or supplementary subframing.

FLOOR DECK ACCESSORIES
1.85



PIERCING-TYPE HANGER TAB



INTEGRAL HANGER TAB

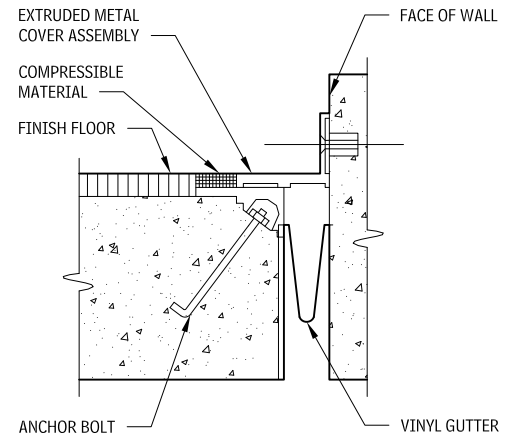
MAX. LOAD:
60 LB (27 KG)
PER TAB

FLOOR CONSTRUCTION EXPANSION CONTROL

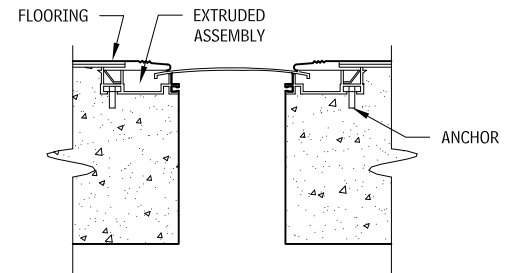
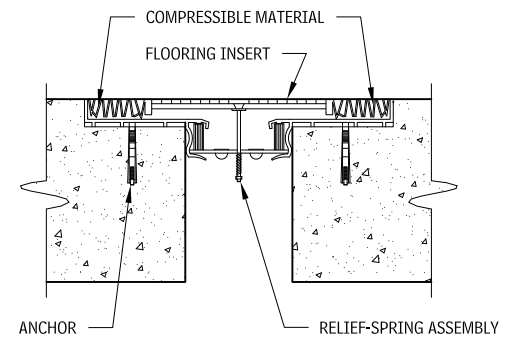
A large selection of prefabricated assemblies to cover interior expansion joints is available. Fire-rated barrier-type inserts are available and applicable to most assemblies.

Expansion joint covers that will respond to differential movement, both laterally and horizontally should be provided at joints in structures, located where seismic action may be expected or where differential settlement is anticipated.

EXPANSION JOINT COVER AT FLOOR AND WALL
1.86

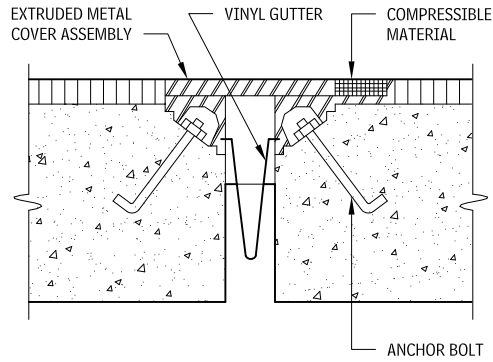


SEISMIC JOINT COVERS WITH FLOORING INSERT
1.87

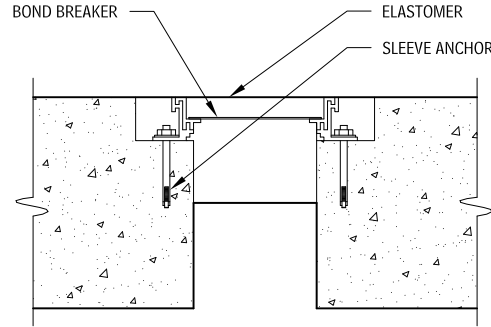


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JOINT COVER AT FLOOR
1.88



ELASTOMERIC JOINT COVER—REMOVABLE
1.89

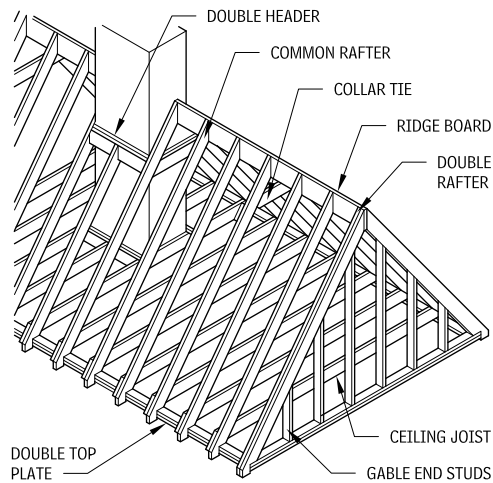


ROOF CONSTRUCTION

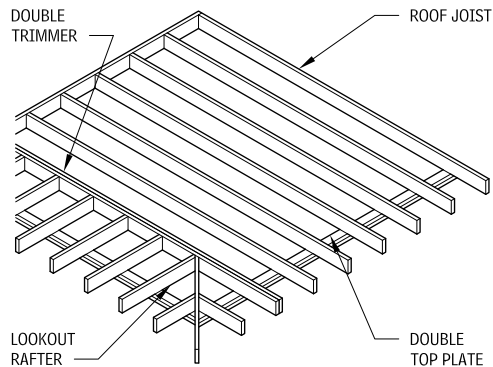
ROOF TYPES AND FRAMING

Interior design and construction can interact with roof framing in the placement or removal of interior partitions and during the installation of ceilings and ceiling-mounted equipment. Interior space is often shaped by roof forms, and structural elements may be exposed to view.

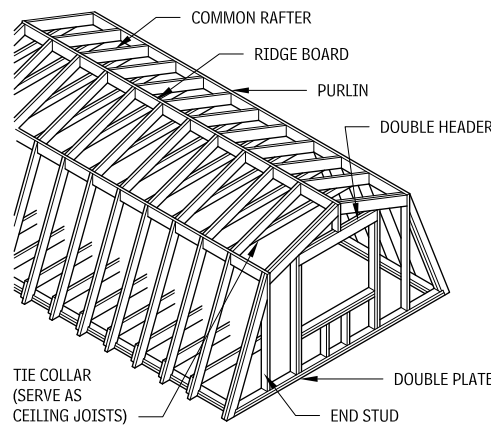
GABLE ROOF
1.90



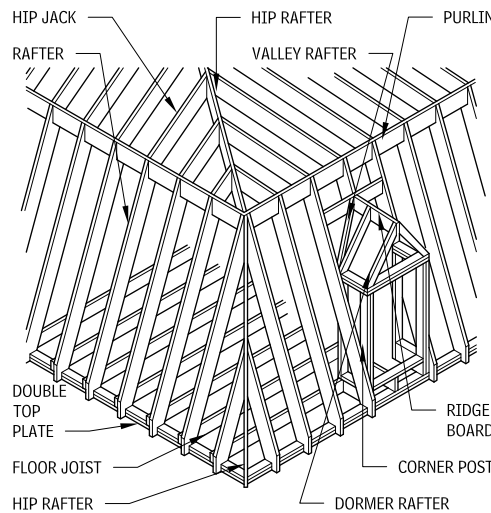
FLAT ROOF
1.91



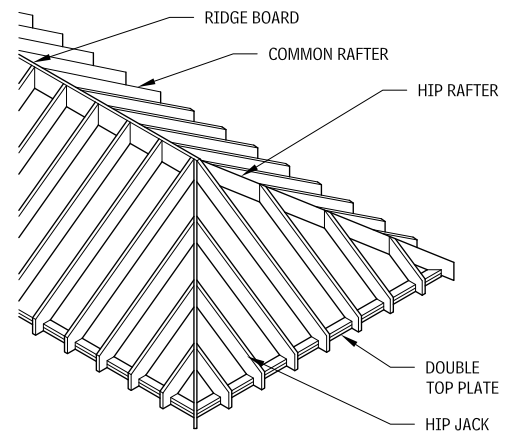
GAMBREL ROOF
1.92



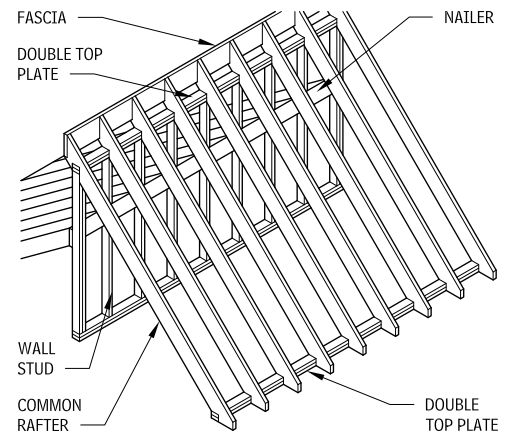
MANSARD ROOF
1.93



HIP ROOF
1.94

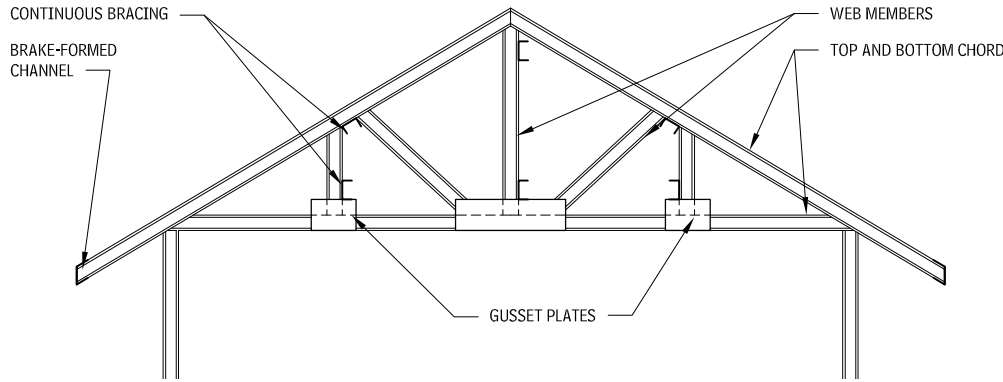


SHED ROOF
1.95

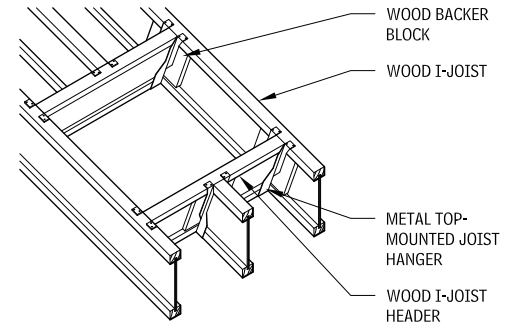


Contributors:
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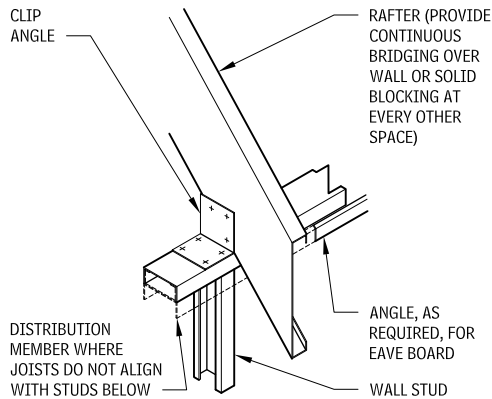
COLD-FORMED STEEL ROOF TRUSSES
1.96



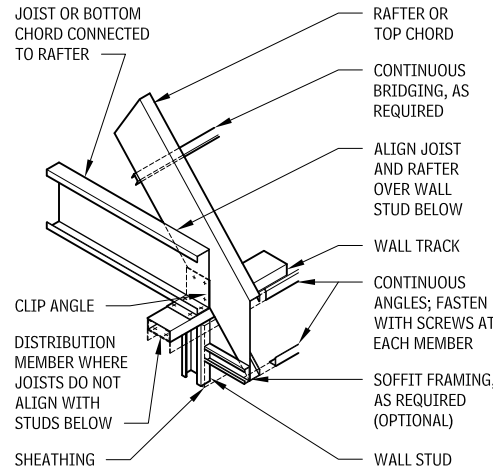
WOOD I-JOIST SKYLIGHT FRAMING DETAIL
1.100



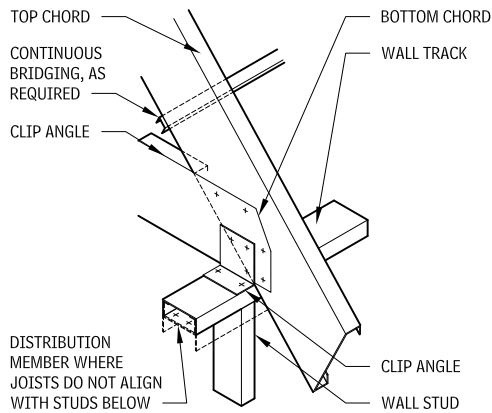
ROOF EAVE AT CATHEDRAL CEILING
1.97



ROOF EAVE DETAIL
1.99



ROOF TRUSS EAVE DETAIL
1.98



Skylights must be carefully integrated with roof framing. Check code and manufacturer's requirements for all ventilation hole sizes cut in blocking web.

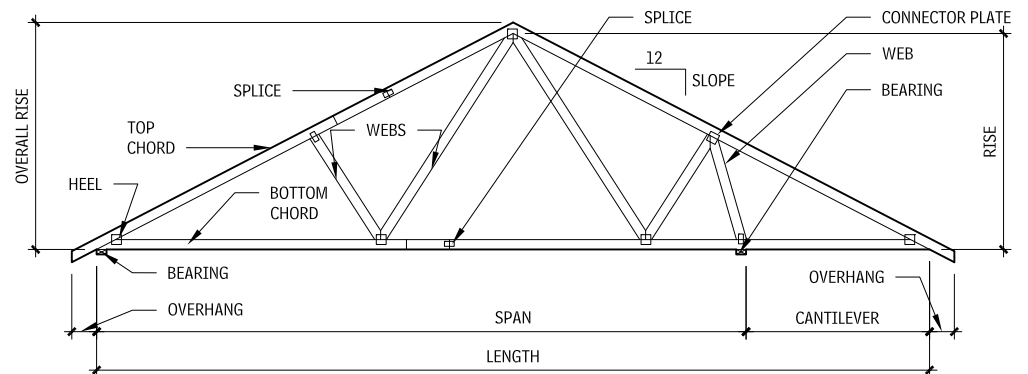
SHOP-FABRICATED WOOD TRUSSES

Shop-fabricated wood trusses have been used in building construction since 1953, when the metal connector plate was invented. Metal plates are available in a range of styles and tooth orientations. The metal plates are punched with barbs that grab onto the wood truss, thus reducing the hand nailing required to fabricate a structure. Plate size for a given truss is based on a combination of the tooth withdrawal strength of the plate, the tensile and shear strength of the steel, and the net sectional area of the lumber.

This system is primarily used for roofs with either pitched or parallel chord trusses. Titanium is occasionally employed for floors with parallel chord trusses. Individual trusses are cut from 2 × 4 or 2 × 6 dimensional lumber and can be spaced 24 in. (610 mm) or 48 in. (1,219 mm) on center. For typical residential construction, 24 in. (610 mm) on center is used. Exceptionally long spans are possible with shop-fabricated wood trusses, allowing the large, unencumbered interior spaces often required in commercial, agricultural, and other nonresidential building types.

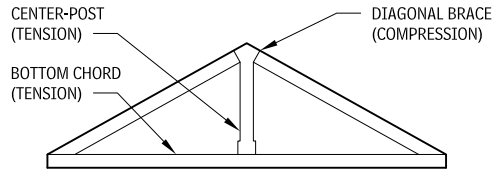
Providing adequate bracing for trusses is essential, both during installation and as a component of the overall roof design. Truss members must be held in place with supports that meet them at right angles. Truss chords and web members are placed in a vertical, plumb position, and maintain that position, resisting applied design loads throughout the life of the structure. Permanent bracing and anchorage are expected to be an integral part of construction, and strongbacks are often used for this purpose.

