SECTION SIXTEEN
VERTICAL CIRCULATION

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Circulation, as usually applied in architecture, is the movement of people and goods between interior spaces in buildings and to entrances and exits. Safe, convenient, rapid circulation is essential for all buildings under both normal and emergency conditions. Such circulation may be channeled through any of several different types of passageways, such as lobbies, corridors, ramps, stairways, and elevator hoistways. General requirements for these have been discussed in previous sections. This section presents in more detail design and construction considerations in provision of means of vertical circulation, the movement of people and goods between floors of multistory buildings.

Vertical circulation of traffic in a multistory building is the key to successful functioning of the design, both in normal use and in emergencies. In fact, location of elevators or stairs strongly influences the floor plan. So in the design of a building, much thought should be given to the type of vertical circulation to be provided, number of units needed, and their location, arrangement, and design.

Traffic may pass from level to level in a multistory building by ramps, stairs, elevators, or escalators. The powered equipment is always supplemented by stairs for use when power is shut off, or there is a mechanical failure, or maintenance work is in progress, or in emergencies. In addition to conventional elevators, other types of human lifts are occasionally installed in residences, factories, and garages. For moving small packages or correspondence between floors, dumbwaiters, chutes, pneumatic tube systems, powered track conveyors, or vertical conveyors also may be installed. Ladders may be used for occasional access to attics or roofs.

16.1 CLASSIFICATION OF VERTICAL CIRCULATION SYSTEMS

Vertical circulation systems may be divided into two classes. Class I systems are intended for movement of both people and goods and include ramps, stairs, escalators, and elevators. Class II systems, including dumbwaiters and vertical conveyors, in contrast, may not be used for movement of people.

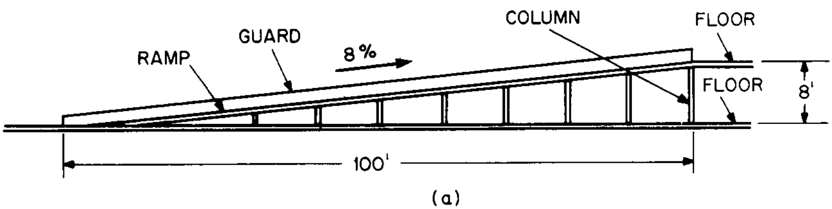
Class I systems may be divided into two subclasses, A and B. Class IA systems can be used by people both under normal and emergency conditions as a means of egress. This class includes ramps, stairs, and escalators (powered stairs) that meet requirements for means of egress specified in building codes or the National Fire Protection Association ‘‘Life Safety Code’’ (see Art. 3.5.10). Systems not acceptable as an emergency means of egress comprise Class IB. (Such systems nevertheless may be used for emergency evacuation of a building, but the capacity of Class IA systems alone must be sufficient for rapid, safe evacuation of the maximum probable building population.)

16.2 RAMPS

When space permits, a sloping surface, or ramp, can be used to connect different levels or floors (Fig. 16.1). As a means of saving space in some garages, every floor serves as a ramp. Each floor is split longitudinally, each section sloping gradually in opposite directions to meet the next level above and below.

Ramps are especially useful when large numbers of people or vehicles have to be moved from floor to floor. So they are frequently adopted for public buildings, such as railroad stations, stadiums, and exhibition halls. And they are either legally required or highly desirable for all buildings, especially to accommodate persons in wheelchairs. In all cases, ramps should be constructed with a nonslip surface.

Ramps have been built with slopes up to 15% (15 ft in 100 ft), but 8% is a preferred maximum. Some idea of the space required for a ramp may be obtained from the following: With the 8% maximum slope and a story height of, say, 8 ft, a ramp connecting two floors is 100 ft long (Fig. 16.1*a*). The ramp need not be straight for the whole distance, however. It can be curved, zigzagged (Fig. 16.1*b*), or spiraled. Level landings, with a length of at least 44 in in the direction of travel, should be provided at door openings and where ramps change slope or direction abruptly. Ramps and landings should be designed for a live load of at least 100 lb/



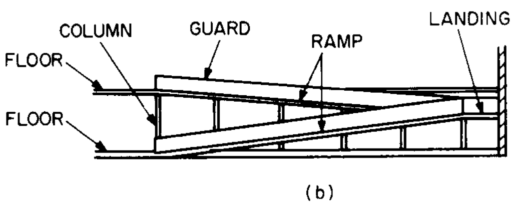


FIGURE 16.1 Types of ramps: (*a*) straight ramp; (*b*) zigzag ramp.

ft^2. Railings should be designed for a load of 200 lb applied downward or horizontally at any point of the handrail or for a horizontal thrust of 50 lb/ft at top of rail. Guards higher than the minimum required guard height of 42 in should be designed for 50 lb/ft applied 42 in above the floor.

Inside Ramps. Local building codes and the National Fire Protection Association ''Life Safety Code'' contain general requirements for acceptability of a ramp as a means of emergency egress (see Art. 5.10). Egress ramps are classified as Class A or Class B. The latter may be as narrow as 30 in, whereas Class A must be at least 44 in wide. (This width can accommodate two adults abreast.) Also, the ''Life Safety Code'' restricts Class A ramps to slopes of 10% or less and Class B ramps to slopes of not more than 1 in 8. In addition, for Class B, the vertical distance between landings may not exceed 12 ft, but no limit is placed on this distance for Class A. Building codes usually require Class A ramps only for places of assembly of more than 1000 persons. For other types of occupancy, codes may permit the choice of ramp class to be based on emergency exit capacity required.

The capacity, in persons per 22-in unit of ramp width, may be taken as 100 in the downward direction and 60 in the upward direction for Class B ramps. For Class A ramps, the capacity may be taken as 100 persons per unit of width in either direction.

To be acceptable as a means of egress, a ramp inside a building more than three stories high or a building of noncombustible or fire-resistant construction is required to be of noncombustible construction. The ramp also should be protected by separation from other parts of the building in the same way as other means of egress. There should be no enclosed usable space, such as closets, under the ramp, nor should the open space under the ramp be used for any purpose. (Other enclosed ramps, however, are permitted to be located under the ramp.)

For all inside ramps, guards—vertical protective barriers—should be provided along the edges of ramps and along the edges of floor openings over ramps, to prevent falls over the open edges. Requirements for type of construction and minimum height for such barriers are the same as those for stairs (see Art. 16.3). Handrails are required only for Class B ramps.

Outside Ramps. A ramp permanently installed on the outside of a building is acceptable as a means of egress if the life-safety requirements for inside egress ramps are met. For outside ramps more than three stories high, however, guards along ramp edges should be at least 4 ft high. Also, for such ramps, provision should be made to prevent accumulations of snow or ice.

Powered Ramps. In some buildings, such as air terminals, in which pedestrians have to be moved speedily over long distances, traffic may be transported on a moving walk, a type of passenger-carrying powered device on which passengers stand or walk. In the moving walk, the treadway, guards, and handrails are continuous and travel parallel to the direction of motion, which may be horizontal or on a slope up to 15°. (For greater slopes, an escalator should be used. See Art. 16.4.) Although moving walks can transport passengers at speeds up to 180 ft/min, speeds are generally between 90 and 120 ft/min.

Inclined moving walks are classified as powered ramps. Such ramps are acceptable as a means of egress if they meet the egress requirements of stationary ramps. (Moving walks are acceptable if they meet the requirements for exits. See Art. 3.10.5.) Powered ramps, however, must be incapable of operation in the direction opposite to normal exit travel.

The installation of moving walks and powered ramps should meet the requirements of the "American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks," ANSI A17.1.

Basically, moving walks and powered ramps consist of a grooved treadway moved by a driving machine; a handrail on each side of the treadway that moves at the same speed as the treadway; balustrades, or guards, that enclose the treadway on each side and support the handrails; brakes; control devices; and threshold plates at the entrance to and the exit from the treadway. The purpose of the threshold plates is to facilitate smooth passage of passengers between treadway and landing. The plates are equipped with a comb, or teeth, that mesh with and are set into grooves in the treadway in the direction of travel. Their purpose is to provide firm footing and to prevent things from becoming trapped between the treadway and the landing.

The treadway may be constructed in one of the following ways:

1. Belt type—a power-driven continuous belt.
2. Pallet type—a series of connected, power-driven pallets. (A pallet is a short, rigid platform, which, when joined to other pallets, forms an articulated treadway.)
3. Belt pallet type—a series of connected, power-driven pallets to which a continuous belt is fastened.
4. Edge-supported belt type—a belt supported near its edges by rollers in sequence.
5. Roller-bed type—a treadway supported throughout its width by rollers in sequence.
6. Slider-bed type—a treadway that slides on a supporting surface.

Powered ramps resemble escalators in construction (see Art. 16.4). For example, both types of transporters are supported on steel trusses. The driving machine may be connected to the main drive shaft by toothed gearing, a coupling, or a chain. Movement of the treadway and handrails can be halted by an electrically released, mechanically applied brake, located either on the driving machine or on the main drive shaft and activated automatically when a power failure occurs, when the treadway or a handrail breaks, or when a safety device is actuated. For moving walks and ramps, safety devices required include switches for starting, emergency stopping, and maintenance stopping, and a speed governor that will prevent the treadway speed from exceeding 40% more than the maximum design speed.

Balustrades should be at least 30 in high, measured perpendicular to the treadway. Hand or finger guards are installed where the handrails enter the balustrades. The handrails should extend at normal height at least 12 in beyond each end of the exposed treadway, to facilitate entry and exit of passengers from or onto a level landing.

Information on passenger capacity of a moving walk or powered ramp should be obtained from the manufacturer. The capacity depends on treadway width and speed. Standard widths are 24, 32, and 40 in. With level entry and exit, ramp speeds generally are a maximum of 180 ft/min for slopes up to 8° and 140 ft/min for slopes between 8° and 15°.

("Life Safety Code," National Fire Protection Association, Batterymarch Park, Quincy, MA 02269; "American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks," A17.1, and "Making Buildings and

Facilities Accessible to and Usable by the Physically Handicapped,'' A117.1, American National Standards Institute, New York, NY 10018.)

16.3 STAIRS

Less space is required for stairs than for ramps, because steeper slopes can be used. Maximum slope of stairs for comfort is estimated to be about 1 on 2 (27°), but this angle frequently is exceeded for practical reasons. Exterior stairs generally range in slope from 20° to 30°, interior stairs from 30° to 35°.

16.3.1 Types of Stairs

Generally, stairs are of the following types: straight, circular, curved, or spiral, or a combination.

Straight stairs are stairs along which there is no change in direction on any flight between two successive floors. There are several possible arrangements of straight stairs. For example, they may be arranged in a **straight run** (Fig. 16.2*a*), with a single flight between floors, or a series of flights without change in direction (Fig. 16.2*b*). Also, straight stairs may permit a change in direction at an immediate landing. When the stairs require a complete reversal of direction (Fig. 16.2*c*), they are called **parallel stairs.** When successive flights are at an angle to each other, usually 90° (Fig. 16.2*d*), they are called **angle stairs.** In addition, straight stairs may be classified as **scissors stairs** when they comprise a pair of straight runs in opposite directions and are placed on opposite sides of a fire-resistive wall (Fig. 16.2*e*).

Circular stairs when viewed from above appear to follow a circle with a single center of curvature and large radius.

Curved stairs when viewed from above appear to follow a curve with two or more centers of curvature, such as an ellipse.

Spiral stairs are similar to circular stairs except that the radius of curvature is small and the stairs may be supported by a center post. Overall diameter of such

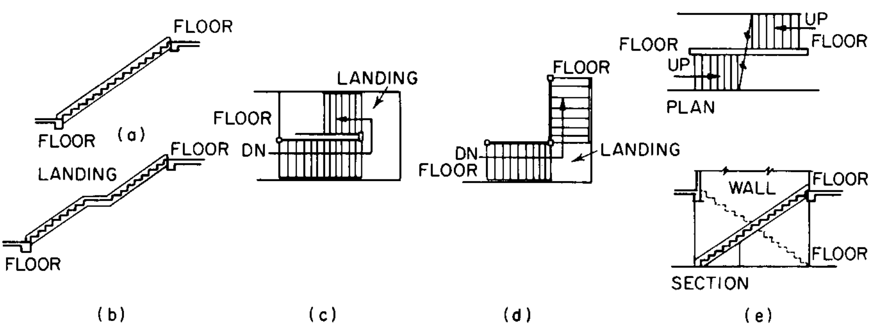


FIGURE 16.2 Arrangement of straight stairs: (*a*) a single flight between floors; (*b*) a series of flights without change in direction; (*c*) parallel stairs; (*d*) angle stairs; (*e*) scissors stairs.

stairs may range from 3 ft 6 in to 8 ft. There may be from 12 to 16 winder treads per complete rotation about the center.

16.3.2 Stairway Components

Among the principal components of a stairway are

Flight. A series of steps extending from floor to floor, or from a floor to an intermediate landing or platform.

Guard. Protective vertical barrier along edges of stairways, balconies, and floor openings.

Landings (platforms). Used where turns are necessary or to break up long climbs. Landings should be level, as wide as the stairs, and at least 44 in long in the direction of travel.

Step. Combination of a riser and the tread immediately above.

Rise. Distance from floor to floor.

Run. Total length of stairs in a horizontal plane, including landings.

Riser. Vertical face of a step. Its height is generally taken as the vertical distance between treads.

Tread. Horizontal face of a step. Its width is usually taken as the horizontal distance between risers.

Nosing. Projection of a tread beyond the riser below.

Soffit. Underside of a stair.

Header. Horizontal structural member supporting stair stringers or landings.

Carriage. Rough timber supporting the steps of wood stairs.

Stringers. Inclined members along the sides of a stairway. The stringer along a wall is called a wall stringer. Open stringers are those cut to follow the lines of risers and treads. Closed stringers have parallel top and bottom, and treads and risers are supported along their sides or mortised into them. In wood stairs, stringers are placed outside the carriage to provide a finish.

Railing. Framework or enclosure supporting a handrail and serving as a safety barrier.

Baluster. Vertical member supporting the handrail in a railing.

Balustrade. A railing composed of balusters capped by a handrail.

Handrail. Protective bar placed at a convenient distance above the stairs for a handhold.

Newel Post. Post at which the railing terminates at each floor level.

Angle Post. Railing support at landings or other breaks in the stairs. If the angle post projects beyond the bottom of the stringers, the ornamental detail formed at the bottom of the post is called the **drop.**

Winders. Steps with tapered treads in sharply curved stairs.

Headroom. Minimum clear height from a tread to overhead construction, such as the ceiling or next floor, ductwork, or piping.

16.3.3 Design Loads for Stairs

Stairs and landings should be designed for a live load of 100 lb/ft^2 or a concentrated load of 300 lb placed to produce maximum stresses.

Guards. To prevent people from falling over edges of stairs and landings, barriers, called guards, should be placed along all edges and should be at least 42 in high. These should support 2-in-diameter handrails, which should be set 30 to 34 in above the intersections of treads and risers at the front of the steps.

Interior stairs more than 88 in wide should have intermediate handrails that divide the stairway into widths of not more than 88 in, preferably into a nominal multiple of 22 in. Handrails along walls should have a clearance of at least 1½ in.

