1 The Essentials of Elevatoring

EARLY BEGINNINGS

Since the time man has occupied more than one floor of a building, he has given consideration to some form of vertical movement. The earliest forms were, of course, ladders, stairways, animal-powered hoists, and manually driven windlasses. Ancient Roman ruins show signs of shaftways where some guided movable platform type of hoist was installed. Guides or vertical rails are a characteristic of every modern elevator. In Tibet, people are transported up mountains in baskets drawn by pulley and rope and driven by a windlass and manpower. An ingenious form of elevator, vintage about the eighteenth century, is shown in Figure 1.1 (note the guides for the one "manpower"). In the early part of the nineteenth century, steam-driven hoists made their appearance, primarily for the vertical transportation of material but occasionally for people. Results often were disastrous, because the rope was of fiber and there was no means to stop the conveyance if the rope broke.

In the modern sense, an elevator* is defined as a conveyance designed to lift people and/or material vertically. The conveyance should include a device to prevent it from falling in the event the lifting means or linkage fails. Elevators with such safety devices did not exist until 1853, when Elisha Graves Otis invented the elevator safety device. This device was designed to prevent the free fall of the lifting platform if the hoisting rope parted. Guided hoisting platforms were common at that time, and Otis equipped one with a safety device that operated by causing a pair of spring-loaded dogs to engage the cog design of the guide rails when the tension of the hoisting rope was released (see Figure 1.2).

ELEVATOR SAFETY DEVICES

Although Otis's invention of the safety device improved the safety of elevators, it was not until 1857 that public acceptance of the elevator began. In that year the first passenger elevator was installed in the store of E. V. Haughwout & Company in New York. This elevator traveled five floors at the then breathtaking speed of 40 fpm (0.20 mps).† Public and architectural approval followed this introduction of the passenger elevator. Aiding the technical development of the elevator was the availability of improved wire rope and the rapid advances in steam motive power for hoisting. Spurring architectural development was an unprecedented demand for "downtown" space. The elevator, however, remained a slow vertical "cog" railway for quite a few years. The hydraulic elevator became the spur

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* In England and other parts of the world, the word "lift" is used. The legally recognized definition of an elevator can be found in ANSI/ASME A17.1, Safety Code for Elevators and Escalators.

† Elevator speed is traditionally stated in fpm (feet per minute) or mps (meters per second).

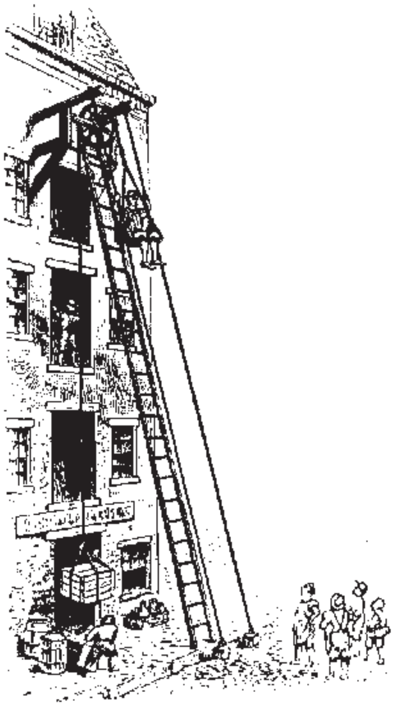
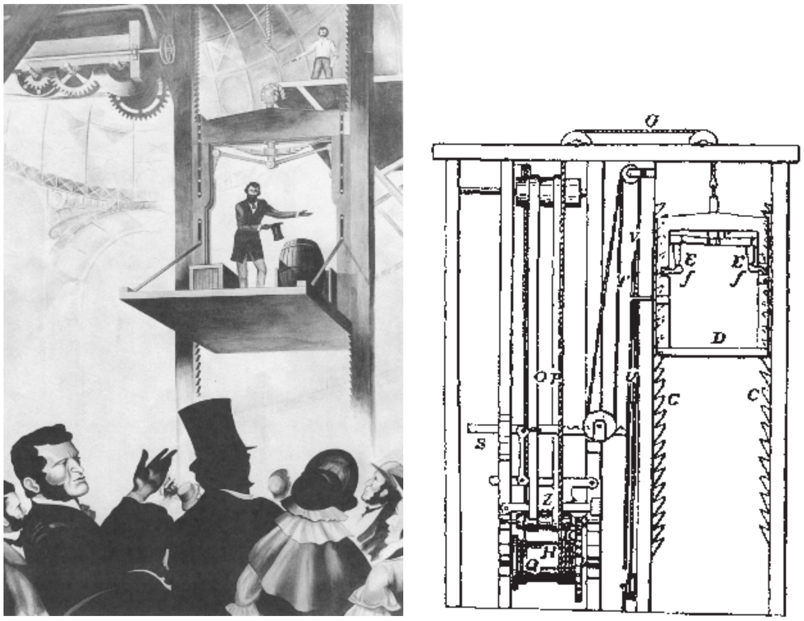


Figure 1.1. A very early type of vertical transportation.



(a) (b)

Figure 1.2. (*a*) Otis's demonstration, Crystal Palace, New York, 1853. (*b*) Otis's patent sketch for a safety device (Courtesy Otis Elevator).

that made the upper floors of buildings more valuable through ease of access and egress. Taller buildings permitted the concentration of people of various disciplines in a single location and caused the cities to grow in their present form during the 1870s and 1880s.

HYDRAULIC ELEVATORS

The hydraulic elevator provided a technological plateau for quite a few years; it was capable of higher rises and higher speeds than the steam-driven hoist-type elevator, limited by its winding drums (Figure 1.3). The hydraulic elevator also evolved from the

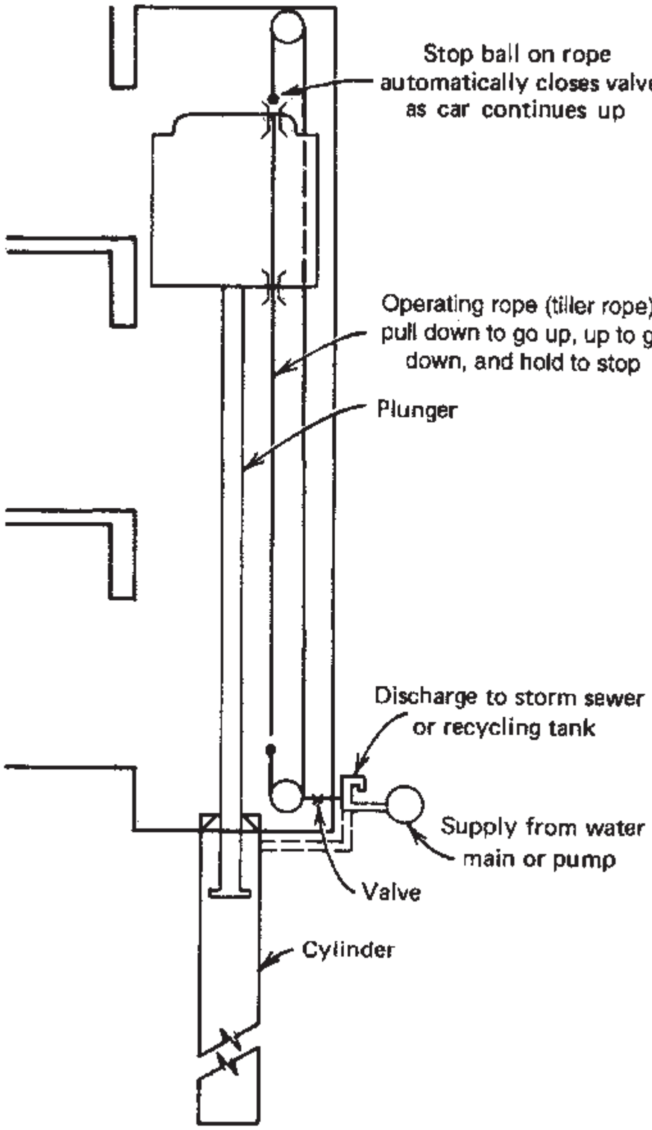


Figure 1.3. Hydraulic elevator with handrope operation.

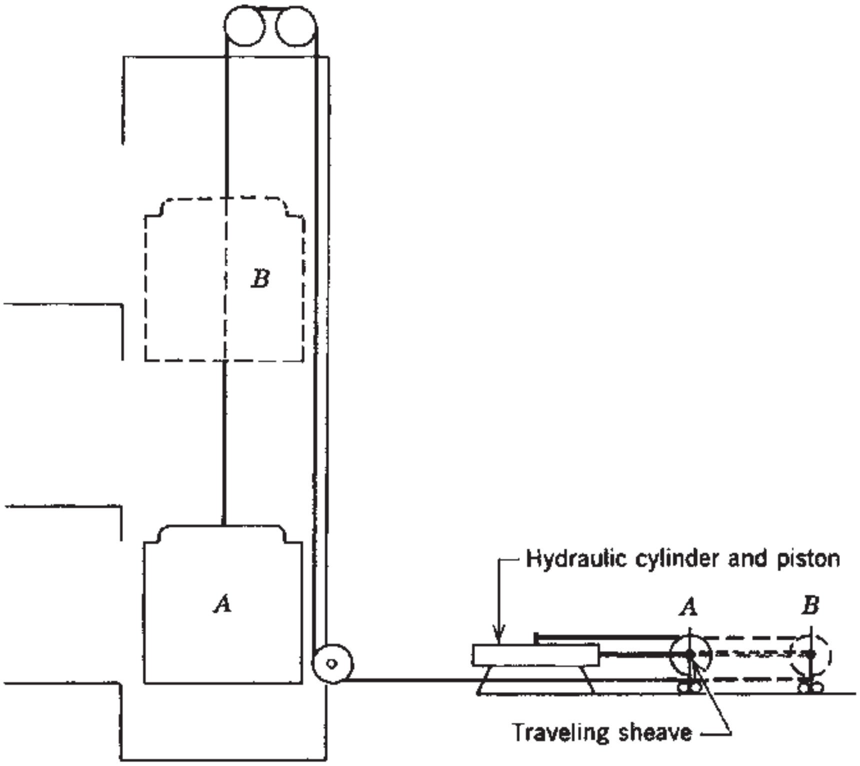


Figure 1.4. Roped hydraulic elevator.

direct ram-driven elevator to the so-called geared or roped hydraulic (Figure 1.4) capable of speeds of up to 700 fpm (3.5 mps) and rises of 30 or more stories. The cylinder and sheave arrangement was developed to use multiple sheaves and was mounted vertically for the higher rises. The 30-story building did not appear until after 1900, well after steel-frame construction was introduced, but the hydraulic elevator served practically all of the 10- to 12-story buildings of the 1880 to 1900 era.

It was in this era that many of the aspects of elevators as we know them today were introduced. Hoistways became completely enclosed, and doors were installed at landings. Before that time many hoistways were simply holes cut in the floor—occasionally protected by railings or grillage. Simple signaling was introduced, using bells and buzzers with annunciators to register a call, which was manually canceled. Groups of elevators were installed, the first recorded group of four elevators being in the Boreel Building in New York City, and the "majordomo" of "elevator buildings"—the starter—entered the scene and was assigned to direct the elevator operators to serve the riding public.

