The architect has not met the standard of care for this building. The firm’s contract with the owner holds the architect responsible for the design of the building, including the work of the structural engineer and any structural load requirements.

The answer is (B).

OFFICE ORGANIZATION

Several aspects should be considered in the organization of an architectural office, including

- work organization
- support staff
- regulations governing architectural practice

Work Organization

A firm’s staff can be organized in various ways in order to work on and complete projects. The most traditional structure is departmental organization, sometimes called horizontal organization or flat organization. In this structure, the staff is organized into departments, each of which specializes in a different function. There may be a marketing department, a design department, a specifications department, a contract documents department, and a construction administration department. Every department works on every project as needed, and a project moves from one department to another in its route from start to finish.

Departmental organization is very efficient, allowing a firm to standardize and fine-tune its processes, make full use of many types of specialists, and create economies of scale. However, it can also make a business inflexible and resistant to innovation and change. Keeping communication open among departments can be a challenge. It can be difficult for employees to gain breadth of experience or to share knowledge outside their specialties.

A studio organization, sometimes called a vertical organization or tall organization, is organized around groups of employees called studios. Each studio is responsible for completing an entire project, from initial planning to production and construction administration. Within each studio, members must have among themselves the expertise needed to accomplish all or most of the work required for their project. Studios can be created and dissolved as the need arises, or they can remain intact and be assigned new projects based on their particular strengths and expertise. For example, a firm may have one studio for retail projects, another to do industrial work, and another to provide office planning.

The advantages of studio organization include close and immediate communication among members of the design team and the synergy that comes from sharing ideas and group problem solving. Studios also work well with a strong project manager system, in which the project manager has daily contact with the design and production teams as well as with the client. Sometimes studio organization is combined with one or more departments that provide very specialized work, such as specification writing.

Smaller firms may work on a very informal basis, where the principal or the partners complete the client contact and design work and then hand off the production and administration to other employees.

Many firms, both large and small, outsource some of their work. Outsourcing is contracting with another company to do some of the work needed for a project. Among architectural firms, the production of construction documents and renderings is often outsourced. Outsourcing is discussed in greater detail in Chap. 3.

Outsourcing requires careful management and coordination, but it can be a way to manage a fluctuating workload without continually hiring and firing employees. Firms may outsource to either foreign or domestic companies.
Financial Ratios

There are many other ratios and values that firm management, accountants, and banks use to measure a business’s financial health. These ratios and values can be compared against industry benchmarks to determine whether corrective action is needed.

- **current ratio**: Total current assets divided by total current liabilities. This is a measure of a firm’s ability to meet current obligations. Generally, the higher the ratio, the better, with 1.5 or more indicating a healthy business and 1.0 being about the minimum acceptable level.

- **net profit before tax**: The percentage of profit based on net revenue—the total annual revenue minus consultants’ fees and reimbursable expenses.

- **overhead rate**: Total office overhead (or total indirect expenses) divided by total direct labor. This ratio should be in the range of 1.30 to 1.50. When used to calculate fees, this ratio is multiplied by the estimated cost of direct labor, and the resulting product is added to the direct labor amount.

- **quick ratio**: A refinement of the current ratio including only cash and cash equivalents, plus accounts receivable, plus revenue earned but not billed, divided by total current liabilities. The quick ratio is a more conservative measure than the current ratio because it includes only the most liquid assets. The quick ratio and the current ratio are commonly included on balance sheets.

- **revenue per technical staff**: The amount of net revenue produced per technical staff member, or those staff members most directly involved with charging direct time and producing jobs. This number can be used to estimate the required net operating revenue for future budgets. If a firm’s operating revenue is known, revenue per technical staff can be used to estimate staffing levels.

- **revenue per total staff**: The amount of net revenue produced per staff member per year, including principals and part-time employees. This ratio is the annual net operating revenue divided by the total number of employees. It can be used in the same way as revenue per technical staff.

Example 2.1

For accounting purposes, a large plotter is considered

(A) a current asset  
(B) a fixed asset  
(C) a liability  
(D) an overhead expense

Solution

An asset is anything a business owns that can be given a value. A current asset is either cash or an asset that is expected to be converted into cash within one year, such as accounts receivable. An item that is used in the long term, such as a plotter, is considered a fixed asset. A liability is a claim made against the total assets of a business, either by a person outside the business or by an owner of the business. An overhead expense, such as salaries, rent, power, or telephone, is an expense incurred in order to keep a business operating whether or not any revenue is being generated.

The answer is (B).

Setting Fees

One of the most important aspects of making an architectural business profitable is setting suitable fees. The most common method is to charge an hourly rate per staff member working on a project. This hourly rate is known as the billing rate, and it may vary with the position and experience of the staff member as well as the type of service provided. (See Chap. 5 for a discussion of the various methods of charging professional fees.) Even if the client asks for a stipulated lump sum fee proposal, that number
• Does the prospective client have a history of litigation with professionals, consultants, and contractors?

• In initial meetings, has the prospective client made unreasonable requests or shown unreasonably high expectations? These should be “red flag” indications. The client may continue to have unreasonable expectations throughout the project. These expectations most often involve schedule and budget constraints, but can also include strong preconceived ideas about design solutions and products.

If the architect decides accept the job, the architect must first negotiate an agreement with the client that determines the scope of the work, fees required, and other aspects of the contract. (See Chap. 5 for more information on owner-architect agreements.) Part of the negotiations may involve developing a preliminary design and construction schedule to help determine the project's feasibility—and the architect's expected fees—before a complete owner-architect agreement is written. Having such an agreement in writing, even if just in the form of a simple letter or memo, reduces potential risk.

If another architect or design professional has been involved with the project, the architect should determine whether any formal or informal agreement currently exists between the owner and the other design professional. The architect should not accept work from the owner unless the agreement with the other architect or design professional has been dissolved. Under the current versions of the AIA Code of Ethics & Professional Conduct, an architect may supplant or replace another architect on a project; however, seeking to interfere with an existing contractual relationship is still often regarded as unethical and in some cases may also be illegal.

SELECTING A PROJECT DELIVERY METHOD

The term project delivery describes the entire sequence of events that is needed to provide an owner with a completed building. It includes the selection of people who will design and construct the project, the establishment of contractual relationships, and some method of organizing contractors to perform the work. This section reviews some of the elements of project delivery and discusses the main project delivery methods.

Responsibility for Design and Construction

Traditionally, the owner hires an architect to design the project and a contractor to build it. The architect acts as agent for the owner, looking after the owner's best interests, with no financial stake in the project. The contractor agrees to provide, for a fixed price and within a certain time period, the materials and labor needed to construct the project according to the plans and specifications. In this project delivery model, the owner has separate contracts with the architect and the contractor.

More recent project delivery methods include a single entity being responsible for both designing and building a project, the involvement of a construction manager, and having all those involved in the design and construction process working together on one team.

Factors in Selecting a Method

Although the owner is often the one who selects the project delivery method (especially if the owner has had experience with other construction projects), the architect may be in the best position to evaluate the many variables that affect the choice. These variables include cost, schedule, project scope, building quality, and risk.

Cost

Cost is an important factor in choosing the project delivery method. Traditionally, owners have chosen the design-bid-build method in order to achieve the lowest cost. There is considerable risk, though, that in the end the building will cost more than the lowest bid.
Using standard AIA documents, there are three ways to establish the contractual relationships between the primary participants in IDP:

- with transitional forms
- with a multi-party agreement
- with a single purpose entity

**Transitional Forms**


**Multi-party Agreements**

A *multi-party agreement* is a single agreement executed by the owner, architect, contractor, and other key project participants for the design, construction, and commissioning of a project. This type of agreement is governed by AIA Document C191, *Standard Form Multi-Party Agreement for Integrated Project Delivery*. As with other IPD documents, the multi-party agreement outlines a collaborative working relationship that encourages the parties to meet the cost and performance goals they jointly established. An IPD project is managed by a project management team; in addition, a project executive team provides a second level of project oversight and conflict resolution. Each team consists of one representative from each major party to the agreement.
As described in Chap. 1, most firms are organized on either the departmental or the studio model. A firm that specializes in a few building types or that wants to maximize efficiency will often use departmental organization; each project moves through each department in the overall design and production process, and individual specialists apply their expertise at each stage. A design-based firm can also manage projects in this way once the principal has developed the overall design. Generalist firms and some specialist firms often use studio organization, where most of the design and production for each project is responsibility of a single group of employees. Some larger offices have studios that specialize in certain building types, combining the advantages of expertise with the advantages of close communication and group problem solving.

**Documentation Methodologies**

The methods a firm uses to document a project and generate the needed construction drawings and specifications can affect productivity and profitability. Each firm uses its own preferred set of software and hardware tools.

For the design development phase, there are a variety of computer programs available to help the architect visualize and analyze project design. Once a project has reached the construction document phase, however, there are just a few computer-aided drafting (CAD) programs to choose from: either a two-dimensional (2-D) drafting program or the document production component of a three-dimensional (3-D) building information modeling (BIM) program. Some firms employ experienced architects who are also proficient with the office’s CAD programs, while other firms use the more traditional model, in which experienced staff design plans and elevations and develop details that are then documented by entry-level staff who are experts at using the CAD or BIM programs. See Chap. 46 for a discussion of BIM.

While most firms use in-house staff to complete drawings, some elect to outsource portions of the work on a project-by-project basis, either locally or to overseas companies. Outsourcing is the practice of contracting with another company for the production of a certain part of the architect's work product. Most often, this includes drafting work that would traditionally be done by junior-level employees, such as construction documents, renderings, and 3-D modeling. Outsourcing can be an economical way to produce construction drawings, and it can help a firm manage fluctuating workloads, reduce production time, and take on more work. However, it also requires additional management and coordination by the firm.

For specifications, most firms either hire the services of a specification-writing firm, or they subscribe to a master specifications system and use the system’s software to produce documents in-house. Some large firms have an in-house specification writer and a master set of specifications. Regardless of how it develops specifications, a firm should follow the guidelines discussed in Chap. 49. The architect always bears the final responsibility for the content of specifications and their coordination with drawings.

**Consultant Coordination**

Professional consultants who will be involved in a project should be brought in as early as possible. Their advice and expertise is vital to determining the scope of the building project (especially if the project involves the renovation of an existing building), developing broad conceptual approaches to designing the building, and understanding the concerns of the client and other design professionals working on the project.

One of the most important tasks an architect has during pre-design is to assemble and coordinate a team of professional consultants to work on the project. Most project teams will include, at a minimum, structural and building systems engineers (mechanical, electrical, and plumbing). Additional consultants may include geotechnical engineers, civil engineers, fire protection engineers, historic preservation specialists, security consultants, interior designers, and audiovisual consultants. The architect can hire consultants to perform energy analyses, create renderings, build models, and perform dozens of other services. What services are expected from each consultant must be determined with the advice of the consultant and the approval of the client.
• The contractor is not required to ascertain that the contract documents are in accordance with the requirements of the certifying authority, but if the contractor becomes aware of such conditions, the contractor must notify the architect.

• If the contractor wants to make a substitution, he or she must include a written description identifying any potential effect the substitution may have on the project’s achievement of a sustainable measure or the sustainable objective.

• The contractor must complete any sustainability documentation required by the sustainability plan or other contract documents. This may include documentation that must be submitted after substantial completion.

• For construction waste management, the contractor must recycle, reuse, remove, or dispose of materials as required by the contract document. As part of this requirement, the contractor must prepare and submit to the architect and owner a construction waste management and disposal plan.

SUPPLEMENTARY AND SPECIAL CONDITIONS OF THE CONTRACT

Because each construction project is unique, not every condition can be covered in a standard document such as AIA Document A201, General Conditions of the Contract for Construction. Each job must accommodate a different combination of client needs, governmental regulations, and local laws.

In most cases, the conditions unique to the job are handled by modifying AIA Document A201. If desired, however, they may also be given in a separate document referred to as the supplementary conditions. Because the AIA contract documents are coordinated with one another and contain numerous cross references, using a separate document is preferable when modifying AIA Document A201 would involve deleting entire sections and renumbering others. There is no AIA standard form for supplementary conditions, but AIA Document A503, Guide for Supplementary Conditions, gives guidance and model language that can be used in modifying or supplementing the General Conditions.

In two cases, additional conditions should be separate from the contract. Matters pertaining only to the bidding process should be included in the bidding documents. Administrative and procedural requirements should be given only as broad provisions in the General Conditions and should be explained in detail in Division 01 (“General Requirements”) of the specifications.

It is impossible to give a complete list of the provisions that may be included in the supplementary conditions, but examples include:

• permission for the architect to furnish the contractor with instruments of service in electronic form
• additional information and services provided by the owner
• the cost for the architect to review the contractor’s requests for substitutions
• provisions for the owner, instead of the contractor, to pay for utilities
• the requirement that the contractor employ a superintendent to coordinate mechanical and electrical work
• provisions for fast-tracked scheduling
• reimbursement by the contractor for extra site visits by the architect that are made necessary by the fault of the contractor
• additional protection for the owner against claims for additional time or for consequential damages
• requirements for more detailed information on costs and overhead
• additional requirements for payment procedures
• requirements for liquidated damages and bonuses
• additional requirements for bonding and insurance
NFPA 252
NFPA 252, *Standard Methods of Fire Tests of Door Assemblies*, is similar to ASTM E119; it evaluates how well a door or other opening assembly resists the passage of flame, heat, and gases. The first part of the test establishes a fire endurance rating; the hose stream test then determines whether the door will stay within its frame when subjected to a standard blast from a fire hose after exposure to fire. Similar tests include UL10B, *Standard for Fire Tests of Door Assemblies*, and UL10C, *Standard for Positive Pressure Fire Tests of Door Assemblies*.

NFPA 257
NFPA 257, *Standard on Fire Test for Window and Glass Block Assemblies*, gives specific fire and hose stream test procedures to use to establish the degree of fire protection, given in units of time, for window openings in fire-resistive walls. This standard determines the degree of protection that the glazing assembly provides from the spread of fire, including flame, heat, and hot gases.

Finish Material Flammability Tests
The three tests most often used for testing the flammability of finish materials in building construction are ASTM E84, NFPA 265, and NFPA 286. (Flammability standards for carpet are described in Chap. 29.) A particular building code will not necessarily include all three. Two more tests, NFPA 289 and NFPA 701, are used to test the flammability of specific kinds of items.

Flammability tests for building and finish materials determine

- whether a material is flammable, and if so, whether it simply burns with applied heat or supports combustion (adds fuel to the fire)
- the material’s degree of flammability (how fast fire spreads across the material)
- how much smoke and toxic gas the material produces when ignited

**ASTM E84**
ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, is one of the most common fire testing standards. This method, also known as the Steiner tunnel test, rates the surface burning characteristics of interior finishes and other building materials.

The test is performed by placing a sample piece of the material in a narrow test chamber with a controlled flame at one end. The material is given a *flame spread index* (FSI) from 0 to 100. The scale is arbitrary; glass-reinforced cement board is assigned an FSI of 0, and red oak flooring is assigned an FSI of 100.

<table>
<thead>
<tr>
<th>class</th>
<th>flame spread index</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (I)</td>
<td>0–25</td>
</tr>
<tr>
<td>B (II)</td>
<td>26–75</td>
</tr>
<tr>
<td>C (III)</td>
<td>76–200</td>
</tr>
</tbody>
</table>

With this test, materials are classified into three groups based on their flame-spread characteristics. These groups and their flame spread indexes are given in Table 8.1.

Class A is the most fire resistant, and Class C is the least. Product literature generally indicates the flame spread of the material, either by class (letter or Roman numeral) or by numerical value. Building codes then specify the minimum flame-spread requirements for various occupancies in specific areas of the building. These are discussed in Chap. 14 under Finishes.

