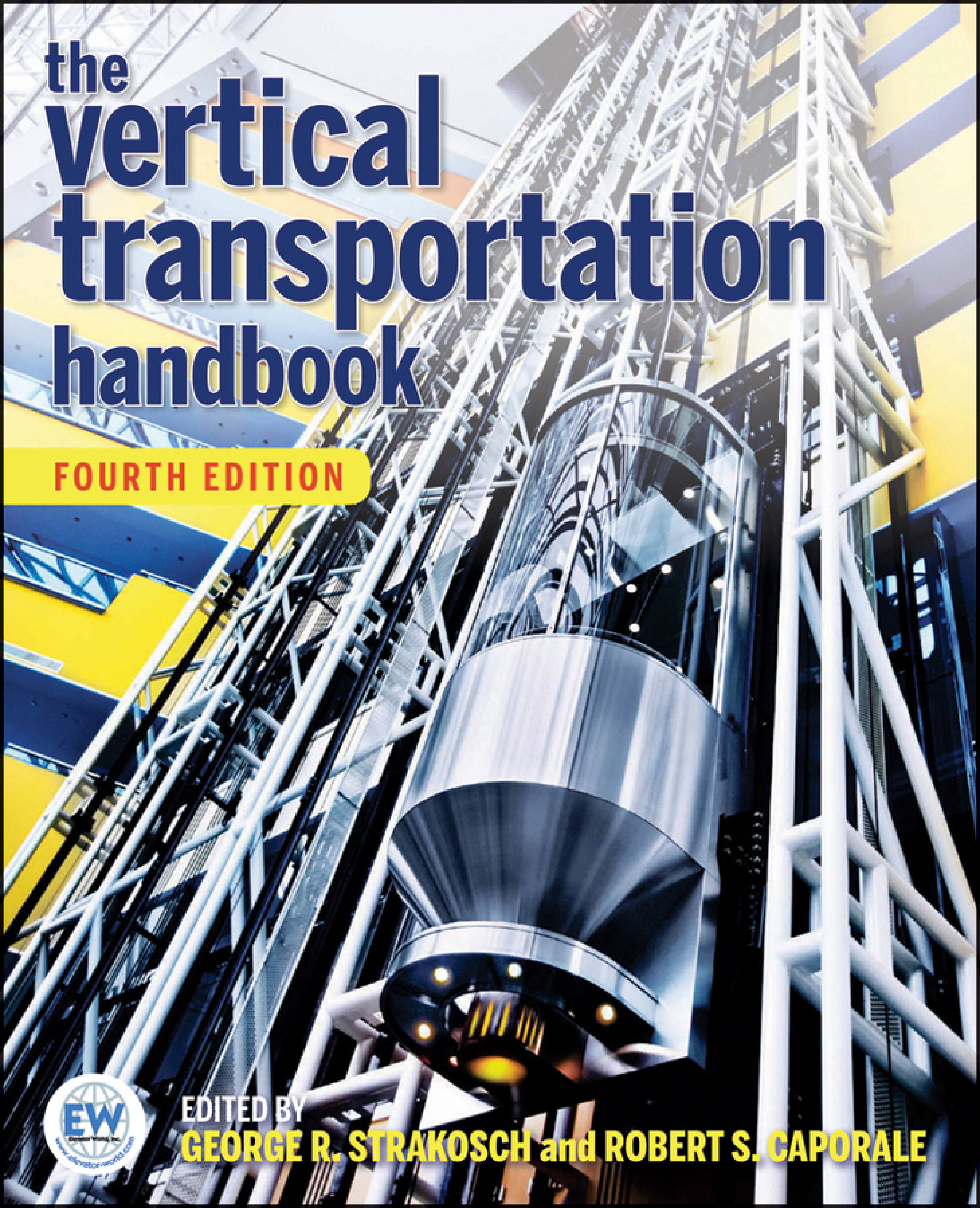
the vertical transportation handbook

FOURTH EDITION



EDITED BY
GEORGE R. STRAKOSCH and ROBERT S. CAPORALE

THE VERTICAL TRANSPORTATION HANDBOOK

THE VERTICAL TRANSPORTATION HANDBOOK

Fourth Edition

George R. Strakosch and Robert S. Caporale, Editors

JOHN WILEY & SONS, INC.

This book is printed on acid-free paper. ∞

Published by John Wiley & Sons, Inc., Hoboken, New Jersey

Published simultaneously in Canada

Library of Congress Cataloging-in-Publication Data

The vertical transportation handbook / George R. Strakosch, Robert S. Caporale, editors. – 4th ed.
p. cm.
Includes index.
ISBN 978-0-470-40413-3 (cloth); ISBN 978-0-470-91971-2 (ebk); ISBN 978-0-470-91972-9 (ebk); ISBN 978-0-470-91973-6 (ebk); ISBN 978-0-470-94981-8 (ebk)
1. Elevators. 2. Escalators. I. Strakosch, George R. II. Caporale, Bob.
TJ1370.V476 2010
621.8′77–dc22

2010005154

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

CONTENTS

PREFACE

It is hard to believe how much the vertical transportation industry has changed since the first edition of *Vertical Transportation* was published in 1967. Back then the industry was dominated by the major manufacturers and installers, Otis being the most prominent of all. The United States was the major source of equipment, and only Otis was worldwide. I was fortunate to be part of the changes that have taken place. My own career—from Otis to the consulting firm of Jaros, Baum & Bolles, to *Elevator World*, and, finally, on my own—has been a reflection of some of these changes. In the early years consultants were a minor factor, but that started to change in the 1970s. Competition among manufacturers started to change as companies such as Haughton and Dover gained substantial shares of the market. Otis and Westinghouse dominated the escalator market, but Montgomery and Peelle made inroads. Elevator contractors and suppliers started to take a substantial share of the low-rise and specialized market, and consultants became a factor.