Guards should be designed for a horizontal force of 50 lb/ft, applied 42 in above the floor, or for the force transmitted by the handrail, whichever is greater. Handrails should be capable of supporting a load of at least 200 lb, downward or horizontally.

16.3.4 Dimensions for Stairs

Ample headroom should be provided not only to prevent tall people from injuring their heads, but to give a feeling of spaciousness. A person of average height should be able to extend his hand forward and upward without touching the ceiling above the stairs. Minimum vertical distance from the nosing of a tread to overhead construction should never be less than 6 ft 8 in and preferably not less than 7 ft.

Stairway Width. Width of a stairway depends on its purpose and the number of persons to be accommodated in peak hours or emergencies. Generally, the minimum width that can be used is specified in the local building code. For example, for interior stairs, clear width may be required to be at least 36 in in one- and two-family dwellings, and 44 in in hotels, motels, apartment buildings, industrial buildings, and other types of occupancy.

Step Sizes. Risers and treads generally are proportioned for comfort and to meet accessibility standards for the handicapped, although sometimes space considerations control or the desire to achieve a monumental effect, particularly for outside stairs of public buildings. Treads should be 11 to 14 in wide, exclusive of nosing. Treads less than 11 in wide should have a nosing of about 1 in. The most comfortable height of riser is 7 to 7½ in. Risers less than 4 in and more than 8 in high should not be used. The steeper the slope of the stairs, the greater the ratio of riser to tread. Among the more common simple formulas generally used with the preceding limits are:

1. Product of riser and tread must be between 70 and 75.

2. Riser plus tread must equal 17 to 17.5.

3. Sum of the tread and twice the riser must lie between 24 and 25.5.

In design of stairs, account should be taken of the fact that there is always one less tread than riser per flight of stairs. No flight of stairs should contain less than three risers.

16.3.5 Number of Stairways Required

This is usually controlled by local building codes. This control may be achieved by setting a minimum of two exits per floor, a restriction on the maximum horizontal distance from any point on a floor to a stairway, or a limitation on the maximum floor area contributory to a stairway. In addition, codes usually have special provisions for assembly buildings, such as theaters and exhibition halls. Restrictions usually also are placed on the maximum capacity of a stairway. For example, the National Fire Protection Association ''Life Safety Code'' sets a maximum capacity for stairways of 60 persons per 22-in unit of width, up or down.

16.3.6 Curved Stairways

Winders should be avoided when possible, because the narrow width of tread at the inside of the curve may cause accidents. Sometimes, instead, **balanced steps** can be used. Instead of radiating from the center of the curve, like winders, balanced steps, though tapered, have the same width of tread along the line of travel as the straight portion of the stairs. (Line of travel in this case is assumed to be about 20 in from the rail on the inside of the curve.) With balanced steps, the change in angle is spread over a large portion of the stairs.

16.3.7 Emergency Egress Stairway

In many types of buildings, interior exit stairways must be enclosed with walls having a fire-resistance rating, to prevent spread of smoke and flames. Wall construction and ratings must be in accordance with local code requirements. Openings in the walls should be protected by approved, self-closing fire doors. Stairs in buildings required by the code to be of fire-resistant construction should be completely made of noncombustible materials. Open space under stairs to be used as a means of egress should not be used for any purpose, including closets, except for another flight of stairs.

In buildings requiring such egress stairways, an alternative type of construction, called a **smokeproof tower,** may be used. A smokeproof tower is a continuous, vertical, fire-resistant enclosure protecting a stairway from fire or smoke that may develop elsewhere in a building. The intent is to limit the entrance into the stairway of products of combustion so that during a 2-h period the tower air will not contain smoke or gases with a volume exceeding 1% of the tower volume. All components of the tower should be made of noncombustible materials, and the enclosure should have a 2-h fire rating. Walls between the stairs and the building interior should not have any openings. If the exterior wall of the tower will not be subjected to a severe fire-exposure hazard, however, that wall may incorporate fixed or automatic fire windows.

Access to a smokeproof tower should be provided in each story through vestibules open to the outside on an exterior wall, or from balconies on an exterior wall, neither exposed to severe fire hazards. Doors should be at least 40 in wide, self-closing, and provided with a viewing window of clear, wired glass not exceeding 720 in^2 in area. It also is wise to incorporate some means of opening the top of the shaft, either with a thermally operated device or with a skylight, to let escape any heat that might enter the tower from a fire. Exits at the bottom of smokeproof towers should be directly to the outdoors, where people can remove themselves quickly to a safe distance from the building.

Stairs outside a building are acceptable as a required fire exit instead of inside stairs, if they satisfy all the requirements of inside stairs. Where enclosure of inside stairs is required, however, outside stairs should be separated from the building interior by fire-resistant walls with fire doors or fixed wire glass windows protecting openings. Some building codes limit the height of outside stairs to a maximum of six stories or 75 ft.

Fire escapes, outside metal-grating stairs, and landings attached to exterior walls with unprotected openings were acceptable at one time as required exits, but are generally unacceptable for new construction.

See also Art. 3.5.10.

("Life Safety Code," National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.)

16.3.8 Wood Stairs

In wood-frame buildings, low nonfireproof buildings, and one- and two-family houses, stairs may be constructed of wood (Fig. 16.3*a*). They may be built in place or shop fabricated.

Construction of a built-in-place stairs starts with cutting of carriages to the right size and shape to receive the risers and treads (Fig. 16.3*b*). Next, the lower portion of the wall stringer should be cut out at least ½ in deep to house the steps (Fig. 16.3*c*). The stringer should be set in place against the wall with the housed-out profile fitted to the stepped profile of the top of the carriage. Then, treads and risers

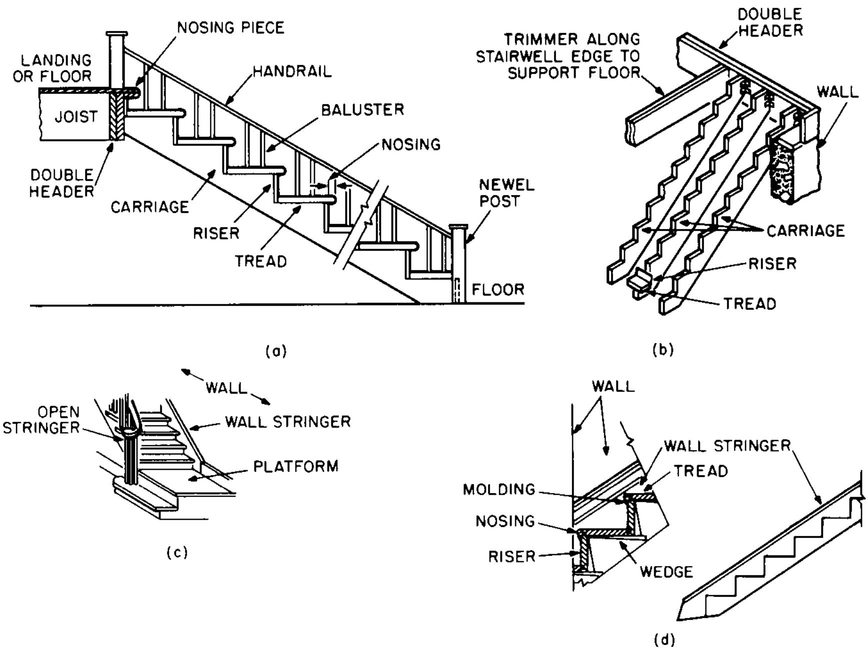


FIGURE 16.3 Typical construction for wood stairs: (*a*) typical stair components; (*b*) carriages cut to receive steps; (*c*) wall stringer cut to receive steps; (*d*) junction of steps with a closed stringer.

should be firmly nailed to the carriages, tongues at the bottom of the risers fitting into grooves at the rear of the treads. Nosings are generally finished on the underside with molding.

If the outer stringer is an open stringer (Fig. 16.3*c*), it should be carefully cut to the same profile as the steps, mitered to fit corresponding miters in the ends of risers, and nailed against the outside carriage. Ends of the treads project beyond the open stringer.

If the outer stringer is a curb or closed stringer, it should be plowed out in the same way as the wall stringer to house the steps. Ends of the treads and risers should be wedged and glued into the wall stringer (Fig. 16.3*d*).

("Manual for House Framing," National Forest and Paper Association, 1250 Connecticut Ave., NW, Washington, DC 20036.)

16.3.9 Steel Stairs

Cold-formed-steel or steel-plate stairs generally are used in fire-resistant buildings. They may be purchased from various manufacturers in stock patterns.

The steel sheets are formed into risers and subtreads or pans, into which one of several types of treads may be inserted (Fig. 16.4). Stringers usually are channel shaped. Treads may be made of stone, concrete, composition, or metal. Most types are given a nonslip surface.

("Metal Stairs Manual," National Association of Architectural Metal Manufacturers, 600 5. Federal St., Chicago, IL 60605.)

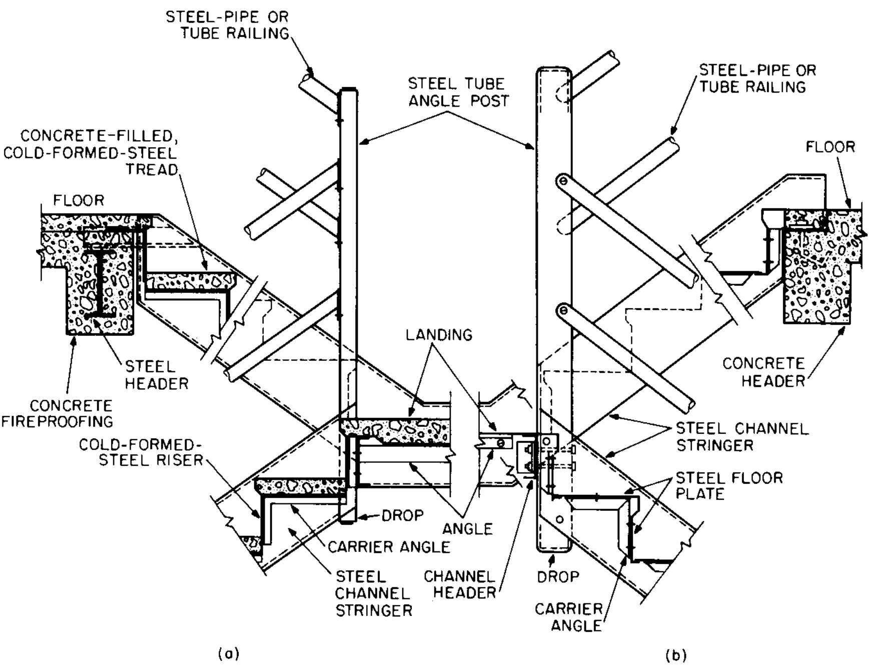


FIGURE 16.4 Types of metal stairs: (*a*) stairs made of cold-formed steel; (*b*) stairs made of steel plate.

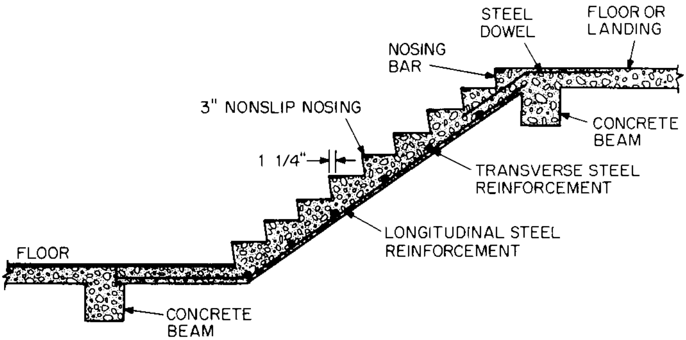


FIGURE 16.5 Reinforced concrete stairs.

16.3.10 Concrete Stairs

Depending on the method of support provided, concrete stairs may be designed as cantilevered or inclined beams and slabs (Fig. 16.5). The entire stairway may be cast in place as a single unit, or slab or T beams may be formed first and the steps built up later. Soffits formed with plywood or hardboard forms may have a smooth-enough finish to make plastering unnecessary. Concrete treads should have metal nosings to protect the edges. Stairs also may be made of precast concrete.

16.4 ESCALATORS

Escalators, or powered stairs, are used when it is necessary to move large numbers of people from floor to floor. They provide continuous movement of persons and can thus remedy traffic conditions that are not readily addressed by elevators. Escalators should be viewed as preferred transportation systems whenever heavy traffic volumes are expected between relatively few floors. Escalators are used to connect airport terminals, parking garages, sports facilities, shopping malls, and numerous mixed-use facilities.

Although escalators generally are used in straight sections (Fig. 16.6), spiral escalators (Fig. 16.7) also are available. Although expensive due to manufacturing complexities, they offer distinct advantages to both the designer and user because of their unique semicircular plan form.

16.4.1 Components of an Escalator

An escalator resembles a powered ramp in construction (Art. 16.2). The major difference is that a powered ramp has a continuous treadway for carrying passengers, whereas the treadway of an escalator consists of a series of moving steps. As for a powered ramp, the installation of powered stairs should conform with the requirements of the "American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks," ANSI A17.1.

An escalator consists of articulated, grooved treads and risers attached to a continuous chain moved by a driving machine and supported by a steel truss framework

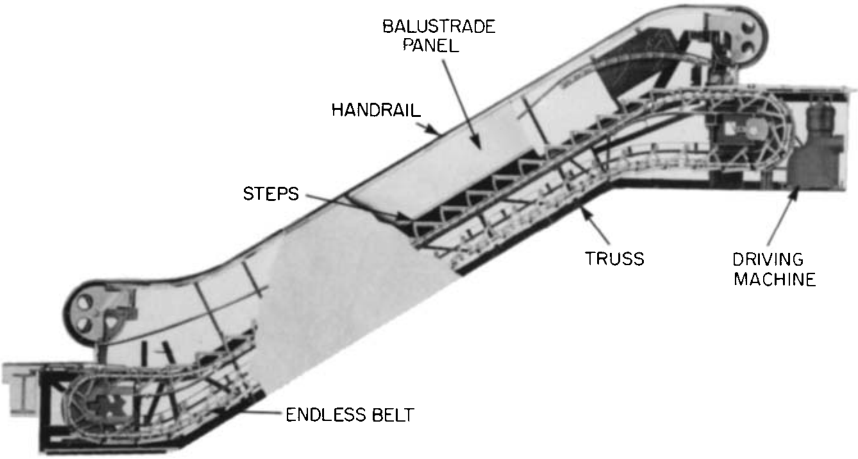


FIGURE 16.6 Details of a straight escalator. (*Courtesy of Otis Elevator Co.*)

(Fig. 16.6). The installation also includes a handrail on each side of the steps that moves at the same speed as the steps; balustrades, or guards, that enclose the steps on each side and support the handrails; brakes; control devices; and threshold plates at the entrance to and the exit from the treadway. The purpose of the threshold plates is to facilitate smooth passage of passengers between the treadway and landing. The plates are equipped with a comb, or teeth, that mesh with and are set into grooves in the treadway in the direction of travel, so as to provide firm footing and to minimize the chance that items become trapped between treadway and the landing.

Each step is formed by a grooved tread portion connected to a curved and grooved riser. The tread and riser assembly is either a single die-cast piece or is assembled to a frame. Both are suspended on resilient rollers whose axles are connected to the step chain that moves the steps. The step rollers ride on a set of tracks attached to the trussed framework. The tracks are shaped to allow the step tread to remain horizontal throughout its exposed travel.