ASTM E84 can also be used to generate a *smoke-developed index* (SDI), a measure of the concentration of smoke emitted by a material as it burns.

**NFPA 265**
NFPA 265, *Standard Methods of Fire Tests for Evaluating Room Fire Growth Contribution of Textile or Expanded Vinyl Wall Coverings on Full Height Panels and Walls*, is also sometimes referred to as the *room corner test*. 
For most locations in the northern hemisphere, the best overall orientation for a building is with its principal facade facing south or slightly east or west of south. An orientation from 5° to 25° east of south, depending on the climatic region, is considered an ideal balance between maximizing heat gains in winter and minimizing heat gains on the east and west facades in summer. See Fig. 12.16.

Window overhangs can be used to shade windows in summer while letting the sun strike windows in winter for passive solar heating. See Fig 9.1. On east and west facades, however, vertical sun baffles are more effective than overhangs, because the summer sun is lower in the morning and afternoon, when it strikes the windows on these sides.

Louver can be used to shield a building and its interior from the sun. Both exterior and interior louvers and shades are effective, but exterior louvers are more efficient because they block the sunlight before it enters. Deciduous trees can also shield low buildings from the sun in the summer, while allowing sunlight to enter the building in the winter.

Solar orientation can influence outdoor activities. In hot, humid climates, it is better to locate patios, outdoor restaurants, and the like where they receive shade from the building or trees. In more temperate climates, the same spaces are best located where they receive warmth from the sun in winter, spring, and fall.

In some cases, solar orientation can also affect the placement of building entries. In cold climates, entries are best placed on the south side, where direct sun can melt ice and snow in the winter.

The orientation of the building in regard to winds is a closely related issue. Chapter 7 and Chap. 12 review the effects of wind on building location and how landscaping can be used to mitigate them. The orientation of a building and the locations of windows, plazas, and other elements can either take advantage of cooling breezes in hot, humid climates during the summer or shield the building and occupants from cold winds in the winter. In most temperate climates, prevailing wind patterns change with the seasons, so a wind analysis is needed to determine the direction of summer and winter winds. Shielding a building as much as possible from winter winds can reduce the heat loss through the walls, and providing for natural ventilation can help cool the building during the summer. Windbreaks can be formed with vegetation, buildings, or other manufactured site elements such as screens and fences.

Design Strategies for Climatic Regions

There are four broad climatic regions in the United States:

- The cool region includes all of Canada, the northern part of the middle United States, and the mountainous regions of Wyoming and Colorado.
- The temperate region includes most of the middle latitudes of the United States, including the northwest and northeast areas of the country.
- The hot-humid region includes the southeastern parts of the country.
- The hot-arid region stretches from Southern California across the desert southwest to portions of southern Texas.

Traditionally, architects have based their climate-specific design strategies on these four regions. Knowing the characteristics of these regions is usually enough to suggest general approaches to design during site analysis.
9. New additions, exterior alterations, or related new construction shall not destroy historic materials that characterize the property. The new work shall be differentiated from the old and shall be compatible with the massing, size, scale, and architectural features to protect the historic integrity of the property and its environment.

New additions and adjacent or related new construction shall be undertaken in such a manner that if removed in the future, the essential form and integrity of the historic property and its environment would be unimpaired.

The National Park Service has established similar guidelines for preservation, for restoration, and for reconstruction. The ten general standards to guide restoration projects are

1. A property will be used as it was historically or be given a new use which reflects the property’s restoration period.
2. Materials and features from the restoration period will be retained and preserved. The removal of materials or alteration of features, spaces, and spatial relationships that characterize the period will not be undertaken.
3. Each property will be recognized as a physical record of its time, place, and use. Work needed to stabilize, consolidate, and conserve materials and features from the restoration period will be physically and visually compatible, identifiable upon close inspection, and properly documented for future research.
4. Materials, features, spaces, and finishes that characterize other historical periods will be documented prior to their alteration or removal.
5. Distinctive materials, features, finishes, and construction techniques or examples of craftsmanship that characterize the restoration period will be preserved.
6. Deteriorated features from the restoration period will be repaired rather than replaced. Where the severity of deterioration requires replacement of a distinctive feature, the new feature will match the old in design, color, texture, and, where possible, materials.
7. Replacement of missing features from the restoration period will be substantiated by documentary and physical evidence. A false sense of history will not be created by adding conjectural features, features from other properties, or by combining features that never existed together historically.
8. Chemical or physical treatments, if appropriate, will be undertaken using the gentlest means possible. Treatments that cause damage to historic materials will not be used.
9. Archeological resources affected by a project will be protected and preserved in place. If such resources must be disturbed, mitigation measures will be undertaken.
10. Designs that were never executed historically will not be constructed.

These guidelines are widely used at the federal level as well as by states, historic district commissions, and planning commissions. However, the architect must research any other specific regulations that may apply.

Surveying the Historic Structure

When surveying a historic building, the components listed in Surveying Existing Buildings apply. In addition, the structural survey of a historic building must include assessments of settlement, deflection of beams, and structural members damaged in previous renovations or for mechanical and electrical services. The physical survey should determine whether original or historic elements have been removed or altered, and if so, what their original appearance was.

The architect should identify the aspects of the building that define its historic character and put them in a list of priorities. These characteristics may include the overall form of the building, its materials, spaces, and workmanship, and other notable features that distinguish it from other buildings. A physical
Figure 12.23 Outdoor Sound Barriers

- For blocking noise from a point source, a short barrier should be at least four times as long as the distance from the barrier to the source, or the distance from the barrier to the receiver, whichever is shorter.

- A barrier should have a density of at least 5 lbm/ft$^2$ and be solid. However, densities greater than this do not improve sound attenuation significantly.

Some other methods of controlling site noise are as follows.

- **Maximize the distance between the source of the noise and the receiver.** In free space, sound from a point source decreases by about 6 dB each time the distance doubles. This is enough of a decrease to be noticeable, but not significant; a decrease of 10 dB is needed for the noise to be perceived as half as loud. When the noise comes from a linear source, such as a highway, it will only decrease by about 3 dB for each doubling of the distance. Locating a building as far as possible from a source of loud noise, such as a busy street, can mitigate the noise that reaches the building. However, on most urban and suburban sites, it will be difficult or impossible to make a significant difference.

- **Avoid hard surfaces near the source of noise.** Hard surfaces reflect sound and help it travel.

- **Avoid parallel hard surfaces.** They can intensify the noise. Where possible, orient buildings, walls, and other hard surfaces at angles from one another.

- **Plant evergreen trees and shrubs densely between the noise source and the receiver.** Plants have limited usefulness as sound barriers unless they are planted in large, deep groupings. To be effective (a sound attenuation of around 10 dB or more), the depth of the grouping must be 100 ft or greater. Planting is more useful when coupled with solid barriers or earth berms.

- **Control sources of noise that are in or near the building.** Locate mechanical equipment, service entrances, loading docks, and other noise sources away from usable outdoor spaces, building entrances, and any other areas where noise should be minimized.

- **Make use of masking sounds.** For example, the sound of a fountain or other source of running water in a usable outdoor space can mitigate noises at lower levels.

- **Design building features to block noise.** The overall shape of a building can be used to create isolated courtyards or block a source of noise. A solid balcony can block the path of a noise from outside before it strikes the glazing near the balcony. For glazing in critical areas, laminated glass can reduce how much noise penetrates the building.

Refer to Chap. 19 for more information on the basics of sound and controlling noise in buildings.

**SITE SECURITY**

*Site security* involves protecting a building or group of buildings from threats, which can range from common vandalism to intruders to vehicle-borne attacks.
A rainwater collection system is composed of a water collection system, a storage cistern, and a water distribution system. The water collection system is commonly a series of gutters and downspouts at the perimeter of the roof area of the building. If a roof is used as the catchment surface, the roofing materials should be selected to minimize contamination of the water and the addition of sediment. Good materials include epoxy-coated metal, clay or slate tiles, and new concrete tiles. Avoid using asphalt shingles, treated wood shakes, old concrete tiles (which may contain asbestos), or lead-containing materials such as flashing. Steep roofs work better than low-sloped roofs because they shed water more quickly, and they are scoured by winds and collect less dust and debris.

The area of the roof or other catchment surface is referred to as the catchment area. The catchment area is measured in terms of its “footprint” as projected onto a horizontal plane; the slope of the roof does not affect the size of the catchment area.

To calculate the amount of rainwater available, multiply the catchment area by the average annual rainfall for the region and by a factor, typically 75% or 0.75, to account for evaporation and other losses. One inch of rain yields about 0.6 gal of rainwater per square foot of catchment area.1

After the rainwater is collected it is stored in a cistern. This is a large tank, placed underground or at a convenient location on the site or on the building. Cisterns can be made from fiberglass, steel, or concrete. They must be watertight and covered to prevent contamination, and opaque to prevent algae growth. They also must be accessible for cleaning. If cisterns can be located above the area of use, water can flow by gravity; otherwise, small pumps are used to distribute the water.

In order to size a cistern with sufficient capacity, the amount of water to be drawn over a period of time must be calculated and subtracted from the available rainwater.

If the collected water will be used for irrigation, the runoff can be filtered first with screens on the gutters and then passed through a series of with graded screens, paper filters, or sand filters. Additional treatment may be needed if the water is to be used flushing toilets and similar nonpotable applications.

Example 13.1

A small commercial building with a roof area of 10,000 ft² is located in an area that receives an annual rainfall of 20 in. 25% of the water is lost in evaporation, run-off, absorption, and impoundment. The amount of rainwater that can be collected in a year is

(A) 9000 gal
(B) 15,000 gal
(C) 90,000 gal
(D) 150,000 gal

Solution

The total annual rainfall is equal to the catchment area times the average annual rainfall.

\[
\text{total rainfall} = \left(20 \frac{\text{in}}{\text{yr}}\right)(1 \text{ year})(10,000 \text{ ft}^2) = 200,000 \text{ in-ft}^2
\]

Multiply the total annual rainfall by 0.75 to account for losses, and convert to gallons.

\[
\text{available rainwater} = (1 - 0.25)(200,000 \text{ in-ft}^2)\left(0.6 \frac{\text{gal}}{\text{in-ft}^2}\right) = 90,000 \text{ gal}
\]

The answer is (C).

1More precisely, 0.623 gallons per in-ft².
ALTERNATIVE ENERGY SOURCES AND ENERGY EFFICIENCY

Alternative energy sources are those that are renewable, such as solar and wind power. While it is seldom possible to satisfy all of a building’s energy needs with alternative energy sources alone, alternative energy can substantially reduce reliance on depletable energy sources such as fossil fuels, and can reduce pollution.

Energy efficiency is the reduction of the energy that must be consumed in providing various services and functions, particularly as compared to standard baselines.

Both of these topics are discussed in Chap. 7. Energy efficiency using conventional fuels and mechanical systems is discussed in Chap. 17.

MATERIALS

The total sustainability of a building project is affected significantly by the selection and use of materials. As with energy consumption and other sustainability issues, material selection must be made with consideration of the entire life cycle of the building. However, sustainability issues must be balanced with the traditional concerns of function, cost, appearance, and performance.

Life-Cycle Assessment

A life-cycle assessment (LCA) is a method of evaluating the environmental impact of using a particular material or product in a building. LCAs are an important part of the Materials and Resources category of the LEED rating system. There are usually four phases to an LCA.

1. Define the goals and scope of the study. Limits must be established for the study and for the units for study, so that alternatives can be compared and the framework for data acquisition can be developed.

2. Perform an inventory analysis. The inventory analysis is often the most difficult part of the assessment, because it involves determining and quantifying all the inputs and outputs of the product under study. These might include the energy needed to obtain the raw materials and to process or manufacture them, the energy used for transportation, the need for ancillary materials, and the pollution or waste disposal methods involved in the manufacturing, use, and disposal processes. The recyclability of the material is also considered. Some of the criteria used for evaluating building materials are listed in the next section.

3. Perform an impact assessment. The impact assessment examines the processes identified in the inventory analysis and evaluates how they will affect the environment. The analysis may include such things as resource depletion, the generation of pollution, and effects on health and social welfare. For example, the energy that is needed to produce a product may make it necessary to increase the electrical generating capacity at the manufacturing plant, which in turn may produce both waterborne and airborne pollution.

4. Perform an improvement analysis and report the results of the study. The improvement analysis, or interpretation, suggests ways to reduce the environmental impact of the raw materials, energy, and processing used to create the product or construction activity.

There are four main stages in a product’s life cycle: raw material acquisition, manufacturing, use in the building, and disposal or reuse. The potential individual elements of each stage are as follows.

Raw Material Acquisition

- acquisition of raw materials through mining, drilling, or other activities and evaluation of the energy consumption associated with these processes
- processing of raw materials
- transportation of raw materials to processing points
To earn LEED credit, the design must be at least 10% better than the reference case in the global warming category and two others of choice, and it cannot be more than 5% worse than the reference case in any of the categories.

**Environmental Product Declarations**

An LCA is a useful tool for understanding the amount of energy, water, and materials consumed in the production and use of a product, as well as what emissions are produced in its manufacture or use. However, an LCA cannot give a complete view of a product, nor does it allow consumers to compare multiple products within a particular category.

An *environmental product declaration* (EPD) is a standardized report of a product’s environmental impact throughout its life cycle. An EPD is based on information gathered from an LCA, but it gives additional information and is verified by a third party in accordance with guidelines established by the International EPD System. These guidelines reference the International Standard Organization’s ISO 14025, *Environmental Labels and Declarations—Type III Environmental Declarations—Principles and Procedures*.

There are two types of EPDs: industry-wide and product-specific. An *industry-wide EPD* covers a generic type of product that several manufacturers make, such as building products like cement, acoustic ceilings or carpet yarn. A *product-specific EPD* is specific to a single manufacturer’s product and usually contributes more to sustainable credits.

One thing that makes an EPD useful for comparing similar products, and differentiates it from an LCA, is the use of *product category rules* (PCR). A product category rule is a set of guidelines for a particular type of product that establishes what data should be collected in the LCA, how LCA results are reported, and what other information must be reported in the EPD. *Product categories* are general types of items, such as flooring, insulation, wood products, and doors. Each type of product has a different environmental impact based on the raw materials used, the energy used in manufacture and transportation, and the emissions created during manufacture, use, and disposal. The use of uniform PCRs makes it possible to compare one product to another more accurately and determine the complete environmental effects of using a particular manufacturer’s product.

EPDs are developed by manufacturers following standards defined in ISO 14025. The process must be administered by a *program operator*, which is an organization that coordinates the involvement of stakeholders, takes responsibility for completing or overseeing the LCA and PCR process, writes the EPD itself, and generally makes sure that the process follows ISO standards. Examples of program operators include ASTM International and the UL Environment and Scientific Certification Systems (SCS).

Developing an EPD is a five-step process.

1. An applicable PCR is found or developed in accordance with ISO 14025.
2. The manufacturer conducts and independently verifies an LCA.
3. The EPD is prepared.
4. The EPD is submitted to an independent third party for review and verification.
5. If approved, the EPD is registered and published.

EPDs can be used along with other product certification systems, such as GREENGUARD for flooring materials or the Forest Stewardship Council for wood products, to help an architect select an environmentally preferable product for a particular use, and for owners to understand the impact of their facility throughout its life cycle.

For more information consult the following sources.