Regarding the latter, I feel I helped the rise of consultants, since they now had a guidebook. The mystery of elevatoring became available knowledge, and the first edition of *Vertical Transportation* was the source. I was delighted, and somewhat put out, when part of my book was entered as an exhibit in a court case without my being given any credit. I also realized how limited my book was and, in the early 1980s, I decided to update it. Being a consultant myself, I could see where additional knowledge was needed and became cognizant of the changes in the industry that were taking place. I also had the benefit of meeting many of the diverse agencies from both the buyer and seller sides. During my tenure at Jaros, Baum & Bolles, I can safely say that I was involved in many of the major buildings planned or built from 1977 to 1987. It was an exciting time for me, and much of the experience is reflected in the second edition of *Vertical Transportation*.

Joining *Elevator World* in 1987 gave me a chance to substantially expand my knowledge of the elevator industry. One of my first chores was to review and classify most of the articles published on various aspects of the industry since *Elevator World* started publication in 1953. The result was the four-volume "Educational Package" currently available and further expanded. That experience led to the recognition of the need for an expanded educational effort to benefit both the suppliers and buyers of equipment and services. After consultations with Bill Sturgeon, the publisher of *Elevator World*, and Bob Jacobs, chairman of the board, we decided that seminars were a good way to initiate an educational effort.

Two 8-hour seminars were developed, one for purchasers, specification writers, and users of elevators and escalators and the other for suppliers, installers, and service providers. Written material and slides covering subjects such as equipment choice, application, space requirements, layout development, the various types of operation and control, and forms of service contracts were also prepared. Once we were ready to go, we picked six cities and did a mass mailing both to the *Elevator World* subscribers and to individuals in various organizations. Our initial seminar was in Boston in March of 1988 and, after expanding our chosen cities to 10, we concluded the series in Los Angeles in December of 1989.

The seminar series gave us a number of collateral results. The need for written educational material expanded, and more literature was required to feed that need. The seminar series was developed into a manual, and other publications, both readily available and newly produced, became popular. We learned that seminars, as such, were too costly and that distance learning was a more effective way to go. A review of the current *Elevator World* Educational Publications Catalog will attest to the expansion that developed.

I started to receive requests for private consulting and, by mutual agreement, reduced my time with *Elevator World*. This also gave me the opportunity to consider expanding *Vertical Transportation* to reflect the current state of the elevator and escalator "art." (I'm sure anyone totally involved in the field will agree that it is both an art and a science.) I realized that the technicalities of the industry had changed so that specialists needed to be enlisted to cover many aspects. The third edition of *Vertical Transportation* was a result of the input of these specialists, and I assumed the role of editor. The industry now had a "handbook," and the effort of the many contributors is greatly appreciated.

The third edition was published in 1998 and became *The Vertical Transportation Handbook* both to reflect the input of the many experts in the field and to update the status of the industry. The basics remained, with minor updates, and they have withstood the test of time. It continued to show the technology of elevators and people's unchanging reactions to elevators—and they still fret about how long it takes after they push the button before an elevator responds.

For the fourth edition we were fortunate to be able to call upon the same experts, with minor exceptions, to update their contributions. They were also asked to address any changes in their areas that have taken place in the past 10 or more years. Regretfully, one of our contributors, Wayne Gilchrist, has passed away, while some others are joined by younger counterparts and continue to contribute their knowledge to the various chapters. The readers and users of the book will benefit from their input.

ACKNOWLEDGMENTS

I am most fortunate to have Bob Caporale as my associate editor for the fourth edition. Bob and I have been friends and associates since I first met him when I joined Jaros, Baum & Bolles in 1977. As editor of *Elevator World* he brings the most up-to-date view of the elevator industry that anyone can, and his help and efforts are one of the main reasons the fourth edition was possible. I will be eternally grateful.

When I entered the elevator industry as a construction helper in 1946, little did I realize that I would be writing this. It was a job that evolved into a career, and I can honestly say I enjoyed most of the time I have spent in its various aspects. To use a hackneyed saying, I've enjoyed the ups and downs and wouldn't trade one moment of the time.

My appreciation is extended to the many people in the industry who have supported my efforts to record the many aspects of the proper application of elevators and escalators. My special appreciation goes to my wife and family, who have helped me create what I feel is my legacy.

George R. Strakosch

This fourth edition of *The Vertical Transportation Handbook* would not have come to fruition were it not for Mouse! Mouse was a big guy who stood 6 feet 4 inches tall, and was one of my best high school buddies, with whom I not only spent much of my teenage years but went on to college with as well. Struggling through the first two years of what in the 1960s was for us young guys a grueling mechanical engineering curriculum, Mouse left school and went to work full time as a draftsman at Jaros, Baum & Bolles (JB&B), an engineering firm in downtown New York City. When I confided in Mouse that my studies were killing me as well, he suggested that I "come on down!" and apply for a job at what we later learned was one of the finest mechanical/electrical engineering companies in the world. After a successful interview with Cal Kort (6 feet 8 inches tall), who not only did the first cut on interviews for the company but also ran the elevator department, I was hired to start work on the world's tallest buildings and largest construction project to date, the twin towers at the World Trade Center. This turned out to be the start of my 45-year career in the elevator industry.