The first electric elevator quietly made its appearance in 1889 at the Demarest Building in New York City. This elevator was a modification of a steam-driven drum elevator, the electric motor simply replacing the steam engine. It continued in service until 1920 when the building was torn down. Electric power was here to stay, and the Otis Elevator Company installed the first automatic electric or push-button elevator in 1894.

With the tremendous building activity of the early 1900s and the increased size and height of buildings at that time, the questions of quantity, size, speed, and location of elevators began to arise. With these questions began the applied technology of elevatoring. A typical but wrong logic pattern of the time was: “Joe Doe has two elevators in his building and seems to be getting by all right. Since my building is twice as big, give me two twice the size.” It rapidly became evident that people in the latter building had to wait twice as long for service as those in Joe Doe’s building, and complaints and building vacancies reflected their dissatisfaction. The example is typical, and soon elevatoring emerged as a special design discipline.

ELEVATORING

Elevatoring is the technique of applying the available elevator technology to satisfy the traffic demands in multiple- and single-purpose multifloor buildings. It involves careful judgment in making assumptions as to the total population expected to occupy the upper floors and their traffic patterns, the appropriate calculation of the passenger elevator system performance, and a value judgment of the results so as to recommend the most cost-effective solution or solutions.

A major part of elevatoring is the understanding of pedestrian flow, pedestrian queuing, and the associated human engineering factors that will provide a nonirritating “lobby to lobby” experience. The traffic demands of passengers, service functions, and materials must be evaluated and all satisfied simultaneously for an optimal solution.

Elevatoring, in the modern sense, is the process of applying elevators and the building interfaces necessary for the vertical transportation of personnel and material within buildings. Service should be provided in the minimum practical time, and equipment should occupy a minimum of the building’s space. The need for refinement in this process became apparent in the early 1900s as the height and cost of buildings increased.

Elevators changed radically in the early 1900s. As electricity became common, and with the introduction of the traction elevator, the water hydraulic was rapidly superseded. Helping its demise was the rapid rise of building heights—the Singer Building, 612 ft (185 m); the Metropolitan Life Tower, 700 ft (212 m); the Woolworth Building, 780 ft (236 m), all in New York City and built by 1912. The roped hydraulic could not be stretched to compete with such rises, and the direct-plunger-driven elevator required a hole as high as the rise. Telescoping rams were tried and proved unsatisfactory. These buildings were made possible by the introduction of the traction elevator into commercial use in 1903.

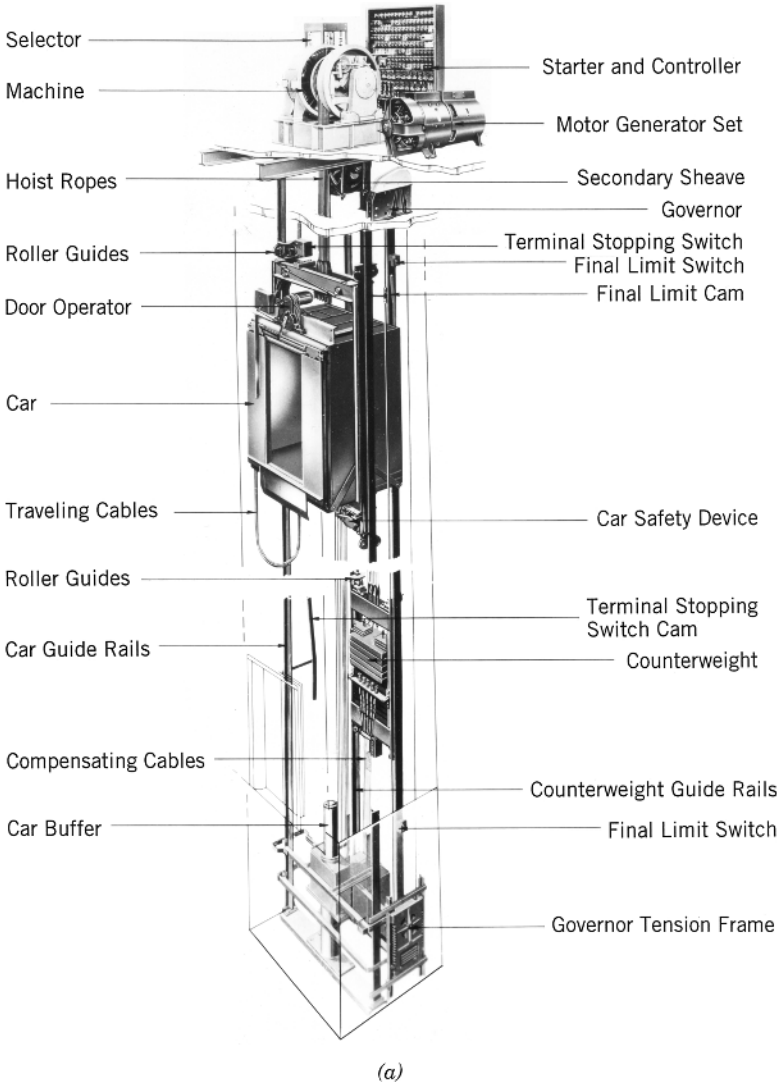
The history of the development of the mechanics of hoisting elevators is far beyond the scope of this volume and is detailed in at least two sources. One is the virtual Elevator Museum developed by William C. Sturgeon and *Elevator World Magazine*, which can be viewed online at www.theelevatormuseum.org, and the other is the volume *A History of the Passenger Elevator in the 19th Century* by Lee E. Gray, a professor of architectural history at the University of North Carolina. The latter also contains an overview of the development of elevatoring as discussed in this chapter.

TRACTION ELEVATORS

Description

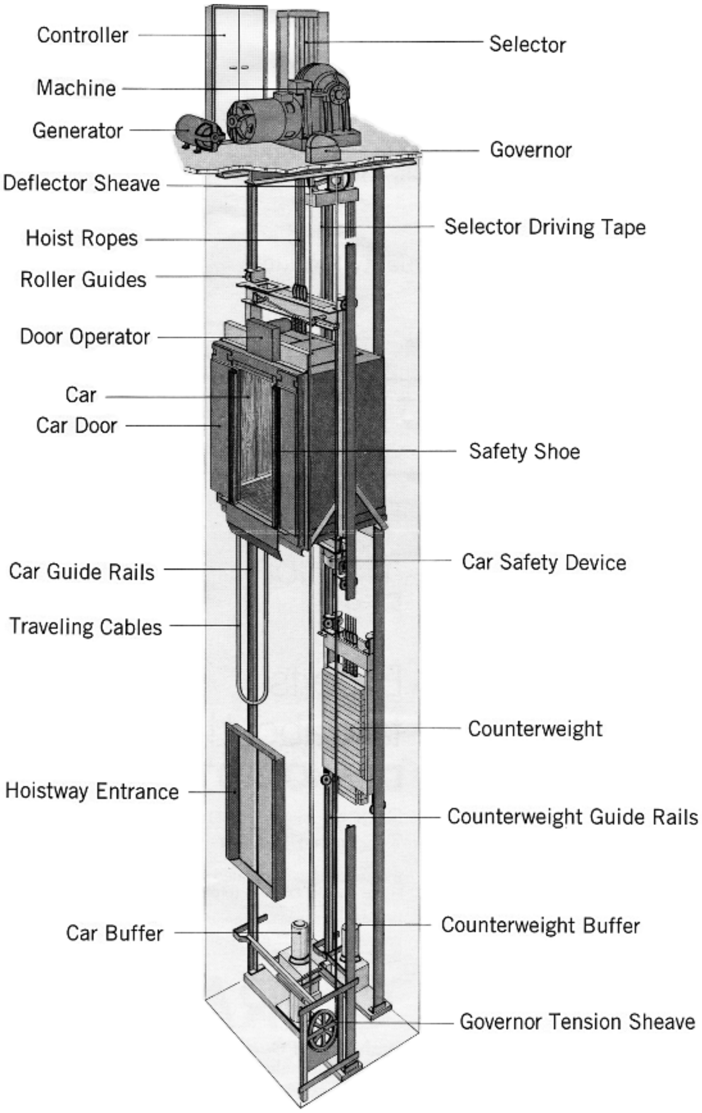
Up until about 1903, either drum-type elevator machines, wherein the rope was wound on a cylindrical drum, or the hydraulic-type elevator (the direct-plunger hydraulic or the roped hydraulic machine) was the principal means of hoisting force. Both had severe rise limitations: the drum type, in the size of the drum; and the hydraulic type, in the length of the cylinder. The drum-type elevator had the further disadvantage of requiring mechanical stopping devices to shut off power to prevent the car from being drawn into the overhead if the machine failed to stop by normal electrical means. On a hydraulic machine this is prevented by a stop ring on the plunger.

The traction machine had none of the rise disadvantage of either the hydraulic or drum machine. The traction principle is a means of transmitting lifting force to the hoist ropes of an elevator by friction between the grooves in the machine drive sheave and the hoist ropes (Figure 1.5*a* and *b*). The ropes are simply connected from the car to



(a)

Figure 1.5. (*a*) Gearless elevator installation (Courtesy Otis Elevator). (*b*) Geared elevator installation (Courtesy Otis Elevator).



(b)

Figure 1.5. *(Continued)*

the counterweight and wrapped over the machine drive sheave in grooves. The weight of both the car and the counterweight ensures the seating of the ropes in the groove; for higher-speed elevators, the ropes are double-wrapped; that is, they pass over the sheave twice.

The safety advantages of the traction-type elevator are manifold: Multiple ropes are used, each capable of supporting the weight of the elevator, which increases the suspension safety factor as well as improving traction. The drive sheave is intended to lose traction if the car or counterweight bottoms on the buffers in the pit. However, this is not universal and depends on the proper condition of ropes, sheave, loading, and so on.

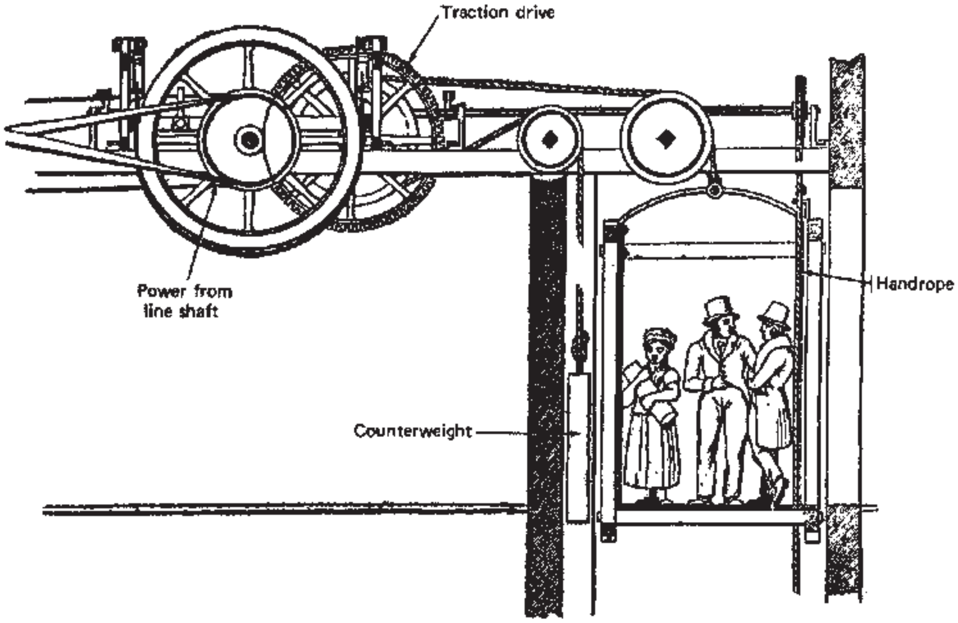


Figure 1.6. Teagle elevator (circa 1845) (Courtesy *Elevator World Magazine*).