16.4.2 Dimensions for Escalators

ANSI A17.1 sets the following limitations on escalator steps (Fig. 16.8):

Minimum depth of tread in direction of travel—15¾ in

Maximum rise between treads—8½ in

Minimum width of tread—24 in

Maximum width of tread—40 in

Maximum clearance between tread and adjacent skirt panel—⅜ in

Maximum distance between handrail centerlines—width between balustrades plus 6 in with not more than 3 in on either side of the escalator (see Fig. 16.8*b*)

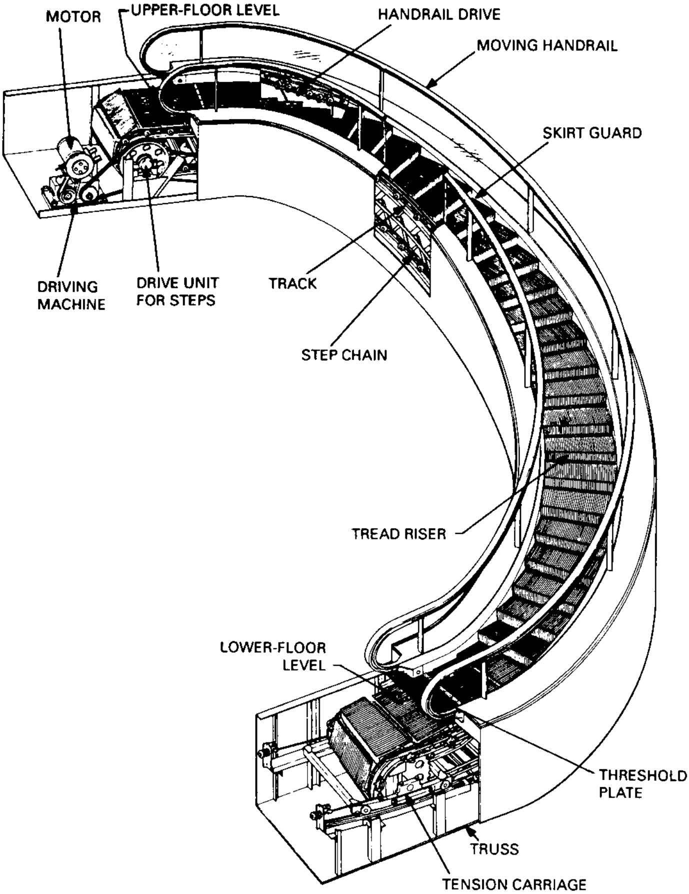


FIGURE 16.7 Components of a spiral escalator (developed by the Mitsubishi Electric Corporation).

The escalator width is measured on the incline between balustrades, as indicated in Fig. 16.8*b*.

It should be at least as wide as the step but not more than 13 in wider than the step.

16.4.3 Safety Devices for Escalators

To provide a firm footing, treads are grooved in the direction of travel. The grooves mesh with the combs or teeth of the threshold plates at top and bottom of the escalator.

The handrails, which move in synchronization with the steps, should be between 30 and 34 in above the treads. The handrails should extend at normal height at

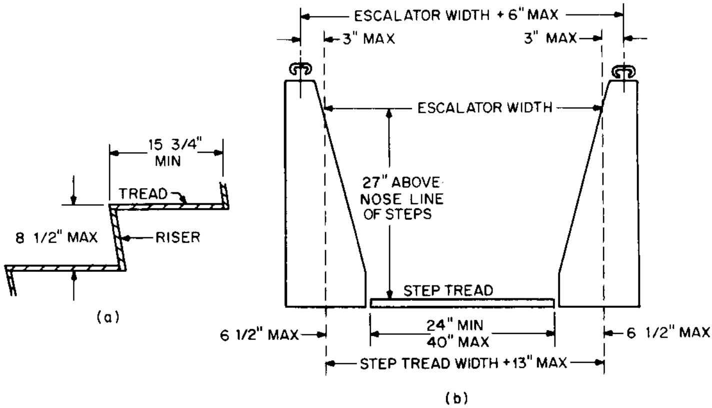


FIGURE 16.8 Limitations on dimensions of a straight escalator.

least 12 in beyond the line of points of the combplate teeth. The balustrades carrying the handrails and acting as a guard to prevent passengers from falling off the sides of the moving steps should be designed to resist simultaneous application of a horizontal load of 40 lb/ft and a vertical load of 50 lb/ft, both applied to the top of the balustrades.

The driving machine may be connected to the main drive shaft by toothed gearing, a coupling, or a chain. Step movement is halted by an electrically released, mechanically applied brake, located either on the driving machine or on the main drive shaft. The brake is activated automatically when a power failure occurs, when the treadway or a handrail breaks, or when a safety device is activated.

Safety devices required for escalators include switches for starting, emergency stopping, and maintenance stopping and an electromechanical speed governor that will prevent the step speed from exceeding the maximum design speed. An emergency stop button, protected against accidental activation, is required to be set in the right-hand (when facing the escalator) newel at the top and bottom landings.

16.4.4 Escalator Speeds and Capacities

Escalators typically operate at 90 or 120 ft/min, as needed for peak traffic, and are reversible in direction. Slope of the stairs is standardized at 30° in the United States, although inclines of both 30° and 35° are used in other parts of the world.

Standard escalator widths are 32 and 48 in. Manufacturers rate their 90-ft/min units at corresponding capacities of 5000 and 8000 persons per hour, although observed capacities, even in heavy traffic, rarely exceed 2000 and 4000 persons per hour, respectively. Although 120-ft/min escalators will move about 30% more volume, they are rarely specified because of the potential for adverse litigation.

16.4.5 Planning for Escalators

The location of moving stairs should be selected only after a careful study of potential traffic flow within the planned project. They should be installed where most attractive to traffic and where convenient for passengers. The facility should be designed and signed in a manner that makes it apparent where the visitor will find the escalator. Since escalators are devices that will fail on occasion, the designer must provide alternative transportation (usually adjacent stairs) for times when the escalator is unavailable for passenger use. More importantly, where escalators will be operating at capacity as a result of specific programmatic considerations, the designer must plan alternative routing for times when one or more escalators is under repair. In retail applications, marketing needs generally motivate selection of escalator locations.

In design of a new building, adequate space should be allotted for escalators. Generous areas should be provided at both loading and unloading areas. Special consideration should be given to the possibility of a disaster resulting at a constricted exit from an escalator when pedestrian traffic is restricted below the escalator's capacity in the path of travel. Similarly, planning of landing areas should consider both queuing space and what happens when an escalator is stopped for some reason while pedestrian traffic continues. In addition, before stacked escalators are planned for an arena, stadium, or other facility having exit peaks, the potential for pedestrian traffic jams should be carefully weighed. If exiting traffic is very heavy in a stacked escalator system, upper levels can easily fill lower-level escalators, creating a jam at the escalator entries and leaving little space for lower-level pedestrians.

For an escalator installation in an existing building, careful study should be made to determine the necessary alterations to assure adequate space and supports.

16.4.6 Structural Considerations in Escalator Installation

Floor-to-floor height should be taken into account in determining loads on supporting members. Generally for floor-to-floor heights of less than 20 ft, the escalator truss need be supported only at top and bottom. Increased vertical rise can create the need for intermediate support points. A structural frame should be installed around the escalator well to carry the floor and wellway railing.

Inasmuch as an escalator is a mechanical device, careful consideration should be given to the potential for noise and vibration in design of the escalator structural supports. Where necessary, the escalator can be mounted on vibration-isolating devices to help reduce noise and vibration.

16.4.7 Escalator Installation

Design of escalators permits a vertical variation of ½ in in the level of the supporting beams from the specified floor-to-floor height. The escalator is shimmed to bring it level. If variations in elevation exceed ½ in, installation is difficult and much time will be lost. To allow for variations in overall escalator length, truss extensions can be provided.

Trusses generally are brought to the job in one section. There, they are raised into position with chain hoists, either through an elevator shaft or on the outside of the building. Typically, the escalator manufacturer does not furnish either the exterior truss cladding or the wellway railings and accessories. Because of the need for economy, escalator manufacturers design for minimal weight in the truss cladding. Hence, care should be taken to coordinate carefully the desired design with the escalator manufacturer.

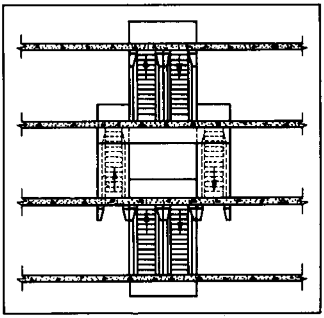


FIGURE 16.9 Parallel arrangement of up and down escalators.

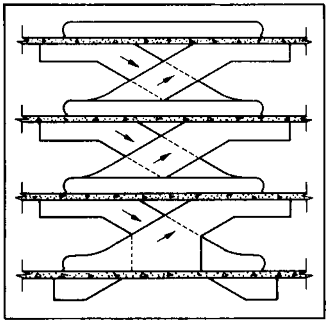


FIGURE 16.10 Crisscross arrangement of up and down escalators.

Escalators usually are installed in pairs—one for carrying traffic up and the other for moving traffic down. The units may be placed parallel to each other in each story (Fig. 16.9), or crisscrossed (Fig. 16.10). Crisscrossed stairs generally are preferred because they are more compact, reducing walking distance between stairs at various floors to a minimum. The curved characteristic of the spiral escalator allows for several alternative arrangements (Fig. 16.11).

16.4.8 Fire Protection of Escalators

Escalators may be acceptable as required means of egress if they comply with the applicable requirements for exit stairs (Art. 16.3.7). Such escalators must be enclosed in the same manner as exit stairs. Escalators capable of reversing direction, however, may not qualify as required means of egress.

An escalator not serving as a required exit should have its floor openings enclosed or protected as required for other vertical openings. Acceptable protection, as an alternative, is afforded in buildings completely protected by a standard supervised sprinkler system by any of the following:

Sprinkler-vent method, a combination of automatic fire- or smoke-detection system, automatic air-exhaust system, and an automatic water curtain.

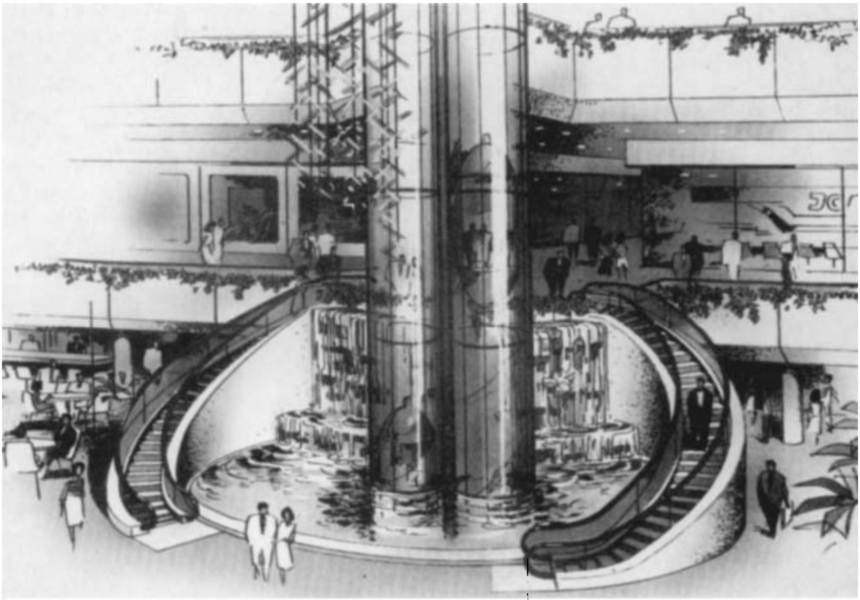
Spray-nozzle method, a combination of an automatic fire or smoke detection system and a system of high-velocity water-spray nozzles.

Rolling shutter method, in which an automatic, self-closing, rolling shutter is used to enclose completely the top of each escalator.

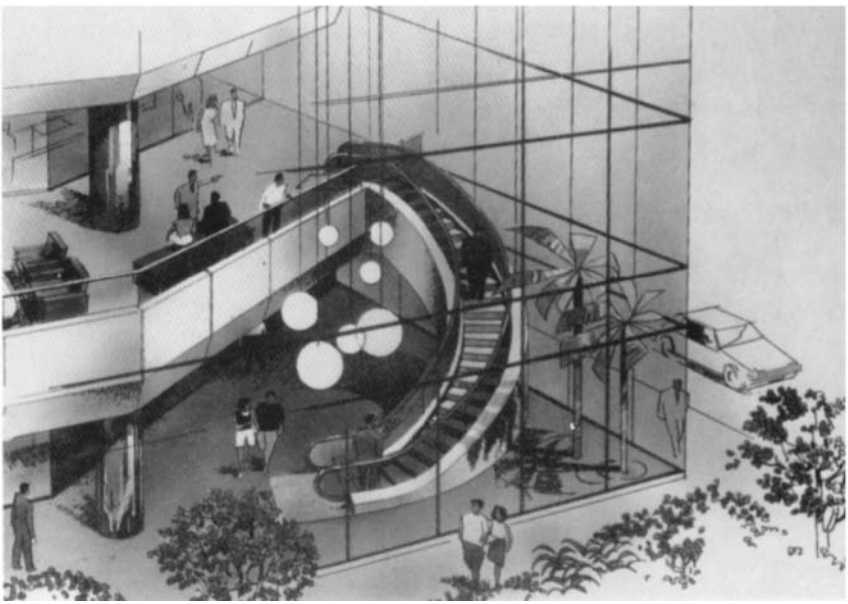
Partial enclosure method, in which kiosks, with self-closing fire doors, provide an effective barrier to spread of smoke between floors.

Escalator trusses and machine spaces should be enclosed with fire-resistant materials. Ventilation should be provided for machine and control spaces.

(“Life Safety Code,” National Fire Protection Association, Quincy, MA 02269; “American National Standard Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks,” A17.1, American National Standards Institute; G. R. Strakosch, “Vertical Transportation: Elevators and Escalators,” John Wiley & Sons, Inc., New York.)



(a)



(b)

FIGURE 16.11 Arrangements of spiral escalators: (*a*) at main entrance or center of a building; (*b*) in a corner.

16.5 ELEVATOR INSTALLATIONS

An **elevator** is a hoisting and lowering mechanism equipped with a car or platform that moves along guides in a shaft, or hoistway, in a substantially vertical direction and that transports passengers or goods, or both, between two or more floors of a building. **Passenger elevators** are designed primarily to carry persons. **Hospital elevators** are also passenger elevators but employ special cars, suitable in size and shape for transportation of patients in stretchers or standard hospital beds and of attendants accompanying them. **Freight elevators** carry freight, which may be accompanied only by an operator and persons necessary for loading and unloading it.

Elevators are desirable in all multistory buildings for movement of passengers and freight. They may be required by local building codes for any buildings over two stories high or for transportation of disabled persons. Elevators, however, are not usually accepted as a means of egress, because no cohesive strategy has been established to assure proper operation of elevators in an emergency.