TYPICAL PITCHED CHORD ROOF TRUSS
1.101

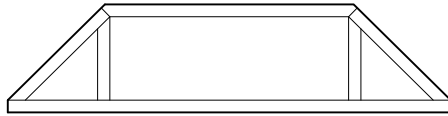


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KING POST AND QUEEN POST
1.102



KING-POST



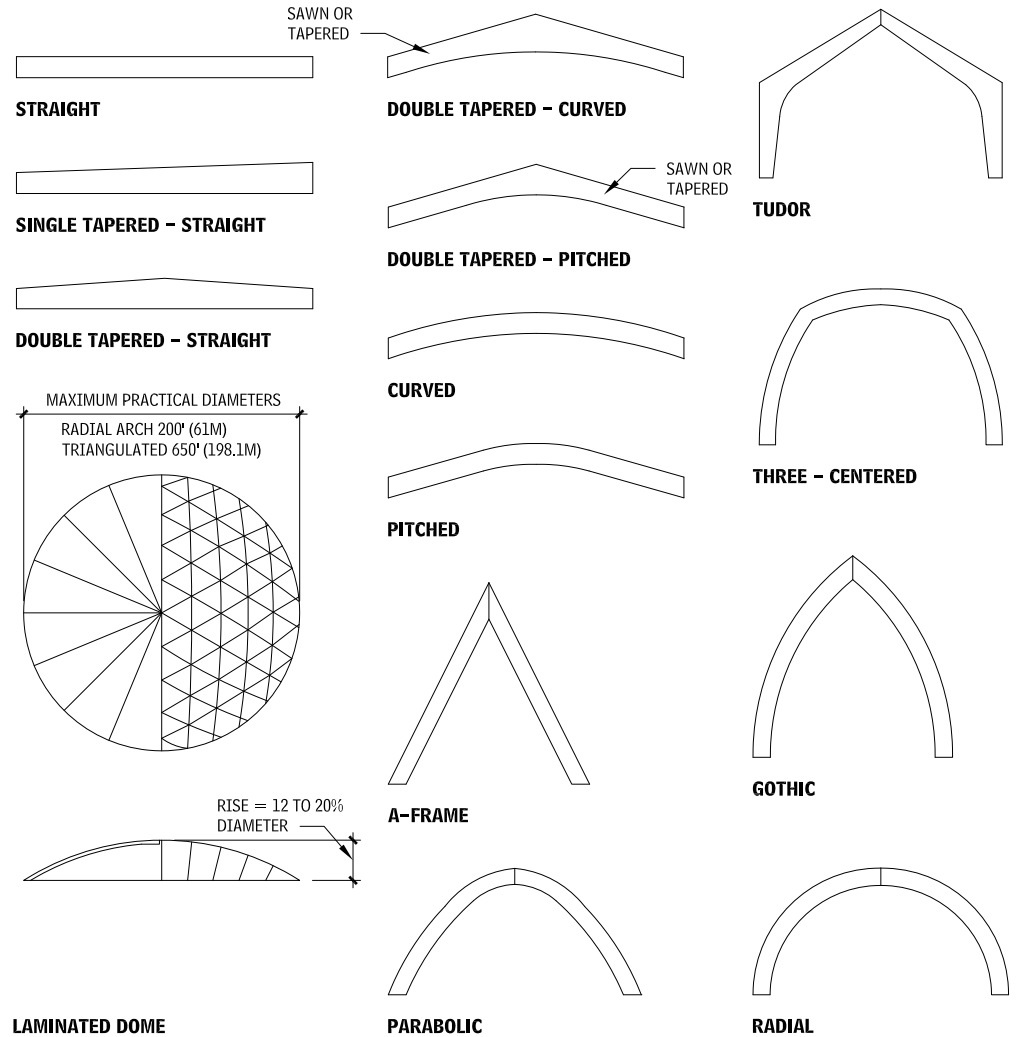
QUEEN-POST

GLUE-LAMINATED CONSTRUCTION

When examining the shapes of structural glue-laminated members, note the following:

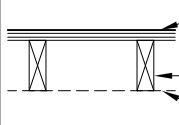
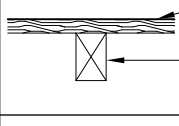

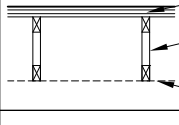
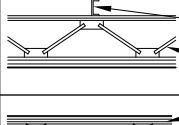
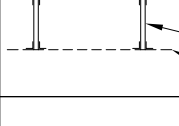
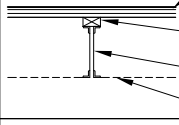
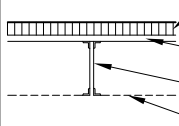
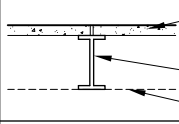
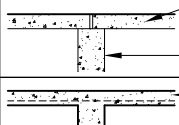
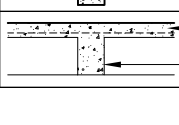

- Beam names describe the top and bottom surfaces of the beam. Sloped or pitched surfaces should be used on the tension side of the beam.
- Three-centered arches and frames produce horizontal reactions requiring horizontal ties or modified foundations.
- Triangulated and radial arches are the two basic types of structural glue-laminated wood dome systems available. Both require a tension ring at the dome spring line to convert axial thrusts to vertical loads.
- More complicated shapes may be fabricated. Contact the American Institute of Timber Construction (AITC) and APA-The Engineered Wood Association.

STRUCTURAL GLUE-LAMINATED SHAPES
1.103


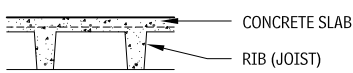


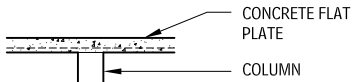
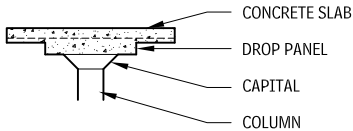
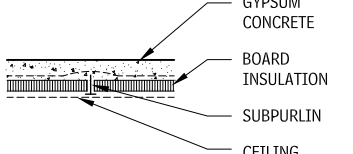


ROOF DECKS, SLABS, AND SHEATHING

**ROOF STRUCTURE ASSEMBLIES
1.104**

TYPE	FIGURE	DEPTH	MEMBER SIZES	SPAN	CEILING REQUIRED	SERVICE PLENUM	THERMAL CAPACITY	IMPACT SOUND	AIRBORNE SOUND
Wood rafter	 SHEATHING WOOD RAFTER CEILING	5" to 13" (127 to 330 mm)	Nom. joist 2 × 6, 8, 10, 12	Up to 22'-0" (6.7 m)	For visual or fire protection purposes	Between rafters— one way	Low	Poor	Fair
Wood beam and plank	 WOOD ROOF DECKING WOOD BEAM (OR GLUE-LAMINATED BEAM)	8" to 22" (203 to 559 mm)	Nom. planks 2, 3, 4	8'-0" to 34'-0" (2.4 to 10.4 m)	For fire protection purposes	Under structure— one way	Medium	Poor	Fair
Stressed-skin panel	 STRESSED-SKIN PANELS	3-1/4" and 8-1/4" (83 to 210 mm)	—	8'-0" to 32'-0" (2.4 to 9.8 m)	No	Under structure only	Low	Poor	Fair
Shop-fabricated wood truss	 SHEATHING SHOP-FABRICATED WOOD TRUSS CEILING	Varies 12" to 120" (305 to 3,048 mm)	—	30'-0" to 50'-0" (9.1 to 15.2 m)	For visual or fire protection purposes	Between trusses	Low	Poor	Fair
Cold-formed metal truss	 STEEL DECKING PURLIN COLD-FORMED METAL TRUSS	Varies	—	100'-0" to 200'-0" (30.5 to 61 m)	For visual or fire protection purposes	Between trusses	Low	Fair	Fair
Steel joist (concrete)	 SUBFLOORING WOOD NAILER STEEL JOIST CEILING	11" to 75" (279 to 1,905 mm)	Steel joists 8" to 72" (203 to 1,829 mm)	Up to 96'-0" (29.3 m)	For visual or fire protection purposes	Between joists	Medium	Fair	Fair
Steel joist (wood roof)	 WOOD ROOF DECKING WOOD NAILER STEEL JOIST CEILING	10" to 32" (254 to 813 mm)	Steel joists 8" to 30" (203 to 762 mm)	Up to 96'-0" (29.3 m)	For visual or fire protection purposes	Between joists	Low	Poor	Fair
Steel joist board insulation	 BOARD INSULATION STEEL DECKING STEEL JOIST CEILING	11" to 75" (279 to 1,905 mm)	Steel joists 8" to 72" (203 to 1,829 mm)	Up to 96'-0" (29.3 m)	For visual or fire protection purposes	Between joists	High	Excellent	Good
Steel frame	 PRECAST CONCRETE SLAB STEEL BEAM CEILING	4" to 12" (102 to 305 mm) plus beam depth	Concrete plank	20'-0" to 60'-0" (6.1 to 18.3 m), generally below 35'-0" (10.7 m)	For visual or fire protection purposes	Under structure	High	Fair	Fair
Precast concrete	 PRECAST CONCRETE SLAB CONCRETE BEAM	4" to 12" (102 to 305 mm) slab, plus beam depth	Concrete plank 16" to 48" (406 to 1,219 mm) W, 4" to 12" (102 to 305 mm) D	20'-0" to 60'-0" (6.1 to 18.3 m), generally below 35'-0" (10.7 m)	No; provides finished flush ceiling	Under structure	High	Fair	Fair
One-way concrete slab	 CONCRETE SLAB CONCRETE BEAM	4" to 10" (102 to 254 mm) slab, plus beam depth	—	10'-0" to 25'-0" (3 to 7.6 m), more with posttension	No	Under structure	High	Good	Good
Two-way concrete slab	 CONCRETE SLAB CONCRETE BEAM	4" to 10" (102 to 254 mm) slab, plus beam depth	—	10'-0" to 30'-0" (3 to 9.1 m), more with posttension	No	Under structure	High	Good	Good

ROOF STRUCTURE ASSEMBLIES (continued)
1.104

TYPE	FIGURE	DEPTH	MEMBER SIZES	SPAN	CEILING REQUIRED	SERVICE PLENUM	THERMAL CAPACITY	IMPACT SOUND	AIRBORNE SOUND
One-way ribbed concrete slab		8" to 22" (203 to 559 mm)	Standard pan forms 20" and 30" (508 and 762 mm) W, 6" to 20" (152 to 508 mm) D	15'-0" to 50'-0" (4.6 to 15.2 m), more with prestressing	For visual purposes	Between ribs— one way	High	Good	Good
Two-way ribbed concrete slab		8" to 24" (203 to 610 mm)	Standard dome forms 19" x 19" (483 x 483 mm), 30" x 30" (762 x 762 mm), 6" to 20" (152 to 508 mm) D	25'-0" to 60'-0" (7.6 to 18.3 m), more with prestressing	No	Under structure	High	Good	Good
Precast concrete single tee		16" to 36" (406 to 914 mm)	16" to 36" (406 to 914 mm) D	30'-0" to 100'-0" (9.1 to 30.5 m)	For visual or fire protection purposes	Between ribs— one way	High	Fair	Good
Precast concrete double tee		16" to 36" (406 to 914 mm)	48", 60", 72", 96", and 120" (1,219, 1,524, 1,829, and 3,048 mm) W, 6" to 16" (152 to 406 mm) D	20'-0" to 75'-0" (6.1 to 22.9 m)	For visual or fire protection purposes	Between ribs— one way	High	Fair	Good
Concrete flat plate		4" to 14" (102 to 356 mm)	—	Up to 35'-0" (10.7 m), more with prestressing	No	Under structure	High	High	Good
Concrete flat slab		5" to 16" (127 to 406 mm)	Min. slab thickness 5" (127 mm) without drop panel, 4" (102 mm) with one	Up to 40'-0" (12.2 m), more with prestressing	No	Under structure	High	Good	Good
Gypsum concrete roof deck		3" to 6" (76 to 152 mm)	—	Up to 10'-0" (3 m)	For visual or fire protection purposes	Under structure	High	Good	Good

Source: Roger K. Lewis, FAIA, and Mehmet T. Ergene, architect, Roger K. Lewis and Associates, Washington, DC.

METAL ROOF DECKING

Some of the many types of metal roof decking include:

- Roof decking
- Composite deck
- Permanent forms for self-supporting concrete slabs
- Raceway (composite or noncomposite)
- Acoustical metal decking
- Acoustical cellular deck (composite or noncomposite)
- Vented roof deck (used with lightweight insulating concrete fill)

ADVANTAGES OF METAL ROOF DECKS

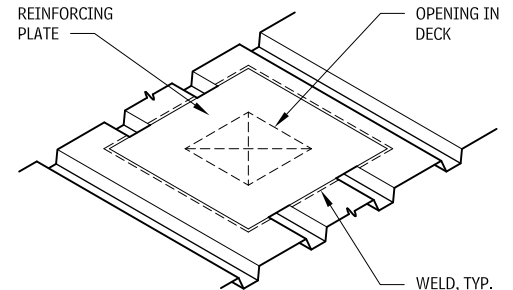
- A high strength-to-weight ratio reduces roof dead load.
- They can be erected in most weather conditions.
- A variety of depths and rib patterns are available.
- Acoustical treatment is possible.
- They can serve as the base for insulation and roofing.
- Fire ratings can be obtained with standard assemblies.
- They can provide a lateral diaphragm.
- They can be erected quickly and economically.
- Using them makes it easy and economical to create roof slopes for drainage when mounted over sloped structural steel.

Roof deck selection must consider construction and maintenance loads, as well as the capacity to support uniformly distributed live loads. Consult the Steel Deck Institute's recommendations and requirements.

Fire-resistance ratings for roof assemblies are published by code authorities, Underwriters Laboratories, and Factory Mutual. Fire-resistance ratings may be achieved by various methods, including applied fireproofing, rated acoustical ceilings, and gypsum board enclosures.

Small openings up to 6 by 6 in. (152 by 152 mm) or 6 in. diameter usually may be cut in a roof or floor deck without reinforcing the deck. Openings up to 10 by 10 in. (254 by 254 mm) or 10 in. diameter require reinforcing of the deck either by welding a reinforcing plate to the deck all around the openings or by providing channel-shaped headers and/or supplementary reinforcing parallel to the deck span. Reinforcing plates should be 14-gauge sheets with a minimum projection of 6 in. (152 mm) beyond all sides of the opening, and they should be welded to each cell of the deck. Larger openings should be framed with supplementary steel members so that all free edges of the deck are supported.

OPENINGS IN DECK 1.105



40 STRUCTURE ROOF CONSTRUCTION

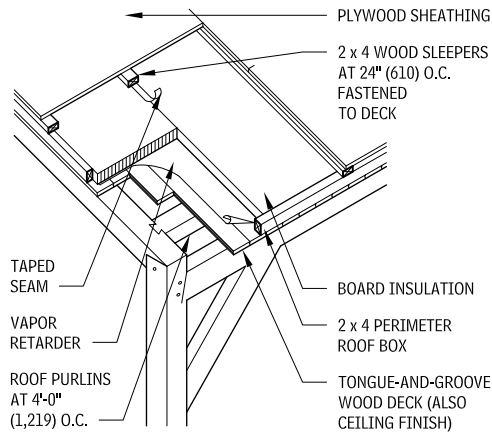
METAL ROOF DECK TYPES 1.106

TYPE	FIGURE	REMARKS	SPAN	WIDTH	MAXIMUM LENGTH
Economy		Most economical deck for shorter spans; use with 1" or more insulation	2'-6" to 8'-0" (0.8 to 2.4 m)	32" to 33" (813 to 838)	42'-0" (12.8 m)
Narrow rib (1" wide)		Use with 1/2" insulation; maximum surface area on top for adhering insulation	4'-0" to 11'-0" (1.2 to 3.4 m)	36" (914)	42'-0" (12.8 m)
Intermediate rib (1-3/4" wide)		Use with 1" insulation	4'-0" to 11'-0" (1.2 to 3.4 m)	36" (914)	42'-0" (12.8 m)
Wide rib (2-1/2" wide)		Use with 1" insulation	5'-0" to 12'-0" (1.5 to 3.7 m)	36" (914)	42'-0" (12.8 m)
Acoustical metal decking		Perforated type for sound absorption only	10'-0" to 20'-0" (3 to 6 m)	24" (610)	42'-0" (12.8 m)
Raceway decking assemblies (1-1/2" deep)		For use as electrical raceway or as acoustical ceiling; bottom plate is perforated for sound absorption.	9'-0" to 12'-0" (2.7 to 3.7 m)	24" (610)	42'-0" (12.8 m)
Raceway decking assemblies (3" deep)		—	10'-0" to 13'-0" (3 to 4 m)	24" (610)	42'-0" (12.8 m)
Raceway decking assemblies (4" to 7-1/2" deep)		—	20'-0" to 30'-0" (6 to 9.1 m)	24" (610)	30'-0" (9.1 m)

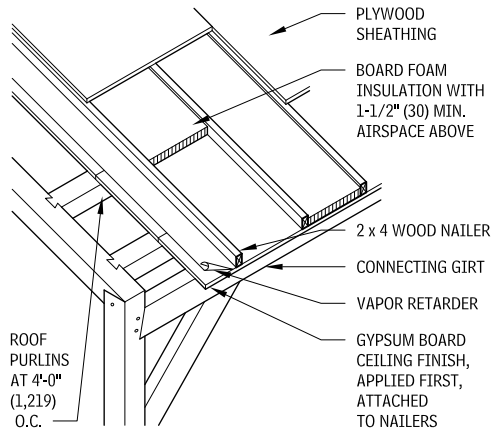
Contributors:
 Donald Neubauer, PE, Neubauer Consulting Engineers, Potomac, Maryland.
 Walter D. Shapiro, PE, Tor, Shapiro & Associates, New York, New York.