The possibility of the car or counterweight being drawn into the overhead in the event of electrical stopping switch failure is reduced.

Traction elevators are capable of exceedingly high rises, the highest (or lowest) being in a mine application in South Africa for a depth of 2000 ft (600 m). The critical factors become the weight of the ropes themselves and the load imposed on the sheave shaft and its bearings. It was the traction elevator, in addition to other advances in building technology, that made today's tall buildings of 100 or more stories practical.

The traction principle has been available for centuries. The capstan on a ship is an example. The first known elevator application was the "Teagle" hoist, which was present in England about 1845, as shown in Figure 1.6. This old print shows the traction drive and the counterweight. Motive force was provided by means of belts to the line shafting in the building where the lift was installed. The operation was by handrope, as described for the hydraulic elevator shown in Figure 1.3. The handrope acted to engage the belt to the drive pulley, usually to the right or left of an idler pulley, to move the lift up or down.

A development that has taken place in the past 10 years or so has been the location of a gearless-type machine in the hoistway either at the side or rear near the top. This results in the so-called "machine room–less" (MRL) elevator and is unique to various manufacturers. This machine has been redesigned into a "pancake" configuration, and the space over the hoistway is minimized. It has only been used in newer buildings, and the basic traction designs discussed in this chapter are still being applied and can be found in thousands of existing buildings and many of the newer ones.

Performance

With the application of electrical drives to elevators, the versatility of electrical versus mechanical controls allowed for certain standards of elevator operation and control, so that time-related factors in an elevator trip could be established. Speed no longer depended on varying water or steam pressure. The Ward-Leonard system of electric motor speed control was introduced early in the 1920s and allowed the smoothness of acceleration and deceleration common in elevators of today.

The Ward-Leonard system employs a motor generator driven by either an ac or dc motor, the output of the generator being directly connected to the armature of the dc hoisting motor. Varying the voltage on the field of the generator varies the dc voltage applied to the hoisting motor armature and, consequently, the speed and torque.

The Ward-Leonard motor-generator hoisting machine combination, generically known as "generator field control," was the quality standard for many decades, from the 1920s through the 1980s. Thousands of elevators still employ it, and Figure 1.5*a* and *b* shows this equipment. The major change is in the machine room. The motor generator is gone, as is the selector shown in the background. The controller is no longer full of relays but replaced by a compact microprocessor and the silicon controlled rectifier (SCR) drive.

Replacement of the motor generator by solid-state control, introduced in the 1970s, has superseded, in most instances, motor generators in both new installations and modernizations. One approach to a solid-state control system is to employ SCRs to convert the line ac into varying dc for the operation of a dc hoisting machine. Most of the higher-speed elevators, 500 fpm and above, use this approach, and it is favored for the modernization of existing elevators as well. A second approach is to employ SCRs to develop a variable voltage, variable frequency (VVVF) ac power for an ac driving machine. This is the favored approach for lower-speed (up to 500 fpm) geared machines.

Most new traction elevators are expected to have the VVVF control as further development of higher-speed gearless-type elevators proceeds. It is almost universally used with the new geared installations and is being applied as an upgrade to the thousands of single-speed, low-speed (100–150 fpm) ac machines that were widely used in the many six-story apartment buildings built in the late 1940s and through the 1950s.

The microprocessor has been a major innovation in the past decade, and practically all of the new and modernized installations employ one or more in both the control and operating systems. Details are to be found in Chapter 7, "Elevator Operation and Control." That chapter also includes many of the ramifications and disciplines needed to apply new technology. Greater emphasis on machine room environmental conditions such as airconditioning and electromagnetic interference must be considered, as well as the quality of the incoming power supply, both under normal conditions and when an emergency generator is used.

In the course of this book the operating characteristics of electric elevators are described, and a basis for time study calculations of elevator trips is established. These time factors will become the basic tools in establishing the number of elevators necessary for any type of building and will be related to the speed at which people can be moved from place to place vertically. As a preliminary, familiarity with modern elevator types is necessary.

GEARLESS TRACTION ELEVATORS

Description

The preceding brief discussion of early elevator history introduced the traction-type elevator. The first high-rise application of this type of elevator was in the Beaver Building in New York City in 1903, followed by such notable installations as the Singer Building (demolished in 1972) and the Woolworth Building. These elevators were of the gearless traction type that is at present the accepted standard for the high-rise, high-speed [over 400 fpm (2.0 mps)], and high-quality elevator installation.

The gearless traction elevator consists of a large, slow-speed (50 to 200 rpm) dc motor of four to eight poles directly connected to a drive sheave of about 30 to 48 in. (750 to 1200 mm) in diameter. An electrically released, spring-applied brake is arranged to apply stopping to the drive sheave. Slow-speed dc motors and ac motors (being introduced), though expensive and massive, are necessary to maintain the necessary torque to directly drive large-diameter sheaves. The larger-diameter sheaves also conform to the bending radius of elevator steel ropes. A limitation is imposed by safety codes as good practice for long rope life and is generally established at a minimum of 40 times the diameter of the wire rope used. For example, a $^1/_2$-in. (13-mm) wire rope would require a minimum sheave size of 20 in. (500 mm).

The slow speed of the direct drive gearless traction machine is necessitated by the speed of the elevator it serves. For example, for a 500 fpm (2.5 mps) elevator and a sheave diameter of 30 in. (750 mm), a top speed of 86 rpm is required. To level this elevator to a landing at a maximum speed of 25 fpm (0.125 mps), 4.3 rpm is necessary. Gearing with higher-speed motors has been introduced by at least one major manufacturer to gain these higher speeds. The continuous operation of elevators [up to 25,000 mi (40,000 km) per year] and the relative ease of maintenance of the gearless machines, as well as their dependability, make them the preferred type for higher speeds.

On higher-speed gearless traction machines of 800 fpm (4.0 mps) or more, the double-wrap principle is generally applied to obtain traction and to minimize rope wear. The ropes from the car are wrapped around the drive sheave, around a secondary or idler sheave, around the drive sheave, and down to the counterweight (Figure 1.7*a*–*c*). The groove seats are round, providing support on the full half of the rope, thus eliminating pinching action and minimizing wear. Traction is obtained by the pressure of the ropes on the sheave. As may be noted, increasing the weight on the car or counterweight increases the force so that friction between the ropes and the sheave increases traction.

Elevator machines are also roped with a single-wrap arrangement, which is applied to both gearless and geared machines. The single-wrap arrangement provides traction by the use of grooves that will pinch the ropes with varying degrees of pressure depending on the shape of the groove and its undercutting (see Figure 1.7 and later discussion). The most effective single-wrap arrangement provides 180 degrees of rope contact with the sheave without a deflecting sheave, as shown in Figure 1.8 (for single-wrap traction [SWT], 2:1 roping).

Conventional elevators are roped either 1:1 or 2:1 (Figure 1.8) for both car and counterweight. In some unusual installations and special applications, 1:1 car and 2:1 counterweight roping has been used. In that event the counterweight must be at least twice as heavy as the weight of the car. The 1:1 arrangement is the most popular for higher speeds and has been used for a load and speed of 10,000 lb (4500 kg) at 1600 fpm (8 mps). The 2:1 arrangement allows the use of a higher-speed, and therefore a smaller but faster, elevator. The mechanical advantage of 2:1 roping requires that only half the weight be lifted, so 2:1 is generally used whenever loads in excess of 4000 lb (1600 kg) must be lifted. The economy of the faster motor, which can be built smaller and lighter than lower-speed dc motors, also makes 2:1 roping attractive for a full range of speed requirements from 100 to 700 fpm (0.5 to 3.5 mps) or more and for any lifting capacity.

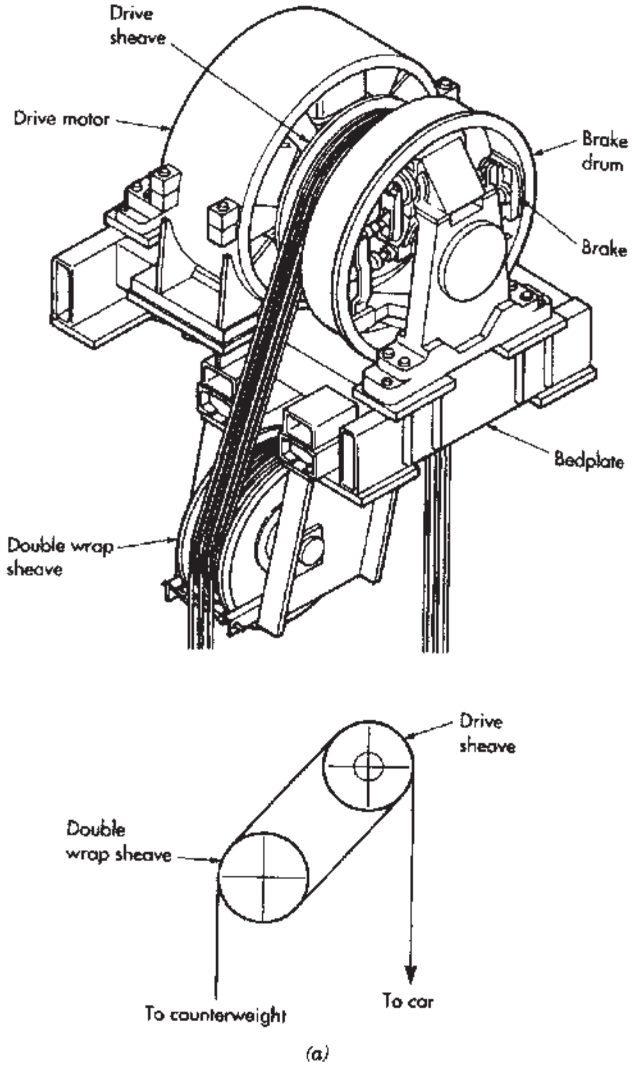


Figure 1.7. (*a*) Double-wrap gearless machine—Otis type 219HT with internal brake (Courtesy Otis Elevator). (*b*) Double-wrap traction arrangement. (*c*) Single-wrap traction arrangement.

Any of the aforementioned 1:1 and 2:1 roping arrangements can be provided with the elevator machine in the basement or at a lower level. The appropriate sheaves are installed in the overhead space to direct the ropes from the machine to the car and counterweight. The preferred arrangement is the single-wrap traction type. A foundation must be provided for the machine that will overcome the uplift and solidly anchor the machine under all conditions of operation and safety application.