Most codes require automatic evacuation of all elevators if fire or smoke is detected on a served floor. These elevators can later be recaptured by emergency personnel. Nevertheless, elevators are vital for firefighting in a high-rise building. Also, they can be used for emergency evacuation of building occupants who cannot use the building stairs. The height of modern buildings makes it mandatory that elevators be included in emergency planning for fire or other disaster.

Most elevators are the roped electric or hydraulic type. For the roped electric elevator, the car is suspended from wire ropes and counterbalanced by a counterweight that mirrors the operation of the elevator. The electric elevator is moved via an electrically powered machine that drives a hardened steel traction **sheave** over which the wire ropes are suspended (Fig. 16.12*a* and *b*). Electric elevators are used exclusively in tall buildings and many low buildings (Art. 16.9). Hydraulic elevator cars (Fig. 16.12*c*) are raised and lowered by an oil pumping system, which actuates a plunger or piston (Art. 16.10). They are frequently used for passenger elevators serving up to four or five floors and for low-rise freight service. Their low performance when compared to electric-type elevators means that they cannot be substituted on a one-for-one basis and provide equivalent service. Where passenger-moving capability is paramount, the hydraulic elevator cannot compete with the electric type.

Elevator installations should meet the requirements of the ''American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks,'' ANSI A17.1. Standardized elevator sizing has been developed by National Elevator Industries, Inc. (NEII). It is desirable that car sizes and shapes be in accord with NEII standards, such as ''Elevator Engineering Standard Layouts'' and ''Suggested Minimum Passenger Elevator Requirements for the Handicapped,'' National Elevator Industry, Inc., 600 Third Avenue, New York, NY 10016.

Structural Considerations for Elevators. Elevators and related equipment, such as machinery, signal systems, ropes, and guide rails, are generally supplied and installed by the manufacturer. The general contractor has to guarantee the dimensions of the shaft and its freedom from encroachments. The owner's architect or engineer is responsible for the design and construction of components needed for supporting the plant, including buffer supports, machine-room floors, and guiderail bracket supports. Magnitudes of loads generally are supplied by the manufacturer with a 100% allowance for impact.

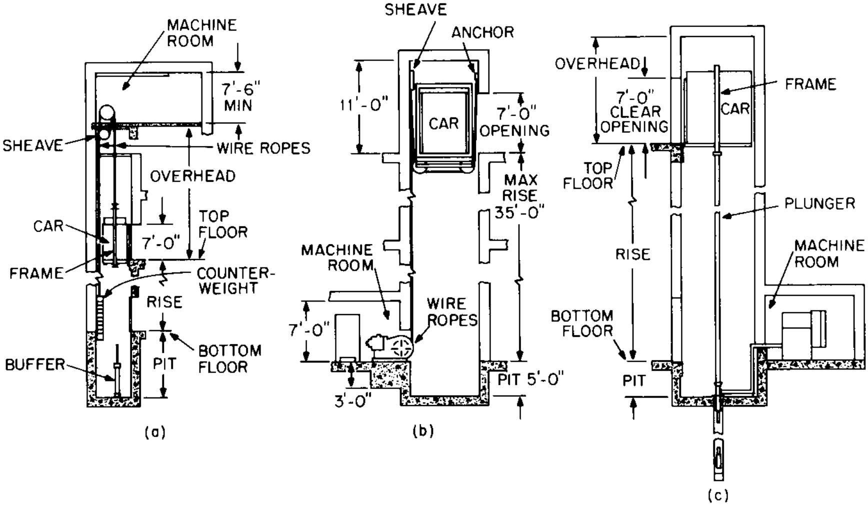


FIGURE 16.12 Types of elevators: (*a*) electric elevator with driving machine at top of hoistway; (*b*) electric elevator with driving machine in basement; (*c*) hydraulic elevator.

For design of machinery, sheave beams, and floor systems, unit stresses should not exceed 80% of those allowed for static loads in the design of usual building structural members. Importantly, deflections on machinery and sheave supporting structures may not exceed 1/1666 the span. This stiffness helps to minimize variations in leveling due to load-induced deflection. Where stresses due to loads other than elevator loads, supported on the beams or floor system exceed those due to elevator loads, 100% of the allowable unit stresses may be used.

Unit stresses, calculated without impact, in a steel guide rail or its reinforcement, caused by horizontal forces, should not exceed 15 ksi, and deflection should not exceed ¼ in. Guide-rail supports should be capable of resisting horizontal forces with a deflection of not more than ⅛ in.

(G. R. Strakosch, ‘‘Vertical Transportation: Elevators and Escalators,’’ John Wiley & Sons, Inc., New York.)

16.6 DEFINITIONS OF ELEVATOR TERMS

(See also Figs. 16.12 to 16.16.)

Annunciator. An electrical device that indicates, usually by lights, the floors at which an elevator landing signal has been registered.

Buffer. A device for stopping a descending car or counterweight beyond its bottom terminal by absorbing and dissipating the kinetic energy of the car or counterweight. The absorbing medium may be oil, in which case the buffer may be called an **oil buffer,** or a spring, in which case the buffer may be referred to as a **spring buffer.**

Bumper. A device other than a buffer for stopping a descending car or counterweight beyond its bottom terminal by absorbing the impact.

Car. The load-carrying element of an elevator, including platform, car frame, enclosure, and car door or gate.

Car-Door Electric Contact. An electrical device for preventing normal operation of the driving machine unless the car door or gate is closed.

Car Frame. The supporting frame to which the car platform, guide shoes, car safety, and hoisting ropes or hoisting-rope sheaves, or the plunger of a hydraulic elevator are attached.

Car Platform. The structure on which the car and its floor are mounted.

Car Switch. A manual operating device in a car by which an operator actuates the control.

Control. The system governing the starting, stopping, direction of motion, acceleration, speed, and retardation of the car.

VVVF Control. A method of controlling the smooth starting and stopping of alternating-current motors, utilizing solid-state, *variable-voltage, variable-frequency* controls. This system is displacing dc motors for medium and high-speed elevators.

Generator-field control employs an individual generator for each elevator, with the voltage applied to a dc driving-machine motor adjusted by varying the strength and direction of the generator field.

Multivoltage control impresses successively on the armature of the driving-machine motor various fixed voltages, such as those that might be obtained from multicommutator generators common to a group of elevators.

Rheostatic control varies the resistance or reactance of the armature or the field circuit of the driving-machine motor.

Single-speed, alternating-current control governs a driving-machine induction motor that runs at a specified speed.

Two-speed alternating-current control governs a two-speed driving-machine induction motor, with motor windings connected to obtain various numbers of poles.

Dispatching Drive. A device that operates a signal in a car to indicate when the car should leave a designated floor or to actuate the car's starting mechanism when the car is at a designated floor.

Driving Machine. See *Machine.*

Emergency Stop Switch. A car-located device that, when operated manually, causes the car to be stopped by disconnecting electric power from the driving-machine motor.

Hoistway. A shaft for travel of one or more elevators. It extends from the bottom of the pit to the underside of the overhead machine room or the roof. A **blind hoistway** is the portion of the shaft that passes floors or other landings without providing a normal entrance.

Hoistway Access Switch. A switch placed at a landing to permit car operation with both the hoistway door at the landing and the car door open.

Hoistway-Door Electric Contact. An electrical device for preventing normal operation of the driving machine unless the hoistway door is closed.

Hoistway-Door Locking Device. A device for preventing the hoistway door or gate from being opened from the landing side unless the car has stopped within the landing zone.

Leveling Device. A mechanism for moving a car that is within a short distance of a landing toward the landing and stopping the car there. An **automatic maintaining, two-way, leveling device** will keep the car floor level with the landing during loading and unloading.

Machine (Driving Machine). The power unit for raising and lowering an elevator car.

Electric driving machines include an electric motor and brake, driving sheave or drum, and connecting gearing, belts, or chain, if any. A **traction machine** drives the car through friction between suspension ropes and a traction sheave. A **geared-drive machine** operates the driving sheave or drum through gears. A **gearless traction machine** has the traction sheave and the brake drum mounted directly on the motor shaft. A **winding-drum machine** has the motor geared to a drum on which the hoisting ropes wind. A **worm-geared machine** operates the driving sheave or drum through worm gears. A **helical-geared** machine operates the driving sheave through a helical-type gearbox.

Hydraulic driving machines raise or lower a car with a plunger or piston moved by a liquid under pressure in a cylinder.

Nonstop Switch. A device for preventing a car from making registered landing stops.

Operating Device. The car switch, push button, lever, or other manual device used to actuate the control.

Operation. The method of actuating the control.

Automatic operation starts the car in response to operating devices at landings, or located in the car and identified with landings, or located in an automatic starting mechanism, and stops the car automatically at landings. **Group automatic operation** starts and stops two or more cars under the coordination of a supervisory control system, including automatic dispatching means, with one button per floor in each car and up and down buttons at each landing. **Selective collective automatic operation** is a form of group automatic operation in which car stops are made in the order in which landings are reached in each direction of travel after buttons at those landings have been pressed. **Single automatic operation** has one button per floor in each car and only one button per landing, so arranged that after any button has been pressed, pushing any other button will have no effect on car operation until response to the first button has been completed.

Car-switch operation starts and stops a car in response to a manually operated car switch or continuous-pressure buttons in a car.

Parking Device. A device for opening from the landing side the hoistway door at any landing when the car is within the landing zone.

Pit. Portion of a hoistway below the lowest landing.

Position Indicator. Device displaying the location of a car in the hoistway.

Rise. See *Travel.*

Rope Equalizer. A device installed on a car or counterweight to equalize automatically the tensions in the hoisting ropes.

Runby. The distance a car can travel beyond a terminal landing without striking a stop.

Safety. A mechanical device attached to the counterweight or to the car frame or an auxiliary frame to stop or hold the counterweight or the car, whichever undergoes overspeed or free fall, or if the hoisting ropes should slacken.

Safety Bulkhead. In a cylinder of a hydraulic elevator, a closure, at the bottom of the cylinder but above the cylinder head, with an orifice for controlling fluid loss in case of cylinder-head failure.

Slack-Rope Switch. A device that automatically disconnects electric power from the driving machine when the hoisting ropes of a winding-drum machine become slack.

Terminal Speed-Limiting Device (Emergency). A device for reducing automatically the speed of a car approaching a terminal landing, independently of the car-operating device and the normal terminal stopping device if the latter should fail to slow the car as intended.

Terminal Stopping Device. Any device for slowing or stopping a car automatically at or near a terminal landing, independently of the car-operating device. A **final terminal stopping device,** after a car passes a terminal landing, disconnects power from the driving apparatus, independently of the operating device, normal terminal stopping device, or emergency terminal speed-limiting device. A **stop-motion switch, or machine final terminal stopping device,** is a final terminal stopping device operated directly by the driving machine.

Transom. One or more panels that close an opening above a hoistway entrance.

Travel (Rise). The vertical distance between top and bottom terminal landings.

Traveling Cable. A cable containing electrical conductors for providing electrical connections between a car and a fixed outlet in a hoistway.

Truck Zone. A limited distance above a landing within which the truck-zoning device permits movement of a freight-elevator car with its door or the hoistway door open.

Truck-Zoning Device. A device that permits a car operator to move, within a specified distance above a landing, a freight-elevator car with its door or the hoistway door open.

16.7 ELEVATOR HOISTWAYS

A hoistway is a shaft in which an elevator travels. To provide access to an elevator car, the shaft enclosure has openings, protected by doors with safety devices, at landings. In a pit at the bottom of the hoistway, buffers or bumpers must be installed to stop a descending car or counterweight beyond its normal limit of travel, by storing or by absorbing and dissipating its kinetic energy (Fig. 16.12). Construction of the hoistway and installation of the associated equipment should meet the requirements of the "American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks," ANSI A17.1.

16.7.1 Hoistway Enclosure

The code requires that hoistways be enclosed throughout their height with fire-resistant construction, except for cases where no solid floors are penetrated. The enclosure should have a 2-h fire rating, and hoistway doors and other opening protective assemblies should have a 1½-h rating. Where fire-resistant construction is not required, laminated-glass curtain walls or unperforated metal, such as 18-ga sheet steel, should enclose the hoistway to a height of 8 ft above each floor and above the treads of adjacent stairways. Openwork enclosures may be used above that level, if openings are less than 2 in wide or high.

At the top of a hoistway, a concrete floor should be provided (but is not necessary below secondary and deflection sheaves of traction-type driving machines located over the hoistway). If a driving machine is installed atop the hoistway, the floor should be level with or above the top of the beams supporting the machine. Otherwise, the floor should be set under the overhead sheaves. The floor should cover the entire top of the hoistway if its area would be 100 ft^2 or less. For larger hoistway cross-sectional areas, the floor should extend from the entrance to the machine space, at or above the level of the platform, for a distance at least 2 ft beyond the general contour of the driving machine, sheaves, or other equipment. In such cases, exposed floor edges should be protected with a toe board at least 4 in high and a railing at least 42 in high and conforming to the requirements of the ''American National Standard Safety Code for Floor and Wall Openings, Railings and Toe Boards,'' ANSI A12.1.

16.7.2 Venting of Hoistways

In significant high-rise-building fires, the elevator hoistways have served as a flue for smoke and hot gases generated by fire. The prevailing thought has been that hoistway venting means could minimize the spread of smoke and hot gases throughout the building. As more has been learned about smoke movement in high-rise buildings, many alternatives have been developed to prevent migration of smoke from the fire floor to noninvolved floors of the structure. Among these alternatives are various systems for hoistway pressurization and mechanical-pressure sandwich systems, where building ventilating units are used to contain smoke during a fire. Although many codes continue to require specific means to address elevator hoistway venting, the overall design for smoke control in the building should be considered in design of elevator hoistways. Consideration for building occupants who may be threatened by fire requires designers to view the structure in a holistic fashion, where all systems can be integrated to maximize life-safety opportunities. The proposed design should be reviewed by the architect, mechanical engineer, and fire protection engineer to ensure that the finished result achieves goals set for the building's life-safety capabilities. The importance of proper elevator hoistway design in high-rise buildings cannot be overemphasized.

16.7.3 Machine Rooms

Construction of enclosures of spaces containing machines, control equipment, and sheaves should be equivalent to that used for the hoistway enclosure. To dissipate machinery heat and to preserve computerized elevator control equipment, the spaces must be air conditioned.

Due to the dangers involved in elevator machinery, nonelevator equipment is not permitted in elevator machine rooms. If the driving machine is located at the top of the hoistway, other machinery and equipment for building operation may also be installed in the machine room but must be separated from the elevator equipment by a substantial metal grille at least 6 ft high. The entrance to the elevator machine room should be guarded by a self-closing, self-locking door. If, however, the driving machine is not at the top of the hoistway, only elevator equipment is permitted in the machine room.

In machine rooms at the top of the hoistway, headroom of at least 7 ft above the floor must be provided. For spaces containing only overhead, secondary, or deflecting sheaves, headroom may be only 3½ ft, but 4½ ft is required if the spaces also contain overspeed governors, or other equipment.

16.7.4 Hoistway Doors

Each opening in a hoistway enclosure for access to elevator cars should be protected with a 1½-h fire-rated door for the full width and height of the opening. ANSI A17.1 lists types of doors that may be used and gives requirements for their openings. Generally, however, single-section swinging doors or horizontally sliding doors are used for freight and passenger elevators and vertically sliding doors are used exclusively for freight elevators.