I was blessed to have been pointed in this direction and taken under the wing of Cal Kort and those who succeeded him at JB&B—most of whom, though not nearly as tall as Cal, were truly giants in the elevator industry. Bill Lewis succeeded Cal Kort and brought George Strakosch (6 feet 3 inches) on board, and I literally worked alongside George for 10 years. I had the incredible opportunity to serve my apprenticeship with the previously mentioned leading elevator industry engineers, as well as Chet Chrobot of Otis Elevator Company and Joe Montesano of Westinghouse Elevator Company, who were their companies' sales engineers assigned to work with JB&B and therefore visited us often. It was these folks—in addition to numerous elevator field engineers, mechanics, and adjusters from all of the major elevator companies—that I spent days and in some cases weeks with, on major projects all over the world, and from whom I learned the intricacies of elevator system design, operation and control, testing, and inspection. As a draftsman, project designer, and NAESA-certified Qualified Elevator Inspector (QEI) for JB&B, I absorbed all of the knowledge that I could from those elevator industry people who surrounded me day after day. I am indebted to all of the people I worked for and with, and in particular to George Strakosch, not only for the knowledge that he imparted to me but especially for the bond that he was instrumental in nurturing between Bill Sturgeon and me. Working for and with these giants of the elevator industry has been a blessing for me, and it is because of all these people that I have been able to be a part of the development of this fourth edition of *The Vertical Transportation Handbook*.

In 1993, after holding engineering positions at DTM Consulting and Syska and Hennessy Engineers, I was hired by Bill Sturgeon to come on board as the associate editor of *Elevator World Magazine*. This was something that in my wildest 1960s and '70s dreams I could never have imagined to be possible . . . but here it was. After working with—and being so significantly influenced by—the brightest minds in the elevator industry, I was now going to be working for another giant: Bill Sturgeon, one of the most intelligent men that I have ever encountered, and from whom I was to learn not only more about the elevator business but also about the publishing of magazines, books, and journals. And as he often said he would, Bill taught me "how to lead the orchestra!" "Being an editor," Bill often stated, "is like being the conductor of an orchestra. A conductor strives to bring out the best in the musicians before him while taking little credit for doing so. Our job," Bill used to say, "is to make those that write for ELEVATOR WORLD sound and look good, and this is the most satisfying job that anyone can have." And he was right! I owe much to Bill Sturgeon, who not only taught me how to lead the band but also allowed and encouraged me to expand my horizons and learn from all of those that I encountered in my life.

When the time came for George Strakosch to update the third edition of *The Vertical Transportation Handbook*, he asked a number of us in the industry to assist him with this project by editing some of the chapters of the previous edition. George had spent years on the first two editions and had done more than the yeoman's share of the work; therefore at that time, for us, it was just a matter of editing and, where necessary, updating and expanding each of our sections.

It is often said that the hardest part of writing is completing the opening sentence, and anyone who writes regularly knows just how true this is. Well, George hadn't just given us opening sentences to work with but entire chapters, and 10 of us gratefully agreed to provide the needed assistance. Not only because we loved the elevator industry but also because, as does everyone who knows him, we loved George! He has always been there to help us and has always done so with an open heart and a smile on his face. This project was truly a labor of love for us all and one that was very satisfying as well.

Much gratitude for this work is also due to the following individuals, without whom the third and consequently this fourth edition of *The Vertical Transportation Handbook* would not have been possible.

Ed Donoghue, often referred to as "The Code God," for his work throughout his career on elevator and escalator codes and standards and for the fine work he has done on the material on this subject.

George Gibson, the mechanical engineer extraordinaire in our industry, for his chapter updates on the mechanical design aspects of elevators in general and special-application elevators in particular.

Wayne Gilchrist, who, although he is no longer with us, is still one of my dearest friends. In my mind I turn to him often for guidance, as if he were still physically at my side . . . which sometimes I think he is. His previous work on the chapter "Automated Materials-Handling Systems" was so thorough for the third edition that it didn't need to be updated for this latest edition. Thanks, Wayne . . . !

Jon Halpern, our brilliant electrical engineering guru, who provided the updates on elevator operation and control.

Len LeVee, the nicest guy you ever want to meet and a fine elevator man, who did the previous work on the economics, maintenance, and modernization of elevator systems.

Joe Montesano, tough as nails when he needs to be, but with the heart and soul of a saint, who updated the chapter on elevator specifications and contracts.

Nick Montesano, my adopted brother, who loves everything elevators and most things escalators, always gets the job done, and does so with precision and thoroughness—and also brings more fun to the job than anyone could ever imagine. Nick took over the task of updating the chapter "Economics, Maintenance, and Modernization" from Len LeVee, who retired from the industry prior to our starting work on the fourth edition of this book.

Al Saxer, the elevator maintenance and modernization master, who pulled together the third-edition chapter "Service and Freight Elevators."

Hank Peelle, another one of the nicest guys I know and an extraordinarily intelligent engineer, who, like the two generations before him, has dedicated his career to looking after the well-being of freight elevators and freight elevator doors. Hank updated Al Saxer's previous chapter on service elevators and added an extensive amount of new material to his section on freight elevators.

Davis Turner, whose brilliance is only surpassed by his sense (and often nonsense) of humor, who has been not only a tremendous help to me in my day-to-day work at *Elevator World*, but who is also an incredibly bright engineer, mathematician, and philosopher. Dave has looked after the escalator work in the third and fourth editions of this book, and we are forever grateful to him for his assistance and for his goofy sense of humor.

Jim Fortune, a true twenty-first-century visionary, who has not only traveled the world over but also designed the elevator systems in some of the world's most remarkable high-rise and super-tall buildings. Jim is a world-renowned expert on the conceptual analysis of super-tall buildings and their elevator systems. His additions to the chapter on the changing modes of vertical transportation reflect his involvement in this important aspect of our industry and his ability to remain on the cutting edge of elevator technology and building design.

Richard Peters, developer of elevator traffic analysis and simulation software, who has become a leading authority on the subject of elevator performance.

Bill Sturgeon is only listed following the others because his is the final chapter in the book. Bill has been my good friend for over 20 years and my mentor for over 15 years and has taught me not only a tremendous amount about the elevator industry from a trade publication editor's perspective but also so much about life in general. He has been an inspiration to me, and I can't thank him enough for all of the encouragement that he has given me, to always do the best that I can and to use all aspects of my conscious and subconscious mind to accomplish tasks. Thank you, Bill, for handing the ball off to me and not only letting me run with it but also constantly encouraging me to take it into the end zone.