The long life, smoothness, and high horsepower of gearless traction elevators provide a durable elevator service that can outlive the building itself. The original gearless machines in the Woolworth Building were reused when that building's elevators were modernized in 1950, again in 1970, and for a third time in 1990. The gearless machine not only

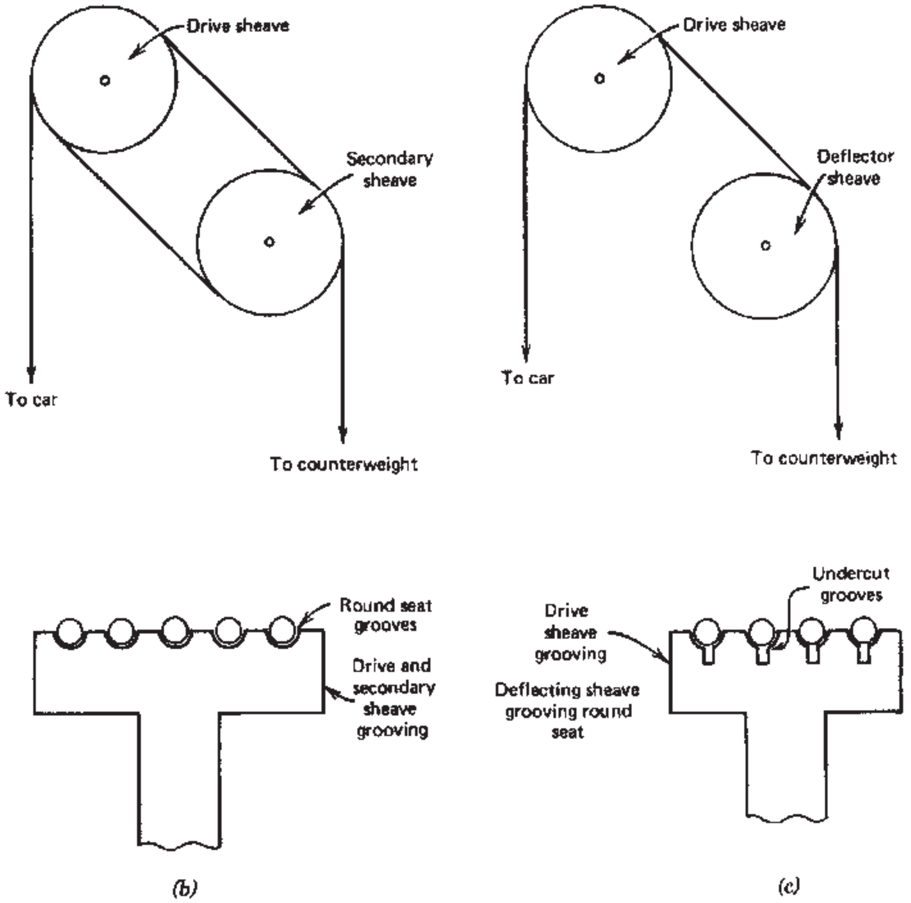


Figure 1.7. *(Continued)*

provides speed, if necessary, but is also capable of the performance essential to any well-elevatored building.

Gearless Machines—Performances

Essential to elevatoring considerations is the requirement that a gearless traction machine, no matter what its lifting capacity or speed, must be capable of optimum floor-to-floor operating time commensurate with passenger comfort. Stated another way, the machine must be capable of starting a filled elevator car, accelerating to a maximum speed for the distance traveled, and slowing to a stop in a minimum time of about 4.5 to 5.0 sec. This must be performed under all conditions of loading, either up or down. The elevator system must be so arranged that such acceleration and deceleration take place without discomfort to the passenger from a too rapid change in the rate of acceleration or deceleration (with optimum jerk). Furthermore, the elevator must be capable of releveling, while passenger load is changing at a floor (correcting for rope stretch), with almost imperceptible movement. The aspects of performance are discussed further in a later chapter.

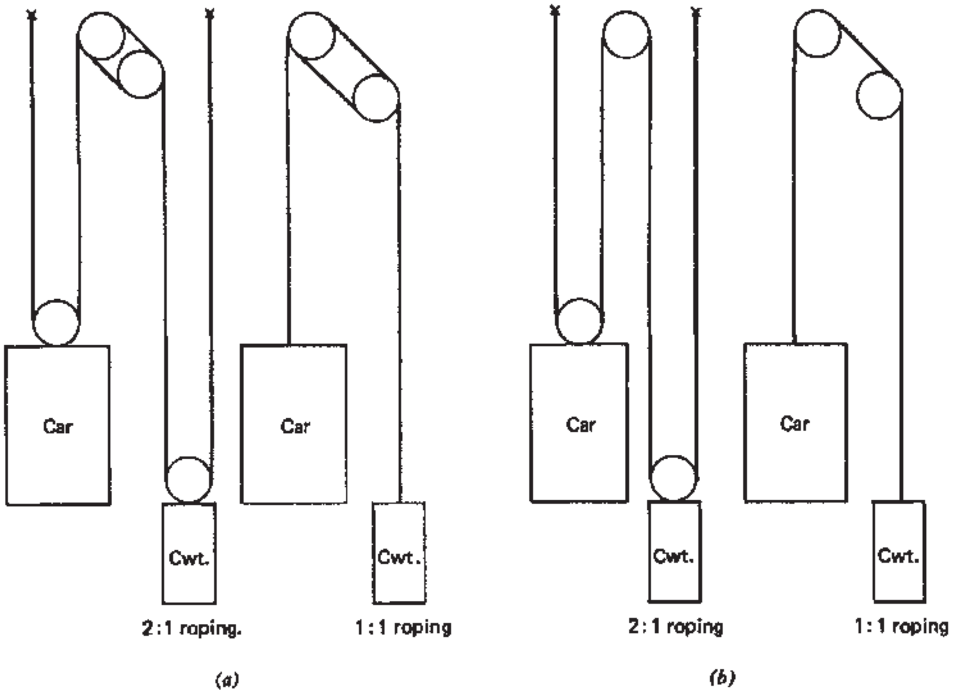


Figure 1.8. (*a*) Double-wrap roping. (*b*) Single-wrap traction roping.

GEARED TRACTION MACHINES

As the name implies, the geared traction elevator machine utilizes a reduction gear with a high-speed motor to drive the traction sheave. A high-speed ac or dc motor drives a worm and gear reduction unit, which in turn drives the hoisting sheave, the net result being the slow sheave speed and high torque necessary for elevator work. A brake is applied by spring to stop the elevator and/or hold the car at a floor level. Recent (1990s) introductions have been planetary gearing and helical gearing to replace the traditional worm gear approach.

The geared traction machine is used for elevators and dumbwaiters of all capacities from 25 to 30,000 lb (10 to 14,000 kg) or more, and speeds from 25 to 450 fpm (0.125 to 2.3 mps). The complete flexibility of worm gear ratios and motor speeds and horsepowers, as well as drive sheave diameters and roping arrangements (1:1, 2:1, and, sometimes, 3:1), makes this vast range of application practical. In some materials-handling applications, geared machines are used for speeds of 600 fpm or more (3.0 mps) with excellent results.

The geared traction elevator is an outgrowth of the earlier drum-type elevators. The steam engine gave way to the electric motor and gear (Figure 1.9), and the drum gave way to the drive sheave (Figure 1.10). The grooved drive sheave was an outgrowth of the traction principle applied to gearless elevators; instead of ropes being wrapped around the sheave, grooves were cut into the sheave and the necessary friction was created by the pinching action of the grooves on the rope (Figure 1.11). Various types of grooving

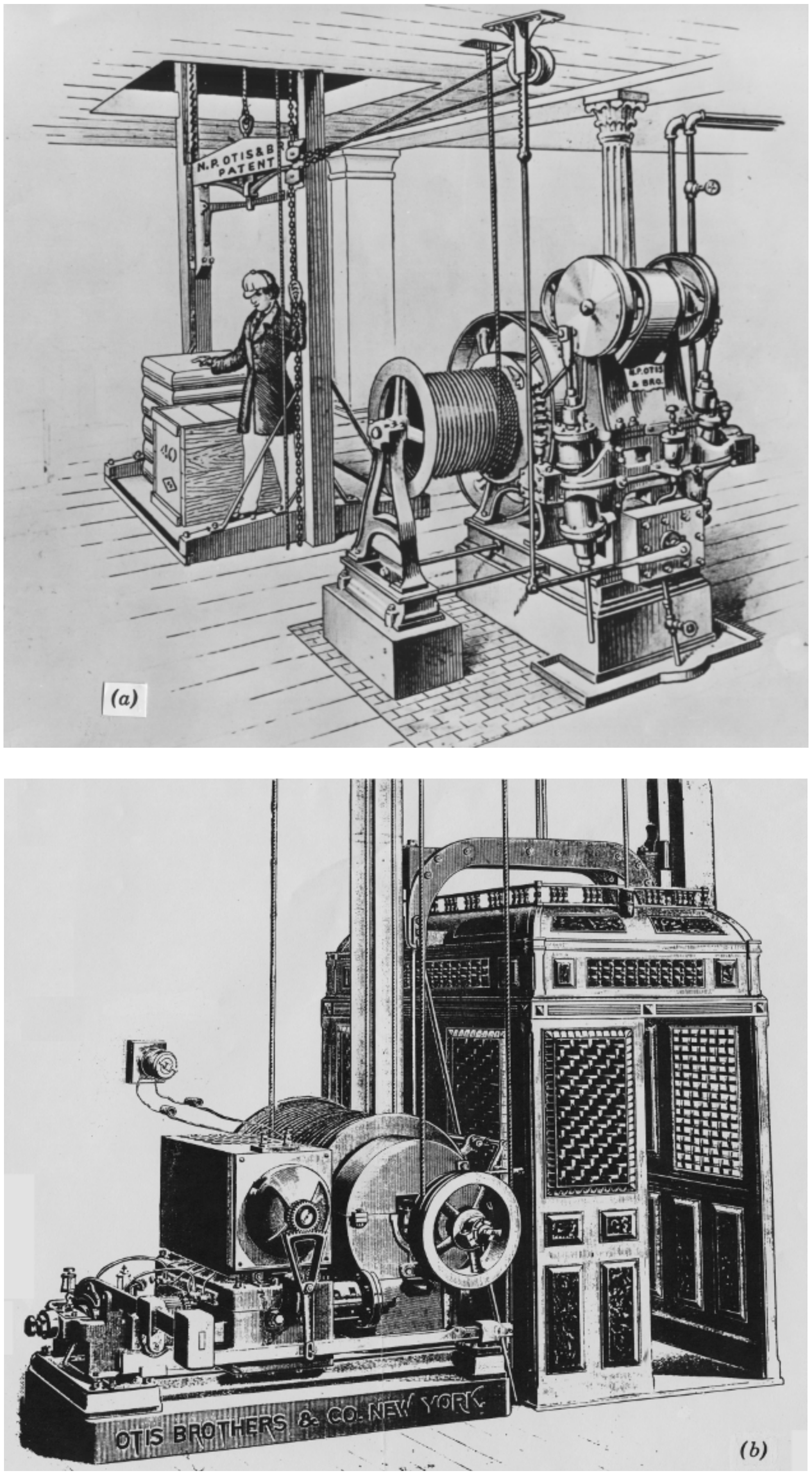


Figure 1.9. (*a*) Early steam-driven hoisting machine. (*b*) Early electric-driven hoisting machine.