Horizontally sliding or swinging doors for automatic elevators should be equipped with door closers. They should close open doors automatically if the car leaves the landing zone. (A **landing zone** is the space 18 in above and below a landing.) A horizontally sliding hoistway door may be kept open while a car is at a landing, but only while the car is being loaded and unloaded or when the door is under the control of an operator or an automatic elevator dispatching system.

For safety reasons, normal operation of the elevator car in a hoistway should not be possible unless all hoistway doors are closed and preferably also locked. For the purpose, the doors should be equipped with door-locking devices, hoistway access switches, and parking devices. A **locking device** holds a door closed, preventing it from being opened on the landing side, except for repair, maintenance or emergency purposes. An **access switch** is placed at a landing and operated to permit movement of a car with the car door and the hoistway door at the landing open, for access to the top of the car or to the hoistway pit. A **parking device** is used to open or close a hoistway door from the landing side at any landing if a car is within the landing zone. Unless all hoistway doors automatically unlock as a car enters their landing zones, at least one landing of the hoistway should be provided with a parking device.

ANSI A17.1 also requires that hoistway doors be equipped with hoistway-unit-system interlocks. These consist of electric contacts or mechanical locks, or a combination of these devices, that prevent operation of the elevator driving machine by the normal operating device unless all hoistway doors are closed and locked.

Hoistway doors should be openable by hand from the hoistway side from a car within the interlock unlocking zone, except when the doors are locked out of service. (Doors at the main-entrance landing or at the top or bottom terminal landing should be incapable of being locked out of service, so that some means of access to the hoistway is always available.) Automatic fire devices controlled by heat should not lock any hoistway door so that it cannot be opened manually from inside the hoistway nor lock any exit leading from a hoistway door to the outside.

Vision panels of clear wired glass or laminated glass, with an area between 25 and 80 in^2, may be inserted in any type of hoistway door and car door, to enable passengers in a car to see if passengers at landings are waiting to enter. ANSI A17.1, however, specifically requires such a vision panel to be installed in all horizontally swinging hoistway doors and in manually operated, self-closing, sliding hoistway doors for elevators with automatic or continuous-pressure operation. But the code does not require a vision panel at landings for automatic elevators provided with a device that indicates the location of the car in the hoistway (hall position indicator).

16.7.5 Guide Rails

The paths of elevator cars and of counterweights, if used, are controlled by vertical guide rails installed in the hoistway. The rails usually are T shaped in cross section and have smooth guiding surfaces along which the car wheels roll. A rail is installed on each side of the shaft to guide the car (Fig. 16.13). When a counterweight is used with electric elevators, to reduce power requirements, a second pair of rails is placed along one wall of the shaft, to guide the counterweight.

The elevator manufacturer usually supplies and installs the guide rails. The owner is responsible for the building structure that supports them.

16.7.6 Buffers and Bumpers

Energy-absorbing devices are required at the bottom of a hoistway to absorb the impact from a car that descends below its normal limit of travel (Fig. 16.12*a*). ANSI A17.1 specifically requires buffers under cars and counterweights in hoistways over accessible spaces. The code also requires buffers or solid bumpers in the pits for passenger elevators with speeds up to 50 ft/min and for freight elevators with speeds up to 75 ft/min, but buffers are required for greater speeds. Oil buffers may be used under elevators at any rated speed, but spring buffers may be used only for speeds up to 200 ft/min.

Solid bumpers, which are permissible only for slow elevators, may be made of wood or other resilient material. As the name implies, spring buffers use springs, whereas oil buffers use the hydraulic pressure of oil against a plunger contacted by a descending car, to bring the car to a gradual stop.

16.7.7 Hoistway Dimensions

The National Elevator Industry standard, ''Elevator Engineering Standard Layouts,'' lists clear inside dimensions required for hoistways for elevator cars covered by the standard. Standard sizes may be modified to meet specific building or structural requirements, so long as adequate clearances are maintained for guide rails and machinery installation. When actual sizing is outside of manufacturer's recommendations, it should be reviewed by the manufacturer or consultant to ensure sufficient room is permitted for the installation. The **Americans with Disabilities Act** lists specific elevator car sizes required for access to buildings.

For proper elevator operation and for safety, both maximum and minimum clearances between hoistways and cars and other moving equipment, as recommended by elevator manufacturers and ANSI A17.1, should be provided. The clearance between a car and the hoistway enclosure, for example, should be at least ¾ in, except on the sides used for loading and unloading. The clearance between the car-platform sill and vertically sliding hoistway doors or the hoistway edge of the

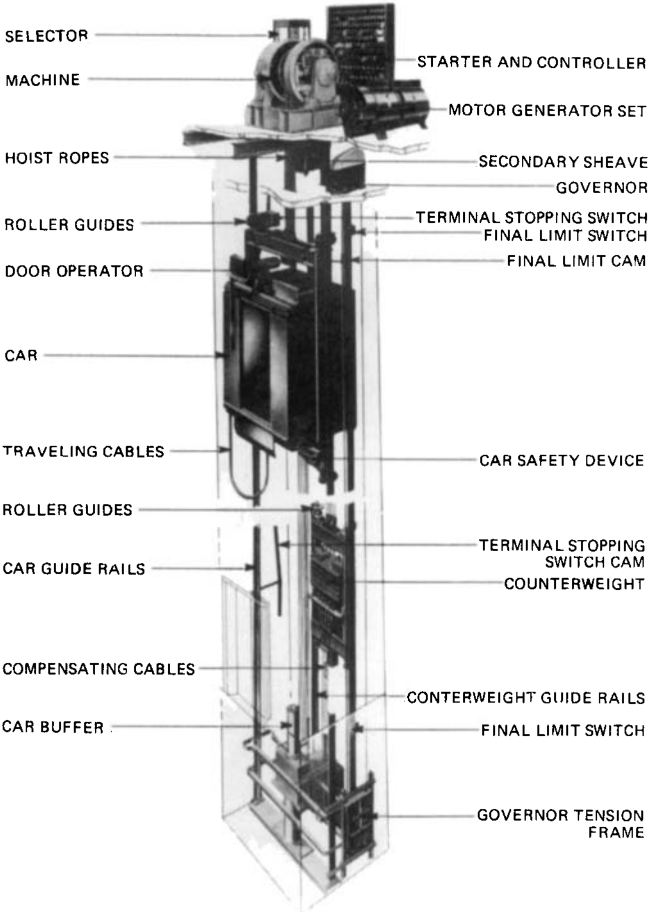


FIGURE 16.13 Electric traction passenger elevator. (*Courtesy Otis Elevator Co.*)

landing sill should be at least ½ in where side door guides are used and ¾ in where corner guides are used, but not more than 1½ in. Maximum clearance between the loading side of the car platform and the hoistway enclosure generally is 5 in but may be as much as 7½ in when vertically sliding hoistway doors are used.

Clearance between a car and its counterweight should be at least 1 in. Between the counterweight and other components, the clearance should be at least ¾ in.

In multiple hoistways, a minimum of 2-in clearance should be provided between moving equipment.

16.8 ELEVATOR CARS

A car consists basically of a platform for transporting passengers and goods. The platform is raised or lowered by wire ropes or a hydraulic piston or plunger. The car is required to be completely enclosed. Car enclosures of sheet metal or plywood are common; some decorative elevators are enclosed in laminated glass. To provide access to the car, openings protected by doors are provided in one or two of the car walls. In addition, the platform and the car enclosures are supported on a structural steel frame (Fig. 16.12).

For electric elevators, the wire ropes that move the car are attached to the frame or threaded around sheaves connected to it. For hydraulic elevators, the frame is seated on the piston. The frame also supports the upper and lower wheels that roll along the vertical guide rails in the hoistway (Fig. 16.13). In addition, car frames of electric elevators carry safety devices that stop an overspeeding elevator mechanically.

Design, construction, and installation of elevator cars should meet the requirements of the ''National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks,'' ANSI A17.1.

16.8.1 Door Controls

Car doors may be horizontally or vertically sliding. They usually are power operated. For safety, they should be equipped with devices that prevent them from opening while the car is moving or is outside the landing zones, the space 18 in above and below a landing. Also, ANSI A17.1 requires safety devices that will keep the car from moving while the doors are open. The Americans with Disabilities Act requires specific door-open dwell times in response to car and landing calls.

Additional devices are needed for power-operated doors to reopen the car and hoistway doors when they start to close on a passenger or other object. The National Elevator Industry standard, ''Suggested Minimum Passenger Elevator Requirements for the Handicapped,'' recommends that the devices be capable of sensing a person or object in the path of a closing door, without requiring contact for activation, at a nominal 5 and 29 in above the floor. Also, the doors should be kept open for at least 20 s after reopening. Still other devices should be installed for other safety reasons, for example, to prevent car and hoistway doors from closing and the car from moving when it is overloaded.

16.8.2 Car Equipment

The interior of the car should be ventilated and illuminated with at least two electric lamps. Lighting provided at the landing edge of the car platform should be at least 5 fc for passenger elevators and 2.5 fc for freight elevators. In addition, an emergency electric-lighting power source should be installed, to operate immediately after failure of the normal power source. For a period of at least 4 h, this system should maintain at least 0.2 fc at a level 4 ft above the car floor and about 1 ft in front of a car station.

The car must also house an approved communication device consistent with rules outlined in the Americans with Disabilities Act. The communication device provides a means for two-way communication with persons outside the hoistway. To be available for use by persons in wheelchairs, an alarm button should be installed in the car. When pressed, this button should sound an alarm outside the hoistway, and an emergency stop switch should be installed about 35 in above the platform. The height of the highest push button or of a telephone should not exceed

48 in. A handrail should be provided about 32 in above the floor along the rear car wall.

It is also required that the car contain a car position indicator, located above the push buttons or the door. It should indicate the number of the floor that the car is passing or at which it has stopped. An audible signal should be given to advise passengers that the car is stopping or passing a floor that is served by the elevator.

Similarly, a visual and audible signal should be given at each hoistway door to indicate in the hall, or lobby, that the car is stopping at that floor in response to a call. The audible signal should sound once for the up direction and twice for the down direction of car travel. Call buttons for summoning cars should be located in the elevator lobbies about 42 in above the floor. A lamp should light when a call is registered and go out when the call has been answered by a car.

An emergency exit should be provided in the roof of each car. Also, means should be available for operating the car from its top during inspection, maintenance, and repair. In addition, an electric light and convenience outlet should be installed on the roof, with a switch near the fixture.

See also Art. 16.9.

16.8.3 Car Capacities and Sizes

Cars are rated in accordance with their load-carrying capacity. For passenger elevators, capacities generally range from 1500 lb for use in apartment buildings to 5000 lb for use in department stores and hospitals. (Approximate capacity in passengers can be estimated by dividing the rated capacity, in pounds, by 150.) Capacities of freight elevators usually range from 1500 lb for light duty up to 10,000 lb for general-purpose work or 20,000 lb for heavy duty.

The National Elevator Industry standard, "Elevator Engineering Standard Layouts," lists standard car platform sizes for various rated capacities for electric and hydraulic passenger, hospital, and freight elevators. The sizes give clear inside width and depth of the cars. To obtain the outside dimensions of a car, add 4 in to the clear width (parallel to car door) and the following to the clear depth:

10 in for passenger elevators with center-opening doors or a single sliding door

11½ in for passenger and hospital elevators with two-speed or two-speed, center-opening doors at one end only

19 in for hospital elevators with two-speed front and rear doors

7 in for freight elevators with front doors only

10 in for freight elevators with front and rear doors

Cars supplied by various manufacturers, however, may differ somewhat in sizes from those recommended in the standard. Consequently, it is advisable to obtain recommended car sizes from the car manufacturer or elevator installer for a specific installation.

16.9 ELECTRIC ELEVATORS

An electric-elevator installation requires, in addition to the car described in Art. 16.8 and the hoistway components described in Art. 16.7, wire ropes for raising and lowering the car and for other purposes, a driving machine, sheaves for controlling rope motion, control equipment for governing car movements, a counterweight, and safety devices (Fig. 16.13).

16.9.1 Driving Machines

Components of an electric driving machine include an electric motor, a brake, a drive shaft turned by the motor, a driving sheave or a winding drum, and gears, if used, between the drive shaft and the sheave or drum. The brake operates through friction on the drive shaft to slow or halt car movement. Hoisting-rope movement is controlled by the driving sheave or the winding drum around which the ropes are wound.

Traction machines are generally used for electric elevators. These machines have a motor directly connected mechanically to a driving sheave, with or without intermediate gears, and maintain and control motion of the car through friction between the hoisting ropes and the driving sheave. Also called a traction sheave, this wheel has grooves in its metal rim for gripping the ropes.

Geared-traction machines, used for slow- and medium-speed elevators, have gears interposed between the motor and the driving sheave. The gearing permits use of a high-speed ac or dc motor with low car speeds, for economical operation. Recently, helical gear machines have been employed effectively for variable-voltage, variable-frequency (VVVF) control ac elevators. Whereas conventional worm-geared machines limit car speeds to 450 or 500 ft/min, the dual efficiency of the helical gearbox coupled with an ac motor produces car speeds of up to 800 ft/min. Progress in solid-state design has virtually eliminated the classic single- and two-speed ac-drive systems.

Gearless traction machines, in contrast, are used with ac or dc motors for elevators that operate at speeds of 500 ft/min or more. This type of elevator machine is essentially a large motor with a traction sheave and brake mounted on a common shaft. Gearless dc and ac motored (VVVF control) machines are effectively used for car speeds of 500 ft/min or more. Since the gearless traction machine consists of a custom-built motor, traction sheave, and brake on a custom motor frame, these machines are the most expensive elevator drive systems.

A **winding-drum machine** gear-drives a grooved drum to which the hoisting ropes are attached and on which they wind and unwind. For contemporary elevators, the winding-drum drive system is applied only to dumbwaiters and light-duty residential units.

16.9.2 Elevator Control

The system governing starting, stopping, direction of motion, speed, and acceleration and deceleration of the car is called control. Multivoltage control (also known as variable-voltage control) or rheostatic control has been commonly used for electric elevators, due largely to the relative simplicity of controlling the dc motor. The advent of larger power transistors has resulted in control systems known as VVVF control, that can be applied to ac motors to produce smooth starting and stopping equal to the classic dc elevator control system.

Multivoltage control usually is used with driving machines with dc motors. For elevator control, the voltage applied to the armature of the motor is varied. Because buildings usually are supplied with ac power, the variable voltage generally is obtained from a motor-generator set that converts ac to dc. This type of control commonly is used for passenger elevators because it combines smooth, accurate speed regulation with efficient motor operation. It also permits rapid acceleration and deceleration and accurate car stops, with low power consumption and little maintenance. But multivoltage control costs more initially than rheostatic control.

Variable-voltage, variable-frequency control is a means used to produce smooth acceleration, deceleration, and stopping of common ac motors at nonsynchronous speeds. VVVF control offers much higher efficiency than that realized through dc motors and is gradually replacing the various means used to control dc motors, along with the dc motor.