This work could also not have been completed without the support of *Elevator World*'s publisher, Ricia Hendrick, and the assistance of the magazine's special projects manager and research associate, Monica Tapper. Thank you, Ricia and Monica, for your support and help on this project.

And to George Strakosch I have to say that I have been truly blessed to have you in my life. Thanks for taking me under your wing and teaching me how to fly without getting in anyone's way. You showed me and so many others how to share knowledge and understanding with others and to always be there to provide inspiration and help to those around us. And for this I will be forever grateful. And a special thanks for having the confidence in me to let me assist you with this important elevator industry project.

And of course thanks to Mouse, who got me into this mess! Thanks, Big Guy.

ROBERT S. CAPORALE

CONTRIBUTORS

ROBERT CAPORALE, Editor
Elevator World Magazine
354 Morgan Avenue, P.O. Box 6507
Mobile, AL 36606

EDWARD A. DONOGHUE, Edward A. Donoghue Associates, Inc.
1677 County Route 64, P.O. Box 201
Salem, NY 12865-0201

JAMES FORTUNE, Fortune Consultants, Ltd.
2102 Mechanic Street
Galveston, TX 11788

GEORGE GIBSON, G. Gibson & Associates
555 Deer Pass Drive
Sedona, AZ 86351

WAYNE A. GILCHRIST, deceased, formerly of the Translogic Corporation

JON HALPERN, Jon B. Halpern & Associates, LLC
49 Hidden Ridge Drive
Syosset, NY 11791

LEN LEVEE, retired, formerly of Len Levee & Associates

JOSEPH MONTESANO, DTM Elevator Consulting
120-02 14th Road
College Point, NY 11356

NICHOLAS J. MONTESANO, DTM Elevator Consulting
120-02 14th Road
College Point, NY 11356

HANK PEELLE
The Peelle Company
373 Nesconset Highway
Hauppauge, NY 11788

Dr. Richard Peters, Peters Research Ltd.
Boundary House
Missenden Road
Great Kingshill, Bucks HP15 6EB, UK

Al Saxer, retired, formerly of Otis Elevator
38 Schoville Road
Avon, CT 06001

William C. Sturgeon, Founder and Editor Emeritus
Elevator World Magazine
354 Morgan Avenue, P.O. Box 6507
Mobile, AL 36606

Davis L. Turner, Davis L. Turner & Associates
27615 Belmonte
Mission Viejo, CA 92692

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

* 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).

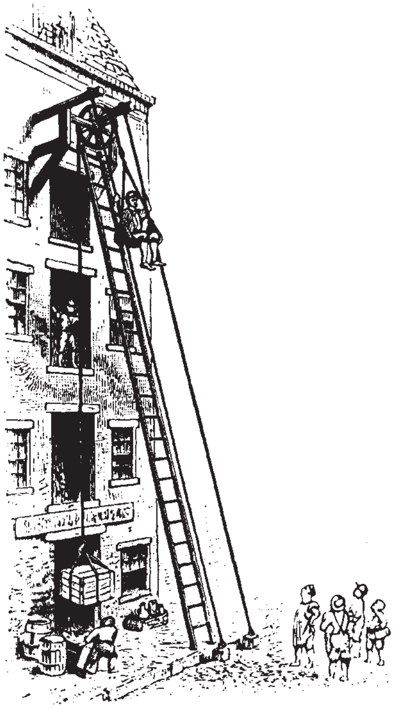
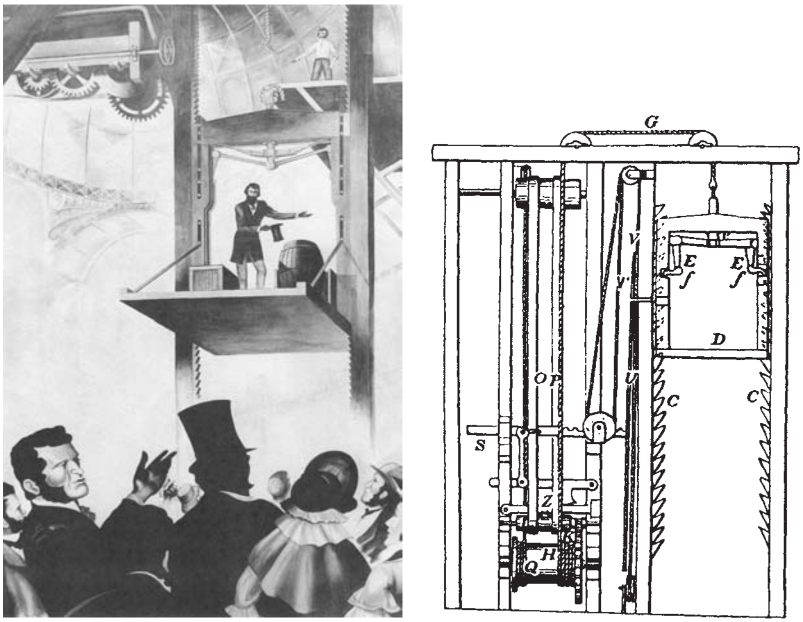


Figure 1.1. A very early type of vertical transportation.