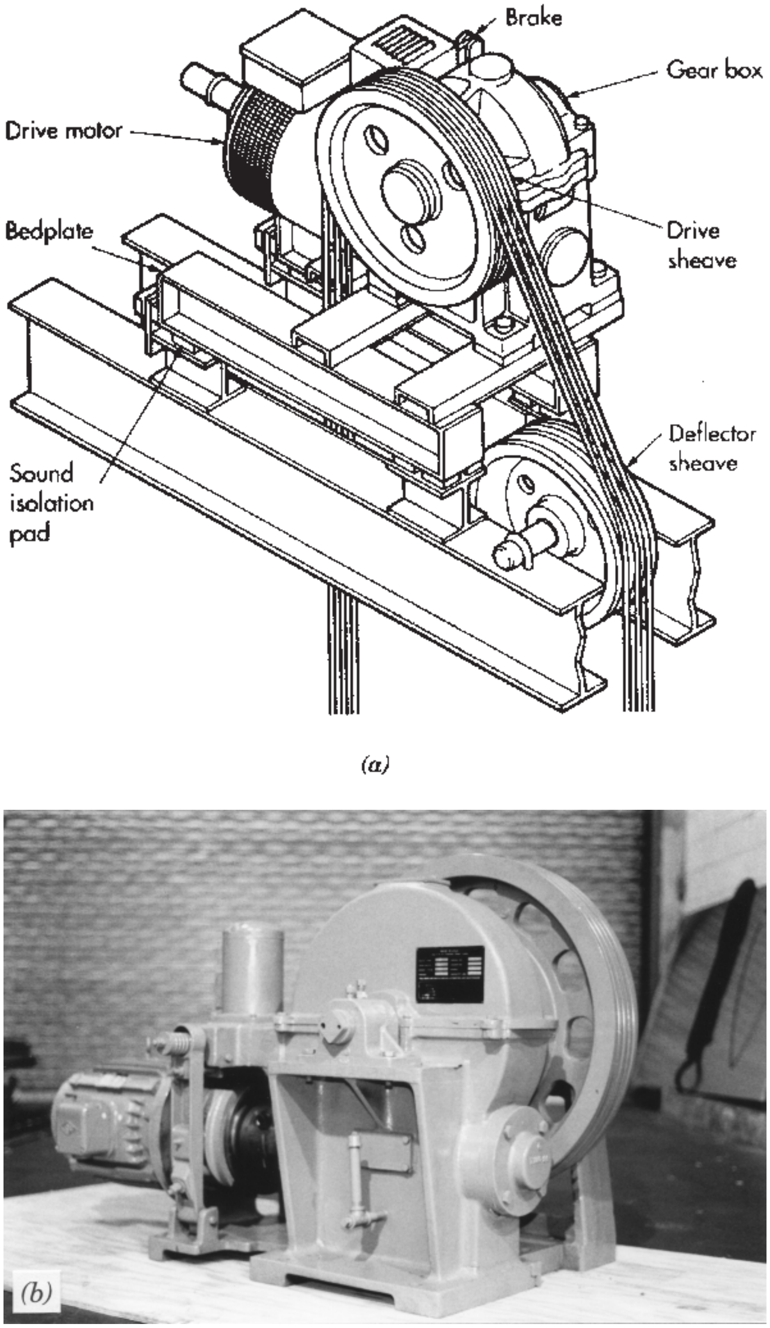


Figure 1.10. (*a*) and (*b*) Typical geared machines (Courtesy Titan Machine). (*c*) Worm gear machine (Courtesy Hollister Whitney).

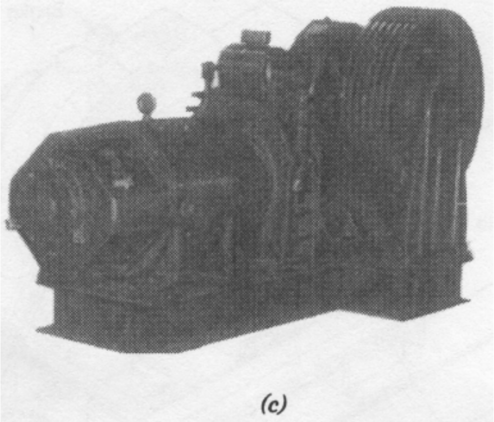


Figure 1.10. *(Continued)*

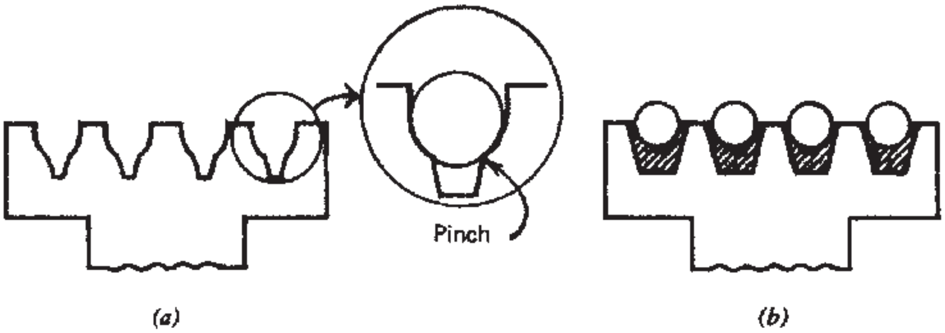


Figure 1.11. (*a*) Undercut sheave groove. (*b*) Sheave groove with polyurethane liner.

are used for different loads and traction requirements. Generally, the sharper the undercut angle, the greater the traction (and, usually, the greater rope and sheave wear).

Polyurethane groove liners capable of providing greater traction and less rope wear are being used by at least one manufacturer.

Geared machines have been driven by either one-speed or two-speed ac motors, by dc motors utilizing the Ward-Leonard means of control, or by ac or dc motors with SCR, VVVF, or other solid-state control. Ac motor machines are often used for speeds from 25 to 150 fpm (0.125 to 0.75 mps) with single- or two-speed motors or with solid-state drives to 450 fpm (2.25 mps). Stopping with single-speed motors is accomplished by disconnecting the power from the motor and stopping the car by a combination of slide and brake action. Two-speed ac operation employs a double-wound motor, a fast-speed winding for full-speed running, and a slow-speed winding (which can be any ratio as high as 6:1, i.e., the slow speed being 1/6 full speed) for stopping, leveling, and, if required, releveling. Operation is generally to start at full speed, run, switch to low speed at a measured distance from the stop, and accomplish the final stop by a combination of brake and slide. The floor-level accuracy of plus or minus $^1/_2$ to 1 in. (13 to 24 mm) can be obtained under all conditions of load, as contrasted with one-speed accuracy of 1 to 3 in. (24 to 75 mm), which will vary with load. Much greater accuracy can be obtained when solid-state ac motor drives are employed, and various upgrades can be retrofitted to existing single-speed elevators. In contrast, the dc Ward-Leonard drive or a solid-state motor drive allows the car to be stopped electrically before the brake is applied, resulting in leveling accuracy from 1/4 to 1/2 in. (6 to 13 mm) under all conditions of load, and much softer stops than produced by the ac machine.

With either ac or dc geared elevators, the floor-to-floor performance can be established, which is essential in calculations in estimating the numbers of elevators for a particular building.

HYDRAULIC ELEVATORS

A third major type of elevator in use today is a modern version of the hydraulic elevator. Most hydraulics are direct-plunger-driven from below (the cylinder extending into the ground as high as the elevator rises), and the operating fluid is oil moved by high-speed pumps rather than water under pressure (Figure 1.12*a*). Rapidly gaining favor are roped or indirect hydraulic elevators as well as many “holeless” types, some utilizing telescoping pistons. Hydraulic elevators today are used for both passenger and freight service in buildings from two to six stories high and for speeds from 25 to 200 fpm (0.125 to 1.0 mps). Single-ram capacities will range from 2000 to 20,000 lb (1000 to 10,000 kg) or more. Multiple rams are used for high capacities of 20,000 to 100,000 lb (10,000 to 50,000 kg). Varied speeds and high capacities are obtained through multiple pumps. Elevatoring performance time considerations of hydraulic elevators are slightly slower than those for geared elevators.

Drilling a hole for a direct-plunger hydraulic elevator has always been of concern, since underground conditions are often unknown. This concern has led to a number of equipment variations, namely, the “holeless” hydraulic and the indirect drive (roped) hydraulic. The former, shown in Figure 1.12*b*, is favored for the lower rise; the plunger (also called a jack or a ram) is mounted on the side of the car and connected to the top of the car structure. A variation is the use of a telescoping plunger (Figure 1.12*c*), which allows extended travel. Heavier cars can be accommodated by two plungers, one on each side of the car.

The indirect hydraulic (currently termed “roped hydraulic”) consists of an underslung roping arrangement, with the ropes driven by a vertically traveling sheave mounted on a jack located at the side of the car. (See Figure 1.12*d*; a sheave, A, is mounted on top of the plunger, B, and ropes, C, are slung over the sheave and hitched to the car.) This is a 1-to-2 roping arrangement, since 1 ft of plunger travel allows 2 ft of car travel. As with any suspended elevators, an elevator code requirement is to provide a safety device to prevent falling if the hoisting rope fails.

A growing concern regarding direct-plunger hydraulic elevators is the condition of the cylinder after being buried in the ground for a number of years. Earlier units had a minimum of external protection, whereas those installed recently are usually encased in PVC or other anticorrosion material. Any loss of oil in the pump unit must be thoroughly investigated, and an underground leak correction often involves total replacement.