TIMBER FRAME ROOF DECKING

WOOD SLEEPERS AND TONGUE-AND-GROOVE CEILING ON ROOF PURLINS
1.107



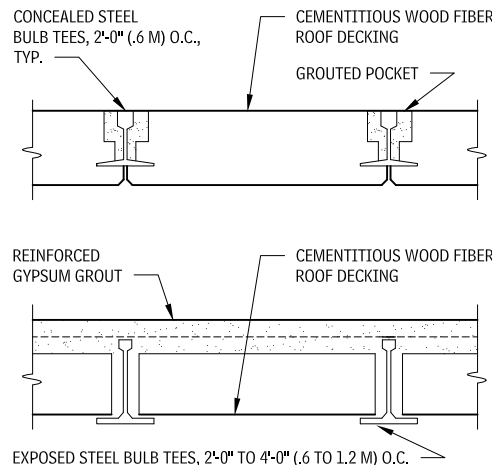
WOOD NAILERS ON ROOF PURLINS
1.108



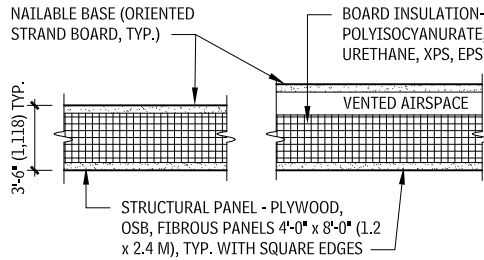
CAST ROOF DECKS

Cement panels may be used instead of oriented strand board (OSB) or plywood for noncombustible construction.

CAST ROOF DECKS
1.109



STRUCTURAL PANELS
1.110



ROOF, EAVE, AND ATTIC VENTILATION

Ventilation of attics can cause as many problems as it solves, if not designed and constructed carefully. The best understanding of the interrelated issues surrounding the control of heat, air, and moisture (HAM) inside attics, and the transfer of HAM to the building interior, suggests that, like crawl spaces, it may be preferable to treat the attic as part of the interior conditioned environment. This is especially true when heating, ventilating, and air conditioning (HVAC) equipment and ductwork are located in the attic.

The following are recommendations for insulated and conditioned attics:

- Codes require ventilation of enclosed attics and enclosed rafter spaces where ceilings are applied directly to the underside of roof rafters, but this does not specifically exclude installing insulation within rafter spaces exposed in a conditioned attic. Verify with local building codes in effect for all requirements.
- From a practical standpoint, it is much more difficult to install a vapor barrier on the inside face of batt or sprayed insulation between joists and especially roof trusses because of the many penetrations. Therefore, control of the temperature of the first condensing surface is crucial to the success of many of these systems.
- Attic ventilation has a much smaller impact on asphalt shingle temperatures than roof orientation and shingle color.
- Provide heating and cooling to attics.

The following assemblies control vapor by ensuring that the surface temperature of the first surface on which condensation would form is above the predicted dew point, with some margin of safety. These assemblies allow for some seasonal wetting and drying of interior materials.

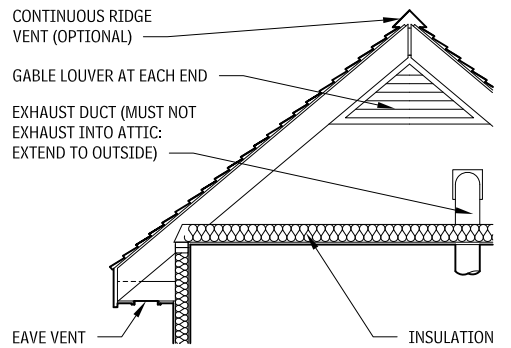
- *Blanket insulation between joists/trusses:* Cover roof sheathing with board insulation to raise the inside temperature of the sheathing above the dew point. Determine the thickness of both insulations, based on external and internal environmental conditions. Provide an air barrier with building felts or by offsetting joints in board insulation. Detail for continuity.
- *Board and blanket insulation between joists/trusses:* Fill space between joists with board insulation located tight against the underside of the sheathing. Carefully seal all joints and penetrations with sealant. Determine the thickness of the board insulation, based on external and internal environmental conditions, to raise the inside surface above the dew point. Provide blanket insulation over the joist space to the thickness required for the total R-value.
- *Sprayed insulation:* Closed-cell, high-density sprayed insulation will act as an air barrier and does not require an applied vapor barrier. Open-cell, low-density sprayed insulation may require covering with latex paint or gypsum board to limit vapor transfer. Control vapor flow.

Roof assemblies control vapor by installing a vapor retarder on the warm side, except in mixed climates, where no vapor barrier is installed and the system is allowed to dry to both the interior and the exterior, depending on the season. Plywood is recommended over OSB in mixed climates, because of plywood's greater capability to store moisture.

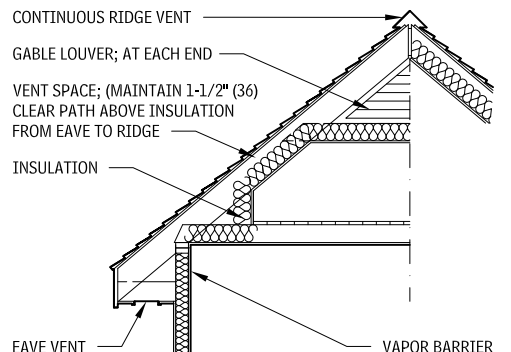
There are common methods to properly ventilate an attic or rafter space:

- Separate the attic from the conditioned portion of the home with a continuous air barrier, with joints and penetrations sealed.
- Provide a weather barrier with joints and penetrations sealed airtight to the warm side of the insulation, unless analysis reveals it is not required in mixed climates. In hot or mixed climates, the underlayment for asphalt shingles must be vapor permeable.

VENT APPLICATIONS
1.111



GABLE ROOF WITH UNOCCUPIED ATTIC



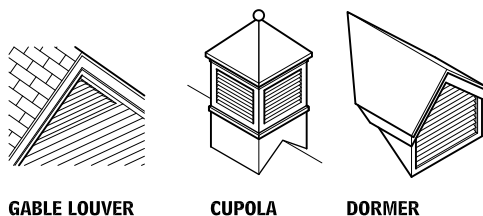
GABLE WITH OCCUPIED SPACE UNDER ROOF

Contributors:
APA—The Engineered Wood Association, Tacoma, Washington.
Bloodgood, Sharp, Buster Architects and Planners, Des Moines, Iowa.
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

- Do not install any HVAC equipment or ductwork in the attic.
- Do not install any water pipes within the attic.
- Ensure that all vents from clothes dryers, kitchen exhausts, bathroom exhausts, and similar sources of conditioned air do not discharge into the attic and that any ducts for such vents routed through the attic are carefully sealed.
- Use baffles to ensure that eave and cornice vents have a free air space to the attic past insulation at narrow points.

Refer to www.buildingscience.com for further information.

ROOF LOUVER TYPES 1.112

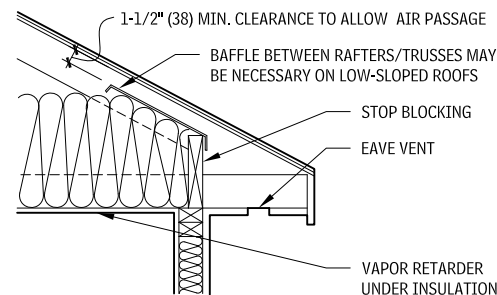


GABLE LOUVER

CUPOLA

DORMER

INSULATION BLOCKING AND BAFFLE 1.113



STAIRS AND RAMPS

STAIRS

Stairways are an essential component in the circulation and egress systems of most buildings. In the United States, they are also the site of accidents that, annually, result in approximately 4,000 deaths and 1 million injuries requiring hospital treatment. For these reasons, stairway design is strictly controlled by building regulations.

REGULATIONS

The information contained in this section summarizes most International Building Code (IBC) and access regulation requirements. The information in this chapter is based on IBC 2009 and ADA/ABA Accessibility Guidelines 2004. Check authorities having local jurisdiction for additional requirements.

Consult the IBC for stairway requirements to determine dimensional limits for treads, risers, landings, and stair widths. Verify that local codes are not more restrictive. Refer to the Americans with Disabilities Act (ADA) for accessibility requirements regarding stairs.

Treads and risers within a flight must be uniform in size within close tolerances. Treads must be slip resistant. Carpeting or other stair coverings should be applied securely and should not create a nosing radius greater than permitted. Handrails, guardrails, and stairways themselves must meet structural load requirements.

ACCESSIBILITY

Access regulations in some localities require that flooring material strips of contrasting color be located at the top approach to a stair and at the lowest tread. These markings are intended to aid the visually impaired in identifying the limits of the stair. The application of such markings may be appropriate even where not required, particularly where a high proportion of elderly or visually impaired users are anticipated.

STAIR TYPE

Stair type refers to its design and plan layout. Stair types vary and are subject to code requirements. Stair type selection depends on the space available, the starting and ending points required of the stair, and the appearance desired. Egress stairs must be enclosed as required by building codes, but the designer can vary the openness of nonegress stairs.

Layout refers to the overall horizontal and vertical dimensions required to meet functional and building code requirements. This includes determining the width, total rise, and run of the stair as well as space for landings.

STAIR DIMENSIONS

Tread and riser dimensions are proportionally related to each other. The tread and riser proportion, or pitch, affect safety as well as the ease of using the stair. Code requirements are minimums.

Minimum stair widths are defined by building and accessibility codes, based on occupancy, tread and riser dimensions, handrail dimensions and positions, headroom requirements, and distance between landings.

Details of construction include how the treads and risers are supported, handrail profiles and construction, materials used, and other finish considerations, including slip resistance.

Maintain a minimum headroom of 6 ft 8 in. (2,032 mm).

Avoid flights with fewer than three risers, to minimize tripping hazards. If one or two risers are used, increase the tread depth and clearly mark the level changes.

The use of door alcoves is recommended to prevent stairway doors from obstructing the egress travel path.

MINIMUM WIDTH

The minimum width of any straight stair is 36 in. (914 mm) when the occupant load is less than 50. The minimum width is 44 in. (1,118 mm) when the occupant load is 50 or more. Handrails may encroach no more than 4-1/2 in. (114 mm) on each side. For large occupancies, calculate the minimum width according to the exit width provisions of the IBC. When the stair serves an area of evacuation assistance, the minimum clear width between handrails must be 48 in. (1,219 mm).

In residential occupancies, wider stairways allow for easier movement of furniture. For commercial occupancies, wider stairways allow for more comfortable circulation when two people are passing or carrying objects.

HORIZONTAL STAIR LAYOUT

Steps involved in sizing the horizontal layout of the stair are as follows:

1. *Determine the riser height:* The number of risers required determines the number of treads required.
 - For standard straight stairs, begin the calculation by taking the total rise of the stairway, in inches, and dividing by 7 in. (179 mm). This is a comfortable riser height and is the maximum allowed for most commercial stairways.
 - If the result is not a whole number, select the next-highest whole number and divide that number into the total rise. This establishes a riser height of less than 7 in., which is a whole number and is the number of risers required.

- The number of treads is one less than this number for a straight-run stair and two less for a return or L-shaped stair (the landing takes the place of one tread).
- For straight-run residential stairways where allowed by code, divide by 7.75 in. (197 mm). This is the maximum allowable riser height for Group R-3 occupancies and within dwelling units in Group R-2 occupancies.

2. *Determine the proportion between the riser and the tread dimensions:* Stair dimensions are based on the normal stride of a person while ascending and descending a stair.

- Several formulas relating rise and tread have been proposed through the years, but one of the most common is:

$$2R + T = 25 \text{ or } T = 25 - 2R$$

where R is the riser height and T is the tread depth.

- The IBC specifies a minimum tread depth of 11 in. (279 mm) for commercial stairs and 10 in. (254 mm) for residential stairs.
- For straight-run, L-shaped, T-shaped, and wide-U stairs, the total run is the number of treads multiplied by the tread depth.
- For return stairs, an unequal number of risers and treads in the lower and upper flight is recommended, to allow the first riser of the upper landing to lead the last riser of the lower landing by one tread depth. The handrail can then make a clean switchback without having to offset vertically.

DESIGN GUIDELINES FOR STAIRS

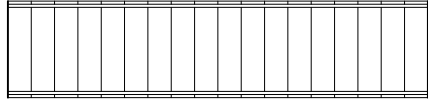
1. Width of stair:
 - Dwelling stairs: minimum 36-in. (914-mm) treads
 - Public exit stairs: minimum 44-in. (1,118-mm) treads
 - Rescue assistance area (ADA): 48 in. (1,219 mm) between handrails
2. Treads:
 - Dwellings: 10 in. (254 mm) minimum (nosing to nosing)
 - Other (ADA): 11 in. (279 mm) minimum (nosing to nosing)
 - Uniform depth within one flight
3. Risers:
 - Dwellings: 7-3/4 in. (197 mm) maximum
 - Other (ADA): minimum 4 in. (102 mm); maximum 7 in. (178 mm)
 - Uniform height within one flight
4. Nosing: maximum 1-1/4 in. (32 mm) with 60° under nosing; maximum 1/2 in. (13 mm) radius at edge

Contributors:

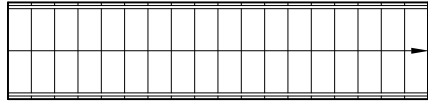
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.

Erik K. Beach, Rippeteau Architects, PC, Washington, DC.