(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

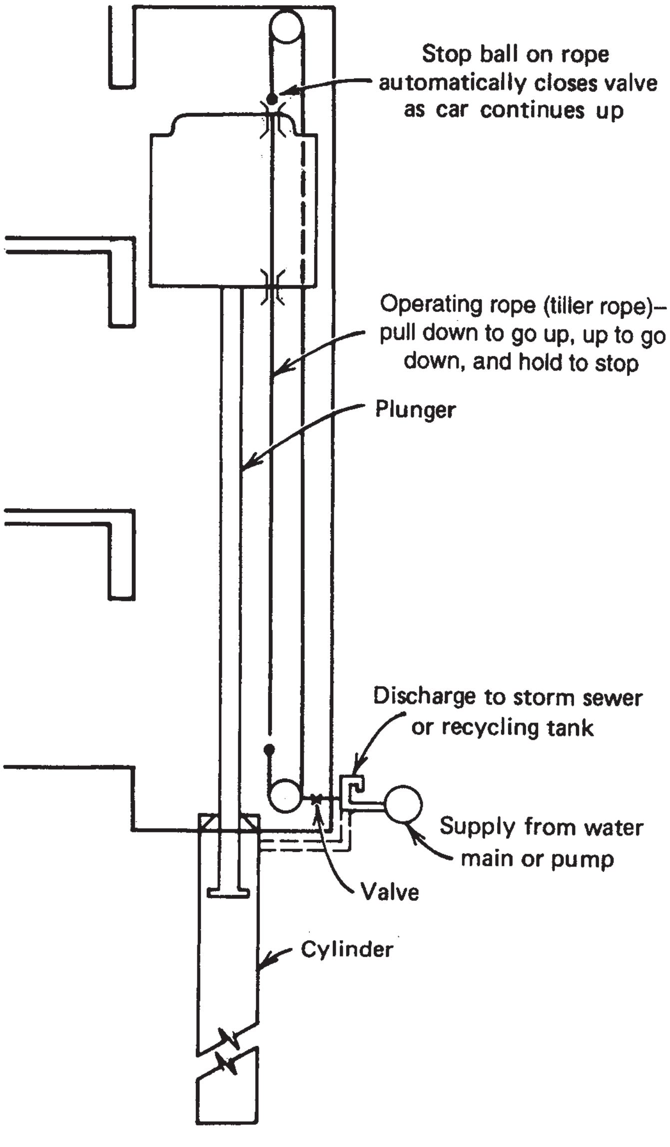


Figure 1.3. Hydraulic elevator with handrope operation.

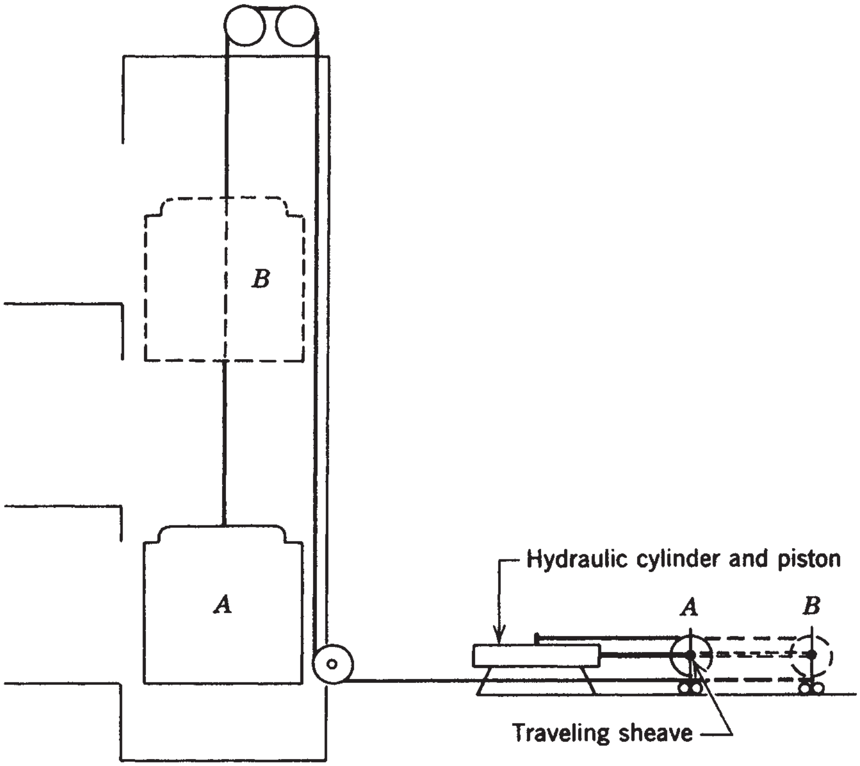


Figure 1.4. Roped hydraulic elevator.

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.

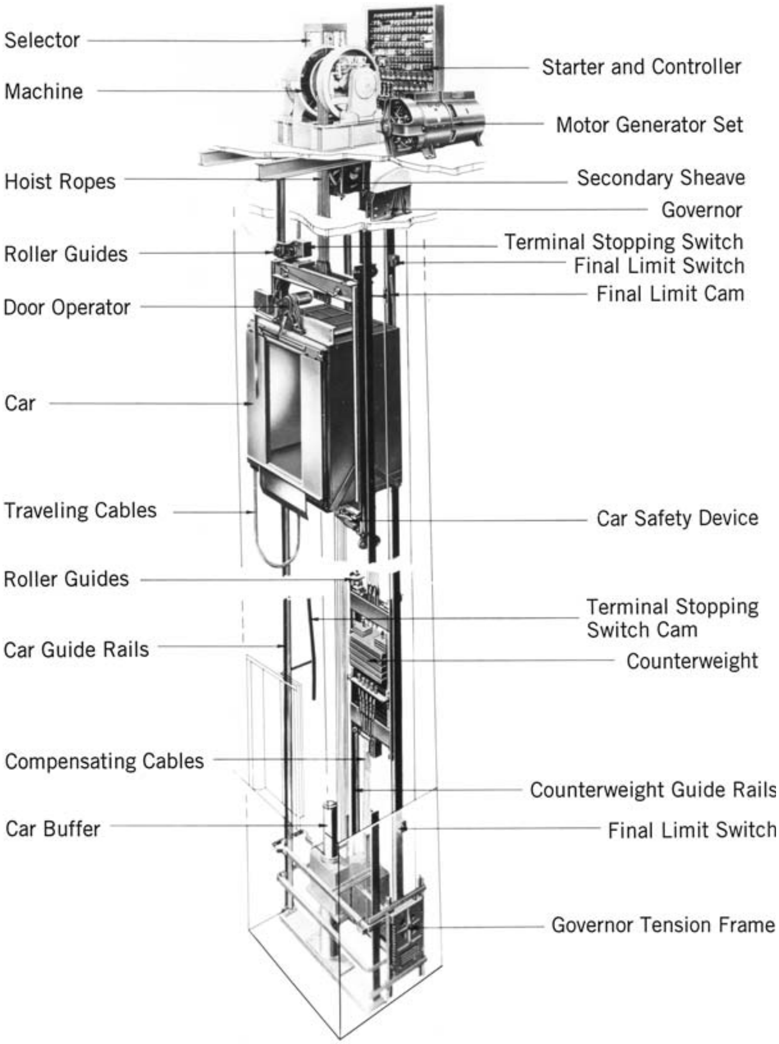
The history of the development of the mechanics of hoisting elevators is far beyond the scope of this volume and is detailed in at least two sources. One is the virtual Elevator Museum developed by William C. Sturgeon and *Elevator World Magazine*, which can be viewed online at www.theelevatormuseum.org, 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