- American Center for Life Cycle Assessment (ACLCA), lcacenter.org
- Global Environmental Declarations Network (GEDnet), gednet.org
- Institute for Environmental Research and Education (IERE), iere.org
• International Agency for Research on Cancer (IARC), a part of the World Health Organization. IARC classifies chemicals that are known to be carcinogenic. (www.iarc.fr)

• Chronic Reference Exposure Levels. California Office of Environmental Health Hazard Assessment. This list identifies hazardous chemicals recognized by this office, with links to more information about each chemical. (oehha.ca.gov/air/general-info/oehhc-acute-8–hour-and-chronic-reference-exposure-level-rel-summary)

• California Health and Welfare Agency, Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65) identifies chemicals known to cause cancer and reproductive toxicity. (oehha.ca.gov/proposition–65)

• California Air Toxics. California Environmental Protection Agency, Air Resources Board (ARB). The ARB maintains a list of toxic air contaminants (arb.ca.gov/toxics/toxics.htm)

Chemical contaminants from outdoor sources can be introduced to a building when air intake vents, windows, or doors from parking garages are improperly located, allowing pollutants from the outside to be drawn into the building. Indoor pollutants from exhausts and plumbing vents can also be sucked back into the building through improperly located air intakes.

Biological contaminants such as mold, bacteria, and viruses may develop from moisture infiltration, standing water, stagnant water in mechanical equipment, and even from insects or bird droppings that find their way into the building.

Poor ventilation allows indoor pollutants to accumulate to unpleasant or unhealthy levels and affects the general sense of well-being of building occupants. One of the most difficult aspects of providing proper ventilation is balancing the need for proper ventilation with energy conservation. However, this problem can be solved by using heat exchangers and other conservation methods. (See Chap. 17.) Guidelines for minimum levels of ventilation are given later in this section.

**Symptoms of Poor Indoor Air Quality**

Poor indoor air quality causes many symptoms, from temporary, minor irritations to serious, life-threatening illnesses. These are grouped into three classifications.

*Sick building syndrome* (SBS) is a condition in which building occupants experience a variety of health-related symptoms that cannot be directly linked to any particular cause. Generally, symptoms disappear after the occupants leave the building. Symptoms may include irritation of the eyes, nose, and throat; dry mucous membranes and skin; redness of the skin; mental fatigue and headache; respiratory infections and cough; hoarseness of voice and wheezing; hypersensitivity reactions; and nausea and dizziness.

*Building-related illness* (BRI) describes a condition in which the health-related symptom or symptoms of a building’s occupants are identified and can be directly attributed to specific building contaminants. The symptoms do not immediately improve when the occupant leaves the building. Legionnaires’ Disease, a type of severe pneumonia, is an example of BRI.

*Multiple chemical sensitivity* (MCS) is a condition induced by exposure to VOCs or other chemicals. People with MCS may develop acute, long-term sensitivity and show symptoms each time they are exposed to the chemicals. These sensitivities can remain with some people for the rest of their lives. In many cases, only a slight exposure to the chemical can be enough to produce symptoms.

**Strategies for Maintaining Good Indoor Air Quality**

Methods of maintaining good indoor air quality that the architect can use or suggest to the building owner can be classified into five broad categories: eliminate or reduce the sources of pollution, control ventilation rates in the building, establish good maintenance procedures, control occupant activity as it affects IAQ, and provide appropriate filtration.
Clean Air Act (CAA) of 1970. This law regulates air emissions from area, stationary, and mobile sources. This law requires the EPA to establish the National Ambient Air Quality Standards (40 CFR Part 50) to protect public health and the environment. These standards establish acceptable levels for six principal pollutants; carbon monoxide, lead, nitrogen dioxide, ozone, particle pollution, and sulfur dioxide. The CAA has been amended several times since 1970, most recently in 1990, to extend deadlines for compliance and add other provisions.

ANSI/ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality. This is an industry standard and, as such, compliance with it is voluntary unless the building code has incorporated all or a part of this standard by reference, thereby giving it the force of law. In addition to setting minimum outdoor air requirements for ventilation, the standard includes provisions for managing sources of contamination, controlling indoor humidity, and filtering building air, as well as requirements for HVAC system construction and startup, and operation and maintenance of systems.

ANSI/ASHRAE Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. This is also a voluntary industry standard which may be incorporated into a building code by reference. The standard applies to single-family houses and multifamily buildings of three stories or less, including manufactured and modular homes. It defines the roles of and minimum requirements for mechanical and natural ventilation systems as well as requirements for the building envelope.

National Volatile Organic Compound (VOC) Emission Standards for Architectural Coatings (40 CFR Part 59). This rule implements part of the CAA and sets limits on the amount of volatile organic compounds that manufacturers and importers of architectural coatings can put into their products.

South Coast Air Quality Management District (SCAQMD) Rule 1113, Architectural Coatings. This rule limits the VOC content of architectural coatings used in the South Coast Air Quality Management District in California. The limits it sets are more restrictive than the national VOC.

Emission standards published by the EPA. Rule 1168 limits the VOC content of adhesives and sealants.

California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65). This law prohibits businesses from discharging chemicals that cause cancer or reproductive toxicity into sources of drinking water and requires that warning be given to individuals exposed to such chemicals. The California Environmental Protection Agency’s Office of Environmental Health Hazard Assessment (OEHHA) is the lead agency for the implementation of Proposition 65.

GREENGUARD Certification. To achieve GREENGUARD Certification, products are tested in accordance with ASTM Standards D5116 and D6670, the EPA’s testing protocol for furniture, and the State of Washington’s protocol for interior furnishings and construction materials. GREENGUARD lists emission levels that products must meet before they are certified by the organization.

Documentation of the Threshold Limit Values and Biological Exposure Indices, American Conference of Governmental Industrial Hygienists (ACGIH). This document defines exposure limits—called threshold limit values (TLVs) for chemicals in the workplace.

ASTM D5116, Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products. This guide describes the equipment and techniques suitable for determining organic emissions from small samples of indoor materials. It cannot be used for testing complete assemblages or coatings. Another standard, ASTM D6803, is used for testing levels of volatile organic compounds in paint using small environmental chambers.

ASTM D6670, Standard Practice for Full-Scale Chamber Determination of Volatile Organic Emissions from Indoor Materials/Products. This practice details the method to be used to determine the VOC emissions from building materials, furniture, consumer products, and equipment under environmental and product usage conditions that are typical of those found in office and residential buildings. It is referenced by other standards or laws as a way to determine the level of VOC emissions.
• ASTM E1333, Standard Test Method for Determining Formaldehyde Concentrations in Air and Emission Rates from Wood Products Using a Large Chamber. This test method measures the formaldehyde concentration in air and the emission rate from wood products in a large chamber under conditions designed to simulate product use.

For a listing of additional regulations and industry standards related to sustainability, refer to the section later in this chapter.

RECYCLING AND REUSE

Recycling and reuse of materials and products is an important part of the total life cycle of a building. When a building is demolished or elements are removed, as many materials as possible should be recycled into other products or reused for their original purpose. In turn, new buildings should incorporate as many recycled and reused materials as possible to provide a market for those products. Ideally, all materials specified for a building project should be durable, biodegradable, or recyclable.

Adaptive Reuse

Adaptive reuse encourages reusing as much of the existing building stock as possible instead of constructing new buildings. Buildings can be either updated to return to their original use or adapted to a new use. Turning an old warehouse into residences is a common example of adaptive reuse. A project can receive LEED credit for reusing or renovating historic buildings or renovating abandoned or blighted buildings.

On a smaller scale, individual products can be reused in new buildings. These include building elements such as plumbing fixtures, doors, timber, and bricks. For example, heavy timber can be reused by re-sawing and planing. In most cases, using these old materials adds to the architectural character of the new building.

Reuse of existing materials conserves natural resources, reduces the amount of energy required to construct new buildings or products, lessens air and water pollution due to burning or dumping, and keeps materials from entering the waste stream.

Recycled Materials

Recyclability is the capacity of a previously used material for reuse as a resource in the manufacture of a new product. Melting down old steel to manufacture new steel is an example of recyclability.

Recycling materials is often difficult because the construction process requires the joining and integration of materials; when the products are removed from the building, it is difficult to separate different substances so that they can be individually marketed. Most of this separating must be done by hand, and in some cases (e.g., gypsum wallboard), the cost of separating all the component parts may be more than the cost of sending the material to a landfill.

Before selecting and specifying materials, the architect should research the recycled content of each product. A project can receive LEED credit for reusing as much of the existing building stock as possible instead of constructing new buildings. Buildings can be either updated to return to their original use or adapted to a new use. Turning an old warehouse into residences is a common example of adaptive reuse. A project can receive LEED credit for reusing or renovating historic buildings or renovating abandoned or blighted buildings, credit by using products that optimize the extraction process, which may include using reused materials or using recycled content.

Recycling of consumer products can be encouraged by providing bins, sorting and storage rooms for recycling, and other provisions as part of the building design. In some areas, local codes require that a portion of the trash area be reserved for recycling bins.

Building Disposal

If discarded products and materials cannot be reused or recycled, they must be incinerated or placed in a landfill for disposal. If a biodegradable material is placed in a landfill, it can break down quickly and
FloorScore
The FloorScore program of the Resilient Floor Covering Institute (RFCI) tests and certifies hard-surface flooring products and adhesives that comply with strict indoor air quality requirements in California’s Section 01350 specification and qualify for use in high-performance schools and office buildings in California. Products bearing the FloorScore seal have been certified by Scientific Certification Systems as meeting the requirements. For more information, visit the RFCI website at rfci.com.

Forest Stewardship Council (FSC)
The Forest Stewardship Council (FSC) is an international organization that oversees the development of national and regional standards for responsible forest management based on its FSC Principles and Criteria for Forest Stewardship. It accredits certifying organizations that comply with these principles.

The FSC logo on a wood product ensures that materials have come from environmentally conscious management and have followed the other FSC principles. For more information on the FSC, visit the FSC website at fsc.org.

Green Label Plus
The Green Label Plus program of the Carpet and Rug Institute (CRI) is a voluntary testing program for carpet, cushion, and adhesive that conforms to CHPS. Products carrying the Green Label Plus mark are certified as being low-emitting and meet the CHPS requirements as defined in California’s Section 01350 specification. For more information, visit the CRI website at carpet-rug.org.

Green Seal
Green Seal is an independent, nonprofit organization that strives to achieve a more sustainable world by promoting environmentally responsible production, purchasing, and products. Among other programs, Green Seal develops environmental standards for products in specific categories and certifies products that meet these standards. The organization meets the criteria of the International Organization for Standardization’s ISO 14020 and ISO 14024 for eco-labeling. Green Seal’s product evaluations are conducted by third-party organizations using a life-cycle approach that considers energy, resource use, and emissions to air, water, and land, as well as other effects on health and the environment. The Green Seal is awarded to products that meet the high standards of the program. For more information, visit the Green Seal website at greenseal.org.

GreenFormat
GreenFormat is a web-based database developed by the Construction Specifications Institute (CSI) to allow manufacturers to self-report sustainability properties of their products using a standard questionnaire format. The information is reported in six categories:

- general information
- product details
- product lifecycle
- manufacturer sustainability policies
- manufacturer support documentation
- manufacturer certification

Designers, contractors, and others can search the database according to these criteria. Although the information is self-reported, sustainability claims are verified by relating questions on the questionnaire to standards and certifications. For more information, visit the GreenFormat website at csinet.org.
DEFINITIONS

coproducriterion: A marketable by-product from a process. Materials traditionally considered to be waste but that can be repurposed as raw materials in a different manufacturing process are considered coproducts.

demand control ventilation: A system designed to adjust the amount of ventilation air provided to a space based on the extent of occupancy. The system normally uses carbon dioxide sensors but may also use occupancy sensors or air quality sensors.

detention: The temporary storage of storm runoff in a detention facility to control peak discharge rates and to provide gravity settling of pollutants. The detention facility is designed to provide for a gradual release of stored water at a controlled rate.

drainage easement: The legal right granted by a landowner to a grantee, commonly a governmental entity, allowing the use of private land for stormwater management.

embodied energy: The total energy required to extract, produce, fabricate, and deliver a material to a job site, including the collection of raw materials, the energy used to extract and process the raw materials, transportation from the original site to the processing plant or factory, the energy required to turn the raw materials into a finished product, and the energy required to transport the material to the job site.

fee in lieu: Payment of money by a developer in place of meeting all or part of stormwater performance standards.

hydrologic soil group (HSG): Soils, classification for runoff potential. A classification of soils based on their potential for runoff when thoroughly wet. As defined by the National Resources Conservation Service (NRCS), there are four groups ranging from Group A, which contains soils high in gravel and sand that have high permeability and low runoff potential, to Group D, which contains clayey soils that have low permeability and high runoff potential.

infiltration: The process of percolating stormwater into the subsoil.

post-consumer: Referring to a material or product that has served its intended use and has been diverted or recovered from waste destined for disposal, having completed its life as a consumer item.

post-industrial: Referring to materials generated in manufacturing processes, such as trimmings or scrap, that have been recovered or diverted from solid waste. Also called pre-consumer.

pre-consumer: see post-industrial.

recovered materials: Waste or by-products that have been recovered or diverted from solid waste disposal. This term does not apply to materials that are generated from or reused within an original manufacturing process.

renewable product: A product that can be grown or naturally replenished or cleansed at a rate that exceeds human depletion of the resource.

sustainability: The condition of being able to meet the needs of the present generation without compromising the needs of future generations.

watercourse: Any body of water, such as a lake, pond, river, or stream.

waterway: A channel that directs surface runoff to a watercourse or to a public storm drain.
**Table 14.9 Allowable Number of Stories Above Grade Plane**

<table>
<thead>
<tr>
<th>occupancy classification</th>
<th>see footnotes</th>
<th>type I (A)</th>
<th>type II (B)</th>
<th>type III (A)</th>
<th>type IV (B)</th>
<th>type V (HT)</th>
<th>type V (A)</th>
<th>type V (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>NS</td>
<td>UL 5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 6</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A-2</td>
<td>NS</td>
<td>UL 11</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A-3</td>
<td>NS</td>
<td>UL 11</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A-4</td>
<td>NS</td>
<td>UL 11</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A-5</td>
<td>NS</td>
<td>UL UL</td>
<td>UL UL</td>
<td>UL UL</td>
<td>UL UL</td>
<td>UL UL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL UL</td>
<td>UL UL</td>
<td>UL UL</td>
<td>UL UL</td>
<td>UL UL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>NS</td>
<td>UL 11</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>NS</td>
<td>UL 5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 6</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>F-1</td>
<td>NS</td>
<td>UL 11</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>F-2</td>
<td>NS</td>
<td>UL 11</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>H-1</td>
<td>NS</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-2</td>
<td>NS</td>
<td>UL 3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-3</td>
<td>NS</td>
<td>UL 6</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-4</td>
<td>NS</td>
<td>UL 7</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 8</td>
<td>6</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>H-5</td>
<td>NS</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-1 Condition 1</td>
<td>NS</td>
<td>UL 9</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 10</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>I-1 Condition 1</td>
<td>NS</td>
<td>9</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>10</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>I-2</td>
<td>NS</td>
<td>UL 4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>NP</td>
<td>1</td>
<td>NP</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 5</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-3</td>
<td>NS</td>
<td>UL 4</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>I-4</td>
<td>NS</td>
<td>UL 5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 6</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>NS</td>
<td>UL 11</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R-1</td>
<td>NS</td>
<td>UL 11</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>S13R</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R-2</td>
<td>NS</td>
<td>UL 11</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>S13R</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R-3</td>
<td>NS</td>
<td>UL 11</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S13R</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R-4</td>
<td>NS</td>
<td>UL 11</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S13R</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>S-1</td>
<td>NS</td>
<td>UL 11</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>S-2</td>
<td>NS</td>
<td>UL 11</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 12</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>U</td>
<td>NS</td>
<td>UL 5</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>UL 6</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: UL = Unlimited; NS = Buildings not equipped throughout with an automatic sprinkler system; S = Buildings equipped throughout with an automatic sprinkler system installed in accordance with IBC Sec. 903.3.1.1; S13R = Buildings equipped throughout with an automatic sprinkler system installed in accordance with IBC Sec. 903.3.1.2.