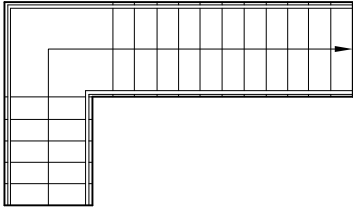
STAIR TYPES
1.114



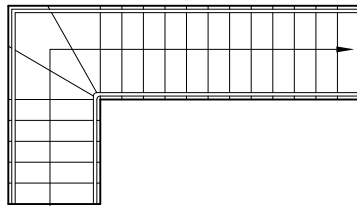
DIRECT FLIGHT



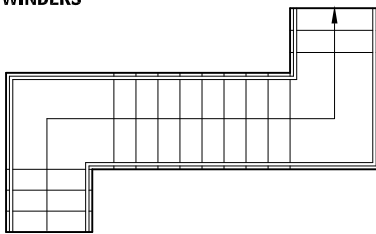
STRAIGHT RUN



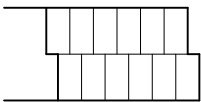
L-SHAPED



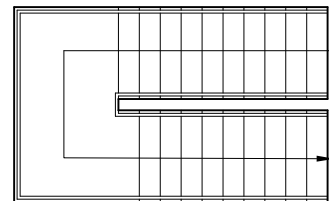
WINDERS



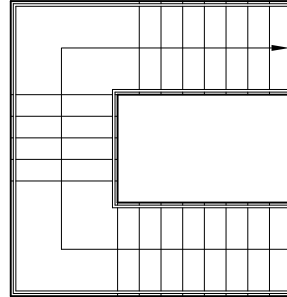
Z-SHAPED



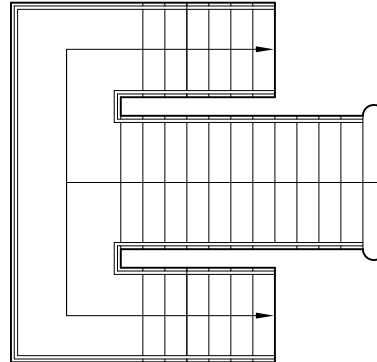
ALTERNATING STEP



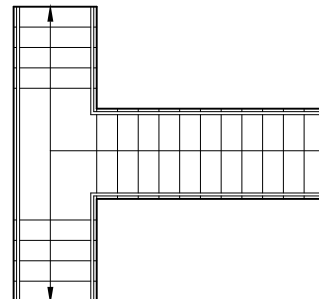
DIVIDED RETURN



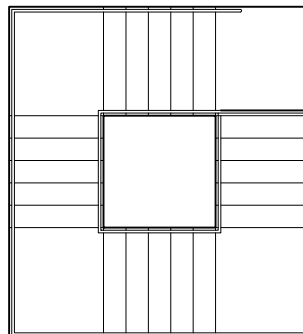
WIDE-U, RETURN FLIGHT



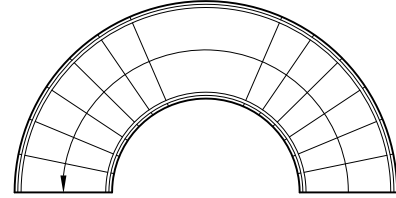
SPLIT-U



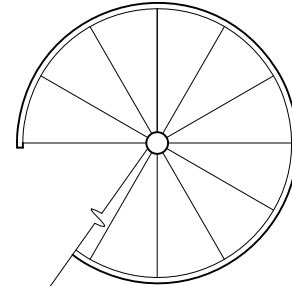
T-SHAPED



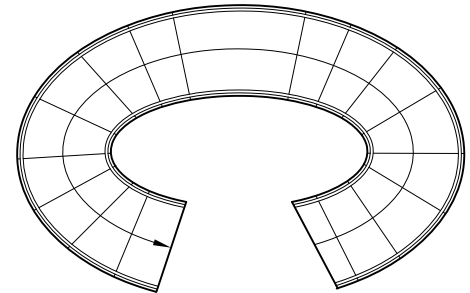
O-SHAPED



CURVED

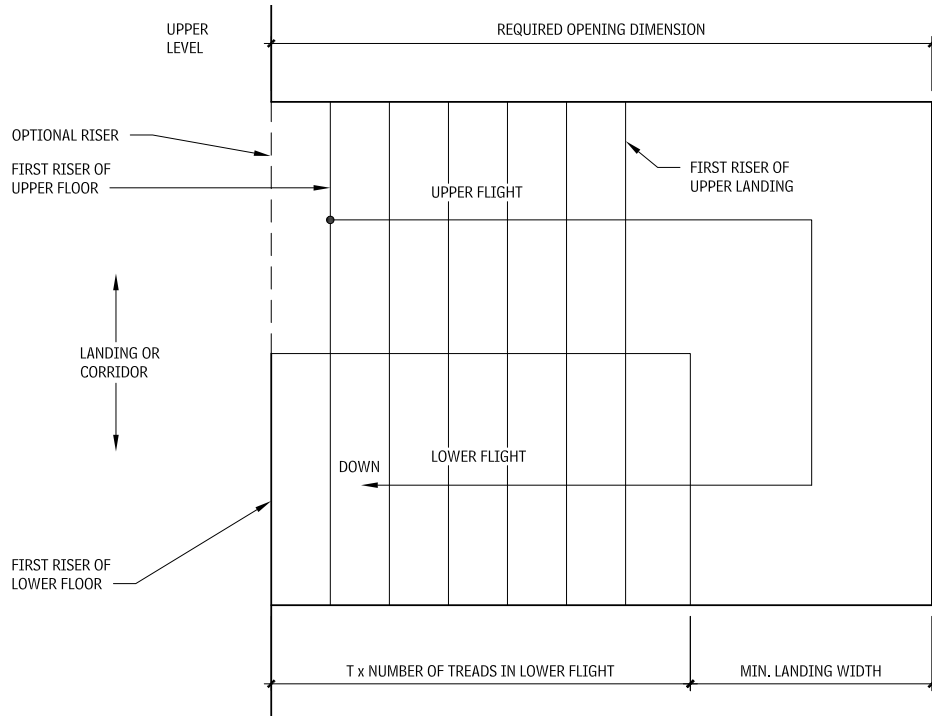


SPIRAL

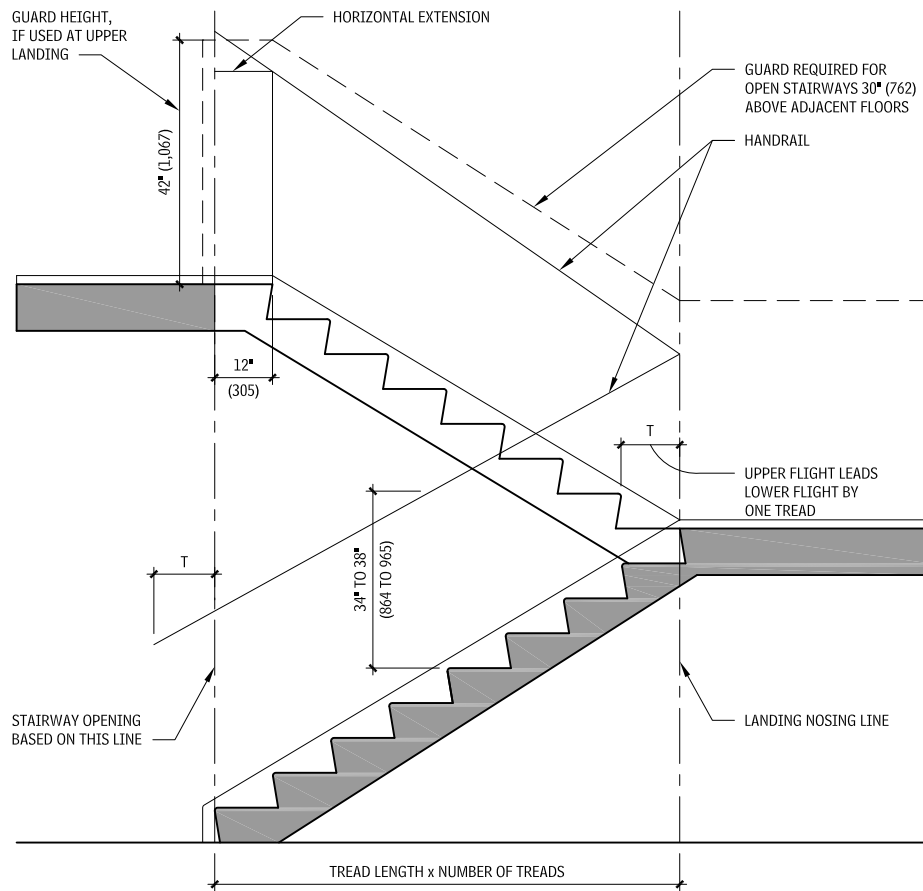


CURVED OVAL

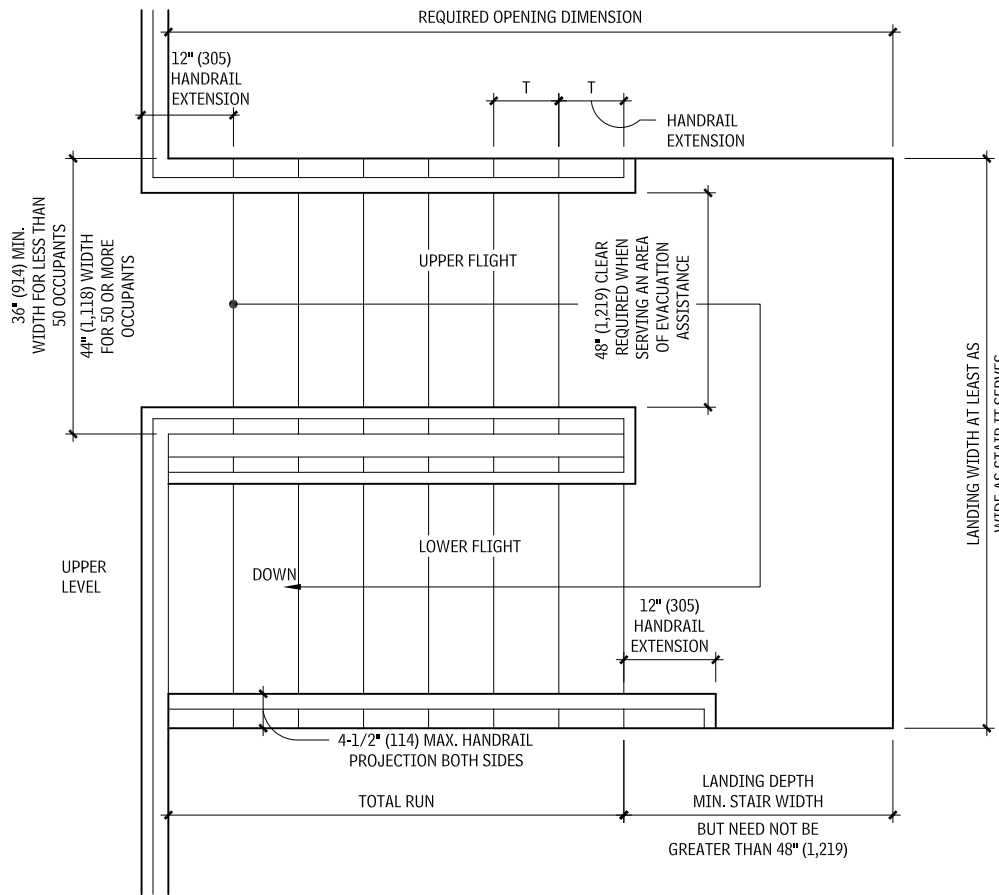
RETURN STAIR PLAN LAYOUT
1.115



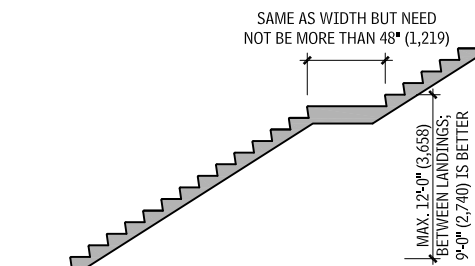
RETURN STAIR SECTION LAYOUT
1.116



HORIZONTAL LAYOUT
1.117



LANDINGS—SECTION
1.118



HANDRAILS, BALUSTRADES, AND GUARDS

HANDRAILS

Handrail requirements are governed by building and accessibility codes. Typically, handrails are required on both sides of stairs. Exceptions include dwelling units and private dwellings. In these cases, only one handrail is required. Handrails are not required for changes in room elevations of three or fewer risers in dwelling units and sleeping units in Group R-2 and R-3 occupancies. Handrails are also not required in Group R-3 occupancies where there is a single riser at an entrance or egress door. Handrail gripping surfaces must be continuous, without interruption by newel posts or other obstructions. Handrails in dwelling units are allowed to have newel posts at landings and volutes at the lowest tread.

For wide stairways used as a means of egress, intermediate handrails are required so that all portions of the stairway width are within 30 in. (762 mm) of a handrail. On monumental stairs, handrails must be located along the most direct path of egress travel.

HANDRAIL AND GUARD HEIGHTS

Per ADA/ABA Accessibility Guidelines, the height of a handrail above stair nosings should be 34 to 38 in. (864 to 965 mm).

For open stairways more than 30 in. (762 mm) above the floor, the IBC also requires a guard 42 in. (1,067 mm) above the nosing in addition to a handrail.

Guards should be 42 in. (1,067 mm) minimum in most commercial construction. The IBC allows guards to be 36 in. (914 mm) on open-sided walking surfaces in Group R-3 occupancies (dwellings). Guards on the open sides of stairs in Group R-3 occupancies and within individual dwelling units in Group R-2 occupancies must be a minimum of 34 in. (864 mm) measured from the nosing. Where the top of a guard also serves as a handrail on the open sides of stairs in Group R-3 and individual dwelling units of Group R-2 occupancies, the top of the guard must not be less than 34 in. (864 mm) and not more than 38 in. (965 mm) above the nosings.

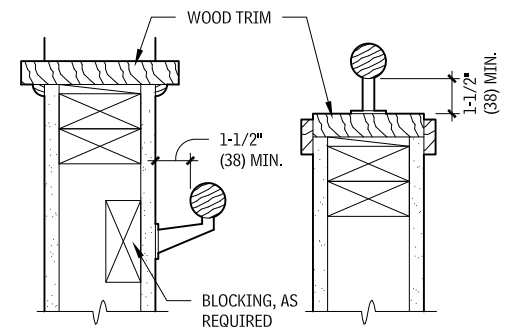
Handrails should be easy to grip and fit the hand. The recommended diameter is 1-1/4 to 1-1/2 in. (32 to 38 mm) for round handrails and a similar size for an elliptical or rounded square-edge section. Handrails should be structurally designed so that both downward (vertical) and lateral (horizontal) thrust loads are considered.

Extensions of handrails at the top and bottom of stairs may affect the total length of the required run. Verify extensions required by local codes or ADAAG when designing a stair.

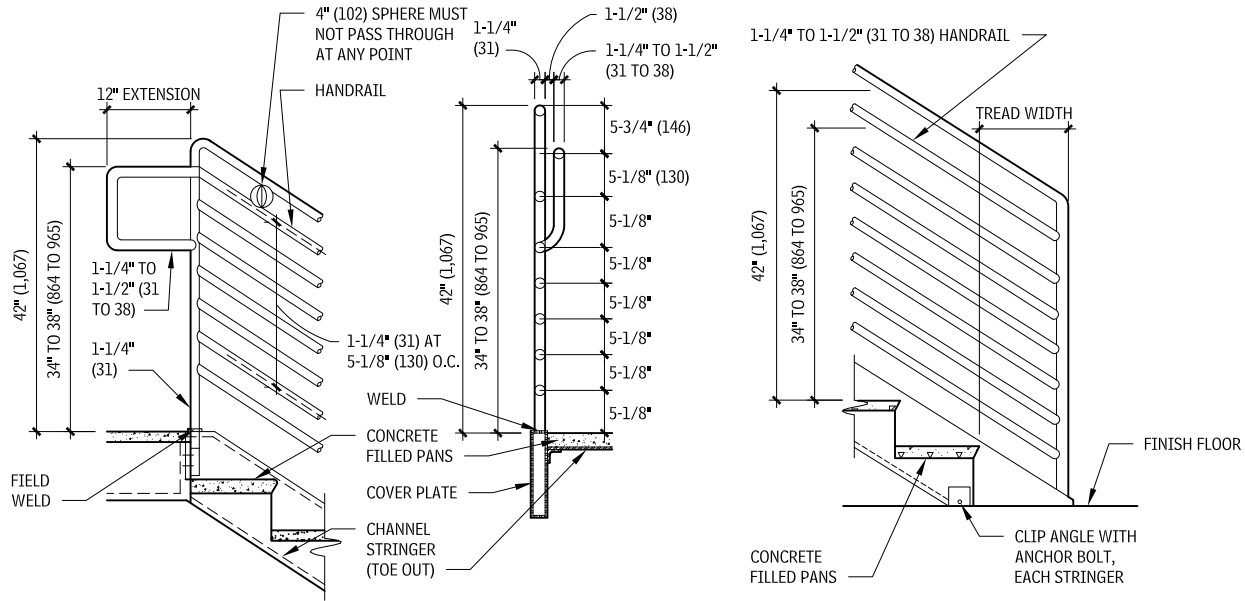
Handrails must extend beyond the top and bottom treads, as required by code. At the inside turn of return stairs, the handrail must be continuous. The ends of the handrail must return to either the wall or a guard, or to the floor, or they must be continuous to the next handrail of an adjacent stair flight.

The IBC and ADA require a minimum clearance of 1-1/2 in. (38 mm) between the inside of the handrail and the wall. Some studies have suggested that a better dimension is 2 in. (51 mm). This larger dimension is good for general graspability and works better for a person wearing gloves. For children, an additional handrail should be 1-1/8 to 1-1/2 in. (29 to 32 mm) in diameter and mounted 22 to 28 in. (559 to 710 mm) above the nosing line.