16.9.3 Car Leveling at Landings

Elevator installations should incorporate equipment capable of stopping elevator cars level with landings within a tolerance of ½ in under normal loading and unloading conditions. Because changing car loads vary the stretch of the hoisting ropes, provision should be made to compensate for this variation and keep the car platform level with the landing. Most elevators employ automatic leveling.

Automatic leveling controls the driving motor to level the car. Elevators typically employ a two-way, automatic leveling device to correct the car level on both overrun and underrun at a landing and hold the car level with the landing during car loading and unloading.

16.9.4 Terminal Stopping Devices

For safety, provisions should be made to control car movement as it approaches a terminal landing and to keep it from passing the terminal. For the purpose, special speed-limiting and stopping devices are needed.

An **emergency terminal speed-limiting device** is required to reduce car speed automatically as the car approaches the terminal landing. This should be done independently of the functioning of the operating device, which actuates the elevator control, and of the normal terminal stopping device if it should fail to slow the car down as intended.

The **normal terminal stopping device** slows down and stops the car at or near a terminal landing independently of the functioning of the operating device. It should continue to function until the final terminal stopping device operates.

The **final terminal stopping device** is required to interrupt automatically the electric power to the driving-machine motor and brake after the car has passed a terminal landing. But this device should not operate when the car has been stopped by the normal terminal stopping device. When the final terminal stopping device has been actuated, normal car operating devices should be rendered incapable of moving the car.

16.9.5 Car and Counterweight Safeties

A safety is a mechanically operated device that is capable of stopping and supporting the weight of an elevator car and its load when the device is actuated by a car-speed governor. The safety should be actuated when the car travels at more than 15% above its rated speed.

Car safeties are generally mounted on the *safety plank,* or bottom member of the car frame. When tripped, springs on the safeties push shoes against the guide rails hard enough to make the car slide to a stop. (When a hoistway is located above an accessible space, safeties, such as those used for cars, should also be provided on the counterweight frame.) The safeties are typically released by upward motion of the car.

The governor may be conveniently located in the machine space, where the device will not be struck by the car or the counterweight if either should overtravel. The governor may measure car speed from the rotation of a sheave around which is wound a wire rope connected to the car and held under tension. When the car goes too fast, the governor trips jaws that grip a wire rope connected through linkages to a safety and release a spring to actuate the safety. Also, electrical switches on the governor and the safety are opened to remove power from the driving machine and apply a friction brake to the drive shaft.

16.9.6 Counterweights

Power requirements of the driving machine for moving the car are reduced by hanging a counterweight on the hoisting ropes. Use of a counterweight also is advantageous for maintaining traction between the hoisting ropes and the driving sheave. The weight of the counterweight usually is made equal to the weight of the unloaded car and the ropes plus about 40% of the rated load capacity of the car (Fig. 16.14).

A counterweight usually is made up of cut steel plates set in a steel frame. Moving up as the car moves down and down when the car moves up, the counterweight is kept in a fixed vertical path by upper and lower guide rollers that are attached to its frame and roll along a pair of guide rails.

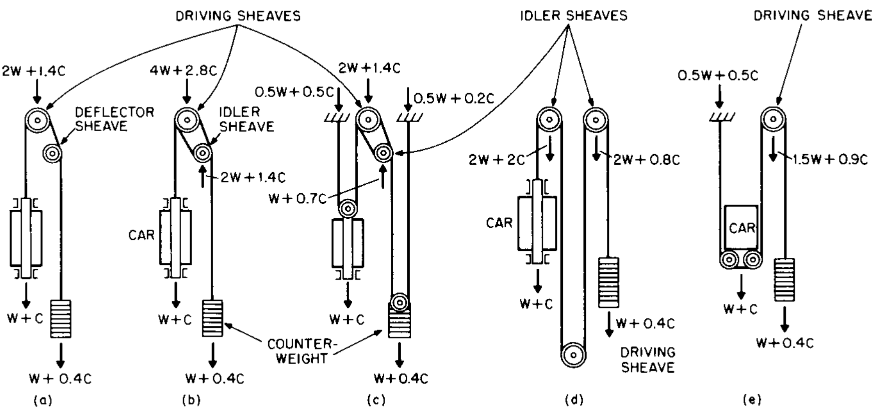


FIGURE 16.14 Types of roping for electric traction elevators. Rope tension and loads imposed on sheaves and supports depend on the type of roping, car weight *W*, and car capacity *C*.

16.9.7 Roping for Elevators

The "American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks," ANSI A17.1, requires that a car be suspended from at least three hoisting ropes for traction-type machines and two ropes for winding-drum machines. At least two ropes are needed for a counterweight. All these ropes should be at least ½ in in diameter.

A wire rope for an elevator installation comprises a group of steel strands laid helically around a hemp core. Each strand, in turn, consists of steel wires placed helically around a central wire and has a symmetrical cross section.

For a given weight of a car and load, the method of roping an elevator has a considerable effect on car speed and loading on the hoisting ropes machine bearings, and building structural members. The simple arrangement of hoisting ropes, cars, and counterweight shown in Fig. 16.14*a*, for example, is called **1:1 roping,** because car speed equals rope speed. The ropes are attached to the top of the car frame, wind around the driving sheave, bend around a deflector sheave, and then extend downward to the top of the counterweight. This rope arrangement is also known as **single-wrap roping** because the ropes pass over the driving sheave only once between the car and the counterweight. The 1:1 single-wrap roping often is used for high-speed passenger elevators.

For single-wrap roping, the rim of the driving sheave is given wedge-shaped or undercut grooves, to obtain sufficient traction. The sheave grips the ropes because of a wedging action between the sides of the grooves and the ropes. The pinching, however, tends to shorten rope life.

For good traction with less rope wear, **double-wrap roping** (Fig. 16.14*b*), is frequently used for high-speed passenger elevators instead of single-wrap. For double-wrap roping, the ropes are attached to the top of the car frame, wind twice around the driving sheave and secondary sheave, and are then deflected down to the counterweight by the secondary sheave. Because of the double wrap, less grip is needed at the driving sheave. As a result, its rim may be given U-shaped or round-seat grooves, which cause less rope wear. The 1:1 double-wrap roping shown in Fig. 16.14*b*, however, applies twice the load to the driving sheave for the same weight of car and counterweight as does the single-wrap roping in Fig. 16.14*a* and requires a heavier design for affected components.

For the double-wrap roping shown in Fig. 16.14*c*, rope speed is twice the car speed. The arrangement, called **2:1 roping,** is suitable for heavily loaded, slow freight elevators. For this arrangement, a higher-speed, less costly motor can be used for a given car speed than with 1:1 roping. The ropes in this case are not attached to the car and counterweight as for 1:1 roping. Instead, the ropes wind around idler sheaves on car and counterweight, and the ends of the ropes are anchored at the top of the hoistway at beams. As a result, the load on the driving and idler sheaves is only about one-half that for 1:1 roping.

In most buildings, driving machines are located in a penthouse. When a machine must be placed in a basement (Fig. 16.14*d*), the load on the overhead supports is increased, rope length is tripled and additional sheaves are needed, adding to the cost. Other disadvantages include higher friction losses and a larger number of rope bends, requiring greater traction between ropes and driving sheave for the same elevator loads and speeds; modestly higher power consumption; and potentially greater rope wear.

Figure 16.14*e* shows a type of 2:1 roping suitable for slow, low-rise elevators. In contrast to the roping in Fig. 16.14*c*, only one end of the hoisting ropes is dead-ended at the top of the hoistway. The other end is attached to the counterweight.

Also, the ropes pass around idler sheaves at the car that are placed on the underside of the car frame.

16.9.8 Elevator Operating Systems

The method of actuating elevator control is called elevator operation. Many types of operation are available and some are complex and sophisticated. These may cost more than the simpler systems for installation and operation, but the sophisticated systems accomplish more automatically and handle traffic more efficiently. Following are descriptions of several types of operation:

Car-Switch Operation. With a manually operated car switch or continuous-pressure buttons in the car, an operator controls movement and direction of travel of the car. To ensure that the operator controls car movement, the handles of lever-type operating devices should return to the stop position and latch there automatically when the operator's hand is removed. In automatic car-switch, floor-stop operation, the operator releases the lever or button to stop the car at a landing. Slowing and stopping are then accomplished automatically.

Signal Operation. The car can be started only by an operator pushing a start button in the car. The operator can register stops in advance by pressing and releasing a push button in the car corresponding to the predetermined floor number. Persons calling for the elevator can similarly register a stop by pushing an up or down hall button. The car automatically stops at landings for which signals were registered, regardless of the direction of car travel or of the sequence in which buttons at various floors were pressed. When a landing is served by two or more elevators, the first available car approaching the floor in the specified direction makes the stop automatically.

Automatic Operation. An operator is not needed for automatic operation. Starts and stops are signaled by passengers in the car or by hall buttons or by an automatic operating mechanism. The car starts either in response to this mechanism or when a passenger presses a car or hall button. Responding to signals from car or hall buttons, the car travels to and stops at the signaled landings, and car and hoistway doors open automatically. Following, in order of increasing sophistication, are descriptions of several types of automatic operation.

Single Automatic Operation. The car starts when a passenger presses and releases a car button corresponding to a landing. The car then travels to that floor and stops. The car also starts when a hall button is pressed, travels to that landing, and stops. After any button has been pressed, depression of any other button has no effect on car movement until the stop signaled by the first button has been made.

Selective Collective Automatic Operation. When a car button corresponding to a landing is pressed, the car travels to that floor but also, on the way, makes other stops signaled. Hall calls are answered in the order in which landings are reached in each direction of travel, regardless of the sequence in which signals were received. Up calls are served when the car is traveling upward, and down calls are answered when the car is traveling downward.

Group Automatic Operation. This is an extension of selective collective operation to a group of cars serving the same landings. A supervisory control system automatically dispatches cars to answer calls and coordinates the operation of the group. A call is answered by the first car to approach a landing in the proper direction. In response to a timer, the car leaves a terminal at predetermined intervals, which can be varied in accordance with traffic requirements. Group operation with automatic dispatching increases the number of passengers the elevators can carry in a given time.

16.9.9 Elevator Group Supervision

The supervisory control system for group automatic operation of elevators should be capable of making adjustments for varying traffic conditions. It should control car motion so that cars in the best location for answering calls do so. In the past, group control systems employed an elaborate relay network to ''program'' elevator motion. The advent of microprocessors, however, has dramatically changed elevator control systems.

The state-of-the-art group control system employs limited *artificial intelligence* features, which control the dispatching of high-speed elevator groups more efficiently. One such supervisory control system contains a database based on practical knowledge, traffic data, and experience of elevator group-control experts. The system is able to maximize every elevator operation by application of the database and through knowledge it has obtained from ongoing traffic monitoring functions, such as call quantity and car loading. Decisions also involve use of *fuzzy logic,* which allows the elevator group control to make decisions based on fragmentary and fuzzy intelligence concepts. For example, use of the incorporated ''intelligence'' and ''common sense'' in the decision-making process maximizes the effectiveness of the system and assists in determining whether or not potential car assignments will result in shorter waiting times or cause congestion in elevator lobbies.

In another approach, the system is designed to alleviate lobby congestion during heavy up-peak traffic periods. Elevators make fewer stops per round trip, with the result that cars return to the lobby faster. The floors about the lobby served by the group are divided into sectors of contiguous floors. The number of sectors is normally one less than the number of elevators in the group. As an elevator returns to the lobby during an up-peak period, it is assigned to service one of the sectors. Passengers can easily determine which floors each car is serving by checking the Information Display System screens located next to or above each elevator entrance. The same car will not necessarily serve the same sector on successive trips. Care is taken to ensure that each sector will receive equal service by the assignment of sectors in a round-robin manner.

In still another approach, unlike any other control system presently in use, the system is arranged to *know* the passenger quantity and destination before the call is answered by the elevator. This is achieved through the use of a keypad call-entry system installed at each landing. The prospective passenger enters the destination into the keypad, and the elevator control system immediately assigns an elevator to that call. The passenger is notified graphically which elevator will respond to the call. Since the efficiency of elevator movement is greatly improved, this system offers the opportunity to reduce the quantity of elevators used to meet specific traffic conditions.

16.9.10 Additional Elevator Safety Devices

Automatic elevators require several safety devices in addition to those usually installed in elevators with operators. These devices include:

An automatic load weigher to prevent doors from closing and the car from starting when it is overloaded

Car and hall buttons that passengers can push to stop the doors from closing and to hold them open

Means for preventing doors from closing when the entrance is obstructed

Emergency power system that is activated as soon as the primary system fails

Lights to indicate landings for which calls have been registered

Two-way communication with a supervisor outside the hoistway

(G. R. Strakosch, ‘‘Vertical Transportation: Elevators and Escalators,’’ John Wiley & Sons, Inc., New York.)

16.10 HYDRAULIC ELEVATORS

For low-rise elevators, hydraulic equipment may be used to supply the lift. Two basic designs are available: one where the car sits atop a plunger or piston which operates in a pressure cylinder (Fig. 16.15), and the other where two plungers are located inside the elevator shaft to lift the elevator either by direct connection to the carframe or indirectly using hoist ropes. Oil serves as the pressure fluid and is supplied through a motor-driven positive-displacement pump, actuated by an electric-hydraulic control system.

To raise the car, the pump is started, discharging oil into the pressure cylinder and forcing the plunger up. When the car reaches the desired level, the pump is stopped. To lower the car, oil is released from the pressure cylinder and is returned to a storage tank.

Single-bearing cylinders (Fig. 16.16*a*) are a simple type that operate like a hydraulic jack. They are suitable for elevator and sidewalk lifts where the car is guided at top and bottom, preventing eccentric loading from exerting side thrust on the cylinder bearing. A cylinder of heavy steel usually is sunk in the ground as far as the load rises. The plunger, of thickwalled steel tubing polished to a mirror finish, is sealed at the top of the cylinder with compression packing. Oil is admitted under pressure near the top of the cylinder, while air is removed through a bleeder.

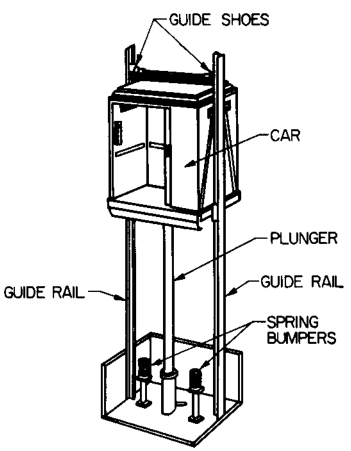


FIGURE 16.15 Hydraulic elevator.

A different cylinder design should be used where the car or platform does not operate in guides. One type capable of taking off-balance loads employs a two-bearing plunger (Fig. 16.16*b*). The bearings are kept immersed in oil.

Another type, suitable for general industrial applications, has a movable bearing at the lower end of the plunger to give support against heavy eccentric loads (Fig. 16.16*c*). At the top of the cylinder, the plunger is supported by another bearing.