- See IBC Chaps. 4 and 5 for specific exceptions to the allowable height in this chapter.
- See IBC Sec. 903.2 for the minimum thresholds for protection by an automatic sprinkler system for specific occupancies.
- New Group H occupancies are required to be protected by an automatic sprinkler system in accordance with IBC Sec. 903.2.5.
- The NS value is only for use in evaluation of existing building height in accordance with the International Existing Building Code.
- New Group I-1 and I-3 occupancies are required to be protected by an automatic sprinkler system in accordance with IBC Sec. 903.2.6. For new Group I-1 occupancies Condition 1, see Exception 1 of IBC Sec. 903.2.6.
- New and existing Group I-2 occupancies are required to be protected by an automatic sprinkler system in accordance with IBC Sec. 903.2.6 and Sec. 1103.5 of the International Fire Code.
- For new Group I-4 occupancies, see Exceptions 2 and 3 of IBC Sec. 903.2.6.
- New Group R occupancies are required to be protected by an automatic sprinkler system in accordance with IBC Sec. 903.2.8.

Example 14.1

An office building is being built with Type IIB construction and a sprinkler system. Each floor will have the same area. The allowable area factor increase has been determined to be 25%. What is the maximum allowable area for the building?

(A) 300,000 ft$^2$
(B) 370,000 ft$^2$
(C) 460,000 ft$^2$
(D) 550,000 ft$^2$

Solution

From the problem statement, the allowable area factor increase is $I_f = 0.25$. From Table 14.9, for occupancy classification B, Type IIB construction, and a sprinkler system, the maximum number of stories above grade plane is $S_a = 4$. From Table 14.10, the tabular allowable area is $A_t = 69,000$ ft$^2$, and the tabular allowable area factor, $NS$, is 23,000 ft$^2$. Calculate the allowable area, $A_a$.

$$A_a = (A_t + (NS)I_f)S_a = (69,000 \text{ ft}^2 + (23,000 \text{ ft}^2)(0.25))(4) = 299,000 \text{ ft}^2$$

Check the allowable area for an individual floor by using a value of $S_a = 1$.

$$A_a = (A_t + (NS)I_f)S_a = (69,000 \text{ ft}^2 + (23,000 \text{ ft}^2)(0.25))(1)$$

$$= 74,750 \text{ ft}^2$$

If each floor has the same area ($299,000 \text{ ft}^2/4 = 74,750 \text{ ft}^2$), each is well under the maximum allowable for an individual floor.

Example 14.2

A building has a 240 ft perimeter. 180 ft of the perimeter fronts an open space 20 ft wide. (The building could be a square 60 ft on a side.) Most nearly, the value of the factor $I_f$ is

(A) 0.1
(B) 0.2
(C) 0.3
(D) 0.4

Solution

Use Eq. 14.3 to calculate the value of $I_f$.

$$I_f = \left(\frac{F}{P} - 0.25\right)W$$

$$= \left(\frac{180}{240} - 0.25\right)(20)$$

$$= 0.33$$

The answer is (C).
### Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$</td>
<td>area of a building assembly $\text{ft}^2$</td>
</tr>
<tr>
<td>$C$</td>
<td>conductance $\text{Btu/hr-ft}^2\cdot\text{°F}$</td>
</tr>
<tr>
<td>$e$</td>
<td>emittance $\text{hr-ft}^2\cdot\text{°F}/\text{Btu}$</td>
</tr>
<tr>
<td>$E_s$</td>
<td>total solar radiation $\text{Btu/hr-ft}^2$</td>
</tr>
<tr>
<td>$b_h$</td>
<td>coefficient of heat transfer $\text{Btu/hr-ft}^2\cdot\text{°F}$</td>
</tr>
<tr>
<td>$k$</td>
<td>thermal conductivity (for 1 in thickness) $\text{Btu/hr-ft}^2\cdot\text{°F}$</td>
</tr>
<tr>
<td>$q$</td>
<td>rate of heat loss $\text{Btu/hr}$</td>
</tr>
<tr>
<td>$q_v$</td>
<td>rate of sensible heat loss or gain due to infiltration or ventilation $\text{Btu/hr}$</td>
</tr>
<tr>
<td>$R$</td>
<td>resistance $\text{hr-ft}^2\cdot\text{°F}/\text{Btu}$</td>
</tr>
<tr>
<td>$\Delta T$</td>
<td>temperature difference $\text{°F}$</td>
</tr>
<tr>
<td>$T_e$</td>
<td>sol-air temperature $\text{°F}$</td>
</tr>
<tr>
<td>$T_o$</td>
<td>outdoor dry-bulb temperature $\text{°F}$</td>
</tr>
<tr>
<td>$U$</td>
<td>coefficient of heat transmission $\text{Btu/hr-ft}^2\cdot\text{°F}$</td>
</tr>
<tr>
<td>$V$</td>
<td>volumetric airflow rate $\text{ft}^3/\text{min}$</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>absorbance $-$</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>thermal emissivity $-$</td>
</tr>
</tbody>
</table>

### HUMAN COMFORT

Human comfort is based primarily on the quality of the following environmental factors.

- temperature
- humidity
- air movement
- temperature radiation to and from surrounding surfaces
- air quality
- sound
- vibration
- light

For each of these factors, there are certain ranges within which people are comfortable and can function most efficiently. Acoustics and lighting are reviewed in later chapters. This section discusses human comfort relative to the thermal environment. Chapter 16 deals with the mechanical systems used to modify internal environments to maintain human comfort.

### Human Metabolism

The human body is a heat-producing machine. It takes in food and water and, through the metabolic process, converts these to mechanical energy and the other bodily processes necessary to maintain life. Because the body is not very efficient in this conversion, it must give off excess heat in order to maintain a stable body temperature.

The body’s heat production is measured in metabolic units, or mets. A met is the energy produced per unit of surface area per hour by a seated person at rest. One met is 18.4 Btu/hr-ft$^2$. Given the average surface area of an adult, this means that at rest, the human body gives off from 360 Btu/hr to 400 Btu/hr. This increases to around 700 Btu/hr to 800 Btu/hr for moderate activities like walking and work, and up to 2000 Btu/hr for strenuous exercise.

The body loses heat in three primary ways: convection, evaporation, and radiation. It can also lose heat by conduction, but this accounts for a very small portion of total body heat loss.

Convection is the transfer of heat through the movement of a gas or liquid. This occurs when the air temperature surrounding a person is less than the body’s skin temperature, around 85°F. The body heats the surrounding air; the heated air rises and is replaced with cooler air.

Heat loss through evaporation occurs when moisture changes to a vapor as a person perspires or breathes.

Radiation is the transfer of heat energy through electromagnetic waves from one surface to a colder surface. The body can lose heat to a cooler atmosphere or to a cooler surface.

Conduction is the transfer of heat through direct contact between two objects of different temperatures.
Ohm’s law for AC circuits, Eq. 17.3, is similar to Eq. 17.1.

\[ I = \frac{V}{Z} \]  

The calculation for power in AC circuits, is similar to Eq. 17.2, but with the power factor included.

\[ P = VI(\text{pf}) \]  

Energy can be measured in watt-hours (W-hr), but is more commonly measured in thousands of watt-hours, or kilowatt-hours (kW-hr). To calculate the energy used in a system, multiply power by time, as shown in Eq. 17.5.

\[ E = Pt \]  

There are two basic types of electric circuits: series and parallel. These are shown in Fig. 17.11. In a series circuit, the loads (represented in the diagrams by zigzag lines) are placed in the circuit one after another. The current, \( I \), remains constant throughout the circuit, but the voltage potential changes, or drops, across each load.

In a parallel circuit, the loads are placed between the same two points. The voltage remains the same, but the current is different across each load. However, adding up the individual currents results in a total current that is applied to the circuit as a whole.

If one load is removed in a series circuit (e.g., a light bulb burns out in a string of lights), the entire circuit is opened. For this reason, and because of the voltage drops across individual loads, series circuits are not used in building construction.

**Example 17.1**

What is the approximate current in a 120 V circuit serving nine 150 W downlights?

(A) 11 A  
(B) 15 A  
(C) 20 A  
(D) 26 A
calcium or magnesium ions are exchanged for the sodium ions in the zeolite. The water softener must be recharged periodically by passing a brine solution through the zeolite; this is done automatically by the water softening equipment. Water run through an ion exchange unit must be pretreated to reduce suspended solids.

- **Reverse osmosis (RO)** removes contaminants by using a semipermeable membrane that allows only water to pass through and not dissolved ions. RO is useful for removing inorganic chemicals, bacteria, and suspended particles. The unit is cleaned by forcing clear water through the membrane, which leaves the contaminants behind in a brine that must be carefully disposed of.

_Electrodialysis_ places charged membranes at the inflow stream of water to attract counterions. Electrodialysis can remove barium, cadmium, selenium, fluoride, and nitrates. Electrodialysis systems are expensive to buy and operate, and they require high water pressure and a source of direct current power.

**Disinfection**

_Disinfection_ destroys microorganisms that can cause disease in humans. There are several methods used to disinfect water. The EPA Surface Water Treatment Rule (SWTR) requires disinfection of water supply systems that get their water either from surface water or from groundwater under the direct influence of surface water.

- **Chlorination**, the most common form of treatment, kills organisms by introducing chlorine into the water stream. The chlorine may be in the form of a gas, liquid, or solid, depending on the type of system used.
- **Chloramine** is used in a way similar to chlorination, but it is a weaker disinfectant than chlorine. Chloramine is produced by adding ammonia to water that contains chlorine, or by chlorinating water that contains ammonia. Chloramine is generally used as a secondary disinfectant to prevent bacterial regrowth in a distribution system.
- **Ozonation** disinfects water through the use of ozone, a powerful oxidizing and disinfecting agent. Ozonation is used mainly as a primary disinfectant, and typically requires a secondary disinfectant for water supplies. It is typically used for treating cooling tower water to prevent _Legionella pneumophila_, scale, and algae.
- **Ultraviolet (UV) light** destroys a cell’s ability to reproduce and is effective against bacteria and viruses. UV light is not effective against _Giardia_ or _Cryptosporidium_ and is not useful for water that contains high levels of turbidity, suspended solids, or soluble organic matter. UV light must be used with a secondary disinfectant to prevent regrowth of microorganisms.
- **Nanofiltration** uses filter membranes that are capable of trapping particles as small as one nanometer (one billionth of a meter, or $10^{-9}$ m) in size. At this scale the filter can remove bacteria, viruses, pesticides, and organic material. Because the filter is small, the water must be forced through at high pressure.

**Distillation and Aeration**

Additional methods of water treatment include distillation and aeration.

_In distillation_, water is treated by boiling it and then condensing the vapors. This results in very clean water with all solids, bacteria, salts, and other materials removed. Distillation is often used to treat seawater.

_Aeration (or oxidation)_ is used to improve the taste and color of water. It also aids in the removal of iron and manganese by oxidizing them so that they can be more easily removed by filtration. Aeration is a simple process through which as much of the water as possible is exposed to air through the use of sprays, fountains, or waterfalls. For drinking water treatment, the water should be aerated in an enclosed space or in a tank.
In building situations, however, single concentrated loads are the exception. A cable structure supports uniform loads. There are two typical uniform loading conditions for cable structures: (1) where the load is uniformly applied on the horizontal projection of the cable and (2) the load is uniformly applied along the length of the cable. See Fig. 18.12(b) and (c). A uniform horizontal load results in the cable assuming the shape of a parabola, and a uniform load along the length of the cable (such as supporting its own weight) results in a catenary curve.

For these loading conditions, the optimum sag for a parabolic cable is three-tenths of the span, and for a catenary curve the optimum sag is one-third of the span. In practice, however, these sags are not achieved because the low sags would interfere with the function of the building.

For cable-supported structures, there must always be some way of balancing the tensile forces in the cable. This is done with compression members or by extending the cable across a support to a foundation that holds the cable in place, or with some combination of both.

For circular buildings, the tensile forces can be balanced with a continuous compression ring at the perimeter of the roof as shown in Fig. 18.21(b). If the building is not circular, the cable can be draped over a compression member and anchored to a massive foundation. See Fig. 18.21(c). Circular buildings with cable roofs pose a particular problem, however, because the lowest point of the roof for drainage is in the middle of the span.

Cable-suspended structures have the same problem as membrane structures. Because they can only resist loads in tension, they are inherently unstable in the wind and with concentrated loads or other types of changing loads. Sometimes the flexibility of the cable structure can be stabilized simply with the weight of the roof or other structure. More often, additional cables and a stiffening structure must be included.

### Design and Selection Considerations

Many of the design considerations concerning one-way long span systems apply to two-way systems as well. There are, however, a few additional factors that must be taken into account.

#### Function

Most two-way systems are used exclusively for roofs because of their three-dimensional configuration. Two-way, long span systems are also used primarily for enclosing large, open, single-use spaces such as sports arenas and auditoriums. Therefore, the size and use of the building is the first consideration in deciding on the type of two-way system to use.

Additional functional considerations include provisions for drainage, insulation, and waterproofing. Of course, some shapes, such as domes, some thin-shell structures, and air-supported roofs, are well suited for positive drainage. Others, such as cable-suspended roofs with their low point in the center, membrane structures that drain toward the interior, and some folded plates that trap water in their folds, present definite problems.

Insulating a long span, two-way structure can be a problem since such structures are often selected because of their appearance and architectural drama, in addition to their ability to bridge large distances. Adding insulation to the interior may be difficult or impossible, or may mar the internal appearance. Placing insulation on the exterior may be equally difficult, especially if the shape is complex.

Waterproofing presents similar problems for some types of systems. Structures such as space frames, frame domes, and cable-suspended structures have many parts and facets, resulting in a large number of joints that are always difficult to waterproof easily. Other forms, such as domes and folded plates, can easily be covered with liquid-applied waterproofing membranes.

#### Cost and Economy

Most two-way structures are very efficient in their use of material and can easily span long distances. However, other factors mitigate these advantages. The most notable disadvantage with many two-way systems is the increased labor cost required for either their fabrication or erection, or both. A space
frame is an example of one such framing type with a great number of connections. The problem can be minimized somewhat by using large module sizes, which reduces the number of connections. This means a lower labor cost and lower material costs for the nodes, which are usually the most expensive material part of a space frame.

Likewise, thin-shell structures are very efficient in material use, but are often prohibitively expensive to form because of all the complex curves and careful placement of concrete required.

Occasionally, some prefabrication of shells, folded plates, and space frames is possible to save money. Shot concrete can also be used to speed up concrete placement on thin shells.

For some two-way systems, the attachment of roofing and glazing to the structure may be uneconomical. For example, a geodesic dome must have provisions for attaching the nonstructural, somewhat flexible skin to the rigid framing members. Then, each joint between the panels must be sealed against the weather. For a large dome, this process can be very expensive.

**Shipping**

Shipping is less of a problem with two-way systems than it is with one-way systems, because most of the assembly is done on site. Components such as connectors and members of a geodesic dome, or the cable for a cable-suspended structure, can easily be shipped to the site.

**Acoustics**

Some shell configurations and membrane structures can focus sounds. If the use of the building requires a good acoustical environment, the choice of a two-way system should be carefully evaluated since adding acoustical control can be difficult and expensive to achieve.

**Assembly and Erection**

Since most of the construction of a two-way system is done on site, either by casting concrete or assembling small pieces, shipping large members to a job site or building in remote areas is usually not a problem. However, this advantage is often offset by the higher erection costs due to more labor components.