RAILINGS AT WALLS
1.119

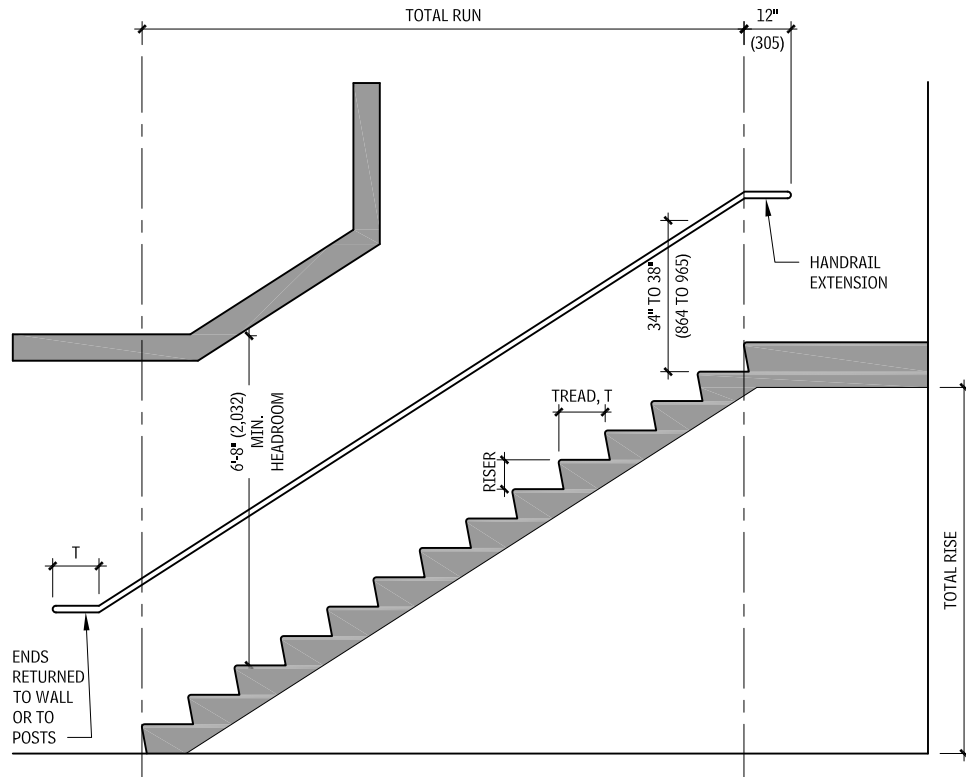


HANDRAILS
1.120

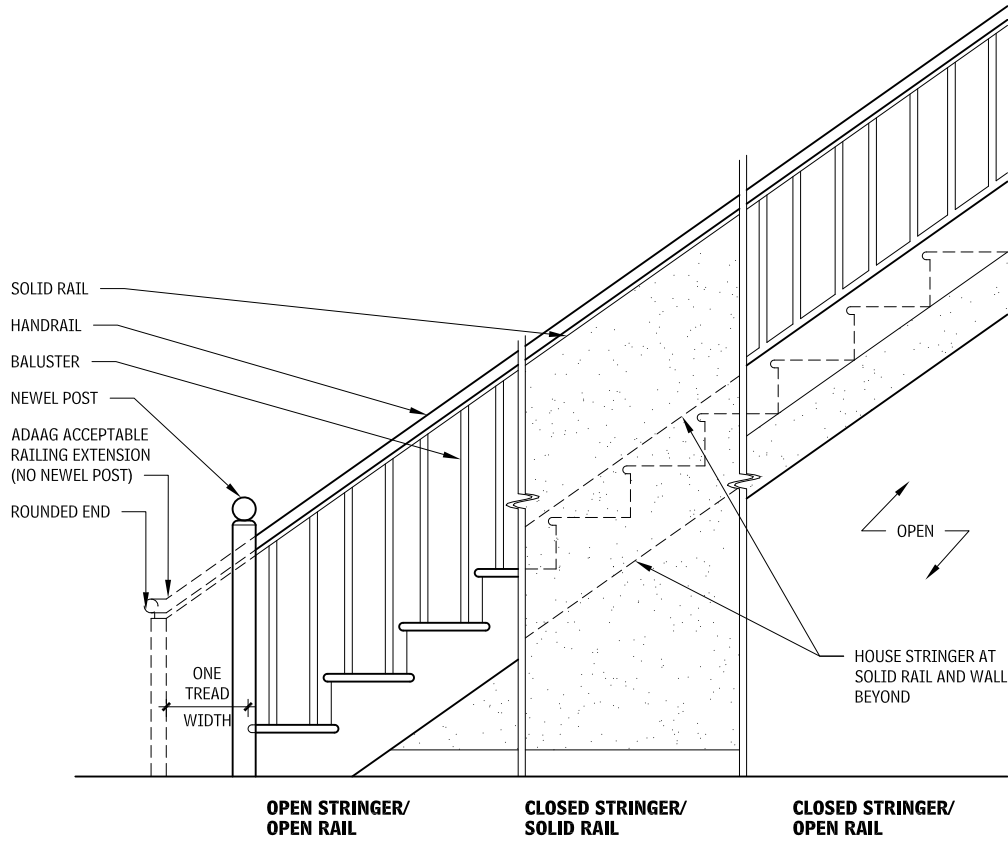


STEEL STAIR HANDRAILS

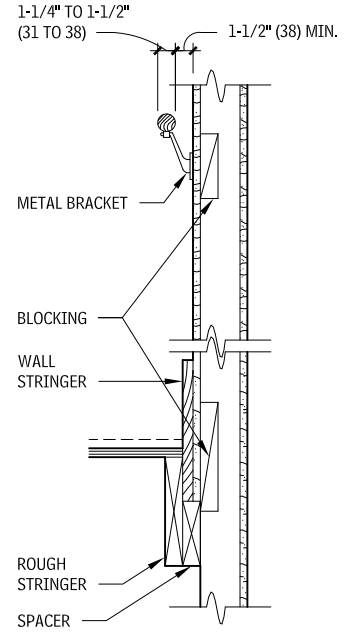
HANDRAIL DIMENSIONS
1.121



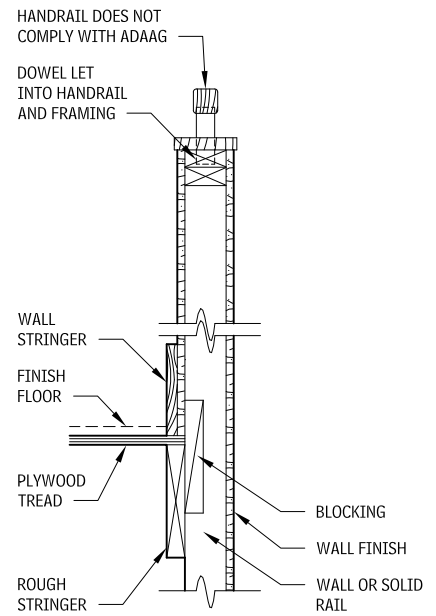
ELEVATION OF FACE STRINGER
1.122



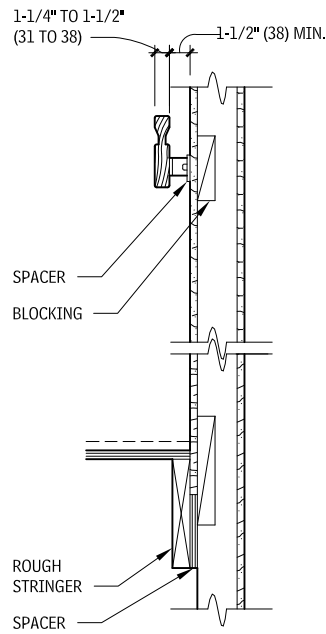
FULL WALL STRINGER
1.124



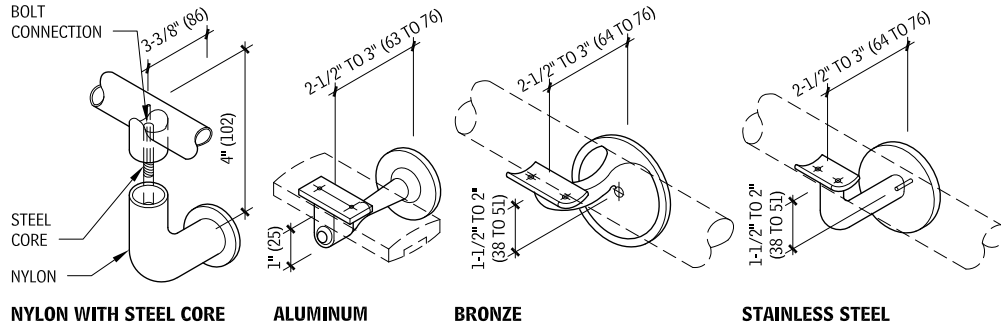
NOTCHED WALL STRINGER
1.125



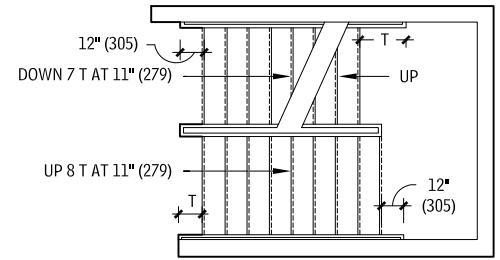
NO WALL STRINGER
1.123



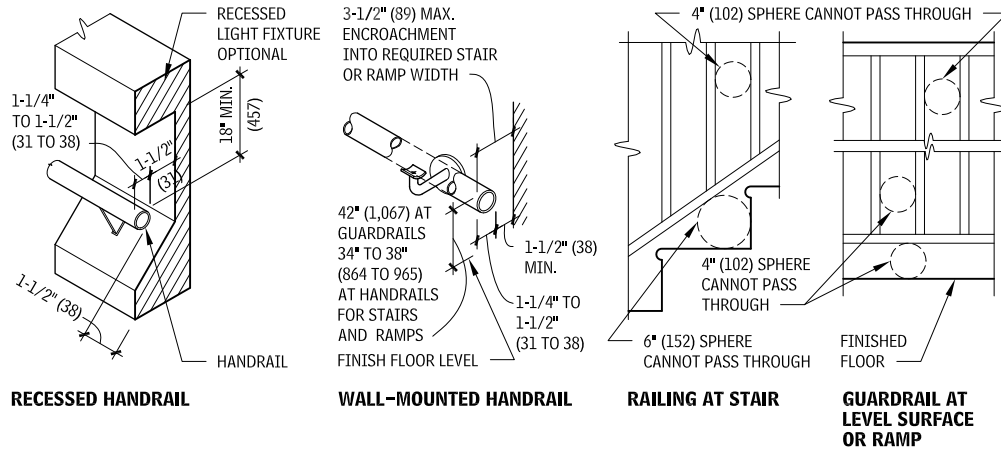
WALL BRACKETS
1.126



PLAN SHOWING HANDRAIL EXTENSIONS
1.129



ACCESSIBLE HANDRAIL AND GUARDRAIL DIMENSIONS
1.127



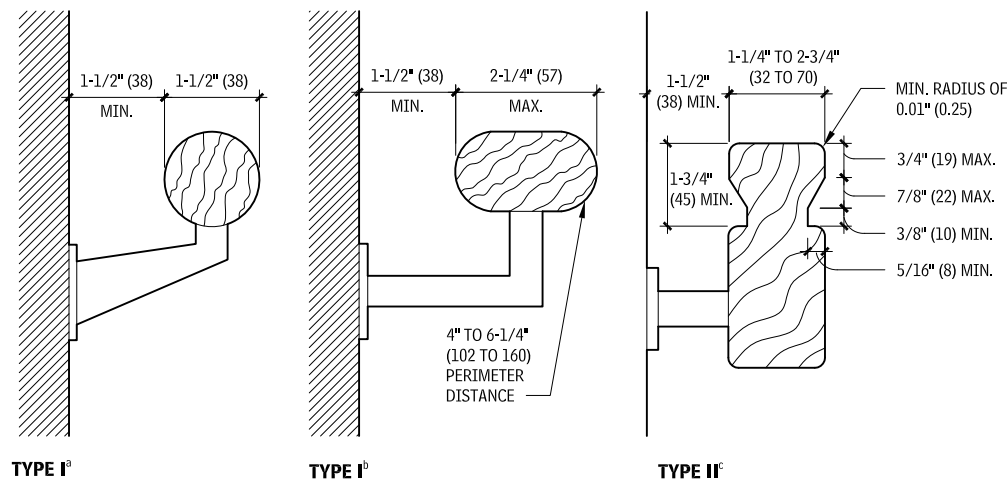
DESIGN GUIDELINES FOR METAL STAIR HANDRAILS

- Stair rails:
 - Height in dwellings: 36 in. (914 mm)
 - Height in exit stairs: 42 in. (1,067 mm)
 - Arrange rails so that a sphere 4 in. (102 mm) in diameter cannot be passed through
 - Arrange rails to discourage climbing
 - Concentrated load nonconcurrently applied at the top rail must be 200 pounds force (1,156 N) in vertical downward and horizontal directions. The test loads are applicable for railings with supports not more than 8 ft (2.4 m) apart
- Handrails:
 - Dwellings: on one side only, required
 - Other (ADA): required on both sides
 - Height: 34 to 38 in. (864 to 965 mm)
 - Grip surface: 1-1/4 to 1-1/2 in. (32 to 38 mm)
 - Clearance at wall: 1-1/2 in. (38 mm)
 - Projecting or recessed
 - Extension at top of run: 12 in. (305 mm)
 - Extension at bottom of run: horizontal depth of tread
 - When a guardrail more than 38 in. (965 mm) high is used, a separate handrail should be installed
 - Nothing should interrupt the continuous sliding of hands
- Regulators and standards: building codes, ADA, ASTM International, American National Standards Institute (ANSI), National Fire Protection Association (NFPA), and Occupational Safety and Health Administration (OSHA)

The IBC and ADA require handrails to be circular in cross section, with a dimension between 1-1/2 and 2 in. (38 and 51 mm). Other shapes are allowed if the perimeter dimension is between 4 and 6-1/2 in. (102 and 165 mm) and the maximum cross-sectional dimension does not exceed 2-1/2 in. (64 mm). Edges must have a minimum radius of 1/8 in. (3 mm).

The 2009 IBC requires that handrails be easily grasped and allows for two types, Type I and Type II. Type I handrails are required for most construction, but Type II handrails are also allowed for Group R-3 (residential) occupancies, within dwelling units in Group R-2 occupancies, or accessory to the individual dwelling units in Group R-2 occupancies. Edges must have a minimum radius of 0.01 in. (0.25 mm).

HANDRAIL GRASPABILITY
1.128

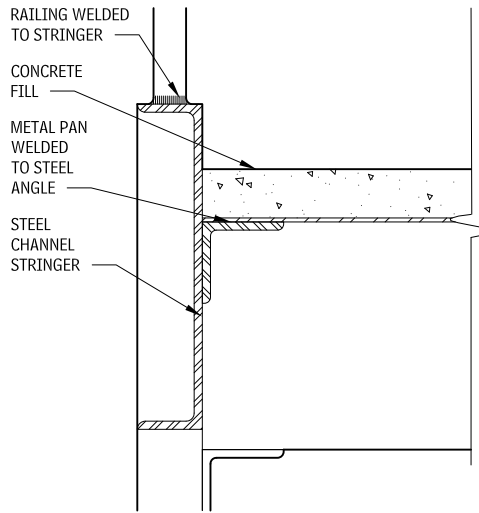
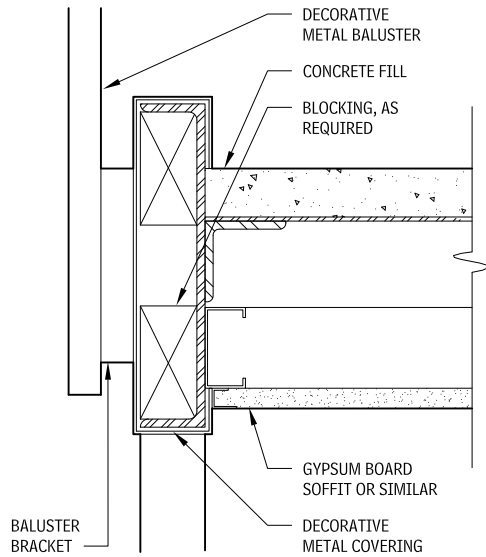


NOTES

- IBC and ADA require handrails to be circular in cross section, with a dimension between 1-1/4 and 2 in. (32 and 51 mm).
- Other shapes are allowed if the perimeter dimension is between 4 and 5-1/2 in. (102 and 159 mm) and the maximum cross-sectional dimension does not exceed 2-1/4 in. (57 mm).
- Other configurations are possible if finger recess is provided on both sides and grasping area meets these requirements.