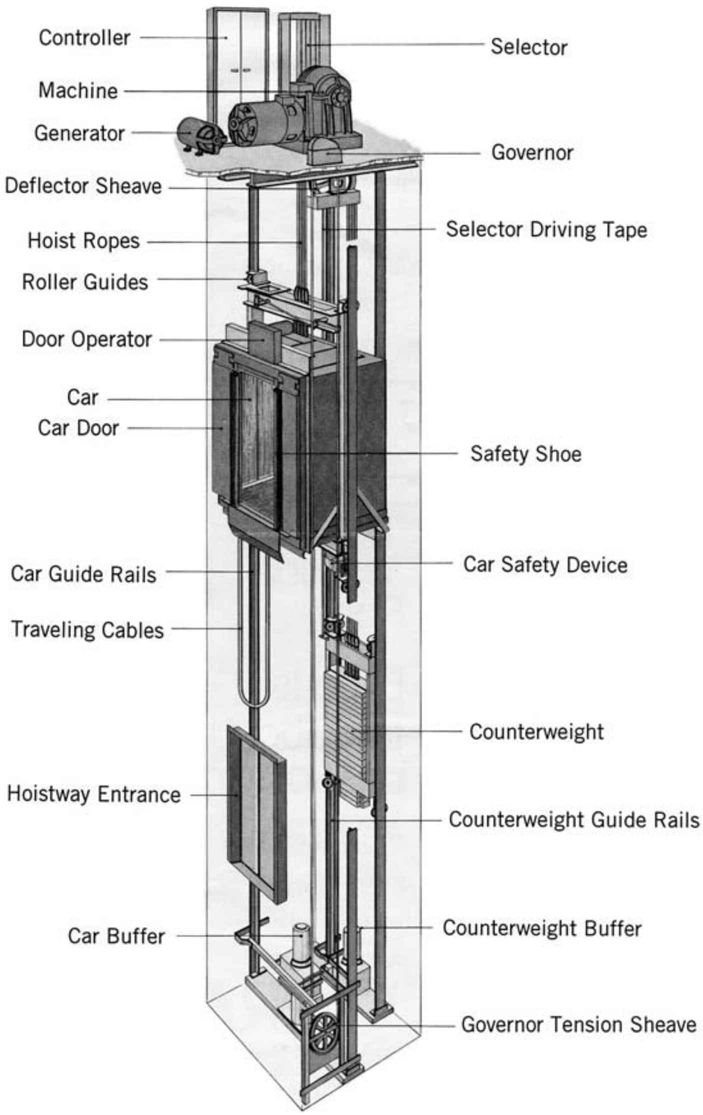
Up until about 1903, either drum-type elevator machines, wherein the rope was wound on a cylindrical drum, or the hydraulic-type elevator (the direct-plunger hydraulic or the roped hydraulic machine) was the principal means of hoisting force. Both had severe rise limitations: the drum type, in the size 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.

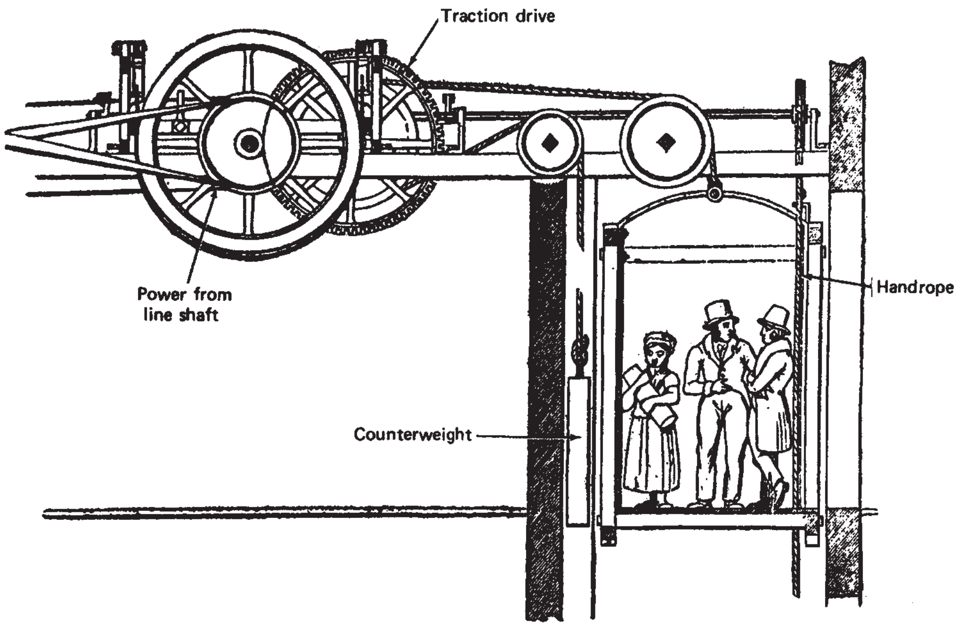


Figure 1.6. Teagle elevator (circa 1845) (Courtesy *Elevator World Magazine*).