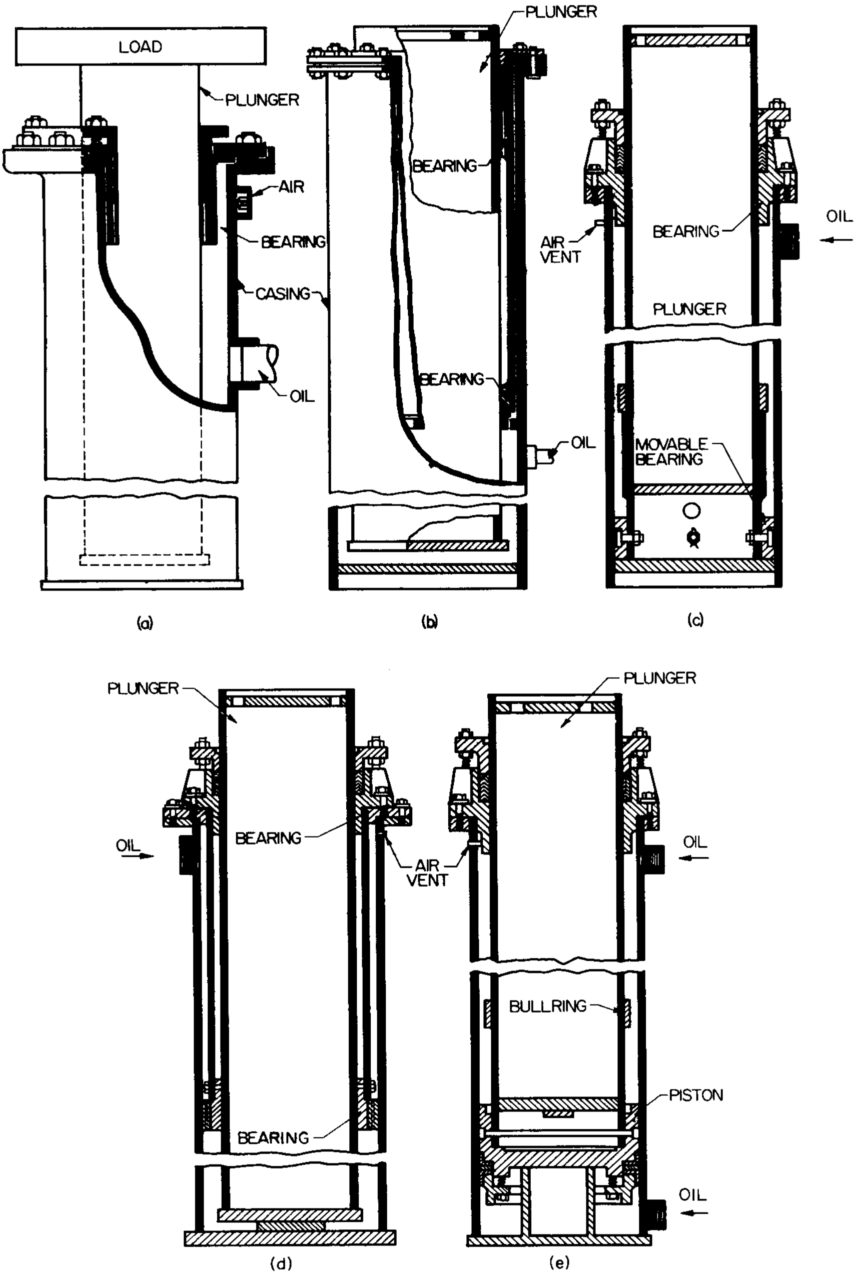


FIGURE 16.16 Jacks commonly used for hydraulic elevators: (*a*) single-bearing plunger for guided loads; (*b*) two-bearing plunger for off-balance loads; (*c*) movable-bearing plunger for heavy service; (*d*) cage bearing for long-stroke service; (*e*) double-acting plunger.

For long-stroke service, a cage-bearing type can be used (Fig. 16.16*d*). The cage-bearing is supported by a secondary cylinder about 3 ft below the main cylinder head. Oil enters under pressure just below the main cylinder head, passes down through holes in the bearing, and lifts the plunger.

When the car or platform is not heavy enough to ensure gravity lowering, a double-acting cylinder may be used (Fig. 16.16*e*). To raise the plunger, oil is admitted under pressure below the piston; to lower it, oil is forced into the cylinder near the top, above the piston, and flows out below. Jack plunger sizes for the various types range from 2½ in in diameter for small low-capacity lifts to 18 in for large lifts, operating at 150 to 400 psi.

Hydraulic elevators have several advantages over electric elevators: They are somewhat less expensive and simpler. The car and its frame rest on or beside the hydraulic plunger that raises and lowers them. There are sometimes wire ropes. No overhead equipment or penthouse is required. Without heavy overhead loads, hoistway columns and footings can be smaller. Car safeties or speed governors are only required on the roped type. Speed of the elevator is low; so the bumpers need be only heavy springs.

Capacity of hydraulic passenger elevators usually ranges from 1200 to 5000 lb at speeds from 75 to 150 ft/min. With gravity lowering, down speed may be 1.5 to 2 times up speed. So the average speed for a round trip can be considerably higher than the up speed. Standard hospital elevators have capacities of 3500 to 5000 lb at speeds of 75 to 150 ft/min.

Capacity of standard freight elevators ranges from 2500 to 8000 lb at 50 to 125 ft/min, but they can be designed for much greater loads.

(G. R. Strakosch, "Vertical Transportation: Elevators and Escalators," John Wiley & Sons, Inc., New York.)

16.11 PLANNING FOR PASSENGER ELEVATORS

Elevator service is judged by two primary criteria: quantitative, or the number of persons who can be moved by the system within a defined peak traffic period, and qualitative, which expresses the calculated time between departing elevators during the same heavy traffic period.

16.11.1 Number of Elevators Required

The number of passenger elevators required for a particular building depends on the number of persons expected to work or live in the building. Traffic is measured by the number of persons requiring service during a peak 5-min period. For proposed buildings, a population estimate is generated on the basis of occupancy trends for that specific building type. Peak-traffic projections are based on the type of tenancy expected for the building. From the population and peak-traffic projection, the demand is established as a peak 5-min traffic flow. While peak traffic in most buildings is a rather complex pattern of two-way and interfloor movement, most models assume a simplified traffic pattern in which traffic is primarily incoming or outgoing. The lack of a complex model is more a result of the poor understanding of the existing model than of the absence of sophisticated measuring devices.

After the peak 5-min traffic flow is established, an estimate may be made of the quantity of elevators required. The ability of a specific system to handle the traffic is tested against the projected traffic level. The 5-min handling capacity of an elevator is determined from the round-trip time.

$$HC = \frac{300}{T} P \tag{16.1}$$

where HC = handling capacity of car, persons in 5 min or 300 s
P = car capacity, persons
T = round-trip time of car, s

The minimum number of elevators n required can then be computed from

$$n = \frac{V}{HC} = \frac{VI}{300P} \tag{16.2}$$

where V = peak traffic, persons in 5 min. Equation (16.2) indicates that the minimum number of elevators required is directly proportional to the round-trip time for a car and inversely proportional to the car capacity.

Elevator-related space requirements may not be minimized through the use of the fewest elevators to serve a particular building, since large groups of high-capacity cabs must be employed to serve a large number of floors. Large groups of elevators increase cost of the overall system by increasing the average number of elevator entrances required for the building. For greatest efficiency and lowest cost, elevator group sizes should not exceed six elevators, with four elevators per group as a more practical approach. This method has the added advantage that passenger trip time—that is, the time it takes an individual to travel to a destination during peak traffic—is reduced due to use of smaller cabs and assignment of fewer floors to be served by a particular elevator group.

After an approximate quantity of elevators is found to meet quantitative traffic requirements, qualitative performance should be reviewed. The criteria for qualitative performance is generally based on the quality of service expected for a specific building, as well as the overall quality level of the project. Qualitative service is typically expressed as **interval,** or the calculated time between elevators departing the ground floor. Improving elevator service for a building, however, generally results in increased cost.

After the number of elevators has been computed on the basis of traffic flow, the average interval should be checked. It is obtained by dividing the round-trip time by the number of elevators.

Round-trip time is composed of all of the pieces of a projected elevator trip, including starting, running, and stopping of the elevator car, time for opening and closing doors, and time for passengers to move in and out. Often some factor is added to the round trip time to simulate normal use of the system.

Opening and closing of doors may contribute materially to lost time, unless the doors are properly designed. A 3-ft 6-in opening is excellent, because two passengers may conveniently enter and leave a car abreast. A slightly wider door would be of little advantage. Department stores, hospitals, and other structures served by larger passenger elevators (4000 lb and over) usually require 4-ft door openings.

Center-opening doors, preferred for power operation, are faster than either the single or two-speed type of the same width. The impact on closing is smaller with the center-opening door; hence, there is less chance of injuring a passenger. Also, transfer time is less, since passengers can move out as the door starts to open.

Another factor affecting passenger-transfer time is the shape of the car. The narrower and deeper a car, the greater is the time required for passenger entry and exit during peak-traffic conditions likely to be.

(See also Art. 16.9.8 and 16.9.9.)

16.11.2 Elevators in General-Purpose Buildings

For a proposed diversified-tenancy, or general-purpose, office building, peak traffic may be estimated from the probable population computed from the net rentable area (usually 75 to 90% of the gross area). Net rentable area per person typically ranges from 150 to 190 ft^2. Some rare organizations occupy space at higher densities but averages for specific floors rarely become as dense as one person to 100 ft^2.

Diversified-tenancy office buildings usually have important traffic peaks in the morning, at noon, and in the evening, and very little interfloor traffic. The 5-min morning peak generally is the controlling factor, because if the elevators can handle that peak satisfactorily, they can also deal with the others. In a well-diversified office building, the 5-min peak used is about 12.5% of the population.

For busy, high-class office buildings in large cities, time intervals between elevators may be classified as follows: 26 to 28 s, excellent; between 28 and 30 s, good; between 30 and 32 s, fair; between 32 and 35 s poor; and over 35 s may be unsatisfactory. In small cities, however, intervals of 30 s and longer may be satisfactory.

For express elevators, which make no intermediate stops, intervals of 30 to 35 s may be considered acceptable.

Car speeds used vary with height of building: 4 to 10 stories, 200 to 500 ft/min; 10 to 15 stories, up to 700 ft/min; 15 to 20 stories, up to 800 ft/min; 20 to 50 stories, up to 1200 ft/min; and over 50 stories, up to 2500 ft/min. Practically speaking, 200-ft/min elevators are generally not economically advantageous and have been replaced by 350-ft/min elevators for most passenger applications.

Elevators should be easily accessible from all entrances to a building. For maximum efficiency, they should be grouped near the center. Except in extremely large buildings, two banks of elevators located in different parts of the structure should not serve the same floors. Since one cannot guarantee equal use of the two groups, each group should be designed to handle 60 to 65% of the traffic.

Elevators cannot efficiently serve two lower terminal floors, inasmuch as cars stop twice to pick up passengers who are typically picked up once. The extra stop increases the round-trip time and decreases the handling capacity, resulting in the need for more elevators to satisfy the same traffic criteria. If there is sufficient traffic between the two lower floors, escalators or shuttle elevators should be installed, and one of the levels should be assigned as the sole terminal for the tower passenger elevators.

When laying out a local-travel elevator group, groupings should not exceed four elevators in line. This arrangement can be exceeded for groupings of express elevators where elevator arrivals can be preannunciated. Elevator core configurations must take into account the need for smoke control at elevator lobbies, as well as code limits on dead-end corridors. Lobby widths should be 9 to 12 ft, depending on the size of the elevators.

It is necessary to divide elevator groups into local and express banks in buildings of 15 floors and more, especially those with setbacks and towers, and in low buildings with large rental areas. In general, when more than six elevators are needed, consideration should be given to dividing the building into more elevator groups. In addition to improving service, the division into local and express banks has the advantage that corridor space on the floors where there are no doors can be used for toilets, closets, and stairs.

While the decision to include a dedicated service elevator is often market driven, office buildings of less than 250,000 gross square feet typically ‘‘swing’’ a passenger elevator for off-peak deliveries and moves. Buildings of up to 500,000 or 600,000 gross square feet frequently have only a single service elevator, whereas larger buildings are provided with two or more separate service cabs. Where dedicated service elevators are provided, at least one should be hospital shaped, with the capability of carrying end-loaded 9-ft-long gypsum wall board. A 12-ft ceiling allows easy movement of carpet rolls and long conduit.

16.11.3 Elevators in Single-Purpose Buildings

Elevator requirements and layouts are similar, in general, for both single-purpose and diversified-tenancy office buildings; but several different factors should be taken into consideration: Single-purpose buildings are occupied by one large organization. Generally, the floors that are occupied by the clerical staff are not subdivided into many offices; the net rentable area is about 80% of the gross area. Population densities are higher than for general-purpose buildings. Depending on the kind of business to be carried on, population density varies from 100 ft^2 per person for some life-insurance companies to about 300 ft^2 per person for some attorney's offices.

Although traffic peaks occur at the same periods as in the diversified-tenancy type, the morning peak may be very high, unless working hours are staggered. The maximum 5-min periods may be 13.5 to 16.0% of the population, depending on the type of occupancy. If traffic volumes are high, occupancy of the building should be carefully balanced against elevator requirements. Although many floors may be connected with an eight-car elevator bank, the time wasted on elevators becomes excessive as a result of the number of stops made during each elevator trip.

In the past, system designers specified more elevators to meet interfloor traffic demands of single-purpose buildings. The advent of microprocessor-based controls, however, has dramatically improved system response to complex traffic patterns. With such controls, an elevator system designed to handle the incoming traffic rush will also provide satisfactory service in response to interfloor traffic.

Elevator service in single-purpose buildings is frequently hobbled by location of a cafeteria or similar high-density, facility at some level above the ground floor. If such facilities are served by the office passenger elevators, the total elevator requirement can increase by 15 to 20% as a result of the inefficiency introduced by the cafeteria.

16.11.4 Elevators in Government Buildings

Municipal buildings, city halls, state office buildings, and other government office buildings may be treated the same as single-purpose office buildings. Population density often may be assumed as one person per 140 to 180 ft^2 of net area. The 5-min maximum peak occurs in the morning and may be as large as 16% of the population.

16.11.5 Professional-Building Elevators

Population cannot be used as the sole basis for determining the number of elevators needed for buildings occupied by doctors, dentists, and other professional people, because of the volume of patient and visitor traffic. Peaks may occur in the forenoon and midafternoon. The maximum occurs when reception hours coincide. Traffic studies indicate that the maximum peak varies from two to six persons per doctor per hour up and down.

Since crowding of incapacitated patients is inadvisable, elevators should be of at least 3000-lb capacity. If the building has a private hospital, then one or two of the elevators should be hospital-type elevators.

16.11.6 Hotel Elevators

Hotels with transient guests average 1.3 to 1.5 persons per sleeping room and are typically populated based upon 90% occupancy. They have pronounced traffic peaks in morning and early evening. The 5-min maximum occurs during checkout hour and can be about 12.5 to 15% of the estimated population, with traffic moving in both directions.

Ballrooms and banquet rooms should be located on lower floors and served by separate elevators. Sometimes it is advisable to provide an express elevator to serve heavy roof-garden traffic. Passenger elevators should be of 3000-lb capacity or more to allow room for baggage carriers. Intervals for passenger elevators should not exceed 50 s.

Service elevators are very important in hotels. Hospital-shaped elevators are often preferred for handling linen and food service carts as well as baggage.