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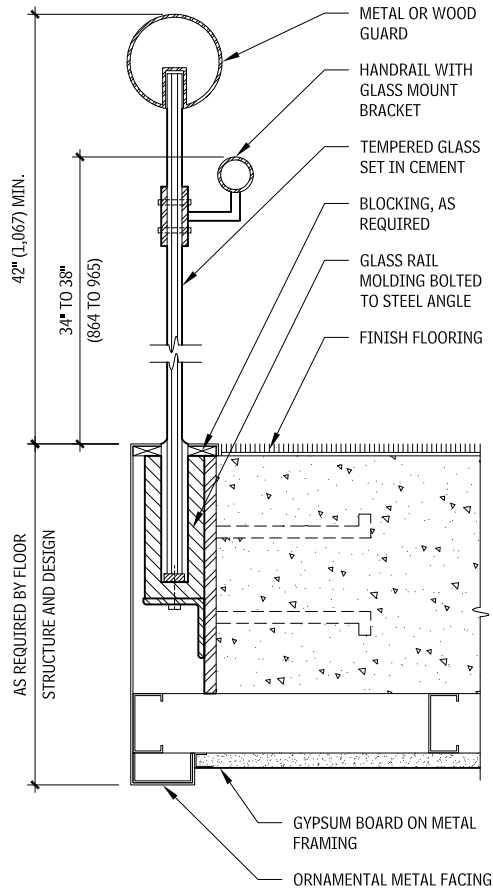
STRINGER DETAILS
1.130



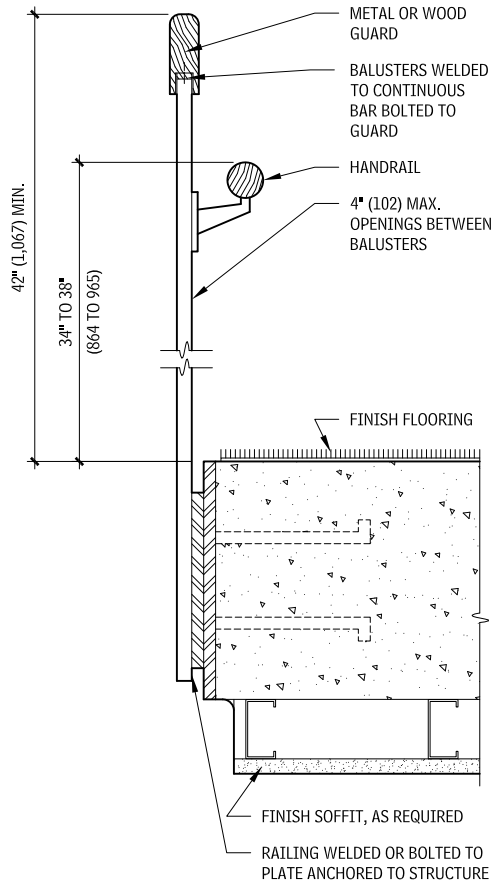
WELDED RAILING

DECORATIVE BALUSTER

RAILING DETAILS
1.131



TEMPERED GLASS



METAL BALUSTER

TREADS, RISERS, AND NOSINGS

TREADS

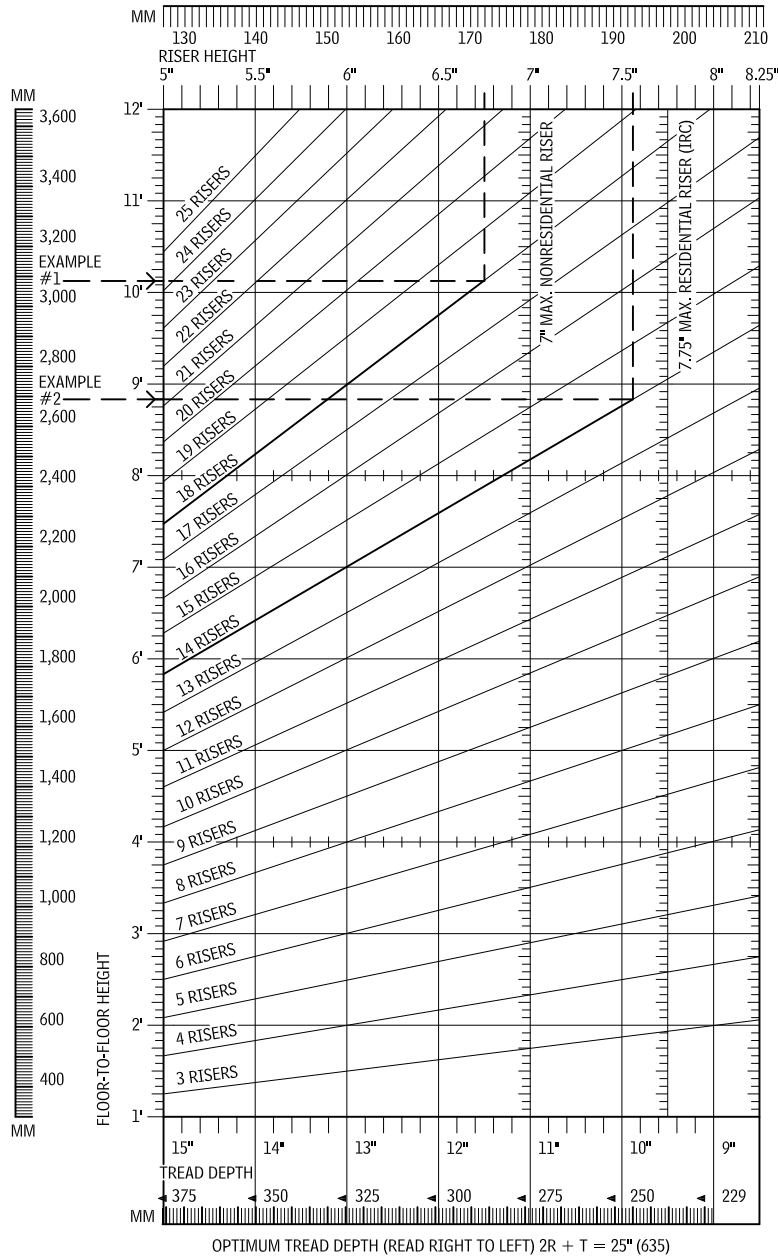
The minimum dimensions for stair treads are indicated in the building codes. If space permits, research has shown that slightly deeper treads than the minimum are more comfortable and safer to use.

Tread material should be nonslip, but not so rough that feet may be caught on the nosing. Traditionally, a coefficient of friction of 0.5 or greater has been a widely accepted standard for slip resistance. In areas where slip resistance is a concern, it is recommended that tread materials be selected with a greater coefficient of friction than the minimum requirements.

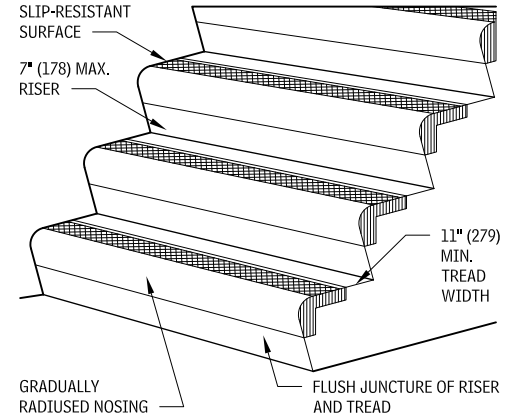
RISERS

Straight, vertical risers are permitted by the IBC and the ADA; however, treads with nosings are more comfortable for the user. Treads must be designed to follow requirements that prevent sharp or abrupt edges, which may catch a person's foot and present a safety hazard. Open risers may not be used in most situations.

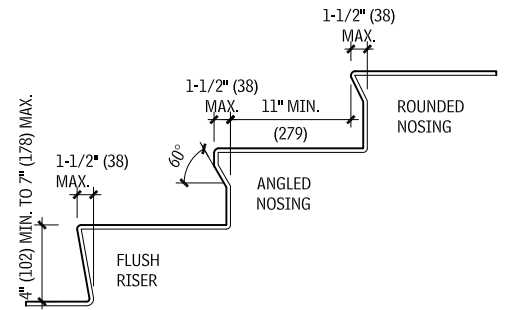
STAIR PROPORTIONING GRAPH
1.132



STAIR ELEMENTS
1.133



RISER DESIGN
1.134

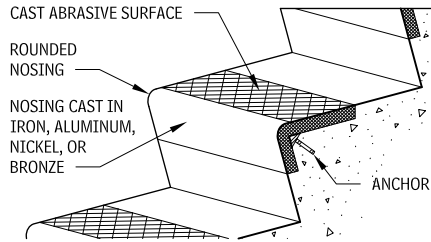


NOSINGS

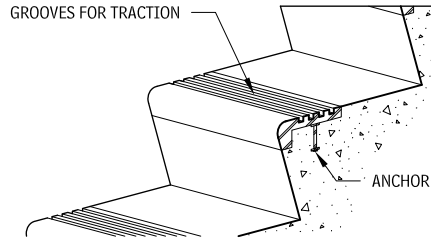
The IBC limits the amount of nosing overhang to 1-1/4 in. (32 mm), whereas the ADA limits the amount to 1-1/2 in. (38 mm). A 1-in. (25-mm) overhang is usually sufficient.

The ADA limits the radius of the leading edge of a tread to 1/2 in. (13 mm), whereas the 2009 IBC limits the radius to 9/16 in. (14 mm). To comply with both regulations, use a maximum radius of 1/2 in. (13 mm).

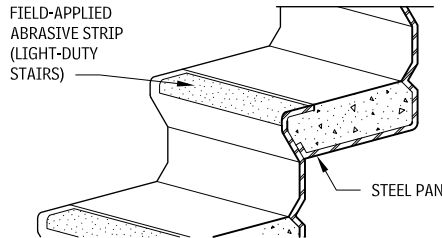
ACCEPTABLE NOSING PROFILES
1.135



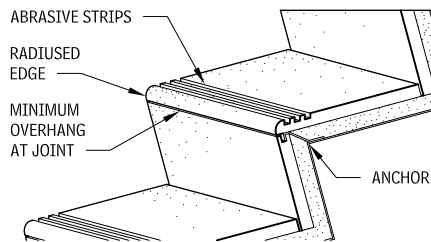
CAST METAL ABRASIVE NOSING



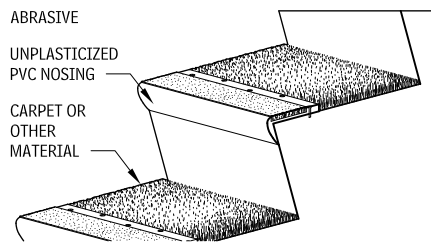
CAST METAL NOSING FOR CONCRETE STAIR



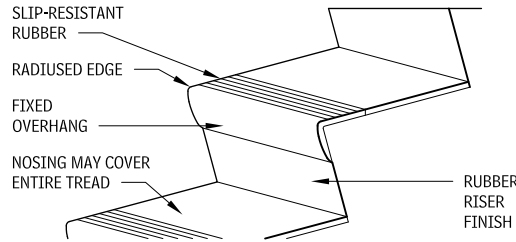
ABRASIVE TAPE ON NOSING



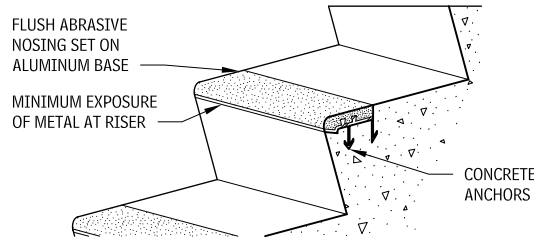
STONE TREAD



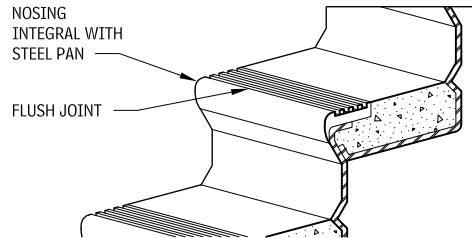
PVC NOSING



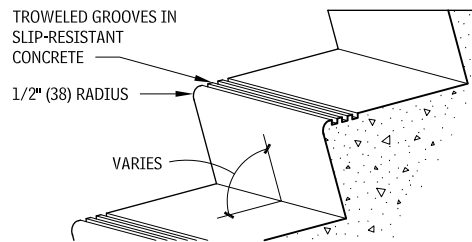
VINYL OR RUBBER NOSING



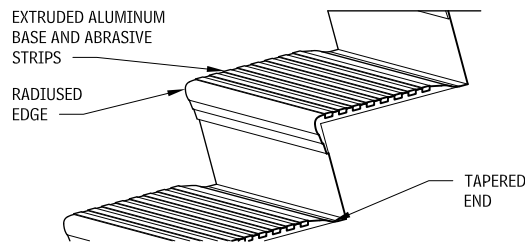
ABRASIVE EPOXY



STEEL SUBTREAD

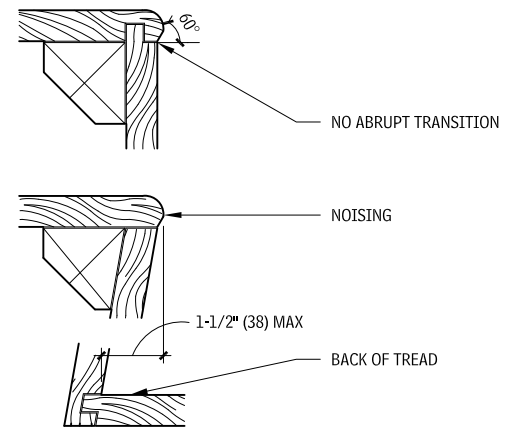


CONCRETE TREAD



FULL-TREAD NOSING

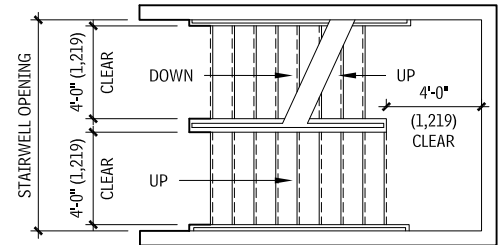
WOOD NOSINGS
1.136



AREA OF RESCUE ASSISTANCE

The ADA and building codes identify requirements for areas of rescue assistance. Areas of rescue assistance are stairway clear widths that allow for easier maneuverability of rescue personnel and physically challenged persons, as well as the clear dimensions at specified areas on landings provided as waiting areas for a person in a wheelchair.

PLAN DIMENSIONS REQUIRED FOR RESCUE ASSISTANCE (ADA)
1.137



WOOD STAIRS

Wood stairs used in private, residential applications usually are not governed by the ADA; however, wood stairs in commercial facilities and places of public accommodation must conform to ADA/ABA Accessibility Guidelines.

Verify requirements that may differ from the general recommendations provided here. In general, a minimum interior stair width of 36 in. (914 mm) should be provided.

The minimum headroom is 6 ft 8 in. (2,032 mm), as measured vertically from a diagonal line connecting tread nosings to the underside of the finished ceiling or stair landing directly above the stair run. The recommended headroom is 7 ft (2,134 mm).

Only handrails and stair stringers may project into the required width of a stair. Use the following guidelines:

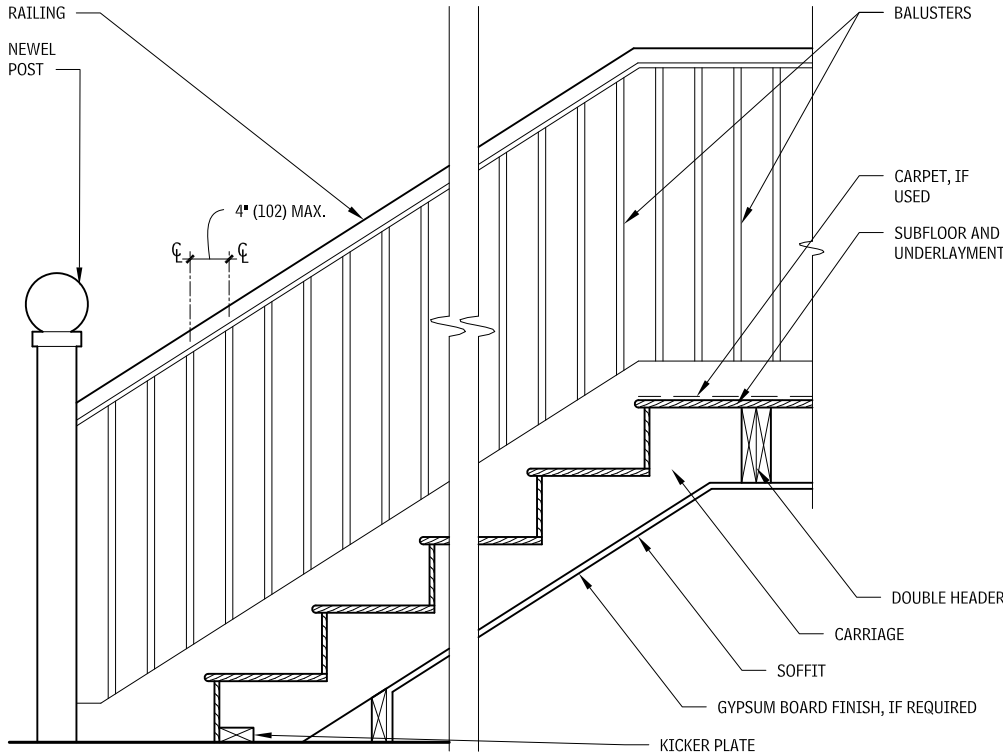
- The maximum handrail projection is 4-1/4 in. (114 mm).
- To comply with ADA/ABA Accessibility Guidelines, no projections are allowed into the minimum required stair width.
- The width of a landing or platform should be at least as wide as the stair.
- The maximum vertical rise of a stair between landings is 12 ft (3,658 mm).
- The riser height should be 4 in. (102 mm) minimum and 7 in. (178 mm) maximum.
- The tread depth should be 11 in. (279 mm) minimum, measured from riser to riser.