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.

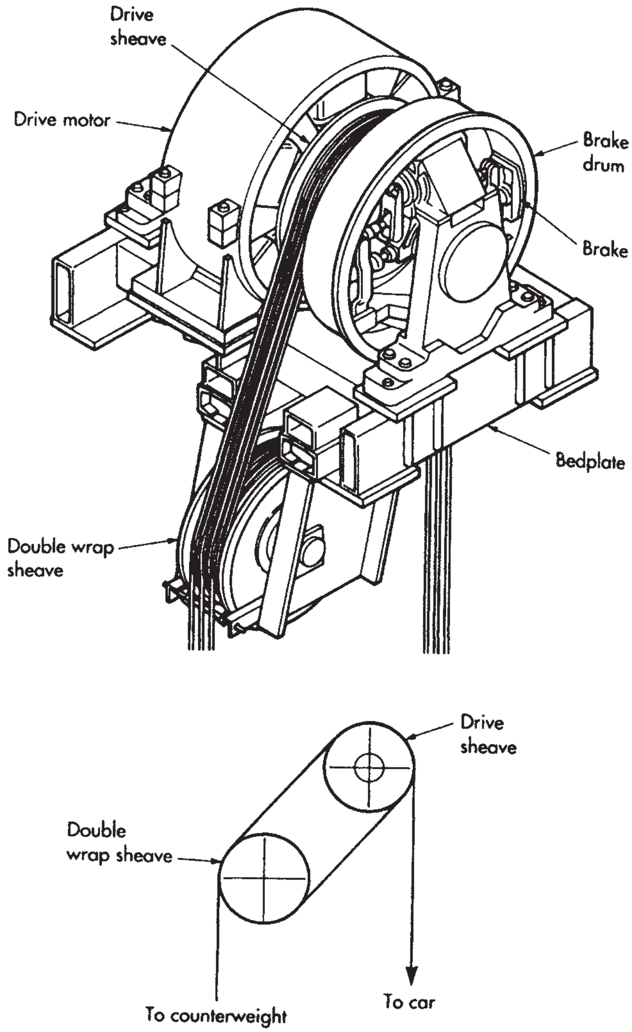
The gearless traction elevator consists of a large, slow-speed (50 to 200 rpm) dc motor of four to eight poles directly connected to a drive sheave of about 30 to 48 in. (750 to 1200 mm) in diameter. An electrically released, spring-applied brake is arranged to apply stopping to the drive sheave. Slow-speed 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.

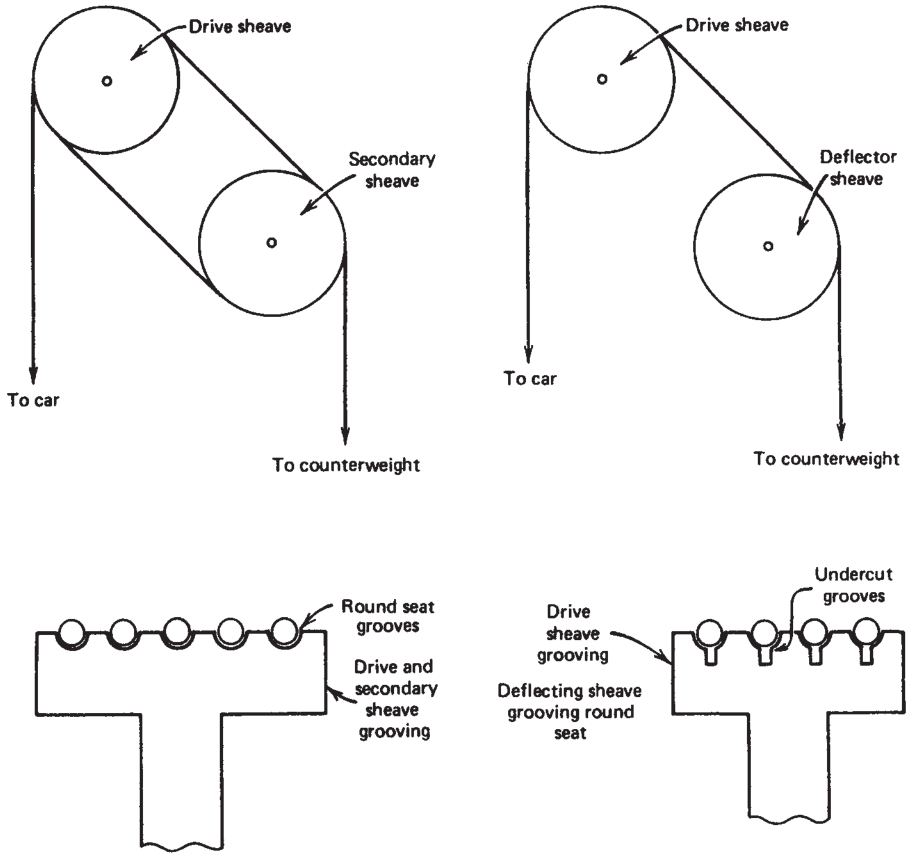


(a)

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



(b) *(c)*

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.