**Technical Considerations**

The technical considerations pertaining to one-way systems apply to two-way systems as well.

**Preliminary Structural Systems**

It is important to do a preliminary sizing of the structural system in the early design stage. This will make it much easier to integrate all systems effectively during the schematic design and design development stages.

The most common method of preliminary sizing is to calculate the depth-to-span ratio, because this can be done even if only the structural layout and the basic use of the system are known. and use this approach.

Many other variables can also affect the sizing of the structural system and should be considered as a part of the analysis. For instance, if the system will be supporting construction that is likely to be damaged by the normal deflections of some members, then the depths of these members should be increased to develop greater stiffness and reduce deflection. A simple approach for this condition would be to double the stiffness of those members. For a bending member, this would result in the following formula.

\[
d = \sqrt[3]{2d_t}^{\frac{3}{2}}
\]

In Eq. 18.1, \(d_t\) is the depth of the member as taken from a standard selection table, and \(d\) is the depth needed to double that member's bending stiffness. A member with depth \(d\) will exhibit one-half the deflection of the member with the tabulated depth \(d_t\).
sound: A small compressional disturbance of equilibrium in an elastic medium, which causes the sensation of hearing.

sound absorption coefficient: The ratio of the sound intensity absorbed by a material to the total intensity reaching the material. Theoretically, 1.00 is the maximum possible value of the sound absorption coefficient.

sound power: The total sound energy radiated by a source per second, in watts.

sound transmission class (STC): An average of a barrier's ability to reduce sound over several frequency bands. The higher the STC rating, the better the barrier's ability to control sound transmission.

transmission loss (TL): The difference, in decibels, between the sound power incident on a barrier in a source room and the sound power radiated into a receiving room on the opposite side of the barrier. The transmission loss varies with the frequency being tested.

**FUNDAMENTALS OF SOUND AND HUMAN HEARING**

**Qualities of Sound**

Sound has three basic qualities: velocity, frequency, and power.

The velocity of sound depends on the medium in which it is traveling and the temperature of the medium. For acoustical purposes in buildings, however, the temperature effect on velocity is not significant. In air at sea level, the velocity of sound is approximately 1130 ft/sec.

Frequency is the number of cycles completed per second, measured in hertz (Hz). One hertz equals one cycle per second.

Frequency, \(f\), velocity of sound, \(c\), and wavelength, \(\lambda\), are related by Eq. 19.1.

\[
f = \frac{c}{\lambda}
\]  \hspace{1cm} 19.1

Power, \(P\), is the quantity of acoustical energy as measured in watts. In free space, a point source emits waves in all directions equally, so the sound intensity, \(I\), at a given point at a distance of \(r\) from the source is equal to the power divided by the area of a sphere of radius \(r\), as shown by Eq. 19.2.

\[
I = \frac{P}{4\pi r^2}
\]  \hspace{1cm} 19.2

To use Eq. 19.2 to find the sound intensity in watts per square centimeter, the radius must be in centimeters. If the radius is in feet and the sound intensity is wanted in watts per square centimeter, Eq. 19.3 can be used.

\[
I = \frac{P}{930 \text{ cm}^2 \text{ ft}^2} 4\pi r^2
\]  \hspace{1cm} 19.3

**Inverse Square Law**

The inverse square law states that the intensity of a force or energy (such as a sound wave) at a given point is inversely proportional to the square of the distance from the source of that energy. It is derived from Eq. 19.2.

\[
\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}
\]  \hspace{1cm} 19.4
If the concrete will be transported from the plant to the site, the mix design of the concrete can be adjusted to allow for the length of the trip; usually the allowable time is less than two hours. When it arrives on site, preliminary performance tests may be performed to verify that the mix is as specified. If the concrete fails the preliminary tests, it may be rejected. If it passes the tests, it is conveyed to the formwork to be placed. The concrete is moved and placed with bottom-dump buckets, by pumping, or in small buggies or wheelbarrows. The method used depends on the available equipment, the quantity of concrete, and the physical size and layout of the job. Concrete can even be placed underwater with a long, cylindrical steel chute called a tremie.

Once at the formwork, the concrete must be placed to avoid segregation, which is the separation of the aggregates, water, and sand from each other. Dropping concrete long distances from the conveying device to the forms is one of the typical causes of segregation. Typically, 5 ft is the maximum distance that concrete should be dropped. Excessive lateral movement of the concrete in forms or slab work should also be minimized.

After placement, the concrete must be consolidated to ensure the following.

• The wet material has flowed into all the forms and around all the rebar.
• It has made complete contact with the steel.
• There has been no honeycombing, the formation of air pockets within the concrete and next to the forms.

Consolidating also removes air voids trapped in the concrete and decreases permeability. For small jobs, hand compaction can be used. More typically, it is done with vibrators.

As-Cast Finishes
Concrete can be finished in a variety of ways. A rough form finish, the simple method of leaving the concrete as is when the forms are removed, shows the pattern of the formwork and joints between forms. Defects and tie holes may be left unfinished or finished. This roughest finish is usually used for concrete that will not be visible.

A smooth form finish is similar in that the profile of the interior of the form will be embossed in the face of the concrete. However, smooth forms of wood, metal, or hardboard are used, and the locations of joints and tie holes are planned so that they are symmetrical. Any fins left from concrete seeping into joints between forms are removed.

Architectural Finishes
Architectural finishes are used where concrete will be exposed and appearance is a consideration. There are several varieties of these finishes.

• form liner: The concrete form is constructed and liners of plastic, wood, or metal are attached to the inside of the formwork. Parallel rib liners are a common type. Joints and form tie holes are treated as desired—either left exposed or patched. Custom form liners can be used to give the finished concrete almost any pattern that the architect designs, or the designer can choose from standard patterns offered by the liner manufacturer. Some form liners are designed to allow thin brick to be installed in the formwork before the concrete is poured; the thin brick becomes the exterior finish with the concrete acting as the “mortar” between the masonry units.

• scrubbed: The surface of the concrete is wetted and scrubbed with a wire or fiber brush to remove some of the surface mortar and expose the coarse aggregate.

• acid wash: The surface of the concrete is wetted with muriatic acid to expose and bring out the full color of the aggregate.

• water jet: A high-pressure water jet mixed with air is used to remove some of the mortar and expose the aggregate.
Lift-slab construction is a technique for multistory construction in which entire floor sections are cast on the ground, one on top of another around pre-erected columns. The slabs are poured with a bond breaker between successive pours. Once cured, the slabs are lifted into place with jacks attached to the columns. The slabs are connected to the columns with weld plates. This type of construction minimizes the amount of formwork required and generally reduces total construction time.

Wall Panels

Wall panels can be cast in a variety of sizes and shapes. For greatest economy, the number of types of panels and openings should be minimized. Wall panels are generally 5 in to 8 in thick (although they can be thicker) and long enough to span columns or beams. If the panels span beams in a multistory building, casting exterior wall panels to span two floors can increase cost savings.

Wall panels can be precast at a plant or cast on site. A typical method of building is with tilt-up construction. With this procedure the panels are cast in a horizontal position near their final location and are lifted into place when sufficiently cured. In many cases, the panels are cast directly on the building’s floor slab with temporary boards forming the edges. A bond breaker is used to prevent the wall panel from sticking to the casting surface. A bond breaker may be a liquid solution or a sheet of plastic, but liquids result in a better finish.

Precast, Prestressed Concrete

Prestressed concrete consists of members that have internal stresses applied to them before they are subjected to service loads. The prestressing consists of compressive forces applied where the member experiences tension in use. This greatly reduces or eliminates tensile forces that the member is not capable of carrying. In addition to making a more efficient and economical structural section, prestressing reduces cracking and deflection, increases shear strength, and allows longer spans and greater loads. Prestressing is accomplished in one of two ways: pretensioning and post-tensioning.

Pretensioning

With this system, concrete members are produced in a precasting plant. High-strength pretensioning stranded cable or wire is draped in forms according to the required stress pattern, and a tensile force is applied. The concrete is then poured and allowed to cure. Once the concrete cures, the cables are cut and the resulting compressive force is transferred to the concrete through the bond between cable and concrete.

Post-tensioning

In post-tensioned construction, hollow sleeves or conduits are included with the installation of the forms on the site, and concrete is poured around them. Within the sleeves are high-strength steel tendons, which are stressed with hydraulic jacks after the concrete has cured. Once the desired stress has been applied, the ends of the cables are secured to the concrete and the jacks are removed. If the tendons are to be unbonded, no further action is taken. In bonded construction, the sleeves are removed and grout is forced into the space between the tendons and the concrete.

Typically, unbonded systems use monostrand tendons, which are composed of seven wire strands wound together and coated with corrosion-inhibiting grease. Monostrand, unbonded post-tensioning is commonly used in slabs and beams for buildings in parking structures, and in slabs on grade. Bonded systems use multistrand tendons, which are composed of two or more tendons stressed with a large, multistrand jack and anchored in a common anchorage device. Multistrand systems are used in bridges and in heavily loaded beams in buildings.
medium-carbon steel has from 0.30% to 0.50% carbon, and high-carbon steel contains from 0.50% to 0.80% carbon. Standard structural steel has from 0.20% to 0.50% carbon.

The most common type of steel for structural use is ASTM A992, which means that the steel is manufactured according to ASTM International specification number A992. The yield point for this steel is 36 ksi. Other high-strength steels include A242, A440, and A441 steel, which have yield points of 46 ksi or 50 ksi.

Steel and other metals can be heat treated in a number of ways. There are many types of heat treatment used to alter the physical properties of the metal. Some of the more common for architectural metals are quenching and tempering, annealing, and case hardening. Quenching and tempering involves heating the steel to a certain temperature, to alter its crystalline structure, and then cooling it quickly. At this point the steel is too brittle, so it is tempered by heating it again at a lower temperature and cooling it slowly. Annealing is a process of heating the metal and then slowly cooling it. This relieves stresses in the metal caused by cold working, and can alter ductility, strength, and other mechanical properties. Case hardening is a process for heating a metal and diffusing a gas or liquid, commonly carbon or nitrogen, into its surface, creating a thin layer of a harder alloy. The metal is then given an appropriate heat treatment.

**Stainless Steel**

Stainless steel is a steel alloy containing a minimum of 11% chromium. In addition, nickel is often added to increase the corrosion resistance and improve cold workability. Additional trace elements such as manganese, molybdenum, and aluminum are added to impart certain characteristics.

Stainless steel is highly corrosion resistant and stronger than other architectural metals. Its resistance to corrosion results from the formation of a chromium-oxide film on the surface of the metal. If the film is scratched or otherwise damaged it will re-form as the metal is exposed to oxygen in the air. This chromium-oxide film layer gives the stainless steel passivity, which means that a layer of nonreactive molecules does not allow metal ions at the surface to migrate into solution. Most stainless steel remains passive, but when this layer is lost by abrasion or chemical etching that introduces free iron or chlorides, the surface can become active. The stainless steel can also become active when exposed to certain chemical agents. This affects not only resistance to corrosion but also to the position of the stainless steel in the galvanic series.

Of the nearly 40 types of stainless steel produced, only eight are used for building purposes, six for products, and two for fasteners. They are labeled by number designation of the American Iron and Steel Institute (AISI) and include the following, which are the most commonly used in construction.

- **Type 302.** This contains 18% chromium and 8% nickel and has traditionally been one of the most widely used stainless steel types. It is highly resistant to corrosion, very strong and hard, and can be easily fabricated by all standard techniques.
- **Type 304.** Type 304 has largely replaced type 302 for architectural uses because of its improved weldability. Its other properties are identical to 302.
- **Type 301.** This alloy is similar to type 302, but with slightly smaller amounts of chromium and nickel. It is still very corrosion resistant. Its advantage is its improved work-hardening properties, which can result in very high tensile strengths.
- **Type 316.** For extreme corrosive environments such as industrial plants and marine locations, this type is often used. It has a higher percentage of nickel than the other alloys and includes molybdenum.
- **Type 430.** This type does not contain any nickel, so it is less corrosion resistant than the other types. Its use is generally limited to interior applications.

Stainless steel is available in a variety of forms including sheets, wire, bars, and plates. Structural shapes of H sections, channels, tees, and angles are also available, as are custom extrusions. Stainless steel can be finished in a variety of ways, including mechanical and coatings.
with insulation between them. These panels are self-supporting and span intermediate supports; roof panels span purlins, and wall panels span horizontal girts.

The simpler panels are available in standard widths and lengths. These are assembled by lapping one corrugation at the edges and overlapping the ends. Common widths include 24 in, 30 in, and 36 in; other widths are available.

The sandwich assemblies are fabricated in lengths to match the requirements of the particular job. They are joined with interlocking edges and a weather seal. When used as wall panels in one-story buildings, they usually reach from the foundation to the roof framing. Two panels must be placed end to end, they are butt-jointed with flashing between.

Preformed panels are available made from aluminum, galvanized steel, or porcelain enameled steel. They are attached to framing with screws, clips, or proprietary fasteners. They are durable, easy and quick to install, and do not require on-site finishing. For industrial buildings and some other types of structures, a sandwich panel can serve as the interior finish as well as the exterior finish if local and energy codes are satisfied. Preformed panels are most economical when used on large, flat, unbroken expanses of walls or roofs.

**MEMBRANE ROOFING**

**Membrane roofing** includes solid, membrane-like materials that are applied in thin sheets to nearly flat roofs, as well as products applied in liquid form that can be used with any roof slope. Although some manufacturers claim that their products are suitable for completely flat roofs, every roof should have at least a 1/4 in/ft slope over its entire surface with the slopes directing water to the roof drainage system, in order to avoid standing water and the possibility of ponding. Steeper slopes (up to 1/2:12) may be recommended in certain areas or at cricket to direct water around obstructions or penetrations in the roof.

**Ponding** occurs when standing water causes a flat roof to deflect, allowing water to collect. This causes more deflection, which allows even more water to collect. The process continues until the roof fails.

Common types of membrane roofing include

- built-up bituminous roofing
- single-ply roofing
- elastic liquid roofing

**Built-Up Bituminous Roofing**

**Built-up roofing** consists of several overlapping layers of bituminous-saturated roofing felts cemented together with roofing cement. The bituminous material can be either asphalt or coal-tar pitch. The basic construction of such a roof is illustrated in Fig. 27.9.

A built-up roof can be installed over either a nailable or a non-nailable deck. For a nailable deck, a base sheet of unsaturated felt is nailed to the deck and covered with a coating of roofing cement. For a non-nailable deck, the base sheet is omitted and a base coat of roofing cement is applied.
With the materials and construction systems available, doors and windows no longer serve simply to provide passage between spaces or admit light. Openings can be selectively designed and specified to fulfill particular functions. For example, a window can admit light but also reduce sound transmission while providing security. A door passage can be designed as an unobtrusive, clear opening while still providing fire protection in the event of an emergency.

**DOOR OPENINGS**

Both metal doors and wood doors can control passage, provide visual and aural privacy, maintain security, supply fire resistance and weather protection, control light, and serve as radiation shielding. When selecting the most appropriate type of door, it is important to understand what kinds of control are needed. Considerations of durability, cost, appearance, ease of use, method of construction, and availability are also important.

There are three major components of a door system: the door itself, the frame, and the hardware. Each must be coordinated with the other components and be appropriate for the circumstances and the design intent. The common parts of a door opening are illustrated in Fig. 28.1. To differentiate the two jambs, the side where the hinge or pivot is installed is called the **hinge jamb**, and the jamb where the door closes is called the **strike side** or **strike jamb**.

The standard method of referring to the way a door swings is called the **door hand** or the **handing** of a door. Specifiers, hardware suppliers, and manufacturers use handing to indicate exactly what kind of hardware must be supplied for a specific opening. Some hardware will only work on a door that swings a particular way because of the way the strike side of the door is beveled. Hardware that can work on any hand of door is called **reversible** or **nonhanded**.