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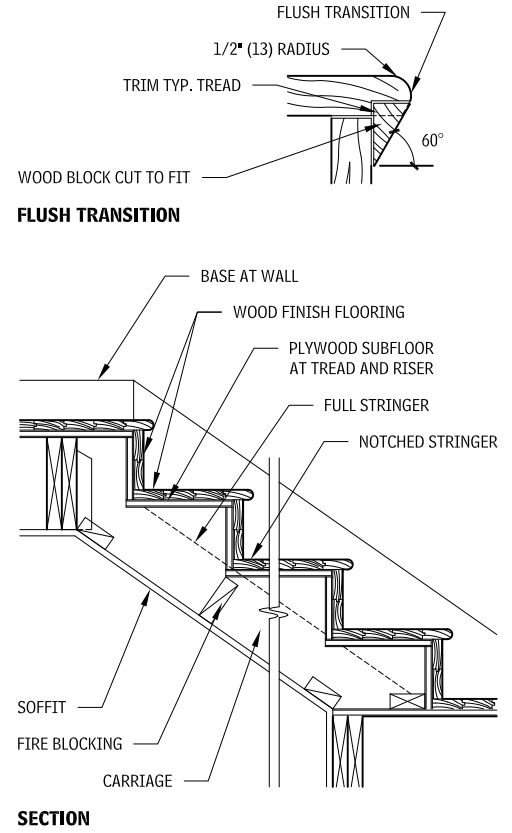
- Variation in adjacent treads or risers should not exceed 3/16 in. (5 mm). The maximum variation allowed in the tread depth or riser height within a flight of stairs is 3/8 in. (10 mm). ADA/ABA Accessibility Guidelines require uniform treads and risers.

- Nosings project 1-1/4 in. (31 mm) maximum. Verify building codes and ADA/ABA Accessibility Guideline requirements.
- Open riser stairs do not comply with ADA/ABA Accessibility Guidelines.

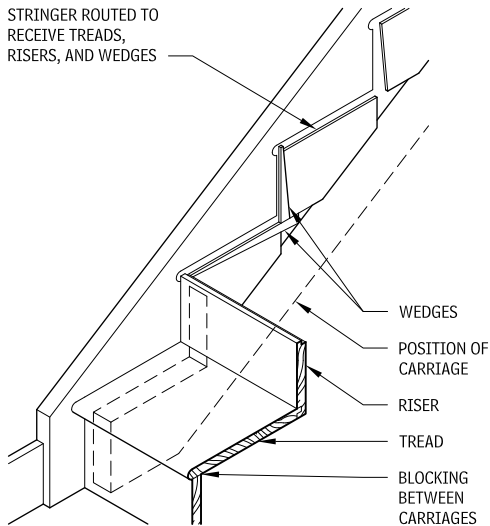
WOOD STAIR SECTION
1.138



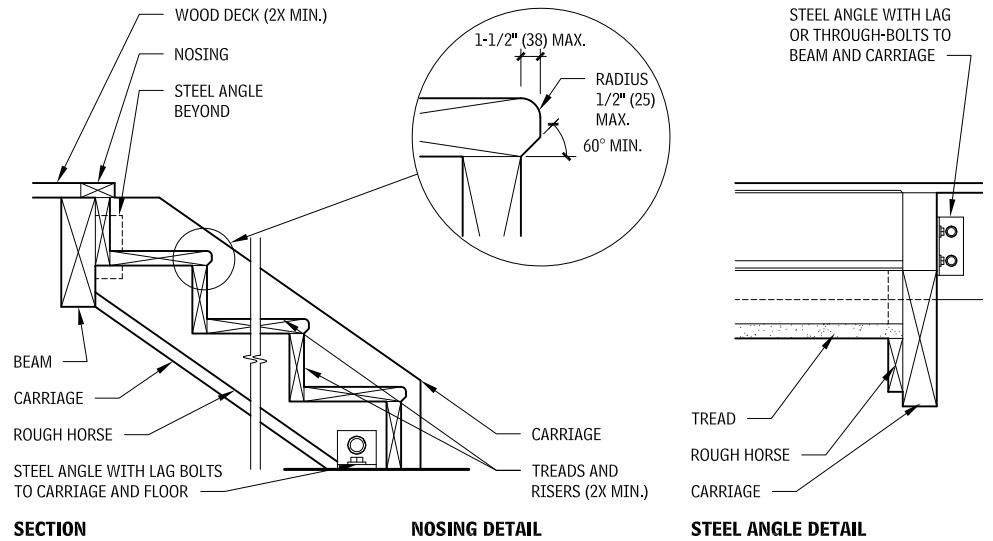
CLOSED RISER STAIR—WOOD FINISH
1.140



TREADS AND RISERS AT HOUSED STRINGER
1.139

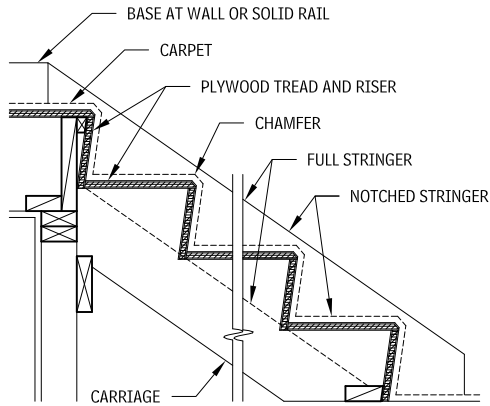


DIMENSIONED LUMBER STAIR
1.141

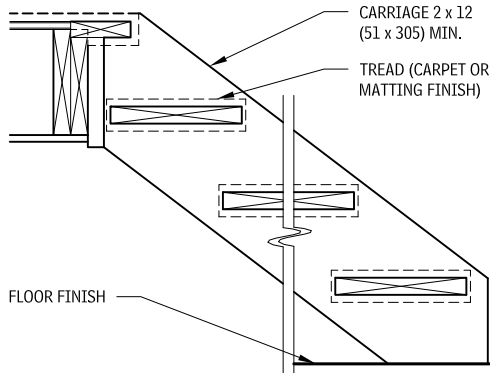


STEEL ANGLE DETAIL

CLOSED RISER STAIR—CARPET FINISH
1.142



OPEN RISER STAIR
1.143

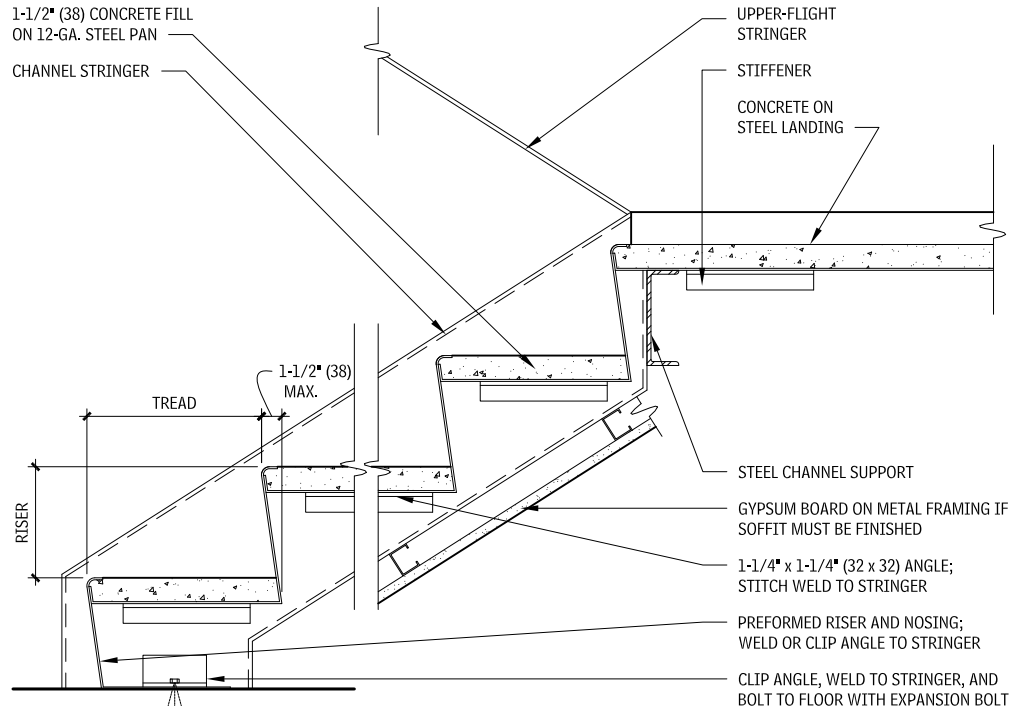


METAL STAIRS

Metal stairs are normally constructed of steel and fabricated in the shop to fit the dimensions required by the opening in which they are to be used.

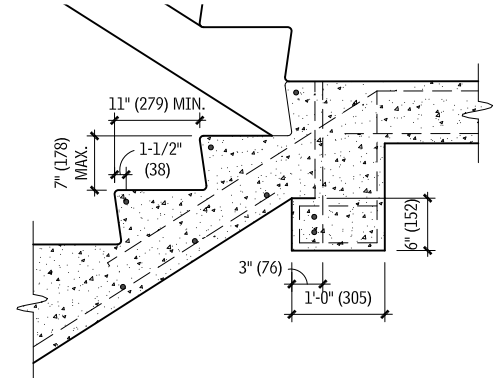
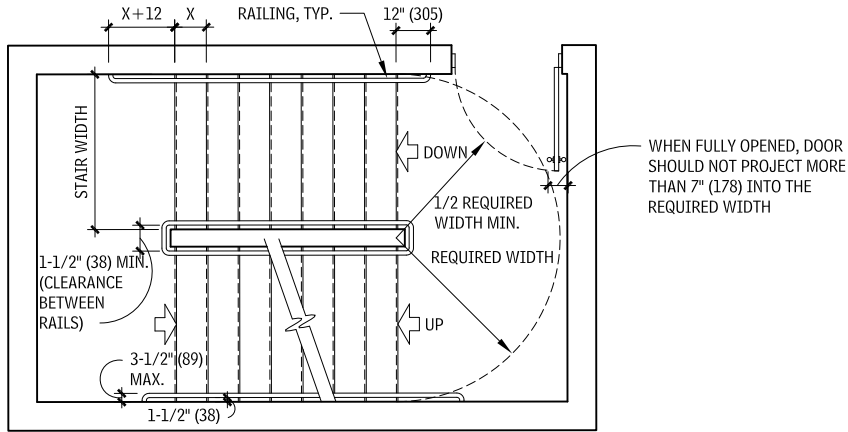
Treads and landings are typically filled with 1-1/2 to 2 in. (38 to 51 mm) of concrete. A finish material can then be applied over the concrete. Balusters are anchored by welding, bolting, or screwing them to the stringers. Glass balusters are anchored into a special U-shaped channel, which is attached to the edge of the stringer. A similar detail can be used for glass railings.

METAL PAN STAIR SECTION
1.144

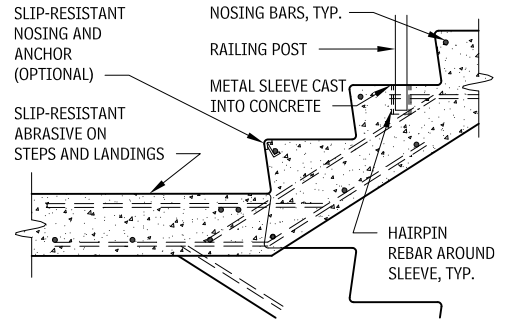


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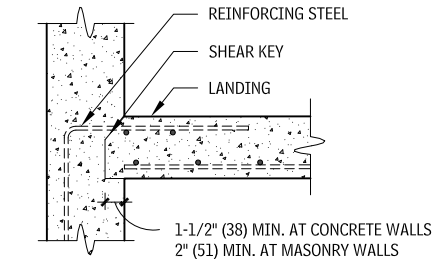
U-TYPE CONCRETE STAIRS
1.145



DETAIL A

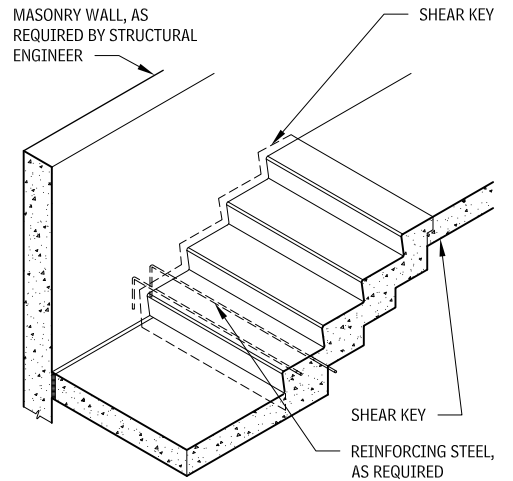


DETAIL B

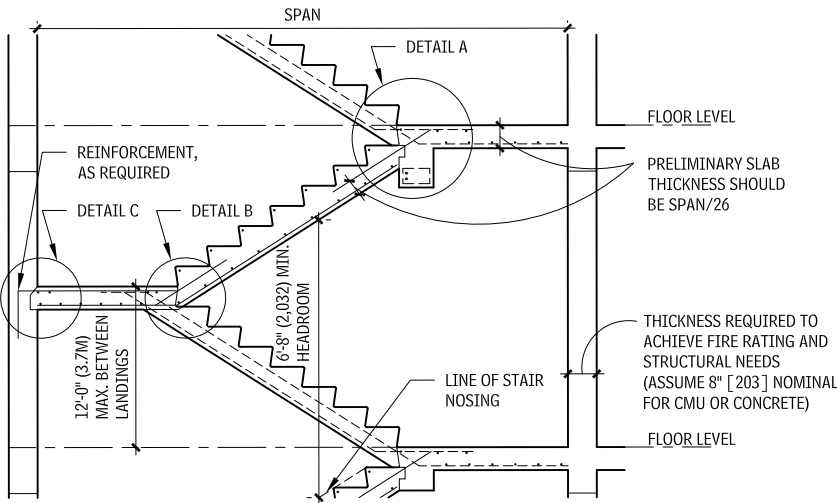


DETAIL C

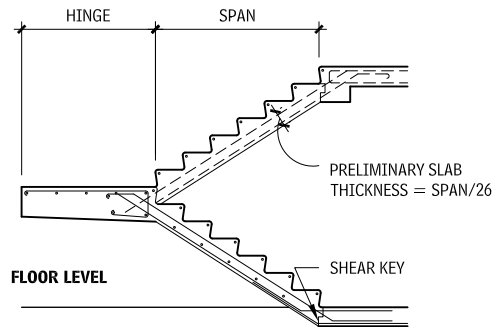
CANTILEVER CONCRETE STAIR
1.148



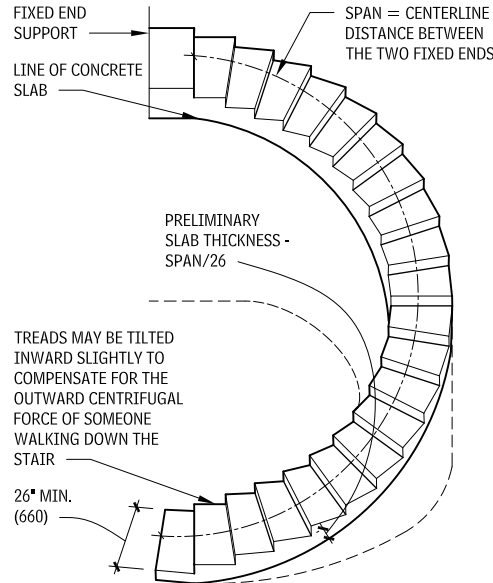
PLAN



SECTION
FREESTANDING CONCRETE STAIR
1.146



HELICOIDAL CONCRETE STAIR
1.147



NOTES

- 1.145 a. Consult structural engineer for reinforcing steel placement.
- b. Verify required dimensions and clearances for code compliance.
- 1.146 Limit hinge dimension to requirements of stair.
- 1.147 Use of helicoidal concrete stairs depends on a fixed-end support and small support deflection.
- 1.148 a. Reinforcing steel must develop full bond in masonry walls and have full development length in concrete walls.
- b. Detail of shear key is similar to Detail C in Figure 1.145.

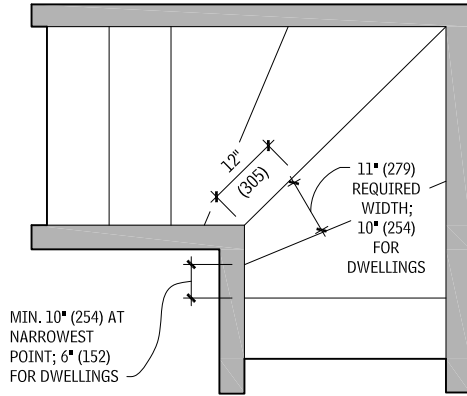
Contributors:
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ALTERNATE STAIR TYPES

Alternate stair types include *winding stairs*, *curved stairs*, and *spiral stairs*. Generally, the IBC does not allow these types of stairs to be used for egress except within private dwelling units. Spiral stairs may also be used as egress from a space not more than 250 sq ft (23 sq m) and serving not more than five occupants.