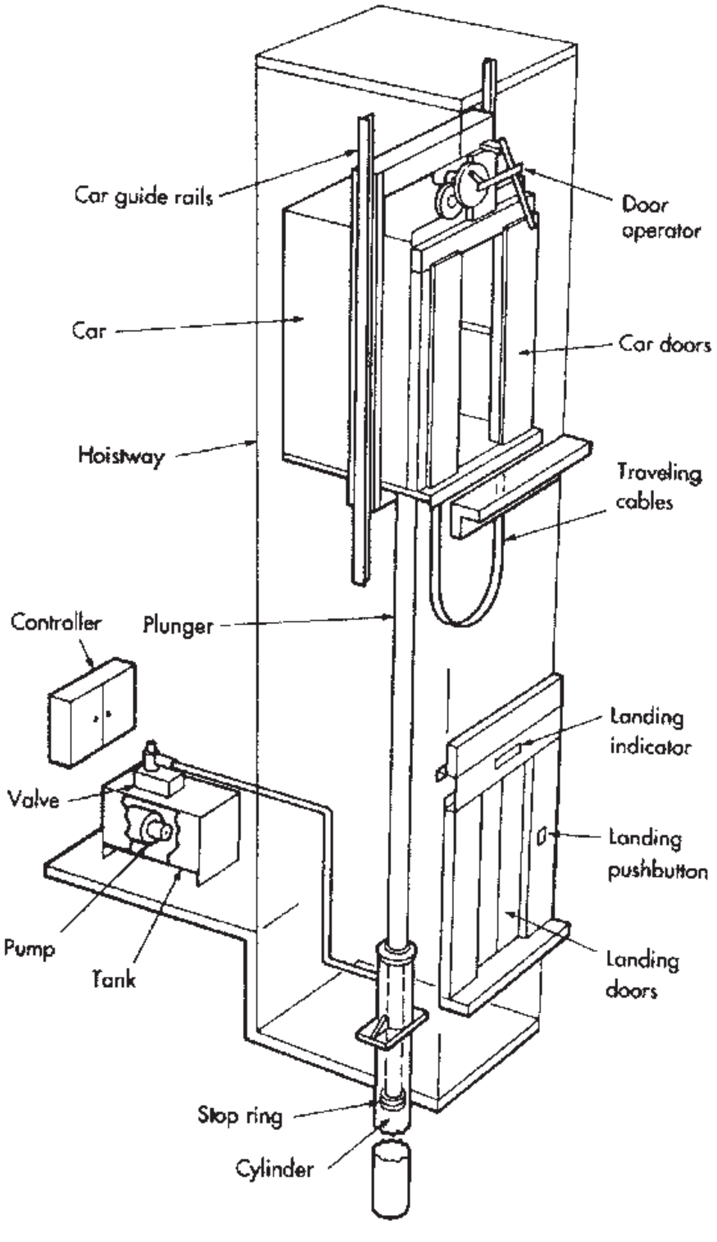


Figure 1.12. (*a*) Hydraulic passenger elevator—direct plunger (Courtesy Otis Elevator). (*b*) Holeless hydraulic elevator (dual plungers) (Courtesy of *Elevator World Magazine.* Reproduced from *The Guide to Elevatoring*). (*c*) Telescoping "holeless" hydraulic elevator (Courtesy of *Elevator World Magazine.* Reproduced from *The Guide to Elevatoring*). (*d*) Roped indirect hydraulic elevator (Courtesy Otis Elevator).

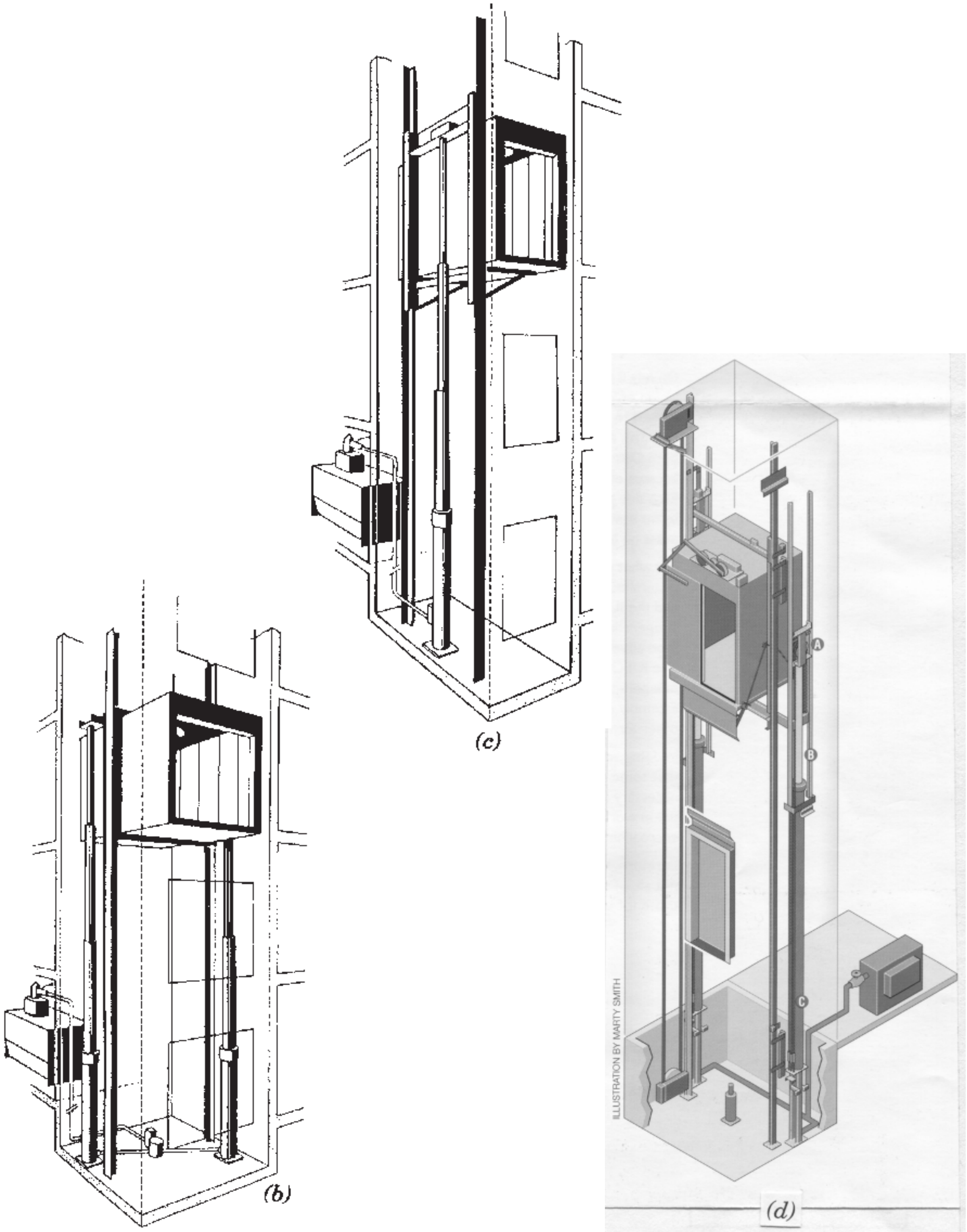


ILLUSTRATION BY MARTY SMITH

Figure 1.12. *(Continued)*

ESCALATORS AND MOVING WALKS

A very important factor in vertical transportation is the escalator (moving stairway) and moving inclined walks. Before the 1950s, escalators were mainly found in stores and transportation terminals. Today their use has expanded to office buildings, schools, hospitals, banks, and other places where large flows of people are expected or it is desired to direct people vertically in a certain path. Escalators and elevators are often used in combination either to provide necessary traffic-handling capacity or to improve elevator operation by directing people to one elevator loading level. They are essential in the lobby of a building with double-deck elevators. Many office buildings and some factories have found escalators ideal for rapid shift changes or rapid floor-to-floor communication.

Inclined, flat, or contoured moving walkways are closely related to the escalator form of vertical transportation (Figure 1.13). The passenger-handling ability of such conveyances is based on speed and density of passenger loading per step. Nominal ratings are in passengers per 5 mins. Qualifications of capacities and application of the moving stairway or walk are discussed in later chapters.

As a historical note, the flat-step escalator was first introduced by the Otis Elevator Company at the Paris Exposition in 1900. This was a “one-way” escalator arranged for either up or down travel. A person could walk on directly but upon exiting encountered a deflecting barrier, forcing the person to step off to the right or to the left (Figure 1.14). This design, known as a “Seeberger” was preceded by the “Reno” type, which was an endless series of inclined “indentations” that were boarded at the same angle of rise. Major development began in 1920, the initial features being flat steps with cleats, followed by flat boarding and debarking areas, narrower step cleats and combs, extended newels, and glass balustrading (Figure 1.15).

Because a number of people, especially those with impaired mobility, either refuse to use or are incapable of using escalators, it has become essential that alternate vertical transportation in the form of a two-stop elevator be provided within sight of the entrance to an escalator. Another reason is that any wheeled vehicle such as a stroller, baggage cart, hand truck, or the like, presents a hazard if its movement is attempted on an escalator.

The value of escalators in vertical transportation is in providing a continuous flow of people, as contrasted with the batch approach of elevators. This continuous flow principle proves valuable where the movement of large numbers of people is required, such as in an airport when an airplane unloads or at a sports event both prior to its start and at the end. A detailed discussion of the application of escalators is presented in Chapter 9.

DUMBWAITERS AND MATERIALS-HANDLING SYSTEMS

Other forms of vertical transportation, discussed in Chapter 15 of this book, are dumbwaiters and materials-handling systems. Modern buildings use these devices for a variety of purposes: delivery of books in libraries, distribution of mail in office buildings, delivery of food and supplies in hospitals, and so on. The dumbwaiter (Figure 1.16) is actually a small elevator, which can have all the performance characteristics of an elevator. Loading and unloading can be either at counter or floor level, and either manual or automatic. Size can vary from letter size to car sizes consisting of any arrangement of 9 ft^2 (0.9 m^2) or less of platform area, and a car with an effective height of no more than 4 ft (1200 mm). This is a limitation imposed by elevator safety codes (covered in detail in Chapter 16),

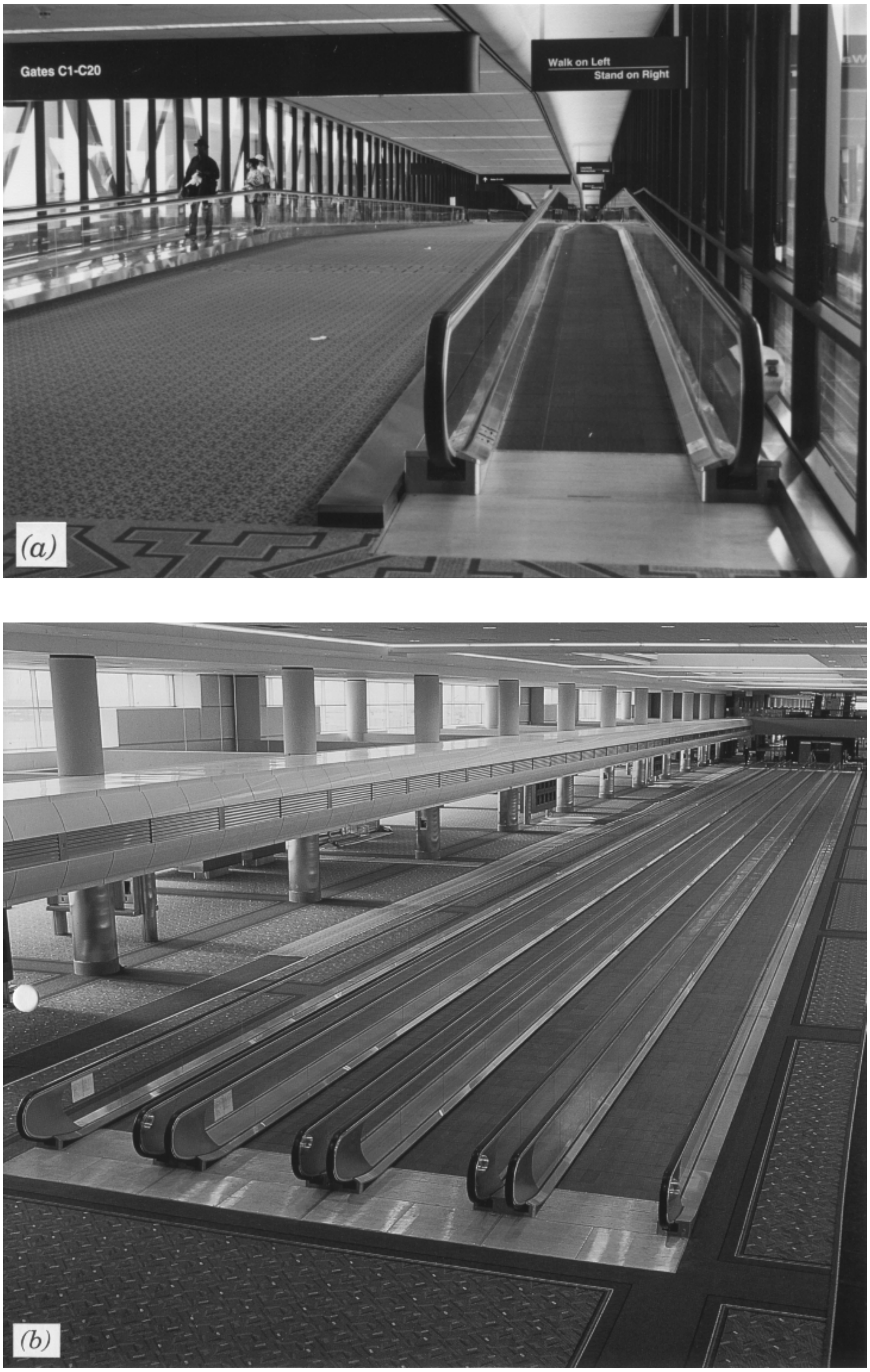


Figure 1.13. Moving walkways: (*a*) inclined, (*b*) flat (Courtesy KONE).