Typically, hotels are provided with one passenger elevator per 125 to 150 rooms. The service elevator quantity is 50 to 60% of the passenger elevator quantity. The ratio of rooms per elevator is lower for better-quality hotels and higher for more modest facilities.

Elimination of noise and vibration from medium- to high-speed elevators is virtually impossible, so hotels should be carefully planned to ensure that guest rooms are not adjacent to elevator hoistways. Rooms that adjoin elevator hoistways may generate complaints throughout the life of the building.

16.11.7 Apartment-Building Elevators

Multistory residential buildings do not have peaks so pronounced as other types of buildings. Generally, the evening peak is the largest. Traffic flow at that time may be 6 to 8% of the building population in a 5-min period. Building population should be estimated in consideration of the market for which the building is designed.

If only one elevator is selected to satisfy traffic conditions for a building of modest height, residents will be forced to use the stairs at times the elevator is out of service for repairs. Where the elevator is considered more than an amenity, two elevators should be provided. Market conditions may require that a separate service elevator also be provided in some urban settings. Typically, a 2500-lb elevator with a 9-ft clear ceiling height can be relied on to carry most furniture.

As is the case with hotels, the potential for noise and vibration should be considered in location of elevators in living units.

16.11.8 Department-Store Elevators

Department stores should be served by a coordinated system of escalators and elevators. The required capacity of the vertical-transportation system should be based on the transportation of merchandising area and the maximum density to which it is expected to be occupied by shoppers.

The **transportation area** is all the floor space above or below the first floor to which shoppers and employees must be moved. Totaling about 80 to 85% of the gross area of each upper floor, the transportation area includes the space taken up by counters, showcases, aisles, fitting rooms, public rooms, restaurants, credit offices, and cashiers' counters but does not include kitchens, general offices, accounting departments, stockrooms, stairways, elevator shafts, or other areas for utilities.

The **transportation capacity** is the number of persons per hour that the vertical-transportation system can distribute from the main floor to the other merchandising floors. The ratio of the peak transportation capacity to the transportation area is called the density ratio. This ratio is about 1 to 20 for a busy department store. So the required hourly handling capacity of a combined escalator and elevator system is numerically equal to one-twentieth, or 5%, of the transportation area. The elevator system generally is designed to handle about 10% of the total.

The maximum peak hour usually occurs from 12 to 1 pm on weekdays and between 2 and 3 pm on Saturdays.

The type of elevator preferred for use with moving stairs is one with 3500-lb capacity or more. It should have center-opening, solid-panel, power-operated car and hoistway doors, with at least a 4-ft 2-in opening and a platform 7 ft 8 in by 4 ft 7 in.

16.11.9 Hospital Elevators

Traffic in a hospital is of two types: (1) medical staff and equipment and (2) transient traffic, such as patients and visitors. Greatest peaks occur when visitor traffic is combined with regular hospital traffic. Waiting rooms should be provided at the main floor and only a limited number of visitors should be permitted to leave them at one time, so that the traffic peaks can be handled in a reasonable period and corridors can be kept from getting congested. In large hospitals, however, pedestrian and vehicular traffic should be separated.

For vehicular traffic or a combination of vehicular and pedestrian traffic, hospital elevators should be of stretcher size—5 ft 4 in to 6 ft wide and 8 or 9 ft deep, with a capacity of 4000 to 5000 lb. Speeds vary from 100 to 700 ft/min for electric elevators, depending on height of building and load. For staff, visitors, and other pedestrian traffic, passenger-type elevators, with wide, shallow platforms, such as those used for office buildings, should be selected (see Arts. 16.11.2 and 16.11.3).

Elevators should be centrally located and readily accessible from the main entrance. Service elevators can be provided with front and rear doors, and, if desired, so located that they can assist the passenger elevators during traffic peaks.

16.11.10 Freight Elevators

In low-rise buildings, freight elevators may be of the hydraulic type (Art. 16.10), but in taller buildings (higher than about 50 ft) electric elevators (Art. 16.9) generally will be more practical. Figure 16.17 shows the components of an electric freight elevator.

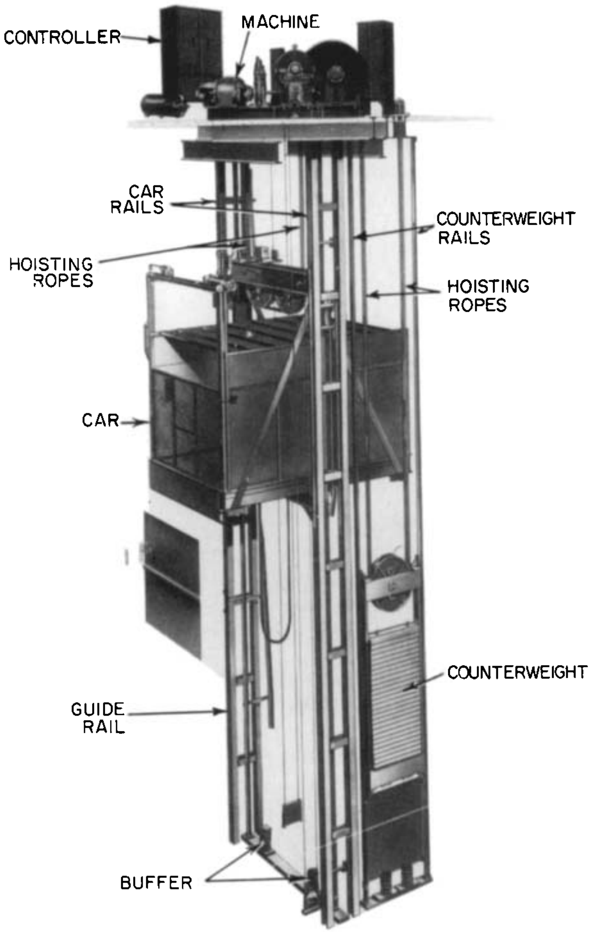


FIGURE 16.17 Electric traction freight elevator. (*Courtesy Otis Elevator Co.*)

In planning for freight elevators, the following should be considered:

1. Building characteristics, including the travel, number of floors, floor heights and openings required for a car. Also, structural conditions that may influence the size, shape, or location of the elevator should be studied.
2. Units to be carried on the elevator—weight, size, type, and method of loading.
3. Number of units to be handled per hour.
4. Probable cycle of operation and principal floors served during the peak of the cycle.
5. Freight elevators are not permitted to carry passengers.

For low-rise, slow-speed applications, especially where industrial trucks will be used, rugged hydraulic freight elevators generally will be more economical than electric freight elevators.

Classification of Freight Elevators. The "American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks," ANSI A17.1, defines three classes of freight elevators. Class A applies to general freight loading. This is defined as a distributed load that is loaded or unloaded manually or by hand truck and no unit of which, including loading equipment, weighs more than one-quarter the rated load of the elevator. Class B elevators may handle only motor vehicles. Class C elevators may be subjected to heavy concentrated loads and fall into one of three subclasses. Class Cl applies to elevators that carry industrial trucks, Class C2 to elevators for which industrial trucks are used only for loading and unloading the cars and are not carried by them, and Class C3 to elevators carrying heavy concentrated loads other than trucks.

Car Capacity of Freight Elevators. The size of car to be used for a freight elevator is generally dependent on the dimensions of the freight package to be carried per trip and the weight of the package and loading equipment. Power trucks, for example, impose severe strains on the entire car structure and the guide rails than do hand trucks. As a power truck with palletized load enters an elevator, most of the weight of the truck and its load are concentrated at the edge of the platform, producing heavy eccentric loading. Maximum load on an elevator should include most of the truck weight as well as the load to be lifted, since the truck wheels are on the elevator as the last unit of load is deposited.

The carrying capacity per hour of freight elevators is determined by the capacity or normal load of the elevator and the time required for a round trip. Round-trip time is composed of the following elements:

1. Running time, which may be readily calculated from the rated speed, with due allowance for accelerating and decelerating time (about 2¼ s for ac rheostatic control with inching, 1¾ s for multivoltage), and the distance traveled.
2. Time for operation of the car gate and hoistway doors (manual 16 s, power 8 s).
3. Loading and unloading time (hand truck 25 s, power truck 15 s). Wherever practical, a study should be made of the loading and unloading operations for a similar elevator in the same type of plant.

Operation of Freight Elevators. The most useful and flexible type of operation for freight elevators is selective-collective with fully automatic doors. Attendant operation requires an annunciator. When operated with an attendant, the car automatically answers the down calls as approached when moving down and similarly answers up calls when moving up. The elevator attendant, when present, has complete control of the car and can answer calls indicated by the annunciator by pressing the corresponding car button. The addition of fully automatic power-operated doors means the elevator is always available for use, unless taken out of service by the attendant.

The standard hoistway door is the vertical biparting, metal-clad wood type. For active elevators and openings wider than 8 ft, doors should be power-operated.

Automatic freight elevators can be integrated into material-handling systems for multistory warehouse or production facilities. On each floor, infeed and outfeed horizontal conveyers may be provided to deliver and remove loads, usually palletized, to and from the freight elevator. The elevator may be loaded, transported to another floor, and unloaded—all automatically.

16.12 DUMBWAITERS

These may be used in multistory buildings to transport small loads between levels. Generally too small to carry an operator or passenger, dumbwaiters are cars that are raised or lowered like elevators. They may be powered—controlled by push buttons—or manually operated by pulling on ropes. Powered dumbwaiters can automatically handle from 100 to 500 lb at speeds from 45 to 150 ft/min. They are available with special equipment for automatic loading and unloading. They also are designed for floor-level loading suitable with cart-type conveyances.

The ''American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks,'' ANSI A17. 1, contains safety requirements for dumbwaiters. Powered dumbwaiters may be constructed like electric elevators with winding-drum or traction driving machines or like hydraulic elevators. Many of the safety requirements for elevators, however, are waived for dumbwaiters. Standard heights for a dumbwaiter are 3, 3½, and 4 ft. ANSI A17.1 restricts platform area to a maximum of 9 ft^2. Rated load capacity usually ranges from 20 to 500 lb. Like elevators, hoistways should have fire-resistant enclosures.

16.13 CONVEYERS AND PNEUMATIC TUBES

When there is a continuous flow of materials, such as mail or other documents to be distributed throughout a multistory building, conveyer systems may provide an economical supplement to elevators. In some installations, 200 lb or more of paper work and light supplies are circulated per minute.

Two types of conveyer systems are employed in commercial buildings. The **selective vertical conveyer** moves plastic tubs from one floor to another, automatically loading and unloading at preselected floors. The tubs typically are made to carry mail and small supplies and have payloads of up to 50 lb each. A typical selective vertical conveyer installation is similar to an escalator (Art. 16.4). A continuous roller chain is driven by an electric motor. Engaging sprockets at top and bottom, the chain extends the height of the building, or to the uppermost floor to be served. Carriers spaced at intervals along it transport trays from floor to floor at a speed of about 70 ft/min.

Another conveyer type, the **tracked conveyer system,** permits both vertical and horizontal document distribution. This system employs self-powered cars, which travel over a track system that allows ''switching off'' at selected station locations (Fig. 16.18). Where a specific floor may have a high volume of traffic, the track may be routed around the floor to one or more remote stations. The destination is programmed at the dispatching station, and the car is automatically switched onto the main track to begin its journey. Cars for this type of conveyer are generally limited to a maximum payload of 20 lb, although some are modified to carry up to 25 lb. The cars travel at about 100 ft/min.

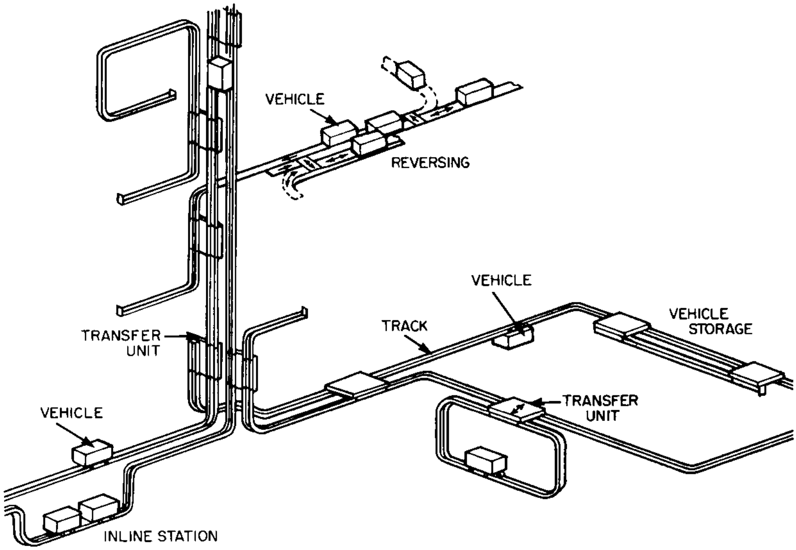


FIGURE 16.18 Electric track vehicle system (developed by Translogic Corporation).

For vertical track sections, a gear engages a continuous rack on the track for positive control in both the up and down directions. A friction-drive system is employed on horizontal track sections. Shaft-mounted machinery is minimized with the tracked conveyer system.

Like elevators, however, vertical conveyers must be enclosed in fire-resistant shafts. Generally, the only visual evidences of the existence of the installation are the wall cutouts for receiving and dispatching runoffs at each floor. In event of fire, vertical sliding doors, released by fusible links, should snap down over the openings, sealing off the conveyer shaft at each floor.

Vertical Conveyers. Operation of vertical conveyers is simple. When the tray or car is ready for dispatch, the attendant sets the floor-selector dial or presses a button alongside the dispatch cutout. For the selective vertical conveyer, trays are placed on the loading station, where they are automatically moved into the path of the traveling carriers. Each tray rides up and around the top sprocket and is automatically discharged on the downward trip at the preselected floor.

The best place to install a vertical conveyer is in a central location, next to other vertical shafts, to minimize horizontal runs in collecting and distributing correspondence at each level. The choice of conveyer types should be based on the needs of the user. The selective vertical conveyer is appropriate where the required movement is entirely vertical, while the tracked conveyer system lends itself to both horizontal and vertical layouts.

Pneumatic Tubes. These are also used to transport small loads within buildings. Units are moved through tubes under air pressure or suction, or both. Items to be transported are carried inside cylinders slightly smaller in diameter than the tubes.

In choosing between vertical conveyers and pneumatic tubes, the designer's first consideration should be the size of the load to be carried. The traveling cylinder is limited as to the size and weight of the material to be moved. Aside from that, an arterial system of pneumatic tubes may satisfy the requirements of a predominantly horizontal building, whereas a vertical conveyer is generally more advantageous in a tall building.

16.14 MAIL CHUTES

Used in multistory buildings for gravity delivery of mail from the various floors to a mailbox in the main lobby, a mail chute is simply a vertical, unpressurized, rectangular tube. With permission of the Post Office, one or more chutes may be installed in office buildings more than four stories high and in apartment buildings with more than 40 apartments.

Usually made of 20-ga cold-formed steel, with a glass front, and supported by vertical steel angles, a chute is about 3×8 in in cross section. In the front of the chute, available in a lobby in each story, a slot is provided for insertion of flat mail into the chute.

The mailbox usually is 20 in wide, 10 in deep, and 3 ft high. It should be placed with its bottom about 3 ft above the floor. The mailbox should be placed within 100 ft of the building entrance.