The hand of a door is determined from outside the door, as shown in Fig. 28.2. The exterior of a building is considered the outside, as are the hallway and lobby sides of a room situations where the distinction is not clear, the outside is considered to be the side of the door where the hinge is not visible.
When standing on the outside looking at the door, if the door hinges on the left and swings away from the viewer, it is a left-hand door. If it hinges on the right and swings away from the viewer, it is a right-hand door. If the door swings toward the viewer, it is considered a left-hand reverse or a right-hand reverse, depending on the location of the hinge or pivot.

A door can be classified by the function it serves, its operation, and the material from which it is made. Each type of classification is useful in selecting the best door for a particular situation. Figure 28.3 illustrates some of the common types of swinging doors, and Table 28.4 shows doors classified by type of operation. Fig. 28.4 summarizes some of the advantages and disadvantages of various door types.

**Figure 28.4**
Door Classification by Operation

### METAL DOORS AND FRAMES

#### Types of Metal Doors

The three most common types of metal doors are flush, sash, and louvered.

- A **flush door** has a single, smooth surface on each side.
- A **sash door** contains one or more glass lites.
- A **louvered door** has an opening with metal slats to provide ventilation.

**Panelled steel doors**, which resemble wood panel doors, are available with insulated cores for residential use. They offer energy conservation and durability in addition to a more traditional appearance.

Metal doors are commonly available in steel, stainless steel, aluminum, and bronze, and many other materials are available on special order. The most common material is steel with a painted finish.

#### Construction

Steel doors, commonly referred to as hollow metal doors, are constructed with faces of cold-rolled sheet steel. The most common thicknesses are 18-gage and 14-gage, although 20-gage is available for light-duty doors. 16-gage is also available. The steel faces are attached to a core of honeycomb kraft paper, steel ribs, hardboard, or other materials. The edges are made of steel channels, with the locations for hardware reinforced with heavier-gage steel. Mineral wool or other materials can be used to provide sound-deadening qualities, if needed.

#### Sizes

Although metal doors can be custom made in almost any practical size, standard widths are 2 ft 0 in, 2 ft 4 in, 2 ft 6 in, 2 ft 8 in, 3 ft 0 in, 3 ft 4 in, 3 ft 6 in, 3 ft 8 in, and 4 ft 0 in. Standard heights are 6 ft 8 in, 7 ft 0 in, and 8 ft 0 in. The standard thickness is 1/2 in.
Hinges are available with or without ball bearings and in three weights. Which type to use depends on the weight of the door and frequency of use. Low-frequency doors, such as residential doors, can use standard-weight, plain-bearing hinges. Most commercial applications need standard-weight, ball-bearing hinges. High-frequency applications, such as office building entrances, theaters, and so forth, need heavy-weight, ball-bearing hinges. In addition, ball-bearing hinges are required for fire-rated assemblies and on all doors with closers.

The size and number of hinges required per door depends on a number of factors. The size is given by two numbers such as 4 × 4/12. The first number is the length of the barrel in inches, and the second number is the width, which is the dimension in inches when the hinge is open.

The width of the hinge is determined by the width of the door and the clearance needed around jamb trim. A guideline is that the width of the hinge equals twice the door thickness, plus trim projection, minus in. If a fraction falls between standard sizes, use the next larger size. Common hinge widths for 1 1/8 in doors are 4 in and 4 1/2 in.

The length of the hinge is determined by the door thickness and the door width, as shown in Table 28.2.

<table>
<thead>
<tr>
<th>door thickness (in)</th>
<th>door width (in)</th>
<th>height of hinge (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/16 to 1/8</td>
<td>≤ 24</td>
<td>2/16</td>
</tr>
<tr>
<td>1/8</td>
<td>≤ 32</td>
<td>3/16</td>
</tr>
<tr>
<td>1/8</td>
<td>&gt; 32–37</td>
<td>4</td>
</tr>
<tr>
<td>1/8</td>
<td>≤ 36</td>
<td>4 1/2</td>
</tr>
<tr>
<td>1/8</td>
<td>&gt; 36–48</td>
<td>5</td>
</tr>
<tr>
<td>1/8</td>
<td>&gt; 48</td>
<td>6</td>
</tr>
<tr>
<td>2, 2 1/4, 2 1/2</td>
<td>≤ 42</td>
<td>5 (heavy weight)</td>
</tr>
<tr>
<td>2, 2 1/4, 2 1/2</td>
<td>&gt; 42</td>
<td>6 (heavy weight)</td>
</tr>
</tbody>
</table>

The number of hinges is determined by the height of the door. Numbers of hinges are commonly referred to in pairs of hinges. Doors up to 60 in high require two hinges (one pair). Doors from 60 in to 90 in require three hinges (one pair), and doors 90 in to 120 in require four hinges (two pair).

**Latches and Locksets**

Latches and locksets are devices that hold a door in the closed position. A latch holds the door in place but has no provision for locking. A beveled latch extends from the face of the door edge and automatically engages the strike mounted in the frame when the door is closed. A lockset also has a special mechanism that allows the door be locked with a key, thumb turn, or electronic device.

There are four types of latches and locks: mortise, preassembled, bored, and interconnected. These are shown in Fig. 28.12. Another type, the integral lock, is no longer produced in the United States, but is still found in older buildings.

A mortise lock or mortise latch is installed in a rectangular area cut out of the door. It is generally more secure than a bored lock and offers a wider variety of locking options. Mortise locks allow the use of a dead bolt and a latch bolt, both of which can be retracted with a single operation. A variety of knob and lever handle designs can be used with the basic mechanism.

Preassembled locks and latches (also called unit locks) come from the factory as a complete unit. They are slid into a notch made in the edge of the door and require little adjustment. Preassembled locks are often found in older buildings but seldom installed in new buildings.

Bored locks and latches (also called cylindrical locks or latches) are installed by boring holes through the face of the door and from the edge of the door to the other bored opening. They are relatively easy install and are less expensive than mortise locks, but they offer fewer operating functions. They are generally used in residential and small commercial projects.

Interconnected locks have a cylindrical lock and a dead bolt. The two locks are interconnected so that a single action of turning a knob or lever handle on the inside releases both bolts.
Two disadvantages of aluminum are its susceptibility to galvanic action and its high heat conduction. However, both of these can be controlled. Galvanic action can be minimized or eliminated with the proper selection of fasteners and flashing. Heat transmission and condensation can be prevented by specifying aluminum frames with thermal breaks, nonmetallic elements in the frame that connect the exterior and interior portions of a window.

Steel windows are fabricated from small sections of hot- or cold-rolled steel. Because of steel’s greater strength, frame sections are small compared with aluminum sections. Steel windows are more expensive and are used where high strength, high security, and a minimum profile size are needed. They can be shop painted, or the steel can be bonderized, given a coating that improves the adhesion of site-applied paint.

Wood Windows

Wood windows are popular because of the variety of types and sizes available, their appearance, their ease of installation, and their good insulating properties. These windows are delivered to the job site as complete manufactured units, including the exterior trim. They are placed in a rough opening and secured to the framing. Installation of interior trim finishes the window opening.

Common types of wood windows include fixed sash, double hung, casement, and horizontal pivoted, either awning or hopper types. Horizontal sliding units are also available, usually made of pine and fir, although other species such as redwood and cypress are occasionally used.

Many manufacturers provide clad wood windows. The exterior, exposed wood members are covered with a thin layer of steel or vinyl to minimize maintenance, and the interior portions are left exposed for painting or other types of wood finish.

Single-strength or double-strength glass is used for glazing windows. Most building codes require glazing to be insulated glass.

Skylights

Skylights are glazed openings in roofs that allow light (and ventilation, if operable) to penetrate the interior. Skylights may be glazed with glass or plastic. If plastic is used it must adhere to building code restrictions on location and maximum size. If glazed with glass, the glass must be laminated or wire glass, tempered or annealed glass is used, it must be protected from above and below with wire screening. These restrictions prevent injury to someone below if the glass breaks and falls.

A skylight should be mounted on curbs to raise the bottom edge above the roof surface, especially if the roof has a low slope. Because condensation of water vapor in a building can be a problem, a condensate gutter and weep holes in the skylight frame should allow collected water to drain to the outside.

Storefronts

Storefronts consist of extruded metal frames (usually aluminum), glass panels, doors, hardware, and miscellaneous fittings designed to be installed as one coordinated system. Storefront systems are used in one-story applications where the glass and its framing are supported within an opening rather than continuously supported across several floors as with curtain wall construction.
Double glue-down uses a high-density cushion glued to the subfloor. Once the glue is dry, the carpet is glued to the cushion. This method combines the advantages of both stretched-in and direct glue-down installations. It is good for high traffic areas but is not as good as direct glue-down for rolling wheeled traffic.

PAINTING

Paint is a generic term for a thin coating used to protect and decorate the surface to which it is applied. Paints are composed of four components: the binder, pigments, liquid (or carrier), and additives. The binder and pigments together are often called the solids.

The binder gives the paint film integrity and holds the particles of pigment together. It is the component that most determines the quality of the paint, including its durability, flexibility, color retention, gloss, and resistance to peeling, scrubbing, and staining.

The pigments are the finely ground, natural or synthetic, insoluble materials that give paint its color and hiding power. The primary pigment is titanium dioxide, which is white. Other colorants are added to produce the desired shade. Extenders may be added to the pigment to reduce the total amount of titanium dioxide, but this results in a lower quality paint. Extenders include clay, silica, silicates, calcium carbonate, and zinc oxide. Without any pigment, the binder would dry to a clear, glossy film like a varnish. As pigment is added, the gloss is reduced. Paint with a low ratio of pigment to binder yields a gloss finish, while a high ratio of pigment to binder gives a flat finish.

The liquid keeps the paint fluid so that it can be applied before it dries. The liquid evaporates after application, leaving a dry film of binder and pigments. In latex paints, the liquid is water; in oil-based paints, the liquid is typically mineral spirits.

Additives are mixed into the paint to impart certain attributes. Mildewcides are added to inhibit mildew from growing on the paint and are especially useful for exterior, kitchen, and bathroom coatings. Rheology modifiers affect the thickness or viscosity of the paint to make it easier to apply and more resistant to spattering and sagging. Surfactants help wet the surface as the paint is applied and keep the paint from separating or becoming too thick to use. Defoamers break bubbles when paint is applied and are useful when painting with a roller. While most of these chemicals are added into the paint during manufacturing, a number of available products can be mixed into the paint at the project site, such as nonskid floor finish or other textures, mildewcides, or extenders that slow drying time.

Paints are broadly classified into solvent-based and water-based types. Solvent-based paints are manufactured with binders containing or dissolved in organic solvents. Water-based paints have binders that are either soluble or dispersed in water. Epoxy, polyurethane, and other specialty coatings use special chemicals as binders to impart unique qualities to the coating that are not found in standard solvent or water-based paints.

Solvent-Based Paint

Clear, solvent-based coatings include varnishes, shellac, silicone, and urethane. When a small amount of pigment is added, the coating becomes a stain, which gives color to the surface but allows the appearance of the underlying material to show through. Stains are most often used on wood, but can also be used on concrete. Clear coatings can be used for interior applications because it is not necessary to have a pigment to protect the surface, as is usually required for exterior applications.

Oil paints use a drying or curing oil as a binder. In the past, linseed oil was standard, but other organic oils have been used. Synthetic, alkyd resin is used as the drying oil. An alkyd is a chemical compound made from vegetable oils and synthetic resins. Oil paints are durable but have a strong odor when applied and must be cleaned up with a solvent, such as mineral spirits. In addition, they cannot be applied to damp surfaces or on surfaces that may become damp from behind. Although the oxidizing process by which oil paints dry produces a hard paint surface, it can cause paint to yellow and crack or chip as it ages, which is particularly apparent when using white or light colored paints.
approved methods for removal and disposal. These requirements can considerably increase the cost of repainting. Sometimes covering the wall with a new layer of gypsum wallboard or simply repainting is an acceptable alternative.

**Volatile Organic Compounds**

*Volatile organic compounds* (VOCs) are hydrocarbon solvents used in paints, stains, and other products. They are released into the air during the application of coatings and react with nitrous oxides and sunlight to form ozone, the same byproduct produced by automotive exhaust and other pollutants. VOCs in paint and other coatings can also cause short-term health effects in sensitive building occupants, such as headache, membrane irritation, nausea, dizziness, or respiratory problems.

As required by the Clean Air Act of 1970, the Environmental Protection Agency (EPA) issued a regulation in 1999 that requires the amount of VOCs in paint and other coatings to be reduced. The amount of reduction depends on the coating and gloss types. The EPA regulation applies to all 50 states, the District of Columbia, and U.S. territories. Some state and local jurisdictions, such as California, have VOC regulations even stricter than the federal rule.

For most interior projects, specifying VOC-compliant paint is not a problem because architects can choose water-based products, which are generally environmentally friendly. In addition, manufacturers offer flat, nonflat, and multicolor wall paints, as well as many floor coverings, stains, and sealers with acceptable VOC levels. Refer to Chap. 13 for more information on sustainability and coatings.

**COLOR**

*Color* is one of the dominant perceptions of the physical world and one of the most powerful tools for architectural and interior design. The perception of color is one of the most complex physical and psychological phenomena, which makes it difficult to understand and use effectively. An emotional response to color depends on a variety of factors: the color and quality of light in the space, cultural references, gender, association with certain product brands, and the meanings that the color has in a society (for example, red means stop, green means go). The way colors are used in a space can affect the way that people behave. This section describes some fundamentals of color and its use.

**Color Basics**

*Color* is a physical property of visible light. Visible light is part of the larger electromagnetic spectrum, which also includes other radiation like X rays and infrared light. Each color is differentiated by its wavelength. Red has the longest wavelength of the visible spectrum, while violet has the shortest wavelength. The eye and brain perceive variations in these wavelengths to give the sensation of color.

When colors created with light are mixed, the wavelengths of both colors are present in the resulting light. For this reason, colors created with light are called *additive colors*. Red light is added to green light, the resulting light contains wavelengths of both colors, and this combination stimulates the eye in a similar way that yellow light stimulates it; therefore the eye perceives yellow light. When all the colors of light are present in equal amounts, we perceive white light.

The color of a physical object, on the other hand, is conveyed by the wavelengths of light that the object absorbs, or subtracts, from the light that strikes it. When white light strikes a blue object, the object absorbs the wavelengths of light except that of blue light, which is reflected to the eye. For this reason, colors created with pigments are called *subtractive colors*. When all the colors of a pigment are present in equal amounts, we perceive no color, or black. When pigments are mixed in unequal amounts, they absorb various wavelengths of the light striking them, and the wavelengths that remain in the reflected light determine the color perceived.
The three primary colors of light are red, green, and blue. In various combinations and quantities, these three colors can create the other colors. They produce white light when combined equally. The three primary colors of pigment are yellow, red, and blue. (The primary colors used in printing are cyan, magenta, and yellow, along with black.) Theoretically, all other colors can be produced by mixing various proportions of the primaries. This arrangement is typically shown on a circle known as the color wheel, illustrated in Fig. 29.17.

Color has three basic qualities: hue, value, and intensity (or chroma). The hue is the attribute by which colors are distinguished from each other; for example, the hue of blue is different from the hue of red. The value describes the degree of lightness or darkness of color in relation white and black. The intensity (or chroma) of a color is defined by the degree of purity of the hue when compared with a neutral gray of the same value. These basic qualities of color are represented diagrammatically in Fig. 29.18. When white is added to a hue, its value is raised and a tint is created. When black is added, its value is lowered and a shade is created. Adding gray of the same value to a hue creates a tone. A tone can also be created by adding the color’s complement, the hue of the color opposite it on the color wheel.