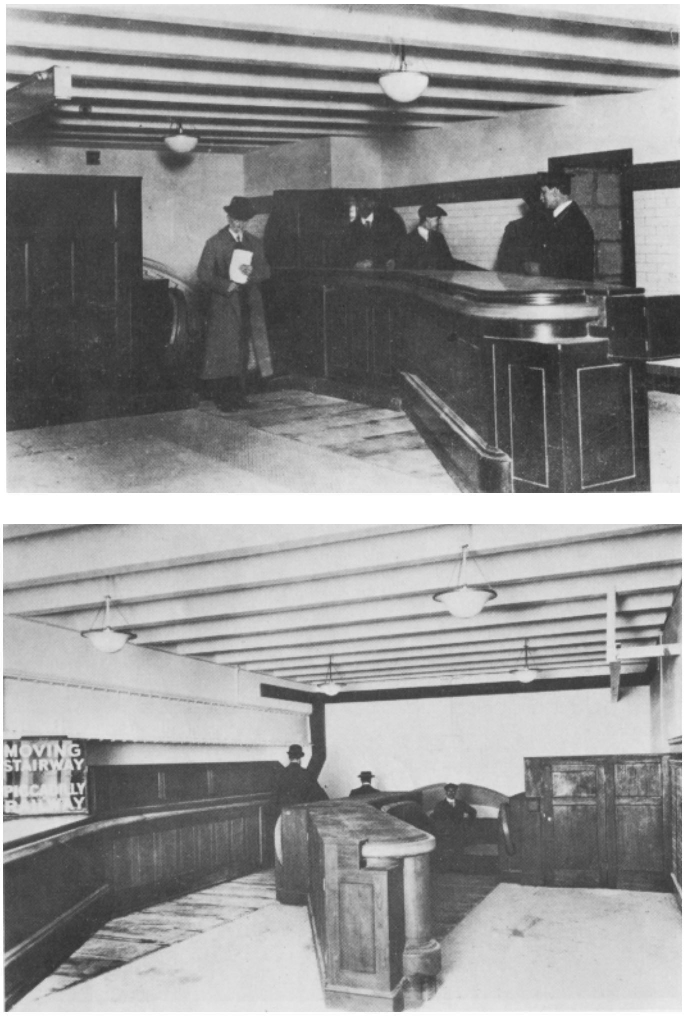


Figure 1.14. “Seeberger” flat-step escalator. Note barrier deflector (Reproduced from *Elevator World Magazine*, January 1992).

and anything over that size must be classified as an elevator. Dumbwaiters need not have safeties and are strictly for materials handling. They are always operated from the landing, not from within the cab as in an elevator.

Other forms of vertical materials-handling systems include tote box conveyors, automatic loading and unloading cart lift systems, and self-propelled vehicle systems either with a dedicated rail system or following a guide path on the floor. These are discussed in detail in a later chapter.

HANDICAPPED LIFTS

A growing segment of the vertical transportation industry is the introduction and development of a special means to accommodate persons in wheelchairs and others with limited

Figure 1.15. Glass balustrade escalator (Courtesy KONE).

mobility. Elevators are the universal means, but retrofitting them to an existing building is either a disproportionate solution or impossible. Ramps are a traditional means; however, they require extended horizontal space to limit the slope. An alternative has been to develop a platform-type lift that can be installed adjacent to the common stairs or, in some applications, within the stairs themselves.

The approaches have a range of application, from a short vertical rise of a few feet to extended rises of a floor height or so to provide access to a mezzanine or balcony (Figure 1.17). Equipment is available in a variety of types: vertical platform lifts with open enclosures, those serving two or three levels, and enclosed, inclined platform lifts either fixed adjacent to stairs or capable of folding and using the same path as the stairs. A simple variation is a lift that is set in an existing stairway and has a fold-down seat for the user (Figure 1.18).

The impetus for accelerated development has been the passage of the Americans with Disabilities legislation, which mandated, in some form or another, access to the various floors in any building used by the public, as well as to work spaces. Although elevators can be used and are essentially mandated for new construction, retrofitting to an existing

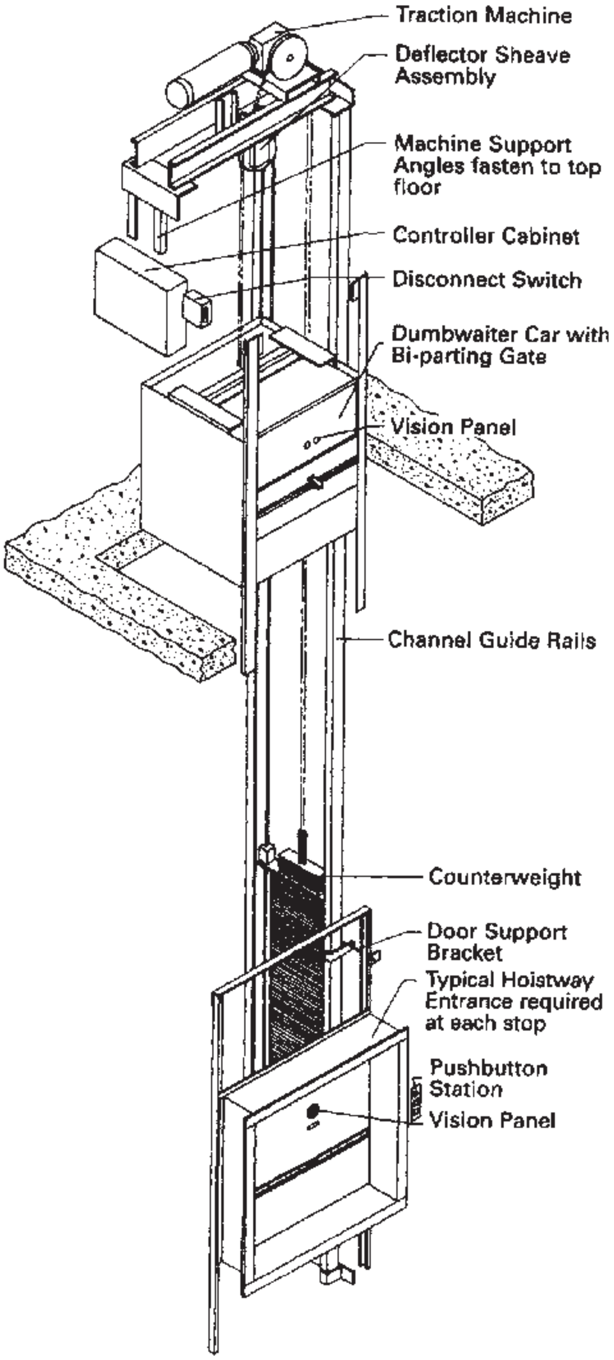


Figure 1.16. Ambassador TR dumbwaiter (Courtesy D. A. Matot, Inc.).

Figure 1.17. A platform-type lift installed adjacent to common stairs (Courtesy The National Wheel-O-Vator Co., Inc.).

Figure 1.18. An inclined lift set in an existing stairway with a fold-down seat for the user (Courtesy The National Wheel-O-Vator Co., Inc.).

building is often impossible or extremely costly. This is especially true in infrequently used buildings such as churches or where the only barrier is a set of stairs leading to an entrance. The handicapped lift is a solution. Any new building being constructed must recognize the need for access and is an unlikely candidate for this lift. The thousands of existing buildings, the aging and increasingly mobility-limited population, as well as economics, have created the demand. Although these lifts are not a major factor in the application of elevators, their use and limitations should be recognized as a means for needed vertical transportation.

Elevator codes have limited size, capacity, and speed and include rules for personnel protection and emergency considerations. In general, rise is limited to 12 ft (3600 mm), speed no greater than 30 fpm (0.15 mps), and capacity no greater than 750 lb (340 kg). Additional code rules prescribe application limits, as well as runway design and hoistway protection. Code references are found in Chapter 16.

In 1996, ASME A17.1 Safety Code rules were promulgated to recognize a new class of elevators, limited in use and application to accommodate the mobility-impaired, but not restricted to that use alone, as are the aforementioned “handicapped lifts.” These are referred to as “limited use/limited application” (LU/LA) elevators. They are restricted in size, rise, and speed but are universal in application and usable for any vertical transportation requirements. They have all the attributes of a regular elevator, such as powered landing and car doors, fully enclosed hoistways, and safety features common to all elevators. Space requirements have been minimized, making them attractive and more economical for limited application.