When these alternate stair types are allowed, they must meet the minimum dimensional requirements of the codes. Riser heights for curved and winding stairs must meet the code maximums of 7 in. (178 mm) for commercial stairs and 7-3/4 in. (197 mm) for residential stairs. Riser heights for spiral stairs must be such that a clear headroom of 78 in. (1,981 mm) is provided, but in no case can the riser height be greater than 9-1/2 in. (241 mm).

WINDING STAIRWAY
1.149

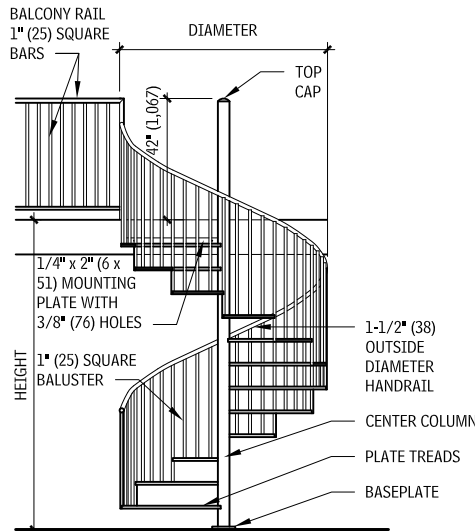


SPIRAL STAIRS

Spiral stairs are composed of wedge-shaped treads supported from a central column, usually 4 in. (102 mm) in diameter. Prefabricated spiral stairs are commonly made from steel.

Spiral stairs are available in custom sizes. To meet building code requirements as a means of egress, stairs must be at least 5 ft (1.5 m) in diameter to meet the 26 in. (660 mm) clear-width requirement, assuming a 4 in. (102 mm) center post. Larger diameters increase perceived comfort, ease of use, and safety.

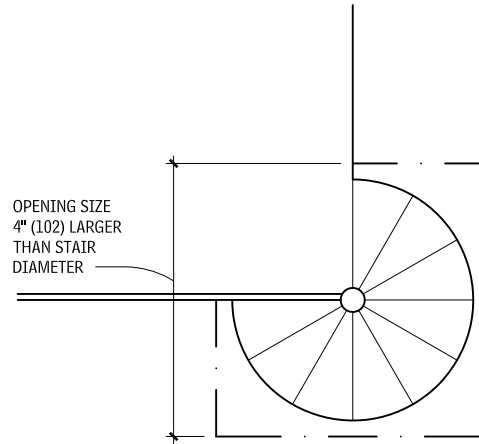
SPIRAL STAIR ELEVATION
1.150



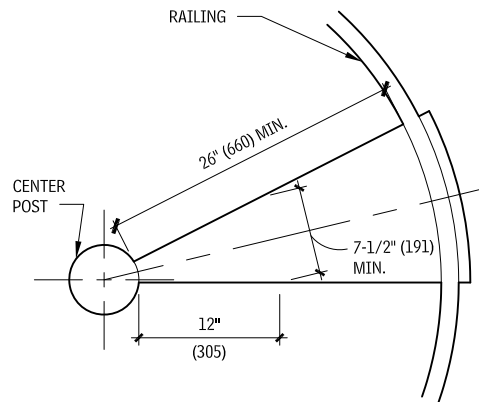
Spiral stairs are available with 22-1/2°, 27°, and 30° angle treads. The most common are 27° and 30° tread angles because these can maintain at least a 7-1/2-in. (190 mm) dimension 12 in. (305 mm) from the center pole. Tread selection depends on the riser height desired, the total rise, the headroom clearance requirements, and the top and bottom riser orientation.

Critical minimum headroom dimensions should be calculated based on a three-quarter turn of the stair, even if a full 360° turn is being used to travel the full rise.

SPIRAL STAIR PLAN VIEW
1.151



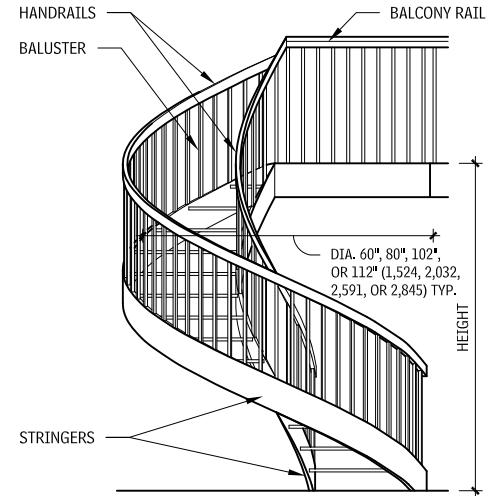
SPIRAL STAIR DETAIL
1.152



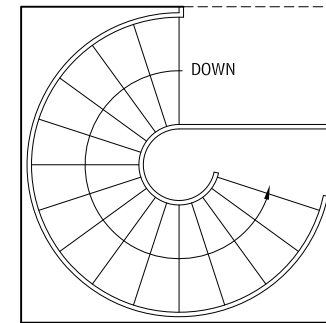
CURVED STAIRS

Design considerations for curved stairs are similar to those for spiral stairs. A fabricated steel tube serves as a one-piece stringer to which treads are bolted or welded. Risers can be open or closed.

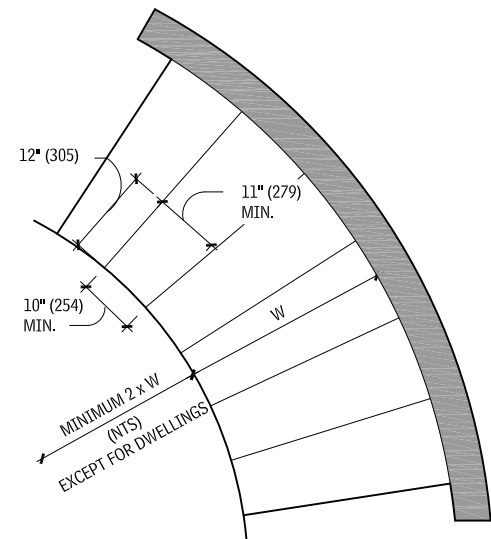
CURVED STAIR ELEVATION
1.153



CURVED STAIR PLAN
1.154



CURVED STAIR DETAIL
1.155



NOTE

1.150 For clarity, only one baluster per tread is shown.

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RAMP DESIGN AND CONSTRUCTION

LECTURE HALL FLOORS

Lecture halls with tiered or sloped floors offer better viewing angles for students than lecture halls with flat floors. Overall rise and run dimensions for sloped floors are determined by desired viewing angles. Most building codes limit the slope of ramped aisles to one unit vertical in eight units horizontal (12.5% slope) in lecture halls with sloped floors. Ramped aisles require a slip-resistant floor surface.

ACCESSIBLE RAMPS

Ramps on accessible routes are required to comply with ADA/ABA Accessibility Guidelines. The 2004 standards require that ramp runs have a running slope not steeper than 1:12 (rise over run), with some exceptions for space limitations in existing sites, buildings, and facilities.

To accommodate the widest range of users, guidelines recommend the provision of ramps with the least possible running slope. Wherever possible, accompany ramps with stairs for use by people who find long ramps a greater barrier than stairs, for example, individuals with heart disease or limited stamina.

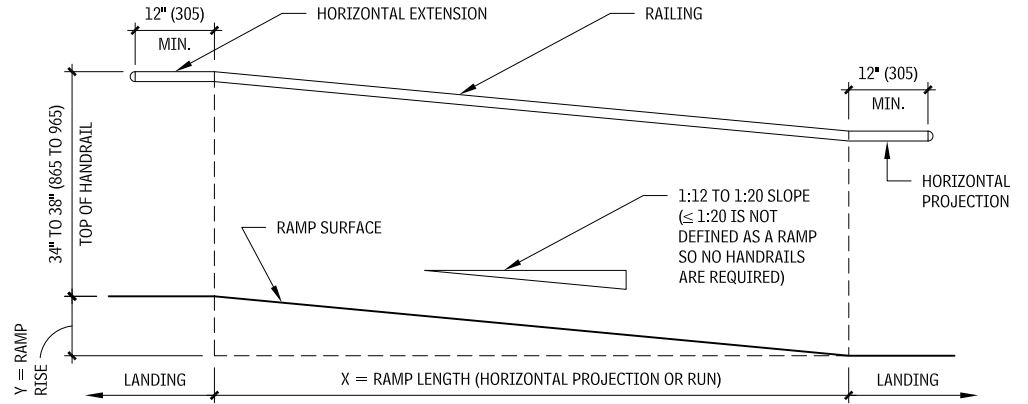
The cross slope of a ramp is the slope of the surface perpendicular to the direction of travel, measured rise over run. ADA/ABA Accessibility Guidelines limit cross slopes of ramp runs to a maximum of 1:48.

Changes in level other than running slope and cross slope are not permitted on ramp runs. Surfaces must be stable, firm, and slip resistant. Carpet or carpet tile must be firmly attached, with a firm cushion or pad where either is used. Acceptable pile textures include level loop, textured loop, level cut pile, or level cut/uncut pile. The maximum allowable pile height is 1/2 in. (13 mm). Exposed edges of carpet must be fastened to the floor surface and trimmed along their entire length.

Edge protection is required on each side of ramp runs and at each side of ramp landings, with some exceptions. A curb or barrier must prevent passage of a sphere 4 in. (102 mm) in diameter, where any portion of the sphere is within 4 in. (102 mm) of the finish floor or ground surface.

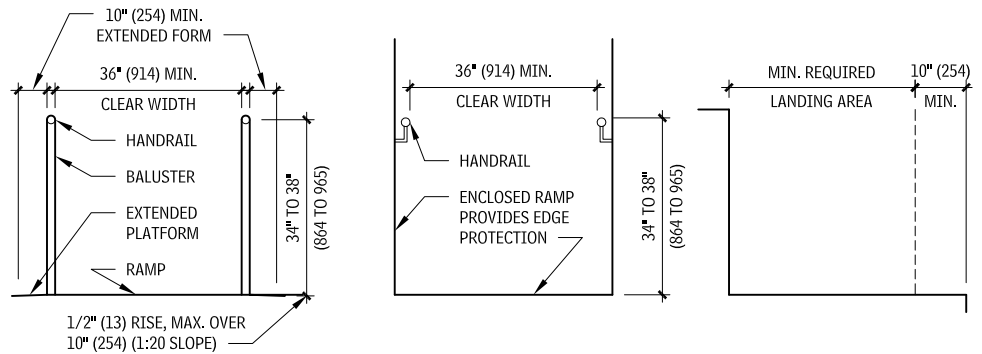
In assembly areas, aisle ramps adjacent to seating that are not serving elements required to be on an accessible route are not required to comply with ADA/ABA Accessibility Guidelines.

COMPONENTS OF A RAMP
1.156



Y CANNOT EXCEED 30" (760) WITHOUT INTERMEDIATE LANDINGS

RAMP AND RAMP LANDING EDGE
1.157

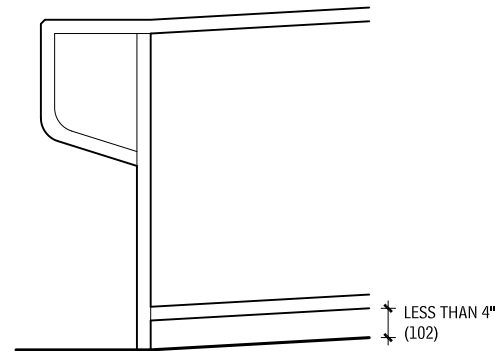


RAMP WITH BALUSTERS

RAMP WITH HANDRAILS

LANDING PLAN

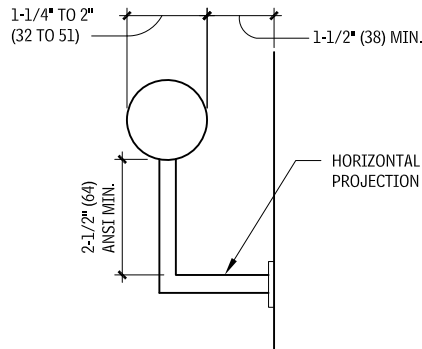
RAMP EDGE BARRIER
1.158



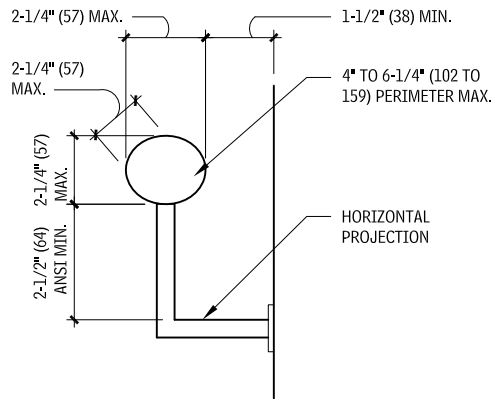
RAMP HANDRAILS

Provide continuous handrails at both sides of ramps and at the inside of handrails of switchback or dogleg ramps. If handrails are not continuous at bottom, top, or landings, provide handrail extensions. The ends of handrails must be returned smoothly to floor, wall, or post.

HANDRAIL DESIGN 1.159

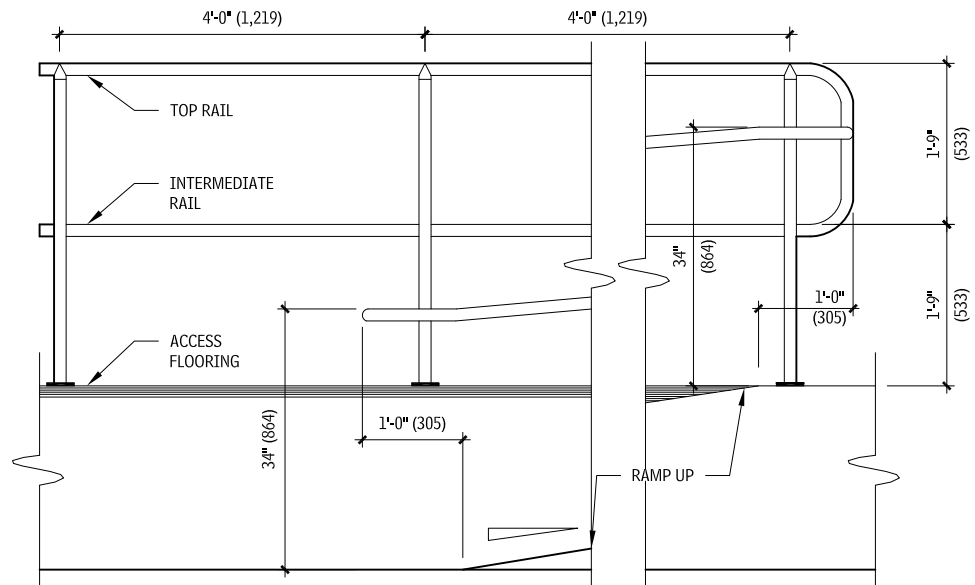


CIRCULAR

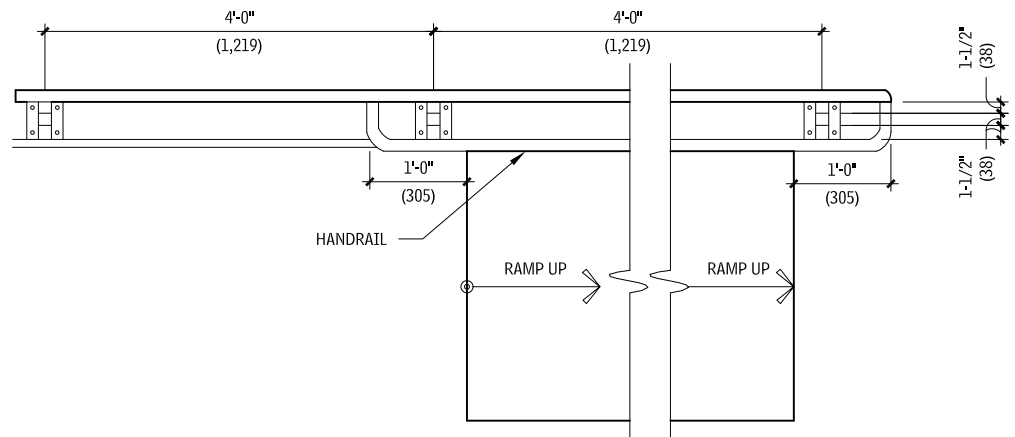


NONCIRCULAR

RAIL AT RAMP 1.160



ELEVATION



PLAN