Color Systems

Many systems have been developed to describe and quantify color. Some focus on light and some focus on pigments, while still others try to define color strictly in mathematical terms. For most interior design purposes, it is necessary to be familiar with at least two of the commonly used systems: the Brewster system and the Munsell system.

The Brewster color system, also known as the Prang color system, is the familiar color wheel that organizes color pigments by their relationship with the three primary colors of red, blue, and yellow. See Fig. 29.17. In this case, primary means that these colors cannot be mixed from other pigments. Mixing pairs of primary colors in equal amounts produces the secondary colors of violet, orange, and green. When a primary color is mixed in equal amounts with an adjacent secondary color, a tertiary color is created.

The Munsell color system defines color more precisely than the color wheel. It uses three scales in three dimensions to specify the values of hue, value, and chroma (intensity). Figure 29.19 shows these scales. There are five principal hues (yellow, green, blue, purple, and red), each designated by a single letter (Y, G, B, P, and R), and five intermediate hues, each halfway between two principal hues and designated by two letters (YR,GY,BG,PB, and RP). These ten hues are arranged in a circle.
Next, each fitting is converted to its equivalent length, the length of pipe that would exhibit the same loss, with the aid of a table that gives equivalent lengths for fittings of various types and diameters. Table 31.5 is one such table.

<table>
<thead>
<tr>
<th>fitting or valve size</th>
<th>pipe size (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/4</td>
</tr>
<tr>
<td>45-degree elbow</td>
<td>1.2</td>
</tr>
<tr>
<td>90-degree elbow</td>
<td>2.0</td>
</tr>
<tr>
<td>tee, run</td>
<td>0.6</td>
</tr>
<tr>
<td>tee, branch</td>
<td>3.0</td>
</tr>
<tr>
<td>gate valve</td>
<td>0.4</td>
</tr>
<tr>
<td>balancing valve</td>
<td>0.8</td>
</tr>
<tr>
<td>plug-type cock</td>
<td>0.8</td>
</tr>
<tr>
<td>check valve, swing</td>
<td>5.6</td>
</tr>
<tr>
<td>globe valve</td>
<td>15.0</td>
</tr>
<tr>
<td>angle valve</td>
<td>8.0</td>
</tr>
</tbody>
</table>

If the plumbing system has not been completely laid out, it may be necessary to estimate the number and locations of fittings.

Add the equivalent lengths of the fittings to the length of the piping and multiply their sum by the rate of pressure loss given in the chart. For example, if the piping is 54 ft long, the equivalent lengths of the fittings add up to 6 ft, and the rate of pressure loss is 8 psi per 100 ft, then the total friction loss in the piping and fittings is

\[
\frac{(54 \text{ ft} + 6 \text{ ft})}{8 \frac{\text{lbf}}{\text{in}^2}} \cdot \frac{\text{in}}{100 \text{ ft}} = 4.8 \text{ psi}
\]

The final step is to calculate the pressure loss through the water meter. Charts that relate pressure loss to meter size and flow rate in gallons per minute are also available for this. When the supply main is 1 1/2 in or greater, the meter is typically one pipe size smaller than the main.

**Thermal Expansion**

One important part of plumbing design in large buildings is allowance for the expansion of piping. This is especially important in high-rise buildings that use long lengths of piping. For example, a 100 ft length of copper pipe can expand well over 1/2 in with a temperature increase of 60°F. PVC pipe expands 3.5 times more than copper pipe. Figure 31.7 shows two common methods of providing for expansion. There are also in-line expansion fittings that do not require the extra space required by those in Fig. 31.8.

**Irrigation Systems**

Irrigation is needed for most landscape plantings, whether to encourage establishment of young plants or to provide additional water when there is not enough rain. However, to reduce potable water use and plan more sustainable buildings, irrigation must be designed efficiently or significantly reduced.
Energy Conservation


In addition to setting requirements for switching and other lighting controls, as discussed in Chap. 17, Standard 90.1 limits the total amount of power that can be used for lighting. The architect and electrical engineer may comply with the requirements through one of three methods:

- building area method
- space-by-space method
- energy cost budget method

The **building area method** limits the total power used in a building by giving a maximum allowable power in watts per square foot of building area, based on the building type. This maximum is the *lighting power density* (LPD) and varies with the type of facility. In Standard 90.1, these values are listed in a simple table. The LPDs given for various facilities are based on the lighting needed for the tasks in the space.

For example, a courthouse is allowed 1.2 W/ft² while a hotel is allowed 1.0 W/ft². The gross lighted floor area of the building is multiplied by the LPD. If there are different area types in the building, the area of each type is multiplied by the appropriate LPD to get the *lighting power allowance* (LPA) for that area. The LPAs for the individual areas are then added together to determine the total LPA for the building. Trade-offs are permitted, so if one area uses less power, the unused allowance can be assigned to another area.

The **space-by-space method** assigns LPDs to common space types. The designer must determine the gross area of each space type in the building and multiply each area by the allowable wattage per square foot. For example, a dining area for a hotel is allowed 1.3 W/ft² while a family dining area is allowed 2.1 W/ft². The LPAs for all areas are added to arrive at a total LPD for the building.

In the space-by-space method, additional lighting power is allowed for certain functions. This includes an increase of 1.0 W/ft² for decorative lighting in the space used. Decorative lighting includes things such as chandeliers, wall sconces, and lighting for art or exhibits. When lighting is installed in retail spaces specifically to highlight merchandise, an additional allowance of 1000 W is given, plus an allowance per unit area that ranges from 1.0 W/ft² to 4.2 W/ft², depending on what type of merchandise is being displayed.

Standard 90.1 gives LPDs for various exterior applications for use with both the building area method and the space-by-space method. Both these methods provide for many exceptions to the LPA, as long as the lighting is controlled by an independent control device. Some of these exceptions include:

- exhibit displays for museums, monuments, and galleries
- lighting that is integral to equipment and instrumentation installed by the manufacturer
- lighting for medical and dental procedures
- open and glass-enclosed refrigerator and freezer cases
- equipment for food warming and food preparation
- growth and maintenance of plants
- areas specifically designed for the visually impaired
- retail display windows, provided that the display is enclosed by ceiling-height partitions
- interior spaces specifically designated as registered interior historic landmarks
Intrusion Detection

Intrusion detection devices can be classified into three types.

- perimeter protection
- area or room protection
- object protection

Perimeter protection devices secure the entry points to a space or building. Entry points include doors, windows, skylights, and even ducts, tunnels, and other service entrances. The following are some common types of perimeter protection equipment.

- Magnetic contacts are used on doors and windows either to sound an alarm when the contact is broken (when the door or window is opened) or to send a signal to a central monitoring and control station. Magnetic contacts can be surface mounted, recessed into the door and frame, or concealed in special hinges.
- Glass break detectors sense when a window has been broken or cut. These devices use either metallic foil or a small vibration detector mounted on the glass.
- Window screens in which fine wires are embedded can set off alarms when cut or broken.
- Photoelectric cells detect when an emitted beam of electrons has been broken, either by a door opening or by a person passing through an opening. These devices can be surface mounted, but they are more secure and look better if provisions are made to recess them in a partition or other construction.

Area or room protection devices detect when someone passes within the device's field of coverage. These devices can warn of unauthorized entry even when perimeter sensors have not been activated. Area intrusion devices include the following.

- Photoelectric beams send a pulsed infrared beam across a space. If the beam is broken, the device can sound an alarm or send a signal to a monitoring station. Photoelectric beams can be focused in large and small areas alike.
- Infrared detectors sense sources of infrared radiation, such as the human body, that exceed normal room radiation. These devices are unobtrusive, but they must have a clear field of view of the area they are protecting.
- Audio detectors are triggered by unusual sounds. When the normal level of noise is exceeded, an alarm is sounded. Microphones can also be used to continuously monitor all sounds in a space through a speaker at a central monitoring station.
- Pressure sensors detect weight on a floor or other surface. Sensor mats can be separate fixtures laid over the existing floor finish, or they can be placed under carpet or other building materials.
- Ultrasonic detectors emit sound waves at very high frequencies. When the waves are interrupted, an alarm signal is activated. The range of ultrasonic detectors varies depending on the specific equipment, but can be used in spaces as large as about 50 ft by 200 ft.
- Microwave detectors emit microwave radiation and sense interruptions in the radiation field. Their use is limited in interior construction, however, because microwave radiation can penetrate most building materials and can be reflected by metal.

Object protection is used to sense movement or tampering with individual objects such as safes, artwork, file cabinets, and other equipment. Capacitance proximity detectors sense touch on metal objects, vibration detectors sense a disturbance of an object, and infrared motion detectors can determine if the space around an object is violated.
Access Control

Access control devices restrict access to secure areas. The simplest access control device is the traditional mechanical lock. High-security locksets are available that provide additional security through the use of key types that are difficult to duplicate, special tumbler mechanisms, and long-throw dead bolts.

Because access and duplication of keys can be a problem even for the most secure mechanical lock, various types of electronic locks are available. Electronic locks not only selectively control access better than keys, but they can monitor who enters and exits a door and record when the access was made.

Any time that an automated lock is mounted on a door that is a part of the means of egress, the door must open in the direction of egress at all times, without use of special equipment or knowledge.

Card readers are common electronic access control devices. When a valid card is passed through or near the reader, a coded magnetic strip or electronic code on the card unlocks the door. Card readers are connected to a central monitoring computer that keeps a log of whose card was used to open a door and when the door was opened. A card reader system can be programmed to limit cards to certain doors, certain hours during the day, and certain days of the week. If a card is lost or stolen, its access code can be quickly and easily removed from the system.

Numbered keypads unlock a door when the user enters the correct numerical code. Although numbered keypads, like card readers, eliminate the key control problem of standard locksets, they do not provide the same programming flexibility. They are not connected to a central station, so may not offer the ability to track or monitor individuals.

Card readers and other devices control the operation of the locking mechanisms, of which there are several types. One type is the electric lock, which retracts the bolt when activated from the secure side of the door. From the inside, the lock can be opened by pressing a button or switch or by mechanical retraction of the bolt with the lever handle. Electric locks need an electric hinge or other power transfer device to carry the low-voltage wiring from the control device to the door and then to the lock.

An electric strike replaces the standard door strike and consists of a movable mechanism that is mortised into the frame. The latch bolt is fixed from the secure side of the door. On activation, the electric strike retracts, allowing the door to be opened. On the inside, the latch bolt can be retracted by mechanical means with the lever handle.

A door can also be secured with an electromagnetic lock. When activated, the lock holds the door closed with a powerful magnetic force. Card readers, keypads, buttons, or other devices deactivate the electromagnet. These can be designed to open on activation of a fire alarm or power failure.

A biometric device can recognize a voice or a biological feature such as the iris or retina of the eye, a hand, or a fingerprint, providing a counterfeit-proof method of identification. These devices are expensive but may be worth the cost when a very high level of security is needed.

Fire Detection and Alarms

There are five basic types of fire detection devices. They are useful for detection at different stages of a developing fire, from the incipient stage (where no visible flame, smoke, or noticeable heat has yet been produced) to the final heat stage.

A fire can smolder and produce smoke long before it reaches the flame stage.

The first type is the ionization detector, which responds to combustion-ionized particles rather than to smoke. Because these devices detect particles from a smoldering fire before it bursts into flames, they are considered early warning detectors. Ionization detectors are not appropriate where fires may produce a lot of smoke but few particles.

Another early warning device is the gas-sensing detector. This type of unit detects combustion gases that are not normally present in the air. These devices are often used in combination with ionization detectors so that both gases and particulate matter can be sensed.
• There must be a properly designed background masking system. The right number of sound-absorbing surfaces is provided, the surfaces will absorb all sounds in the space, not just the unwanted sounds. Background sound must then be reintroduced to maintain the right balance between speech sound and the background noise. This is referred to as the signal-to-noise ratio. Speech privacy will be compromised if the signal-to-noise ratio is too great, as a result of either loud talking or minimal background noise.

**Control of Impact Noise**

*Impact noise* is the sound resulting from direct contact of an object with a sound barrier. It can occur on any surface, but it occurs most often on a floor and ceiling assembly, where it can be caused by footfalls, shuffled furniture, and dropped objects.

Impact noise is quantified by the *impact insulation class* (IIC), a numerical rating of a building floor's effect on sound performance. A floor and ceiling assembly is analyzed in accordance with a standardized test that covers 16 third-octave bands, and the results are compared with a reference plot much as noise criteria ratings are established. The higher the IIC rating, the better the floor reduces impact sounds in the test frequency range.

The IIC value of a floor can be increased in several ways.

• adding carpet
• providing a resilient suspended ceiling below
• floating a finished floor on resilient pads over the structural floor
• providing sound-absorbing material in the air space between the floor and the finished ceiling

**Control of Mechanical Noise**

*Mechanical noise* is similar to impact noise in that the cause is due to direct contact with a building element. However, mechanical noise occurs when a vibrating device is in continuous direct contact with the building structure. There are several ways mechanical noise can be transmitted.

• Rigidly attached equipment can vibrate the building structure or pipes, which in turn radiate sound into occupied spaces.
• The airborne noise of equipment can be transmitted through walls and floors to occupied spaces.
• Noise can be transmitted through ductwork.
• The movement of air or water through ducts and pipes can cause undesirable noise. This is especially true of high-velocity air systems or situations where the air or water changes velocity rapidly.

Depending on the circumstances, mechanical noise can be controlled in several ways.

• Mechanical equipment should be mounted on springs or resilient pads (isolators).
• Connections between equipment and ducts and pipes should be made with flexible connectors.
• Where noise control is integral, ducts should be lined or provided with mufflers.
• Where possible, noise-producing equipment should be located away from quiet, occupied spaces.
• Walls, ceilings, and floors of mechanical rooms should be designed to lessen airborne noise.
• Mechanical and plumbing systems should be designed to minimize high-velocity flow and sudden changes in fluid velocity.
To find the magnitude of the resultant, use the law of cosines. From Fig. 34.11,
\[ c^2 = a^2 + b^2 - 2ab \cos C \]
\[ R^2 = (350 \text{ lbf})^2 + (270 \text{ lbf})^2 - (2)(350 \text{ lbf})(270 \text{ lbf}) \cos 70^\circ \]
\[ R = 361.6 \text{ lbf} \]

To find the direction of the resultant, use the law of sines.
\[ \frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C} \]
\[ \frac{F_x}{\sin \theta} = \frac{R}{\sin 70^\circ} \]
\[ \sin \theta = \frac{F_x \sin 70^\circ}{R} = \frac{(350 \text{ lbf}) \sin 70^\circ}{361.6 \text{ lbf}} = 0.9095 \]
\[ \theta = \arcsin 0.9095 = 65.4^\circ \]

**Components of a Force**

Just as a resultant can be found for two or more forces, so can a single force be resolved into two components. This method is often required when analyzing loads on a sloped surface (a roof, for example) and is necessary to find the horizontal and vertical reactions. As with finding resultant forces, both graphic and algebraic solutions are possible.

**Example 34.7**

Consider the diagonal force shown. What would be the vertical and horizontal reactions necessary to resist this force?

The reactions to the force would be equal in magnitude but opposite in direction to the vertical and horizontal components of the force. To solve the problem algebraically, construct a right triangle with the 3000 lbf force as the hypotenuse and the legs of the triangle as the horizontal and vertical forces.