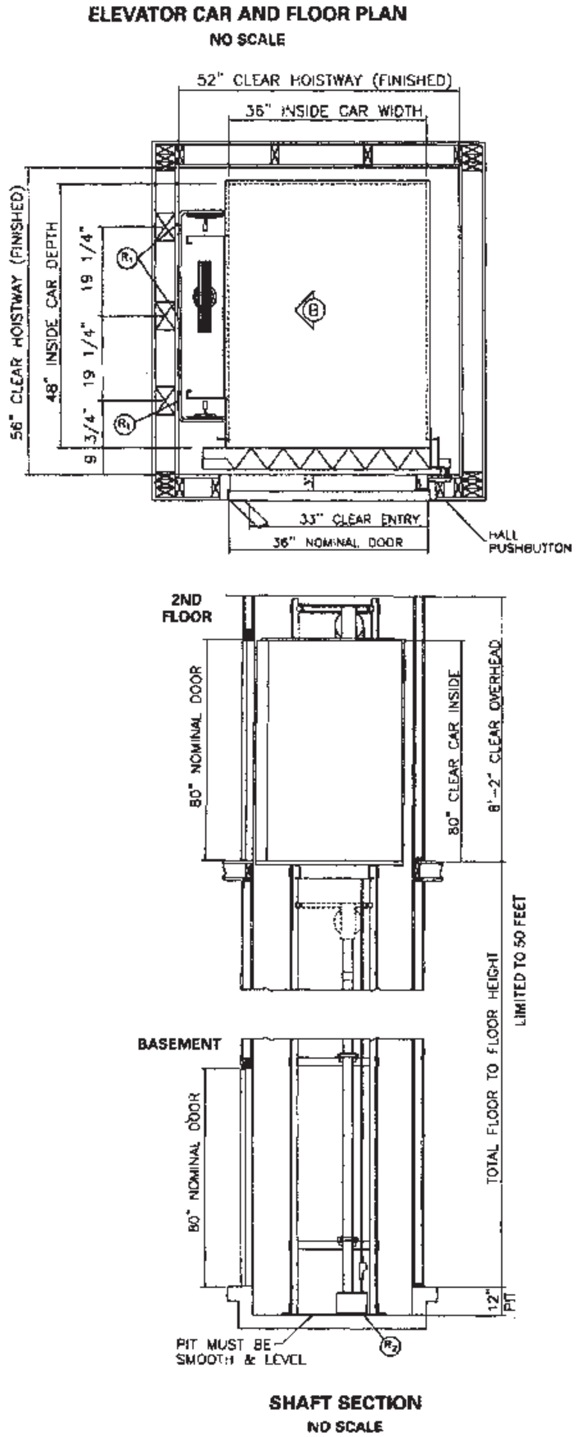
Residential-type elevators have been installed for use in single-family residences from about the late 1880s. In fact, the first of the completely automatic elevators was designed for such application, but was initially too costly for the average residence. In recent years the design of this type of elevator has been refined to a point where it is popular for residential use, and its cost is seldom more than that of an expensive automobile. Recognizing its limited use, a part of the ASME A17.1 Code is devoted to residential elevators and allows more liberal requirements than those established for conventional elevators. This elevator, like the LU/LA, is limited in size, speed, and rise but is ample for expected use by family members, including accommodation for wheelchairs. Figure 1.19 gives the layout details of such an elevator, and a number of manufacturers offer a variety of designs to fit most applications. That shown in the illustration is a “holeless, roped hydraulic”; other models include traction drives.

The foregoing represent the principal forms of vertical transportation; correctly applying these forms is the major thrust of elevatoring. Our earlier simplified definition of elevatoring is restated in the following section.

STUDY OF ELEVATORING

Elevatoring is the analysis of the requirements of vertical transportation of people and materials in a building, under all operating conditions. Such transportation requirements may be studied from a compatibility aspect, as in an office building; from a function aspect, as in a hospital; or from a merchandising point of view, in a department store.

The first essential step in elevatoring is pedestrian planning, that is, determining how many people will require transportation, what the peak traffic will be, and how it will occur—all up, up with partially down traffic, or equally up and down simultaneously.


ELEVATOR CAR AND FLOOR PLAN
NO SCALE

SHAFT SECTION
NO SCALE

Figure 1.19. Residential elevator—holeless, roped hydraulic (Courtesy D. A. Matot, Inc.).

Some well-established guidelines may be available, as will be demonstrated in the various chapters on commercial, institutional, and residential buildings. For some projects, extensive study of the expected pedestrian movements must be made before the process of determining the requirements for elevators or escalators can start.

Once the critical pedestrian traffic is established or estimated, the next steps can be taken.

Elevatoring requires consideration of all the time factors and movements that take place during the operations providing transportation for people and/or materials. These time factors must be related to a total time required for the service, based on the actual or estimated demands. Efficient elevatoring requires minimizing the time factors to maximize service.

The time components of an elevator round trip that will be studied and evaluated are as follows:

Loading Time. The time required for a number of people to board an elevator car, moving stairway, or moving walk, or the time required to load material or a vehicle onto an elevator or lift. Loading time must be considered under many conditions of operation, consisting of narrow or wide elevator cars, wide doors, narrow doors, arrangement of elevators, and partially filled or empty elevators.

Transfer Time. The time to unload (or reload) an elevator at a local stop above the main landing. Transfer time is based on all the considerations of loading time plus, essentially, the density of the passenger or other load remaining on the elevator, and the direction of the transfer—either entering or leaving.

These two elements, loading and transfer time, are the most difficult to quantify because, in general, these times are based on the interaction of people. Estimates have been made based on hundreds of field traffic studies of human behavior, and the conclusions are reluctantly (because of the doubt that such a person exists) based on "the average person."

Transfer time is mitigated by both legislation and environmental considerations. Most elevators are held at a floor for a minimum period of time based on the time it takes to exit and a separate time allowed for entry. The Americans with Disabilities legislation has mandated a minimum of 3 seconds for a person to exit and an extended time to enter, based on the location of the landing call button in proximity to the entrance to an elevator. These factors must be considered in calculating total transfer time. Extended discussion is given in specific application examples. Typical opening and closing times for various types and widths of entrances are found in Chapter 4, Table 4.3.

The other factors in an elevator or escalator trip are the mechanical times, which can be established accurately and ensured by a specification that can be developed before installing an elevator or escalator. These time factors are as follows:

Powered Door-Closing Time. This is a function of door weight (mass). Width of opening and type of opening for horizontally sliding doors—center opening (Figure 1.20*c* and *d*), single-slide (1.20*a*), two-speed (1.20*b*), or the height of the opening for vertical biparting doors (Figure 1.20*e*) for freight application—involve different masses that affect closing speed. The kinetic energy of closing doors is limited by elevator safety codes and is usually established at no more than 7 ft poundal (0.29 joules). In practical terms, this means that the familiar 48-in. (1200-mm) center-opening sliding door will require about 3 sec to close. Closing and opening time is a vital consideration in elevatoring, because the door operation on a typical elevator occurs hundreds of times a day.

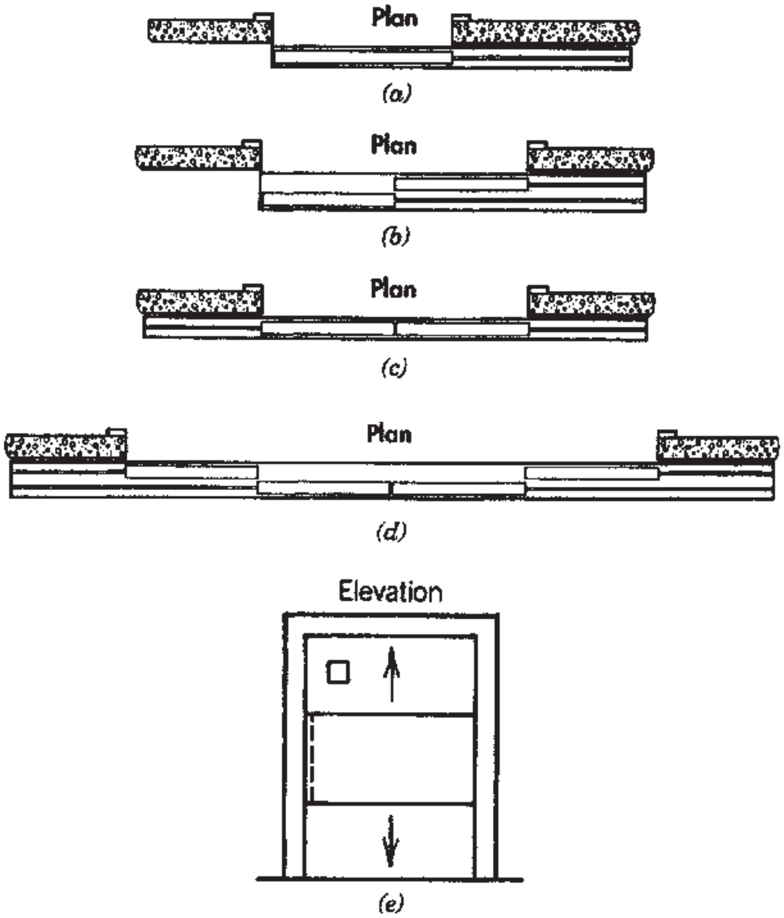


Figure 1.20. Horizontal power-operated sliding doors: (*a*) single-slide, (*b*) two-speed side-opening, (*c*) single-speed center-opening, (*d*) two-speed center-opening, (*e*) vertical biparting.

An elevator cannot leave a floor until the doors are closed and locked, and passengers do not transfer until the doors are essentially fully opened.

Powered Door-Opening Time. This can be minimized by proper arrangement. The door-opening time can and should be much faster than the door-closing time. Doors can start to open while an elevator is leveling under certain conditions. This preopening must be limited so that the opening is not wide enough to allow passenger transfer before the elevator is sufficiently level with the landing to avoid a tripping hazard. The time necessary to open the doors will vary with the width and the type of doors. For example, center-opening doors take less time than single-slide or other types of the same width, and wide openings require more time than narrower openings.

Operating Time. This is a function of the speed control arrangement of the elevator and the number of stops the car will make in a round trip. The considerations necessary are the time required for a one-floor run, a two-floor run, and full-speed operation. The operating speed of escalators or moving ramps is constant, and maximum movement capacity is fixed.

Because the floor-to-floor operations of elevators are repeated over and over again, an estimate of the probable number of stops an elevator will make in the course of a single trip is required. Knowing or estimating the number of stops provides a means to calculate the total time for functions and leads to the cycle time or round-trip time of a single elevator. The number of stops can be established by applying a statistical formula, by inspecting the various attractions of each floor at which an elevator is required to stop, or by a combination of statistical and logical determinations. The various approaches are discussed in Chapter 19, on evaluating elevator performance.

On a single elevator or escalator, once the time required to serve a given number of people is determined, the number and size of elevators or escalators that will serve the critical pedestrian traffic can be established. Although this is the essence of our studies, elevatoring cannot end here.

The grouping and operation, as well as location, of those elevators (or escalators) must also be established so that the installation will provide the expected service. The following chapters establish principles of arrangement and location of elevators and escalators. In addition, a discussion of elevator grouping, stops served, lobby arrangements, skip-stopping, operation, and all of the aspects of elevatoring is presented.

MODERNIZATION

Many elevators installed 50 or more years ago are still in active service. It is estimated that there are at least 300,000 such units with an age of 20 to 25 years in the United States and, perhaps, a million or more in other parts of the world. A well-maintained elevator can easily have a life expectancy of more than 50 years; however, changing social and economic conditions usually demand that such equipment be replaced or upgraded.

The basic structure of the elevator, such as the rails, pit equipment, car frame and counterweight, safety system, and hoisting machine, can often be rehabilitated and reused. Electrical systems, wiring, operating fixtures, door equipment, control equipment, and, perhaps, the motor itself are the prime candidates for replacement. The tenants of a building will not be appreciative of any upgrade unless a new cab and improved door operation are included. Suppliers of equipment and elevator contractors have responded, and there are today a variety of approaches readily available. Later chapters will discuss these in detail.

Modernization in an existing building is a much more labor-intensive project than construction of a new building. A major objective is to maintain a reasonable level of service while a car is out of action for the necessary work. Of serious concern is the single-elevator building where the only alternative is to walk the stairs. The information in this book can be used to evaluate the impact of the change in service while the elevator installation is operating with "N − 1" units, and the authors can only leave the impact of "−1" to the reader's imagination ("−1" is one less than the number of units normally in service).