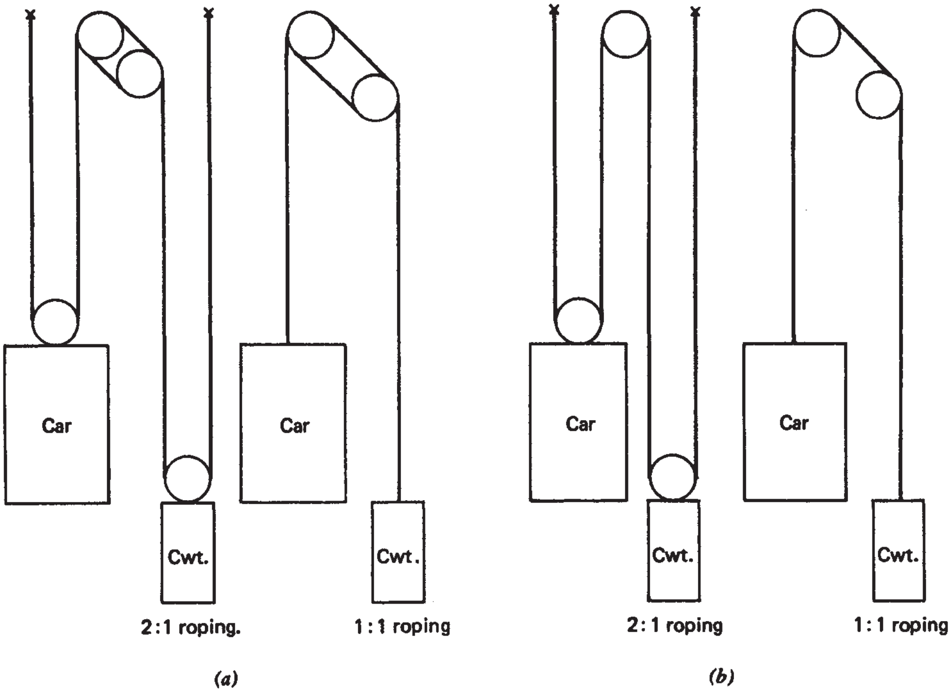


Figure 1.8. (*a*) Double-wrap roping. (*b*) Single-wrap traction roping.

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

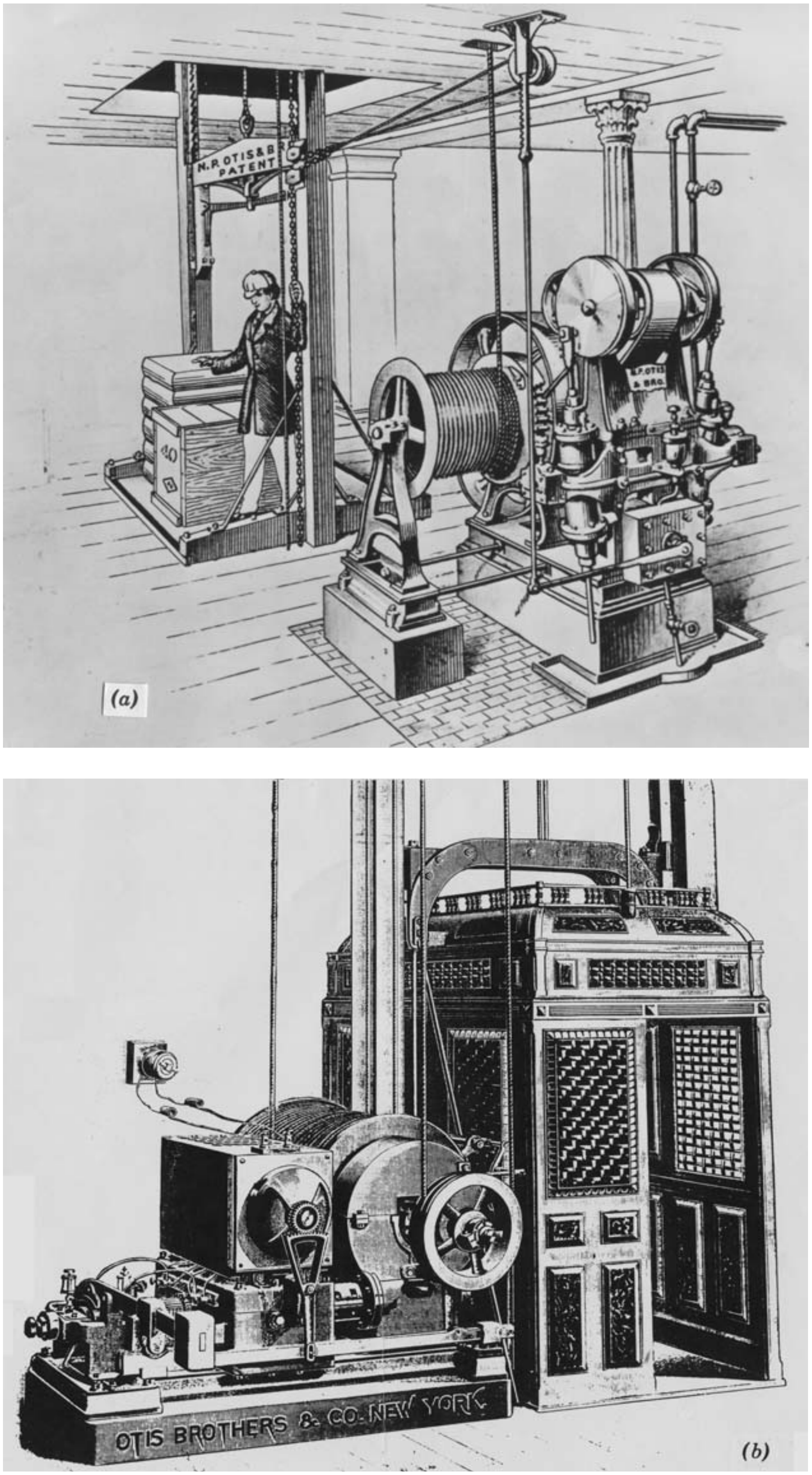


Figure 1.9. (*a*) Early steam-driven hoisting machine. (*b*) Early electric-driven hoisting machine.