Then,
\[ \sin 35^\circ = \frac{F_y}{3000 \text{ lbf}} \]
\[ F_y = 1721 \text{ lbf} \]
\[ \cos 35^\circ = \frac{F_x}{3000 \text{ lbf}} \]
\[ F_x = 2457 \text{ lbf} \]

The same solution could be obtained by drawing the triangle to scale and measuring the legs of the triangle, although this method is not as accurate.
stress at middepth of the beam, where the stress is a maximum, is given by

\[ v_h = \frac{3V}{2bd} \]  

[at neutral axis of beam]  

This formula is obtained by substituting applicable terms in for the specific case of a rectangular beam. Usually, horizontal shear is not a problem except in wood beams where the horizontal fibers of the wood make an ideal place for the beam to split and shear in this direction.

Another important aspect of the behavior of beams is their tendency to deflect under the action of external loads. Although beam deflection usually does not control the selection of beam size (as does bending or horizontal shear stress), it is an important factor that must be calculated. In some cases, it can be the controlling factor in determining beam size. Even though a large deflection will usually not lead to a structural collapse, excessive deflection can cause finish materials to crack, pull partitions away from the floor or ceiling, crush full-height walls, and result in a bouncy floor structure.

![Types of Beams](image)

**Types of Beams**

There are several basic types of beams. These are shown in Fig. 35.3, with their typical deflections under load shown exaggerated.

The simply supported, overhanging, and continuous beam all have ends that are free to rotate as the load is applied. The cantilever and fixed-end beams have one or both sides restrained against rotation. A continuous beam is one that is held up by more than two supports. Of course, there are many variations of these types, such as an overhanging beam with one end fixed, but these are the most typical situations.

There are also two typical kinds of loads on building structures: concentrated load and uniformly distributed load. Graphic representations of these loads are shown in Fig. 35.4. A concentrated load is shown with an arrow and designated \( P \), and a uniformly distributed load is shown as \( w \) pounds per linear foot or \( W \) for the total load.

Loads may either be expressed in pounds or kips (1 kip is 1000 pounds). The resultant of uniformly distributed loads is at the center of the loads. This principle is particularly useful when summing moments of partial uniform loads.

It is worth noting that simply supported, overhanging, and cantilever beams are **statically determinate**. This means that the reactions can be found using the equations of equilibrium. That is, the summation of horizontal, vertical, and moment forces equals zero as described in Chap. 12. Continuous and fixed-end beams are statically indeterminate, and other, more complex calculation methods are required to find reactions in these types of beams. The ARE will deal primarily with determinate beams, so only these types will be described in this section.
There are several types of holes for bolted connections. *Standard round holes* are $\frac{1}{16}$ in larger than the diameter of the bolt. Other kinds of holes may be used with high-strength bolts having $\frac{3}{8}$ in and larger diameters.

*Oversized holes* may have nominal diameters up to $\frac{3}{16}$ in larger than bolts $\frac{7}{16}$ in and less in diameter, $\frac{1}{4}$ in larger than 1 in bolts, and $\frac{3}{16}$ in larger than bolts $\frac{1}{8}$ in and greater in diameter. These holes may only be used in slip-critical connections.

*Short slotted holes* are $\frac{1}{16}$ in wider than the bolt diameter and have a length that does not exceed the oversized hole dimensions by more than $\frac{1}{16}$ in. They may be used in either bearing or slip-critical connections, but if used in bearing, the slots have to be perpendicular to the direction of the load.

*Long slotted holes* are $\frac{1}{16}$ in wider than the bolt diameter and have a length not exceeding $2\frac{1}{2}$ times the bolt diameter. They may be used in slip-critical connections without regard to direction of load, but must be perpendicular to the load direction in bearing-type connections.

Slotted holes are used where some amount of adjustment is needed. Long slotted holes can only be used in one of the connected parts of a joint. The other part must use standard round holes or be welded.

In addition to the load-carrying capacities of the bolts, the effect of reducing the cross-sectional area of the members must be checked. Figure 38.7 shows a typical example of this. In this case, a beam is framed into a girder with an angle welded to the girder and bolted to the beam. With a load applied to the beam, there is a tendency for the web of the beam to tear where the area of the web has been reduced by the bolt holes. This area is known as the *net area*. As shown, there is both shear failure parallel to the load and tension failure perpendicular to the load.

The *AISC Manual* limits the allowable stress on the net tension area to

$$F_t = 0.50F_u$$

38.3

The allowable stress on the net shear area is limited to

$$F_v = 0.30F_u$$

38.4

For A36 steel, $F_s = 58$ ksi and $F_y = 36$ ksi.

The total tearing force is the sum required to cause both forms of failure.

The stress on net tension area must be compared with the allowable stress on the gross section, which is

$$F_t = 0.60F_y$$

38.5
Example 38.3

A \( \frac{3}{8} \) in A36 steel plate is suspended from a \( \frac{1}{2} \) in plate with three \( \frac{3}{4} \) in A325 bolts in standard holes spaced as shown. The threads are excluded from the shear plane, and the connection is bearing type. Assuming full bearing capacity, what is the maximum load-carrying capacity of the \( \frac{3}{8} \) in plate?

Solution

First, check the shear capacity of the bolts. From Table 38.3, one bolt can carry a load of 13.3 kips, or three bolts can carry \((3)(13.3 \text{ kips})\), or 39.9 kips.

Next, check bearing capacity. The thinner material governs, which is \( \frac{3}{8} \) in. In Table 38.4, read from the STD and \( \sigma_{u,\text{full}} \) row under the \( \frac{3}{4} \) in diameter column (with \( F_u = 58 \text{ and ASD} \)). The available strength is 52.2 kips/in thickness. Multiply this value by the \( \frac{3}{8} \) in thickness to get 19.6 kips. Three bolts will then carry \((3)(19.6 \text{ kips})\) = 58 kips.

Finally, determine the maximum stress on the net section through the holes. Once again, the thinner material is the most critical component. The allowable unit stress is

\[
F_t = 0.50 F_u = (0.50)(58 \text{ kips}) = 29 \text{ ksi}
\]

The diameter of each hole is \( \frac{1}{4} \) in larger than the bolt for net sections, \( \frac{1}{8} \) or \( \frac{7}{8} \) in, which is 0.875 in. The net width of the \( \frac{3}{8} \) in plate is

\[
9 \text{ in} - (3)(0.875 \text{ in}) = 6.375 \text{ in}
\]

The allowable load on the net section is

\[
P = (6.375 \text{ in})(0.375 \text{ in})(29 \text{ kips/in}^2) = 69.33 \text{ kips}
\]

The allowable stress on the gross section is

\[
P = (0.6)(36 \text{ kips/in}^2)(9 \text{ in})(0.375 \text{ in}) = 72.9 \text{ kips}
\]
The assumed value for $C_F$ of 1.1 is correct. This value is given in Table 40.2 for a no. 2 grade, 12 in wide and 4 in thick. The $4 \times 12$ is the most appropriate selection to support the load.

### Example 40.2

What is the maximum moment-carrying capacity, in foot-pounds, of a $2 \times 10$ select structural Douglas fir-larch beam with applied dead and floor live load?

**Solution**

Rearranging Eq. 40.1 gives

$$M = SF_b$$

The allowable tabulated unit stress, $F_b$, from Table 40.2 is 1500 psi, and the section modulus (from Table 40.1) of a $2 \times 10$ is 21.391 in$^3$. The load duration factor, $C_D$, for combined dead and floor live load is 1.0. The size factor, $C_F$, from Table 40.2 is 1.1.

$$F_b = C_D C_F C_b = (1.00)(1.1) \left( \frac{1500 \text{ lbf}}{\text{in}^2} \right) = 1650 \text{ psi}$$

$$M = SF_b = \frac{(21.391 \text{ in}^3) \left( \frac{1650 \text{ lbf}}{\text{in}^2} \right)}{12 \text{ in/ft}} = 2941 \text{ ft-lbf}$$

Sometimes, either the width or depth of a beam is established by some limiting factor (such as ceiling clearance), and the other dimension must be found. This is easy to calculate, recalling that the section modulus of a rectangular beam is

$$S = \frac{bd^2}{6} \quad 40.3$$

### Example 40.3

A wood beam spanning 10 ft must be designed to support a concentrated load of 2900 lbf in the center of the span, but there is only enough room for a nominal 8 in deep beam. If the beam can be dense select structural Douglas fir-larch with an allowable unit stress of 1900 psi, what beam width is necessary?

**Solution**

The moment of a beam with a concentrated load is $PL/4$ (from Fig. 35.7). The moment is

$$M = \frac{PL}{4} = \frac{(2900 \text{ lbf})(10 \text{ ft}) \left( \frac{12 \text{ in}}{\text{ft}} \right)}{4} = 87,000 \text{ in-lbf}$$
The required section modulus for the combined load is

\[
S = \frac{24,000 \text{ in-lbf}}{(1.15)(1.1) \left( \frac{1000 \text{ lbf}}{\text{in}} \right)} = 18.97 \text{ in}^3
\]

Use the greater of the calculated section moduli—a 2 × 10 with a section modulus of 21.391 in³ (from Table 40.1). The assumed value for \( C_F \) of 1.1 is correct. This value is given in Table 40.2 for a no. 1 grade, 10 in wide and 2 in thick. The 2 × 10 is the most appropriate selection to support the loads.

**Design for Horizontal Shear**

Because it is easy for wood to shear along the lines of the grain, actual horizontal shear must always be checked against the allowable unit shear stress, \( F_v \). This is especially important for short spans with large loads. Frequently, a beam that is sufficient in size to resist bending stresses must be made larger to resist horizontal shear stresses.

Because horizontal shear failure will always occur before vertical shear failure, it is not necessary to check for vertical shear except for beams notched at their supports.

For rectangular beams, the maximum unit horizontal shear stress is

\[
f_v = \frac{3V}{2bd}
\]

The basic allowable stress in shear, \( F_v \), is found in Table 40.2, and the sizes are found in Table 40.1. This value must be modified for five factors, including those shown in Table 40.2. The following formula is used for allowable shear stress.

\[
F_v^* = F_v C_D C_M C_T C_I
\]

The values of \( C_D, C_M, C_T, \) and \( C_I \) are found in a manner similar to that for finding the values applied to bending stress. Values of \( C_H \) are omitted from Table 40.2. This value should only be used if the architect or engineer will verify the extent of cracking in the wood member.

When calculating the vertical shear, \( V \), the loads within a distance from the supports equal to the depth of the member may be neglected.

**Example 40.5**

Check the beam found in Ex. 40.1 for horizontal shear.

**Solution**

The load is 350 plf for 12 ft, or 4200 lbf total. The vertical shear at each reaction is 2100 lbf. Subtract the load within a distance equal to the depth of the beam, 11\( \frac{3}{4} \) in.

\[
V = 2100 \text{ lbf} - \left( \frac{11.25 \text{ in}}{12 \text{ in/ft}} \right) \left( \frac{350 \text{ lbf}}{\text{ft}} \right) = 1772 \text{ lbf}
\]

The value of \( bd \) is the area, found in Table 40.1 to be 39.375 in².
Deflection can be calculated in one of two ways: by using the deflection formulas for various static loads as given in Fig. 35.7 and in the *AISC Manual*, or by using tables. Both methods are presented.

### Example 41.5

Find the actual deflection of the W12 × 40 beam used in Ex. 41.2.

**Solution**

Using the formula for maximum deflection of a uniformly loaded beam as given in Fig. 35.7,

\[ \Delta = \frac{5wl^4}{384EI} \]

All units must be consistent. In this example, all feet must be converted to inches. Since the load in Ex. 41.2 is 2700 plf and the weight of the beam is 40 plf, the total load is 2740 plf, or 228.3 lbf/in (2740 lbf/ft divided by 12 in/ft). The span must also be converted to inches. From Table 41.3, the moment of inertia for a W12 × 40 beam is 307 in\(^4\). The modulus of elasticity for steel is 29,000,000 psi.

\[ \Delta = \frac{5 \times 228.3 \text{ lbf/in} 	imes (20 \text{ ft}) \times (12 \text{ in/ft})^4}{384 \times 29,000,000 \text{ lbf/in} \times (307 \text{ in}^4)} = 1.108 \text{ in} \]

If deflection were limited to \( \frac{wL^2}{180} \) of the span, the maximum allowable deflection would be

\[ \Delta_{\text{max}} = \frac{(20 \text{ ft}) \times (12 \text{ in/ft})}{360} = 0.67 \text{ in} \]

The actual deflection in this example is more than the maximum, so the selected beam would be inadequate in deflection.

### STEEL COLUMNS

As with columns of any material, the amount of load a steel column can support depends not only on its area and allowable unit stress, but also the unbraced length of the column. As discussed in Chap. 35, columns of moderate to long length tend to fail first by buckling under load. The properties of a column that resist buckling are the area and the moment of inertia. These are mathematically combined into a single value, the radius of gyration. For a nonsymmetrical column, the radius of gyration is different for each axis. Review the section on columns in Chap. 35 for a further explanation.

The effect of a column’s unbraced length and radius of gyration is combined in the slenderness ratio, which is defined for steel columns as the ratio of a column’s length in inches to the radius of gyration.

\[ \text{slenderness ratio} = \frac{l}{r} \]  

In general, the greater the slenderness ratio, the greater the tendency for the column to fail under buckling, and therefore the smaller the load the column can carry. Because most steel columns are not symmetrical about both axes (such as with a wide-flange shape), the least radius of gyration governs for design purposes because it is about this axis that the column will fail first. The radii of gyration, \( r \), about both axes are given in the *AISC Manual*, and some representative values are shown in Table 41.3.

Ideally, for the most efficient column, the radius of gyration should be the same in each direction such as with a pipe column or a square tube column. For light to moderate loads, these types of sections are often used as columns for this reason. However, they are not appropriate for heavy loads and where
Select the lightest 12 in wide-flange shape of A992 steel to support a concentric axial load of 250 kips if the unbraced length is 12 ft and the $K$-value is 1.0.

Solution

In Table 41.7, find the row for $K$ equal to 12. Look in the ASD columns for the allowable loads for various sections.

<table>
<thead>
<tr>
<th>Section</th>
<th>Allowable Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>W12 × 58</td>
<td>401 kips</td>
</tr>
<tr>
<td>W12 × 53</td>
<td>364 kips</td>
</tr>
<tr>
<td>W12 × 50</td>
<td>294 kips</td>
</tr>
<tr>
<td>W12 × 45</td>
<td>264 kips</td>
</tr>
<tr>
<td>W12 × 40</td>
<td>234 kips</td>
</tr>
</tbody>
</table>

The W12 × 45 is the lightest section with an allowable load greater than 250 kips, so this is the best choice.

The same design procedures apply for columns of allowable loads for round pipe and rectangular tube columns.

BUILT-UP SECTIONS

There are many times when standard rolled sections are inadequate or uneconomical to support heavy loads or exceptionally long spans. In these cases, special built-up sections can be fabricated to meet the special needs of the structure. One of the most typical is a plate girder section, which consists of a steel plate as a web and steel plates welded to it for flanges. It is similar to a wide-flange or I-section in shape but is much heavier. These can easily be fabricated deeper than the maximum 44 in deep rolled section available in the United States.

Because the web of a plate girder is thin relative to the girder’s depth, it must usually be reinforced with vertical stiffeners to prevent buckling. These are usually angle sections welded to the web perpendicular to the depth of the section as shown in Fig. 41.1.

Another common built-up section is a standard rolled section with cover plates welded to the top and bottom flanges to provide additional cross-sectional area where the bending moment is the greatest. This combines the advantages of using a standard section with minimizing total weight of the beam. Cover plates can also be welded to columns to provide extra cross-sectional area or to equalize the radius of gyration in one axis with that of the other axis.

OPEN-WEB STEEL JOISTS

Open-web steel joists are standardized, shop-fabricated trusses with webs that comprise linear members and with chords that are typically parallel. However, some types have top chords that are pitched for roof drainage. See Fig. 41.4.